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

ענף הנעה
מחלקת מטוסים
להק ציוד
חיל האויר

יום העיון השלשה עשר
במנועי סילון וטורבינות גז

13th Israeli Symposium on Jet Engines and Gas Turbines

November 6 2014,
Department of Aerospace Engineering,
Technion, Haifa, Israel

BOOK OF ABSTRACTS

יום ה', י"ג חשון תשע"ה, 6/11/2014 (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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Turbo and Jet Engine Laboratory
Department of Aerospace EngineeringTechnion, Haifa
http://jet-engine-lab.technion.ac.il

THE 13TH (Bar Mitva) ISRAELI SYMPOSIUM ON JET ENGINES AND GAS TURBINES

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

Thursday, November 6 2014 (9:00-17:00), Technion, Haifa

This year, as in the previous years, we plan to hold the Israeli Symposium on Jet Engines and Gas Turbines. During the last few years there has seen a considerable expansion of activities in Isreal in turbo jet propulsion. This is in addition to the serial production of small engines, increased electricty 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 13th symposium is the Bar Mitsva one, 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.

During the symposium are 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.

This year there is a special exhibition where different Israeli companies will present some of their products, including complete Israeli made jet engines and associated components.

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

תודתנו נתונה לגופים הבאים אשר תמכו ביום העיון:

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

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THE 13TH (Bar Mitsva) ISRAELI SYMPOSIUM ON JET ENGINES AND GAS TURBINES

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

Thursday, November 6 2014 (9:00-17:00), *Technion, Haifa*

TECHNICAL PROGRAM

8:00 - 9:00	**(Registration) הרשמה**
9:00 - 9:20	Opening **(Auditorium - Room 235)** Professor Yeshayahou Levy, Chairman of the Symposium, Turbo and Jet Engine Laboratory, Faculty of Aerospace Engineering, Technion.
	Professor Yaakov Oshman, Dean, Faculty of Aerospace Engineering, Technion.
	Major Uri Zvikel, Head, Propulsion Systems Branch, Aeronautical Division, MOD.
	Lt. Col. Shlomi Konforty, Head of Propulsion Branch, IAF
9:20 (lecture length)	**(Session First) מושב ראשון** **Session Chairman: Major Uri Zvikel, MOD & Mr. Emanuel Liban, Edmatech**
A1 (35 min)	James A. Kenyon, Pratt & Whitney, USA, **"Trends in Advanced Engine Technology"**
A2 (35 min)	Thurmond Senter, GE Aviation, USA, **"Technology Impact On Future Products"**
A3 (35 min)	Richard Hausen, Honeywell Propulsion, USA, **"Emissions and Ignition Trade Considerations for Small Engines Low Emissions Combustor Design"**
11:05 - 11:25	**(Break and Refreshments) הפסקה וכיבוד קל**
A4 (35 min)	Prof. Michael Casey, PCA Engineers Limited, UK, **"A new approach to map prediction of radial compressors"**
A5 (35 min)	Prof. Damian Vogt, University of Stuttgart, Germany, **"Turbomachinery Blade Vibrations: Causes, Opportunities and Challenges"**
A6 (30 min)	Student's Project: Dorin Avsaid, Alon Dahan, Tomer Yehezkeal, Dor Shitrit, Tamir Ben Nachum, Yonit Zaslavsky, Michael Presman, Maor Schkolnik, Technion, Israel, **"Afterburner and Vectoring Nozzle for a Small Jet Engine"**
A7 (10 min)	Dr. Anat Bonshtien, Fuel Choices Initiative, Prime Minister's Office , **"The Fuel Choices Initiative – Pushing Towards Alternatives"**
13:15 - 14:45	**ארוחת צהריים וסיור במעבדה למנועי סילון** **Lunch &Visit at the Turbo and Jet Engine Laboratory**

Thursday, November 6 2014 (9:00-17:00),

Auditorium - Room 235	
14:45 (duration)	2ND Session, Fluid Mechanics & H.T. מושב שני, מכניקת זורמים ומעבר חום **Session Chairman:** **Dr. Khosid Savely, Rafael**
B1 (20 min)	Dr. Beni Cukurel, Technion, **"Thermal Management Ramifications of Acoustic Resonances in Turbine Blade Internal Cooling Channels"**
B2 (20 min)	Zvi Gorelik, Bet Shemesh Engines, **"Identification and Treatment of Separation Phenomena during the CFD Design on Turbomachinery Blades"**
B3 (20 min)	Dr. Khosid Savely, Manor, Rafael, **"Optimization using CFD: methods and tools for engineers"**
15:45 - 16:00	**הפסקה וכיבוד קל** **(Break and refreshments)**
16:00 - 17:00	**4TH Session, Structure** **מושב רביעי, מבנה** Session Chairman: **Yitzhak Hochmann, Edmatech**
D1 (20 min)	Ido Koresh, Shimshon Bar-ziv, Ahron Halevy, Anat Shenar, Shlomit Zamir, Manor Rafael, Israel, **"Cold Spin Test (CST) of Silicon Nitride Discs for Jet-Engine Applications"**
D2 (20 min)	Dolev Ohad, Rafael, Israel, **"Additive Layer Manufacturing for Jet Engine Applications"**
D3 (20 min)	Captain Shani Eitan , Israel Air Force, **"Numerical and Analytical investigation of cracks in Turbine Exhaust Case Struts of F100 engine"**

Room 165	
14:45 (duration)	3RD Session, Gas Turbines - Operation & Fuel מושב שלישי, תפעול ודלקים לטורבינות גז **Session Chairman:** **Dr. Boris Chudnovski, Israel Electric Company**
C1 (20 min)	Prof. Yeshayahou Levy, Technion **"Alternative Fuels for Gas Turbine and Jet Engines"**
C2 (20 min)	Mordechai Reshef and Dr. Boris Chudnovsky, Israel Electric Company, Dr. Moshe Keren and Shaike Baitel (Dor Chemical), **"Long Term Experience of Methanol Firing in Utility Gas Turbine"**
C3 (20 min)	V. Litinetski, O. Weiss, A. Gutman. Israel Electric Corp. Performance **"Monitoring of IEC Industrial Gas Turbine"**
15:45 - 16:00	**הפסקה וכיבוד קל** **(Break and refreshments)**
16:00 - 17:00	**5TH Session, Systems& Control** **ובקרה מושב חמישי, מערכות** Session Chairman: **Dr. Moshe Shapira, Bet Shemesh Engines**
E1 (20 min)	Dr. David Lior, RJet Engineering, **"Improvements in Cooling of Gas Turbines"**
E2 (20 min)	Ilan Berlowitz, Israel Aerospace Industries, **"A View of the Future of Civil Transport Aircraft Propulsion Systems"**
E3 (20 min)	Dr. Michael Lichtsinder, Bet Shemesh Engine, Israel, **"Twin Spool Engine Control Using Partial Engine Model"**

A1

Trends in Advanced Engine Technology

James A. Kenyon
General Manager Next Generation Fighter Engine Programs Pratt & Whitney, Military Engines

Kenyon will discuss trends in advanced commercial and military engine technology, including critical drivers and highlights of key programs at Pratt & Whitney. The presentation will underscore common elements between commercial and military needs and how these translate into opportunities to leverage technology across programs.

A2

Technology Impact On Future Products

Thurmond Senter

Manager, Military Operations & Systems Technology

Military Propulsion & Power Engineering

GE Aviation

GE Aviation has a proud history of products and technology innovation. Over the past 50 years, continuously infusing technology into the product lines has yielded substantial improvements in engine safety, fuel efficiency, thrust-to-weight, and noise. The technologies driving the current revolution in commercial engine capability are maturing rapidly, and the next generation of engines is entering fielded service now.

The Military Propulsion and Power Engineering department, led by Mark Pearson, provides one engineering face to military customers for advanced technology development, new product introduction, and fielded engine support. GE is investing heavily to address future combat propulsion needs, and has a strong suite of commercial and military-specific technologies that can be implemented into next generation applications for rotorcraft and fixed wing aircraft. GE is a proud partner with our military customers, promoting and advancing cutting edge propulsion technologies, and is prepared to deliver revolutionary capability to the warfighter at affordable cost and acceptable risk.

A3.

Emissions and Ignition Trade Considerations for Small Engines Low Emissions Combustor Design

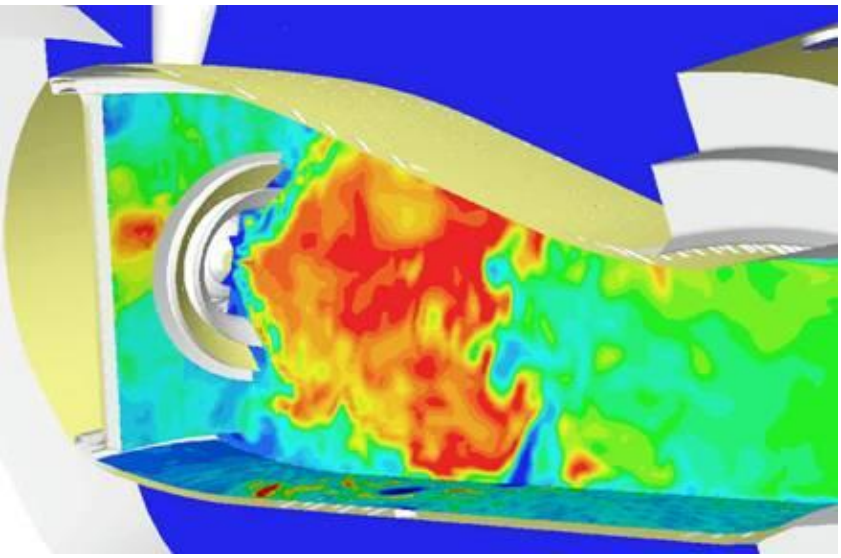
Richard Hausen

manager of the Honeywell Propulsion Engine Combustion group

There is a broad need to develop technologies that reduce criteria pollutants, namely oxides of nitrogen, unburned hydrocarbons, carbon monoxide and smoke from aircraft propulsion engines .

The Single Annular ComBustor for Emissions Reduction (SABER) technology has been developed and introduced into the Honeywell HTF7000 family of engines in order to provide significant reduction in these pollutants. This presentation focuses on the combustor technology and processes that are utilized to reduce the pollutants with particular emphasis on abating oxides of nitrogen (NOx).

The presentation describes the HTF7000 turbofan engine, the requirements and challenges for small engines, and the selected strategy of Rich-Quench-Lean combustion. Analytical and Experimental results are presented for the current generation of Honeywell combustion systems, the Single Annular comBustor for Emissions Reduction (SABER). The analytical results match well to the experimental results, and SABER has demonstrated roughly 23% margin to the CAEP/8 NOx emissions standard, while also meeting significant margins in the other criteria pollutants. This paper further discusses the trades between altitude ignition, engine starting, smoke and emissions and combustor metal temperatures. It also touches on the topic of using flame visualization techniques and atomizer laser sheeting spray results in conjunction with analytical predictions during the development process.



LES model of Honeywell’s low emissions SABER-1 combustor

A4.

A new approach to map prediction of radial compressors

M. V. Casey,

PCA Engineers, Lincoln, England and Institute of Thermal Turbomachinery, University of Stuttgart, Germany

An important requirement during the preliminary design of a centrifugal compressor stage is the ability to estimate the performance map as a guide to the expected operating range and the sensitivity to speed variations when the design is completed. This is a difficult task as the final detailed geometry and many aspects of the aerodynamic design have not been finalised at this point. An additional issue is that the estimated performance map is needed very quickly, typically during engineering discussions on a proposed new development.

The most accurate methods of determining a map to assess competing design solutions are to complete the detailed design and then to make CFD simulations, or even test measurements, and these are not suitable in the preliminary design time-frame. The most common alternative to these approaches is to use empirical correlation-based methods which use separate correlations for different sources of loss. Such methods, however, require fairly detailed information of the stage geometry, at least on a one-dimensional (1D) basis. In addition, experience with such methods also shows that they often require fairly tedious tweaking of coefficients in the empirical models to generate a satisfactory performance map over the whole operating range, and that the characteristic curves still often have unreliable shapes. This lecture describes a new engineering approach to rapidly estimate reliable performance maps.

Measured performance maps of many well-designed radial stages have been analysed to produce non-dimensional characteristic curves for each case (that is, polytropic efficiency, work coefficient and pressure coefficient as a function of tip-speed Mach number and flow coefficient). These show that well-designed stages for a particular duty tend to have fundamentally similar shapes of their non-dimensional characteristics. For these good stages, which of course are the ones of most interest to designers, the map appears to be essentially a consequence of the duty and the type of stage rather than subtle details of the design. From this knowledge, the maps from nearly 100 cases have been analysed to derive a generic set of analytic equations that approximate the variation of efficiency and work input with flow coefficient and tip-speed Mach number. These equations include empirical constants which have been adjusted to match the available experimental data on a wide range of stages, including subsonic and supersonic impellers, open or shrouded impellers, impellers with and without splitter vanes, impellers with and without an inducer, stages with vaned and vaneless diffusers, and turbocharger stages with heat transfer. An example is shown in figure 1.

In this new method, the map is characterised by four pieces of non-dimensional information at the design point; the expected design point efficiency, the values of the non-dimensional flow coefficient and work coefficient, and the design tip-speed Mach number of the stage. Additional information is also needed to characterise the size, the impeller type and the diffuser system so that different values of the empirical coefficients in the equations can be selected to model the characteristics for different types of compressor stage. Figure 2 shows a map of a stage with a vaned diffuser predicted by this method compared to test data, whereby the small white circle on

the high-speed line is the design data specified by the user and the map is predicted from the design data at this single point.

The method works well for stages with vaneless and vaned diffusers. For stages with a vaned diffuser the key aspect is the matching of the vaned diffuser to the impeller. Special consideration has to be given to the relative size of the impeller and diffuser throats as this ratio determines which component chokes at different speeds. A new theory of the impeller-diffuser matching shows that this ratio is a function of the tip-speed Mach number, the impeller work input, the impeller mean inlet diameter and the impeller efficiency. A 1D matching equation is derived from this theory and its validity is confirmed by comparison with a wide range of compressor stages from the open literature and with extensive proprietary data. This matching information can then be simply incorporated into the map prediction method.

The method is a useful addition to the armoury of a compressor designer. It allows a reasonable estimate of the stage performance map to be obtained almost instantaneously at a very early point in the design process and, as it is based on test measurements with many stages, it is reliable and conservative. The equations have been incorporated into a preliminary design code (Vista CCD), a through-flow code (Vista TF) for radial compressor design and into a stage-stacking procedure for multistage industrial compressors (Vista CCM). They are also suitable for inclusion in performance codes for whole-engine analysis systems.

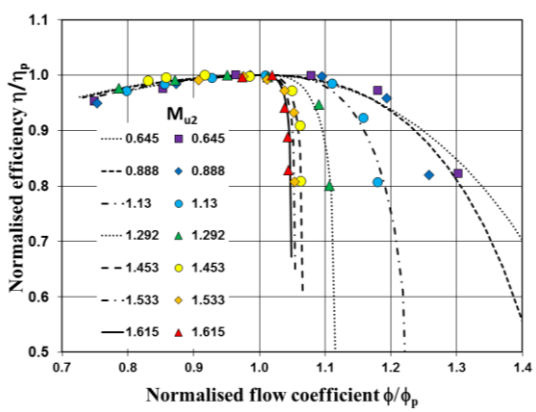


Figure 1: Normalized polytropic efficiency versus normalized flow coefficient for a range of tip-speed Mach numbers for test data (symbols) and analytic equations (lines).

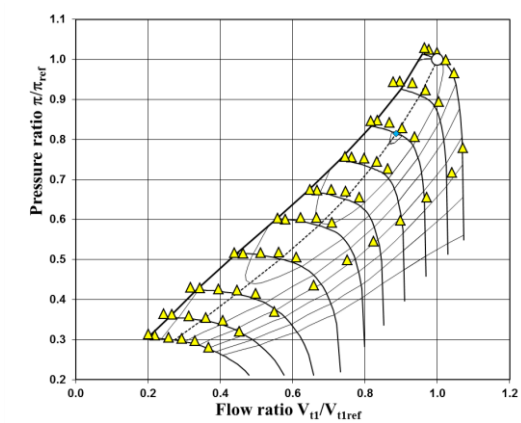


Figure 2: Map predicted by the map prediction method (lines) compared to test data (triangles). The design point at a tip-speed Mach number of 1.6 is shown as a small white circle.

References:

Casey, M., and Robinson, C.J., (2013), "A Method to Estimate the Performance Map of a Centrifugal Compressor Stage", ASME Journal of Turbomachinery, March 2013; Volume 135 (2): 021034-1 - 021034-10. doi: 10.1115/1.4006590

Casey, M., and Rusch, D., (2014), "The Matching of a Vaned Diffuser with a Radial Compressor Impeller and its Effect on the Stage Performance", Proceedings of ASME Turbo Expo 2014: June 16 – 20, 2014, Dusseldorf, Germany, GT2014-25003, to be published in the Journal of Turbomachinery.

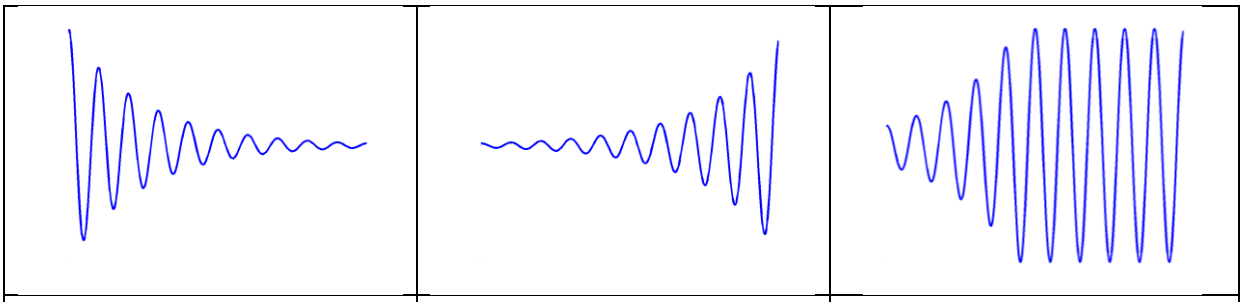
A5.

Turbomachinery Blade Vibrations: Causes, Opportunities and Challenges

Damian Vogt,

University of Stuttgart, Professor in Thermal Turbomachinery, Stuttgart, Germany

Vibrations of turbomachinery blades are a major problem as they potentially harm the integrity of machines. A well-designed turbomachine does not only feature a high efficiency, but also provides safe operation over the entire operating range. Safe operation implies that the static and dynamic loads are kept within allowable ranges. Vibrations that lead to dynamic loads can be of various types. A common approach is to characterize them depending on the cause of vibration as an answer to the question "why does it vibrate?" (self-excitation, forced excitation) as well as depending on the type of damping as an answer to the question "how does it vibrate?" (positively damped vibration, negatively damped vibration, limit-cycle oscillations). The latter types are exemplary depicted in Figure 1.



Positively damped vibration	Negatively damped vibration	Limit-Cycle Oscillation (LCO)

Figure 1. Various types of vibrations featuring different damping behaviour

With respect to possible failure mechanisms, it is the stress situation resulting from the vibration that determines the failure mode; on the one hand, self-excited and negatively damped vibrations usually lead to material failure due to overload in a very short period of time. Flutter and Non-Synchronous Vibrations (NSV) are two examples of such types of vibrations. On the other hand, forced excited and positively damped vibrations or Limit-Cycle Oscillations (LCO) can lead to material failure due to High-Cycle Fatigue (HCF). It is thereby the combination of static mean stress and alternating stress that affects whether a component will fail or not. Commonly, Haigh Diagrams as the ones shown in Figure 2 are employed to assess the HCF tolerance and to conclude on eventual integrity issues.

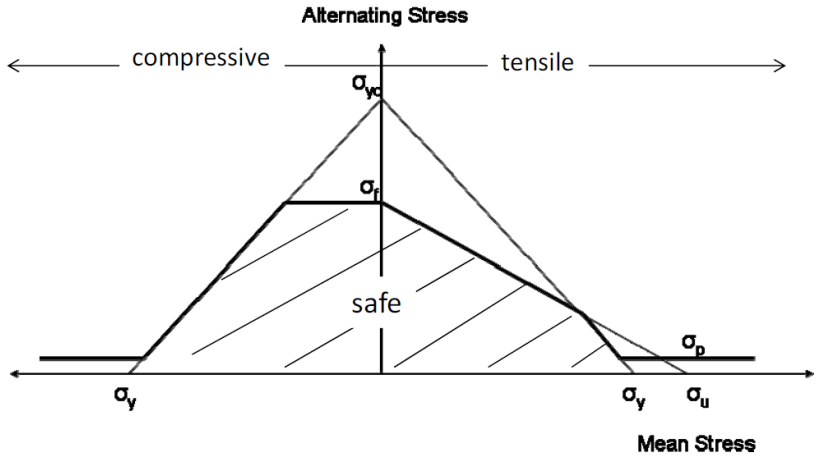


Figure 2. Example of a Haigh Diagram used for assessing the HCF tolerance

The causes of vibrations are manifold. In the planned talk, excitation sources stemming from the aerodynamics only are taken into account. These range from excitation due to adjacent devices (blade rows, diffusers, struts, bends, etc) that all result in speed-synchronous excitation over rotating stall and surge to flutter and NSV. Designing a turbomachinery component for vibration-tolerant operation implies that all of the aforementioned vibration causes are investigated in detail, be it numerically or by means of tests, and remedied in case non-tolerable vibration behaviour is encountered. Possible remedies include modifications of the structural properties of the critical component, modifications of the excitation and/or damping behaviour or use of alternative HCF-tolerant materials.

The key challenge when assessing turbomachinery blade vibrations is to produce accurate and reliable prediction results in a design process at affordable computational costs. As the phenomena of aerodynamically induced vibrations include both structural dynamics as well as aerodynamics, the corresponding analyses must be of multi-physics type covering both the fluid and the structure domains that results in so-called Fluid-Structure Interaction (FSI) analyses. There is a clear trade-off between computational costs and accuracy, which without proper calibration of analysis models easily can feature uncertainties of several 100 percent.

The proposed talk will give an overview of the physical mechanisms involved in turbomachinery blade vibrations, elucidate opportunities to remedy vibrations and discuss challenges commonly encountered when performing analyses in this field.

A6.

Vectoring Nozzle and Afterburner – students' project

Group mates: Dorin Avsaid, Alon Dahan, Tomer Yehezkeal, Dor Shitrit, Tamir Ben Nachum, Yonit Zaslavsky, Michael Presman, Maor Schkolnik. Technion, faculty of aerospace Engineering

Advisor: Prof. Yeshayaou Levy, Technion, faculty of aerospace Engineering

Part 1: Afterburner

The objective of the Afterburner and Vectoring Nozzle project was to experience the process of designing, building and proving of both products. The motivation for creating an afterburner and a vectoring nozzle for a small jet engine is to enhance the performance of a small jet-powered UAV in terms of velocity and maneuverability. The objective of the afterburner segment of the project was to design, build and test an afterburner with a performance goal set to an additional 100N of thrust (approx. 35% increase) with a minimum of pressure loss.

In the first part of the project a theoretical study of all the stages along the afterburner was conducted. General Principals of operation and equations were compiled. Using data from the engine, the afterburner could be designed in more detail. An electric spark plug was chosen for the purpose of igniting the air-fuel mixture arriving at the flame holders, the design of the fuel injection system was made with 12 injectors by taking into consideration thermal expansion. The flame-holder configuration was chosen to be a profile of V-gutter and a comparison between one and two rings of flame holders, considering pressure loss and engine length, was conducted. The results of the comparison lead to the choosing of the two rings configuration. Evaporation and combustion lengths were calculated to give a total length to the after burner, and thus a conceptual model for the afterburner was made.

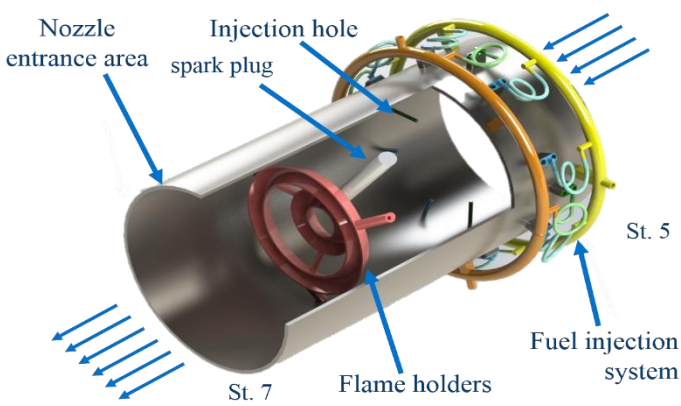


Figure 1- Afterburner stations and parts

At the second part of the project, a stress analysis of the flame holder parts was performed and materials were chosen for each part. In order to test the performance of the model, a prototype of the flame holders and a combustion chamber was constructed. By using the testing facility in the lab, the following parameters tested: temperature increase, combustion efficiency, pressure losses in the afterburner, and flame holder stability.

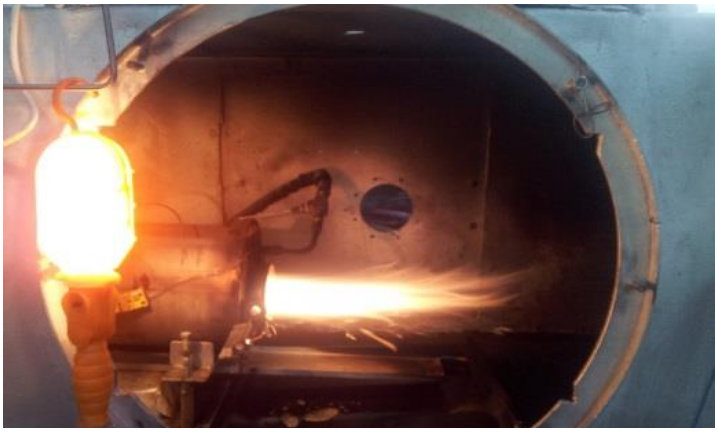


Figure 2- testing the flame holder configuration

Figure 3- manufactured flame holder

Using pitot tubes, thermocouple and gas analyzer we were able to gather the results.

The results show a great efficiency of up to 90% in the combustion process and an increase in temperature that will provide the goal of 35% increase in thrust.

A second experiment was devised in order to verify the accuracy of the depth of penetration equation. The experiment system consisted of: laser to illuminate the droplets, pitot tube, pressure measurement, injection needle, as can be seen in figure 4. Measurements of the penetration depth were done by image-processing. Average penetration depth measurements were taken in a number of points along the stream and were compared to the values given by the theoretical calculation.

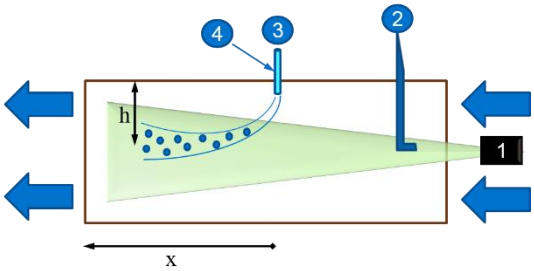


Figure 4- fuel injection experiment system

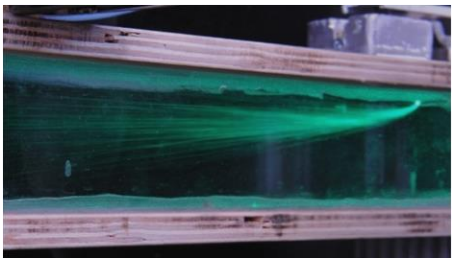


Figure 5- the injected droplets, illuminated by the laser

As seen in figure 6, the theory matches the experimental results very well, with maximal error of 8%. Thus we can conclude that the equation is indeed reliable. The results that were achieved show the effectiveness of the designs, and give an incentive for further development and optimization of the product in the future.

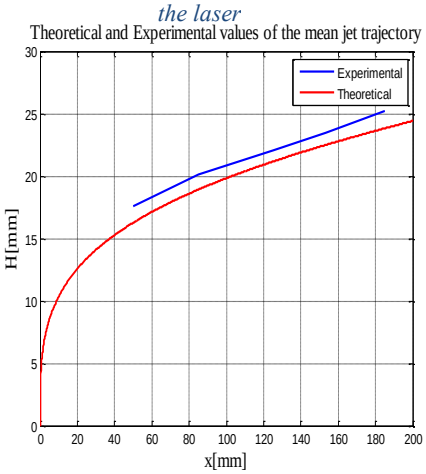


Figure 6- a comparison of the theoretical and the experimental mean jet trajectories

Part 2: Vectoring Nozzle

The project's aim was to design a vectoring nozzle fit for a small jet engine, placed after an afterburner designed in part 1. With the ultimate goal being the enhancement of jet propelled UAVs, the nozzle was to be a convergent one, seeing as it would only operate in subsonic conditions. The objective of the vectoring nozzle is twofold. The first is to allow for an increased mass flow while an afterburner is operational, by controlling the size of the exit cross-sectional area. The second is to enable thrust vectoring to a required angle in any direction around the original thrust axis. The advantages the vectoring nozzle would provide are improved maneuverability, reduced usage of the aerodynamic controls, and the enabling of the use of an afterburner.

The first part of the project consisted of coming up with a preliminary conceptual design for the nozzle. The process involved four stages, in which various concepts were studied and compared. First of all, several concepts were thought of, with only the ability to perform the basic functions of a vectoring nozzle as a limitation. After the initial stage, the concepts' viability and functionality were examined, narrowing the choice to four selected concepts. The third stage, after further study of the four concepts, was a more detailed comparison that included parameters such as pressure loss, dimensional increase of the original engine, and added weight. At the end of the third stage, two concepts remained. The fourth stage in the concept selection was comprised of an in-depth study of the two finalists, which included force analysis on the parts and actuators of the concepts, and time analysis of the vectoring process.

In the end, the “Exotic Fire” concept was chosen for further development in the second part of the project. It should be mentioned that the CAD program SolidWorks has been used throughout the process of design in order to visualize it and make sure of its logical and structural integrity.

After the conceptual design was done, the second part of the project could begin: detailed design of the chosen concept. The main focus was designing the parts so that they could operate under the loads acting on the nozzle caused by the pressure and extreme temperature of the air flow.

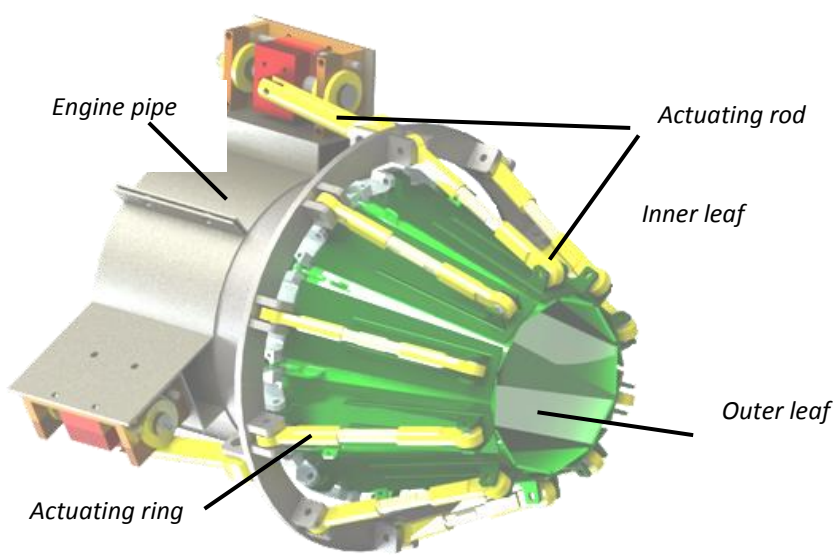


Figure 2- Exotic Fire. Three linear actuators control the actuating ring which determines the leaves thus the nozzle position.

Initially, a force analysis in the nozzle, based on the engine data from Gasturb simulations, was done in two segments: one for the symmetric scenario - opening and closing of the exit cross section (no thrust vectoring), and the

other for the asymmetric scenario of thrust vectoring.

After finding the most extreme forces acting in the system, the geometric dimensions of the load bearing parts could be more accurately determined. Some of the determinations required balancing between two contradicting effects on the system, such as the diameter of the actuating ring and the number of leaves that would form the nozzle. A larger ring would reduce the forces required from the actuators, but would increase the diameter of the engine. Similarly, a larger number of leaves would result in a rounder cross section, but would increase the complexity of the system.

Along with the parts that constitute the main body of the nozzle, the actuators that would provide the movement had to be selected. Along with the forces that they were required to provide, the actuators had to withstand the temperatures around an active afterburner, and for that purpose a temperature distribution study was conducted. Taking into consideration heat transfer from radiation and convection, the temperature distribution around the afterburner was found, and the type of the actuators along with their required distance from the afterburner were determined.

After finalizing the dimension and location of the various parts, a simulation of the nozzle was made in MATLAB. The algorithm simulated the connection between the movement of the actuators to the movement of the leaves, thus allowing to assess the direction of the thrust vector and the effective exit cross-sectional area at different configurations of the actuators. The results were gathered and displayed as a map of the operational limits of the nozzle, and an approximated mathematical control law for the actuators was found.

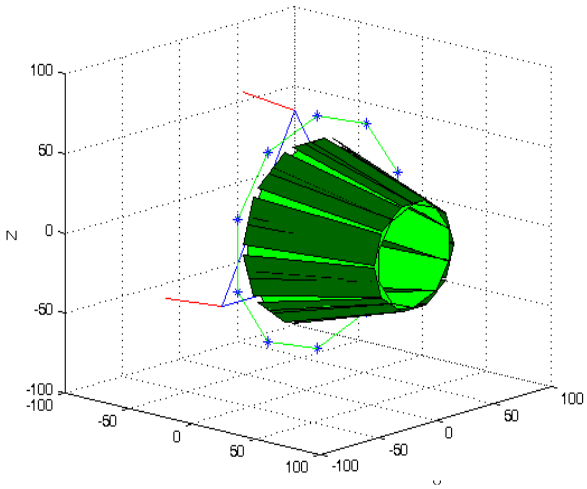


Figure 3-MATLAB model of the nozzle

In this part of the project a Gasturb simulation of the engine was also used to study the effects of changing the exit cross-sectional area on the performance of the engine.

Finally, after all the computer simulations and studies, a 3D model of the nozzle was printed and built in order to test the dynamics of the design and to make sure any assumptions\approximations along the way were valid.

For future research, a metallic prototype, that couldn't be manufactured within the timeframe of the project, should be constructed and be tested in the lab facilities in hot flow conditions according to the experiment plan that has been designed.

The Fuel Choices Initiative – Pushing Towards Alternatives

Dr. Anat Lea Bonshtien

Senior Manager of Technology and Regulation
Fuel Choices Initiative, Prime Minister's Office

The world has a dependency problem; a dependence on oil. It stems mostly from oil's massive and growing use in transportation and its monopoly as an energy source for transportation. Israel's main effort in addressing this global challenge is the national program for alternative fuels in transportation - The Fuel Choices Initiative. The Initiative has been budgeted for ten years in order to create regulatory stability and an investment horizon for market stakeholders, and includes tools to strengthen basic scientific and applied research in the field, simplify bureaucracy, and strengthen entrepreneurship and industry. Nine government ministries are partnered in the initiative and the activities of the Initiative are led, managed and coordinated by a designated administration in the Prime Minister's Office. Our mission is to serve as a catalyst for the reduction of global dependence on crude oil by establishing Israel as a center of knowledge and industry in the field of fuel alternatives. Our strategy is based on:

1. Reduce the share of crude oil in Israel's transportation sector by 30% by 2020 and by 60% by 2025 while supporting green growth. The process will build industry knowhow, position Israel as a center for industry and knowledge in the field, and serve as an example and catalyst for other countries. In addition, cheaper prices, lower carbon emission, and the developing industry in the field will support green growth. To accelerate the process, the Israeli government supports several pilots and demonstration of various technologies .
2. Turn Israel into a center of knowledge and industry of fuel alternative technologies by building infrastructure for development and implementation of the next generation of fuel alternative technologies. This goal is being achieved through investment in research infrastructure, including the establishment of multidisciplinary R&D and implementation centers, investments in start-ups and industry, and a "one-stop shop" for stakeholders in the field. The program emphasizes field experiments and demonstrations of significant scope that will reduce the technology's time-to-market. To complement these tools, we support innovation events and conferences, including a fuel alternatives summit meeting in which the Prime Minister's Prize for Innovation in Fuel Alternatives will be presented .
3. Raise the world's awareness of alternative fuels choices and of Israeli activity in the field and build a global partnership network from around the world in order to accelerate the process of finding solutions. The network will establish working contacts with various governments, research centers, NGOs, and business partners, with the assumption that in order to find substitutes for fuel, the world must join forces .

The presentation will provide a brief overview of the Fuel Choices Initiative goals and description of the program including the systematic approach for implementation of new fuels and technologies (starting from promoting basic research to supporting both regulatory and financially pilots and demonstration alongside providing a regulatory envelope for new fuels and vehicle types). It will then focus specifically on alternative jet fuel - on the growing demand for alternative in that sector and Israel's efforts in that arena.

B1

Thermal Management Ramifications of Acoustic Resonances in Turbine Blade Internal Cooling Channels

Beni Cukurel,

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Throughout the years, various cooling techniques have been developed to keep the turbine vane and blade metal temperatures below allowable limits. Internal cooling techniques route the compressor air, introduced from the blade root, through intricate serpentine passages inside the airfoil. Extracting heat from the rectilinear internal channel walls, the gas is eventually discharged into the main stream from the film cooling holes, trailing edge slots and blade tip.

To promote heat exchange, passage walls are commonly lined with repeated geometrical disturbance elements, which yield improved mixing with the free stream and induce high levels of turbulence to the core flow. This approach is effective in raising the heat transfer to considerably higher levels, at the expense of an inevitably enlarged pressure drop penalty. The common types of such protrusions include a sequence of rib-shaped turbulators which induce periodic tripping of the boundary layer, unbounded shear layer formation and consecutive separation, followed by an eventual flow reattachment and wall-bounded shear layer development.

In an attempt to investigate the acoustic resonance effect of forward and aft serpentine passages on internal convection heat transfer, the present work examines a typical high pressure turbine blade internal cooling system, based on the geometry of the NASA E3 engine. In order to identify the associated dominant acoustic characteristics, a numerical FEM simulation (two-step frequency domain analysis) is conducted to solve the Helmholtz equation present and absent of source terms. Mode shapes of the relevant identified eigenfrequencies (in the 0-20kHz range) are studied with respect to induced standing sound wave patterns and the local node/antinode distributions. An example of leading edge cavity resonance mode for frequency 9013Hz is shown in Figure 1. It is observed that despite the complexity of engine geometries, as a first order approximation, the predominant resonance behavior can be modeled by a same-ended straight duct.

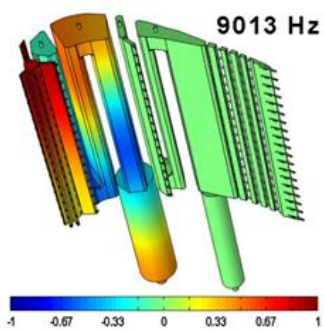
Therefore, capturing the physics observed in a generic geometry, the heat transfer ramifications have been experimentally investigated in a scaled wind tunnel facility at a representative resonance condition. Focusing on the straight cooling channel's longitudinal eigenmode in the presence of an isolated rib element, the impact of standing sound waves on convective heat transfer and aerodynamic losses have been demonstrated by liquid crystal thermometry, local static pressure and sound level measurements. The corresponding mode shape patterns of the facility are predicted numerically and verified experimentally by local SPL measurements. For a squared fence obstacle of 7.5% passage blockage ratio, subjected to passage Reynolds number of 134,000, a longitudinal standing wave is excited by harmonic forcing at 120Hz (St=0.17) and 131dB source SPL.

Contrasting the numerically predicted resonance behavior of a generic turbine blade cooling circuit with experimentally investigated rib flow heat transfer in the presence of a standing sound wave,

there appears to be a strong indication of internal heat transfer modulation associated with the serpentine pass resonance modes. The findings of the numerical simulation indicate the existence of distinct acoustic resonances in the excitation range relevant to typical turbine environment (0-20kHz). Exciting distinct eigenmodes in the serpentine pass give rise to longitudinal standing sound waves, which obey the base and higher harmonic acoustic behavior of straight resonance tube geometry. The experimental heat transfer investigation on the isolated rib obstacle indicates a significant influence on the local flow field and Nu distributions. Although the global heat transfer effect reduces gradually further downstream, the presence of a subsequent rib perturbator would likely counteract this gradual diminution – as encountered in practical applications for typical rib pitch-to-height ratios of ~10-20. Moreover, since the integral pressure drop penalty remains constant, it can be inferred that an augmentation of rib-roughened thermal performance via periodic forcing is conceivable.

The Nusselt number and static wall pressure distributions indicate the flat plate boundary layer ahead of the rib to be entirely impervious to resonance excitation, whereas the separated flow in the wake of the rib is notably affected. Reaching an earlier reattachment, the extent of the recirculation bubble is reduced: shifting the centerline maximum heat transfer location upstream by 3.5 rib heights, or 37%, and inducing a spanwise straightening of the initially curved reattachment line, shown in Figure 2. As the bell-shaped Nu curve shifts upstream with respect to the unexcited case, the heat transfer is locally enhanced by the earlier point of reattachment. The static wall pressure measurements support the previous observations, indicating earlier recovery in the prior separation region. On the other hand, the integral pressure drop penalty remained unaffected by the standing wave excitation.

The present findings demonstrate the influence of standing waves on turbine blade internal heat transfer, which can be a potential mechanism conducive to thermal performance enhancement.



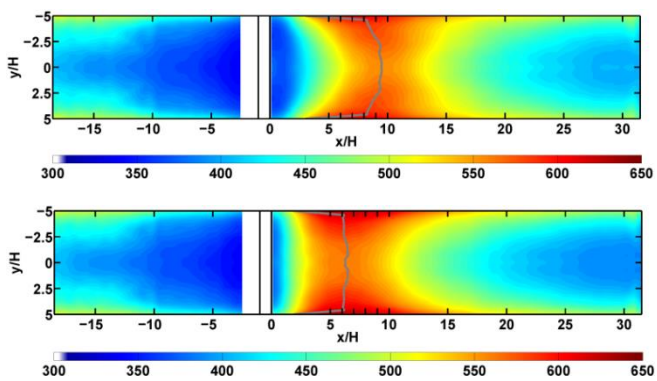


Figure 4: Leading edge cavity Resonance Mode Figure 5: Nu Distribution; Baseline and Excited

References:
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Han, J.C., S. Dutta, and S.V. Ekkad, Gas Turbine Heat Transfer and Cooling Technology. 2000, London, UK: Taylor & Francis.
Cukurel, B., C. Selcan, and T. Arts, Film Cooling Extraction Effects on the Aero-Thermal Performance of Rib Roughened Cooling Channel Flow. ASME Journal of Turbomachinery, 2013. 135(2).
Selcan, C., B. Cukurel, and J. Shashank, “Heat Transfer Implications of Acoustic Resonances in Turbine Blade Internal Cooling Channels”, ASME Turbo Expo 2015, GT2015-43142.

B2.

Identification and Treatment of Separation Phenomena during the CFD Design on Turbomachinery Blades

Zvi Gorelik,

Bet Shemesh Engines Ltd, Westeren Industrial Park, Bet shemesh,

The first step in the aerodynamic design of turbomachinery blades/vanes is a 2-D or through flow calculation of the flow to obtain velocity triangles and build initial airfoil sections geometry.

Following this step CFD analysis is conducted in order to identify eventual problems and to fix them. Most of the problems are cases of flow separation.

The presentation will include in it an explanation about the nature of flow separations and some of the changes in design in use to eliminate such case. To complete the presentation, a case of a separation which was revealed by the CFD analysis of the flow in the last stage stator of an existing two stages axial compressor will be discussed. In this case the usual changes in design were implemented and CFD verified without any success. Finally the problem was solved by an unusual (and normally not recommended) change which created a vane root clearance, where it did not exist previously. To conclude the presentation an explanation of the influence of this change on the flow will be proposed.

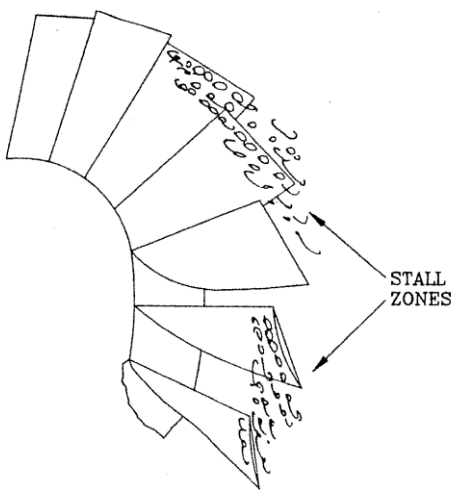
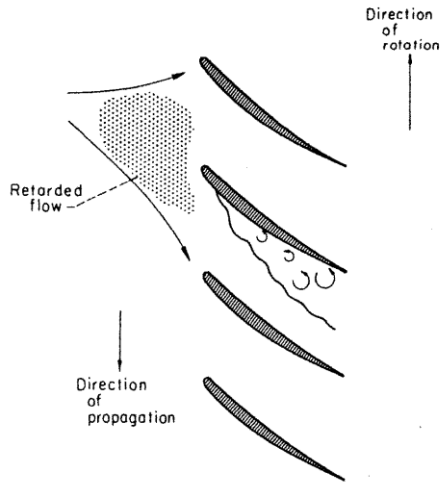


Illustration of Rotating Stall on an Axial Compressor Rotor



ב Propagating Stall in a Cascade Taken from Graham and Guentert (1965), Also shown in Emmons, et al. (1955)

במהלך תכן פרופילים של להבים עבור מדחסים וטורבינות, לאחר שלב התכן הדו-ממדי ובניית פרופילים, מקובל לבצע אנליזה CFD לזיהוי בעיות אפשריות בתכן וטיפול בהן. הבעיות העיקריות שמתגלות בשלב זה הן בעיות ניתוקי זרימה. בהרצאה יינתן הסבר למהות התנתקות זרימה במעבר בין שני להבים ויסוקרו שיטות מקובלות למניעת התופעה. בהמשך יתואר מקרה בו נתגלתה התנתקות זרימה בסטטור דרגה אחרונה של מדחס צירי דו-דרגתי שעבר אנליזה בכוונה לשפר את התכן שלו. במקרה זה נוסו (ברמת CFD) השיטות המקובלות לפתרון הבעיה ונכשלו.

בסופו של דבר נפתרה בעיה ע"י שינוי לא מקובל (ובדרך כלל לא רצוי) של פתיחת מרווח קצה הלהב.

בסיום ההרצאה יוצג גם הסבר פיזיקאלי להשפעה החיובית של שינוי זה.

B3.

Optimization using CFD: methods and tools for engineers

Dr. Khosid Savely,

Manor, Rafael

אופטימיזציה עם CFD: שיטות וכלים למהנדס

הנושאים שיוצגו, עם דגש על שימוש ב- CFD בתכן אווירודינאמי:

- צורך באוטומציה ואופטימיזציה של תהליך תכן הנדסי;
- דוגמאות תכן אופטימאלי;
- בשלות שיטות וכלים מודרניים לאופטימיזציה בתכן.

אופטימיזציה בתכן הנדסי מתפתחת בשני כיוונים: Shape_Optimization ו- Topology_Optimization. כאשר ל- Topology_Optimization יש פוטנציאל גדול יותר, שימוש ב- Shape_Optimization הינו בשל יותר לשימוש הנדסי. במצגת יוצגו דוגמאות של שימוש ב- Shape_Optimization בתכן אווירודינאמי והסבר לגבי אלגוריתם גנטי שמותאם היטב לשימוש באופטימיזציה בתכן. תוצג גם שיטת אופטימיזציה מודרנית שנקראת Adjoint_Optimization .

אוטומציה ואופטימיזציה של תכן אווירודינמי מתבצעים באמצעות שילוב של כלי סימולציה (CFD) עם תוכנה שמאפשרת שליטה בפרמטרים גיאומטריים ושינוי שלהם בכיוון האופטימאלי. במצגת תוצג דוגמה של שילוב בין הכלים להשגת תכן מיטבי.

C1

Alternative Fuels for Gas Turbine and Jet Engines

Prof. Yeshayahou Levy

Head, Turbo and Jet Engine Laboratory, Faculty of Aerospace Engineering, Technion

Typically, the fuel driving turbo jet and turbo shaft engines is kerosene. Further advancements in turbomachinery has lend to the adoption of the technology for the development of turbo generators as well as turbo shaft units for marine and land transportation. All types of engine use similar combustion chamber and operate using similar principles. Turbo jet engines and turbo shaft engines for aeronautical applications make use only kerosene based jet fuel while the turbo shaft for marine application and land based applications operates also on Diesel oil. However turbo generators operates mainly on Natural Gas (NG) while few plants still make use of kerosene (jet fuel) and Diesel oil and several units are designed to operate on either fuel. The world concern about global warming has led to the demand for zero (CO2) emission and as a result, to the development of biofuel that are supposed to be "drop in" fuels, i.e. to perform with 100% compatibility with respect to the original fossil based jet fuel. In addition, recent discovery of NG in Israel has pointed out to the possibility of producing economically methanol out of NG which is mainly composed of methane. The methanol, which is liquid fuel, can be used to drive turbomachinery of either kind, however it has only about 50% of the energy density as compared to conventional jet fuel and therefore twice as much fuel has to be burn in order to produce an equivalent amount of heat.

The presentation focuses on the combustion characteristics of the different alternative fuels and the consequent requirement for the design modifications while converting a unit from one fuel to another. Two examples will be discussed; the first being the conversion of a gas turbine from operating on kerosene based jet fuel to operation on methanol, see preliminary results in Figure 1, and the other refers to conversion of a turbofan engine into a turbo generator while changing its fuel from kerosene to NG.

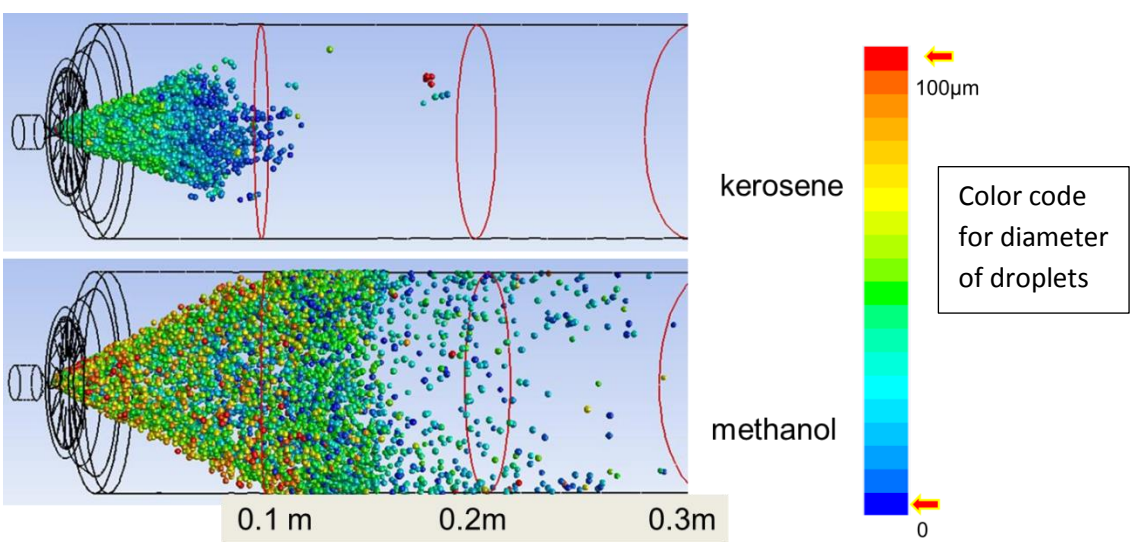


Figure 1. Droplets distribution and diameter during kerosene and methanol combustion in a generic swirl stabilized burner at equivalent thermal power

C2.

Long Term Experience of Methanol Firing in Utility Gas Turbine

[1] B. Chudnovsky, [2]M. Reshef, [3] M. Keren, [3]S. Baitel

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[3]DOR Chemicals, POB 10036 Haifa, Israel, 26110

Recently methanol's use as a fuel is becoming more attractive. This is significantly being influenced by recent trends in the global energy market. Firstly, prices of oil and its related products have been at a record high recently. This has prompted consideration of other alternative energy sources that are not oil dependent. A second key issue has been growing global concern for environment and emphasis being placed on the use of fuels with lower SO_2, NOx and particulates emissions. Methanol offers these advantages, being a derivative of natural gas which is partly de-linked from oil, and is a clean burning fuel.

In this manner in Israel Electric Corporation full scale test of methanol firing of a Pratt & Whitney FT4C TWIN PAC 50 MWe GT was performed. The obtained results clearly show that with minor low cost fuel system retrofit methanol firing leads to significant NOx, SO2 and particulates emission reduction. NOx emissions were reduced by more than 80% and are equal 100 mg/dNm3 at 15%O2. It is less than the required standard even with water injection operation mode (the standard is 120 mg/dNm3 at 15%O2 of NOx emission). SO2 emissions were reduced to zero with methanol firing. Particulate emissions vary from 1.3 to 1.6 mg/dNm3 at 15% O2 with methanol firing, while with LFO this parameter was 13-37 mg/dNm3 at 15% O2.

However, it should be noted that methanol has a significantly lower calorific value, which is, for example, half of diesel oil and requires therefore some specific modification in gas turbine equipment. First, the existing fuel nozzles are too small for the higher volumetric methanol flow and should be replaced by high flow fuel nozzles. The existing fuel supplying pump also should also be upgraded to the higher methanol flow. Modulating valve was also replaced due to the same reason.

The paper first gives an overview of some of the key technical considerations of the gas turbine conversion from diesel oil to methanol firing, and results of long term operation of gas turbine fired by methanol.

Based on the obtained results one may concluded that methanol is an attractive alternative fuel for meeting the energy needs of niche markets in an economic and environmentally sustainable manner, utilizing existing and/or new power generation units.

C3.

Performance Monitoring of IEC Industrial Gas Turbines,

V. Litinetski, O. Weiss, A. Gutman.

Israel Electric Corp.

The paper describes an actual approach to continuous performance monitoring of 250MW-class industrial gas turbines (GT). This approach was gradually developed in Generation Division of Israel Electric Corporation (IEC) and successfully used for more than 10 years in actual gas turbines operation.

The paper underscores that the main goal of the performance monitoring is a detailed analysis of GT operation events, providing a basis for solution of operational problems and decision making as well. Such analyses could effectively be performed only by highly educated personnel having strong knowledge in GT theory, equipment and operation. In fact, this goal could only be achieved with reliable, specially selected, pre-processed and verified operational data that must be properly collected and preliminary evaluated by specially trained personnel.

This monitoring approach is exemplified with several case studies demonstrating results of sophisticated analyses and actual solutions that were required in the course of continuous performance monitoring. The case studies include the following events: Compressor failure; Control System problems (Temperature Control Curve anomalies); optimization of compressor off-line washings; multistage air filter choice and operation. The text is illustrated with actual performance monitoring results.

The paper materials have a general importance; it could be helpful for other gas turbine operators and used in actual performance monitoring of other gas turbine types.

D1.

Cold Spin Test (CST) of Silicon Nitride Discs for Jet-Engine Applications

Ido Koresh1, Shimshon Bar-ziv1, Ahron Halevy2, Anat Shenar1, Shlomit Zamir1

Advanced Materials Department, MANOR, RAFAEL.

Jet Propulsion Department, MANOR, RAFAEL.

סיליקון ניטריד (Si3N4) הינו חומר קראמי בעל חוזק גבוה, עמידות בזחילה ועמידות לחמצון. יתרונותיו של הסיליקון ניטריד על פני חומרים מתכתיים אחרים הינם: צפיפותו הנמוכה (3.25 gr/cc) ויכולת השימור של התכונות הנ"ל בטמפרטורה גבוהה.

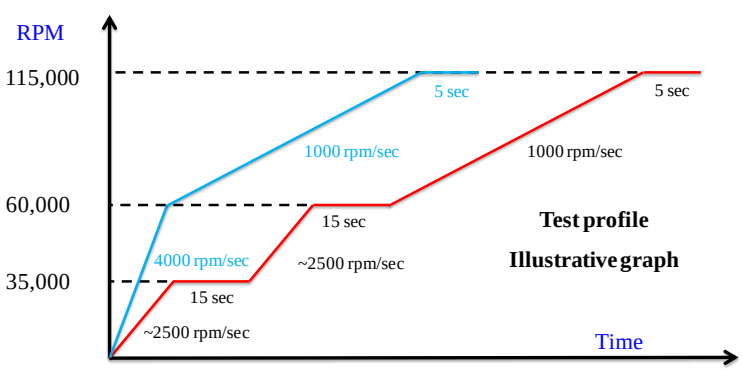
אחד הפרמטרים בשיפור היעילות האנרגטית של מנועי סילון הינו העלאת טמפרטורת העבודה בתא השריפה. מרבית הטורבינות הקיימות כיום בשוק הינם מתכתיות (לדוגמא: סגסוגות ניקל). מכאן חומרי המבנה משמשים כחסם עליון עבור טמפרטורת העבודה בתא השריפה. החלפת חומרי המבנה לסיליקון ניטריד מאפשרת עליה בטמפרטורת העבודה (1100-1400oC) ובכך עליה ביעילות. יישום טורבינה סיליקון ניטריד בטמפרטורה גבוהה מציב אתגרים ודרישות טכנולוגיות: חוזק (flexural strength) גבוהה ושימורו עם העלייה בטמפרטורה, עמידות בזחילה ,חסינות בפני פגיעת גוף זר (FOD – Foreign Object Debris) ועמידות בפני נזקי חמצון.

דסקת סיליקון ניטריד פותחה ברפאל על בסיס טכנולוגית אבקות. אבקת סיליקון ניטריד הכילה תוספים אורגנים (קשרנים - Binders) ואנ-אורגנים (תוספי סנטור - sintering aids), ועברה תהליך CIP (Cold Isostatic Pressing) בטווח לחצים של 1000-3000 atm לקבלת "גוף ירוק". הוצאת התוספים האורגנים מה"גוף הירוק" (גוף כבוש) בוצעה בתהליך שרפה באוויר (500-600oC). הדגם עבר ציפוף נוסף בתהליך סנטור בטמפרטורה גבוהה (1700-1800oC) באווירה אינרטית. צפיפות הדגמים לאחר סנטור הייתה בערך של 3.17 gr/cm3 ופילוג חוזק כפיפה בטווח צר של 642 MPa ±23σ. לבסוף הדגם עבר תהליך השחזה לצורתו הסופית (איור 1).

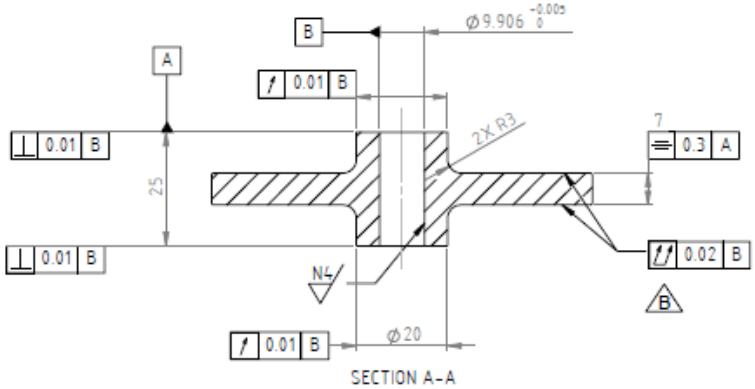
במסגרת ההכנות לניסוי Cold Spin Test (CST) בוצעה אנליזת מאמצים עבור דסקת סיליקון ניטריד המסוחררת במהירות סיבוב של מנוע סילון (115,000 RPM). בשורש הדיסקה התקבל מאמץ מקסימאלי של 395 MPa. לקראת הניסוי בוצעה ביקורת ממדית, בחינת פני הדגמים בסטריאו-סקופ ואיזון סטאטי (0.1 gr·mm).

בניסוי CST נבחנו שתי דסקאות סיליקון ניטריד תוצרת רפאל במהירות סיבוב מקסימאלית של 115,000 RPM זמן שהייה של 5 שניות ופרופיל הניסוי מוצג ב איור *2*. במהלך הניסוי בוצעו שני סוגי פרופיל – קצב עלייה "איטי" המוצג באדום וקצב עלייה "מהיר" המוצג בכחול. כל חלקי הסיליקון ניטריד עברו בהצלחה את הניסוי ויש לציין שלא אותרו פגמים בפני הדגמים עם תום הניסוי.

בלמ"ס - ללא סיווג עסקי



איור 2: פרופיל ניסוי CST - אדום – קצב עלייה "איטי". כחול – קצב עלייה "מהיר" (גרף אילוסטרטיבי).



איור 1 שרטוט דסקת סיליקון ניטריד, D=83.6 mm.

D2

Additive Manufacturing for Jet Engine Applications

טכנולוגיות Additive Layer Manufacturing עבור הנעה סילונית

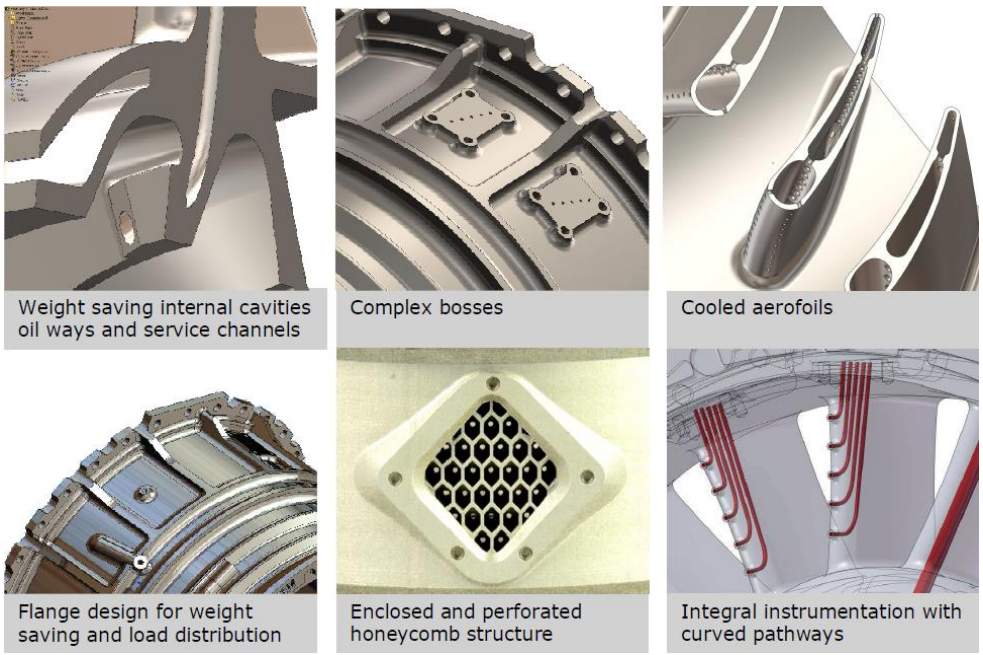
Dolev Ohad,

Rafael, Israel,

אוהד דולב – תחום טכנולוגיות ייצור מתקדמות ,שט"מ ,מנו"ר ,רפאל

תחום ה- Turbo Machining טומן בתוכו שימוש בחלקים מורכבים ובמגוון חומרים. החלקים העיקריים הינם בעלי אופי צורתי תלת מימדי, ניתן לייצרם בשיטות קונבנציונאליות מוכרות כגון יציקה ועיבוד שבבי.

במסגרת הפיתוח הוחלט לחפש דרכים חלופיות בהם ניתן לפשט את הייצור ולצמצם את העלויות. הטכנולוגיה שנבחנה נקראת ALM (Additive Layer Manufacturing) (מוכרת גם כהדפסה תלת ממדית). טכנולוגיה זו קיימת ומוכרת בעולם ובעלת כמה יתרונות בולטים כגון: צמצום כמות חלקים ובנייתם כחלק יחיד, צמצום משמעותי בזמן ייצור, הוזלת מחיר והגדלת רובוסטיות. חברות כגון: GE, Turbomecha, AVIO, Rolls Royce, Part&Whitney ועוד רבים כבר מצאו שימושים שונים בטכנולוגיה בעיקר לחלקים הסטטיים במנועים.
טכנולוגית (ALM(Additive Layer Manufacturing נבחנת כ 4 -שנים ברפאל גם עבור רכיבי מנוע סילון זעיר במגוון חומרים ואפליקציות.
בעזרת טכנולוגיה זו ניתן להגיע לאפשרויות ייצור של גיאומטריות מורכבות ביותר יחד עם
עמידה מצוינת בביצועים הנדרשים ע"פ שיקולי ייצור. שילוב החלקים במסגרת הפיתוח מאפשרת לחסוך זמן משמעותי בהגעה לניסויי הדגמה, אשר מקנים ביטחון להמשך הדרך. שילוב הטכנולוגיה פותח אופקים חדשים ולא מוכרים בעיקר באופי החשיבה והתכנון. בחלקים מסוימים השימוש בטכנולוגיה מאפשר הפחתת משקל ללא פגיעה בחוזק שבעזרתה מקבלים עליה בביצועים. קיימת תכנית הוכחה לטכנולוגיה שבה נבחנים מספר חלקים גם סטטיים וגם סובבים.
במצגת זו יוצגו דוגמאות מעולם ה-Turbo Machining (מחברות בעולם) אשר מצאו שימושים שונים במגוון מוצרים בהם מתקני ניסוי, חלקים סטטים שונים במנועים, שבעזרת הטכנולוגיה יכולים לתת פתרונות יצירתיים ובעיקר רובוסטיים יותר. בתמונות המצורפות נמצאות דוגמאות לשימוש שהטכנולוגיה מציעה וביניהן תעלות אינטגראליות לזרימת אויר קירור, או תעלות למכשור מדידה, שניתן לייצרן אך ורק בטכנולוגיה זו ולא בשום שיטת עיבוד אחרת.



D3.

Numerical and Analytical investigation of cracks in Turbine Exhaust Case Struts of F100 engine

Cap. Shani Eitan,

IAF, Propulsion Branch

High number of crack findings have occurred on IAF F100 engines' Turbine Exhaust Cases' Struts. Crack lengths were above technical manual's limits. Findings led to many engine removals. Repair procedure that was in the manual was never done before by other worldwide fleets.

Decrease in exhausts availability and increase in amount of findings have led to an analytical investigation that examined the mechanical margin of safety of cracked struts.

The loads on the strut (aerodynamic forces due to gas flow, and high temperature) were calculated analytically. Margin of safety was calculated in 3 different methods: 1. Theory of elasticity classic method – calculation based on bending and shear loads in critical section. Cross section with a crack loses its geometric rigidity and therefor increases stresses. 2. Fracture mechanics – calculation using stress intensity factor K1C. 3. Finite Elements Method. Stress analysis using a FEM software and modeling the strut using CAD software.

חקירה אנליטית ונומרית למגבלת סדק בעוקת פליטה (אגזוז) של מנוע F100-DPI

סרן שני איתן ח"א

במנועי הבז והנץ של חיל האוויר נמצאו ממצאי סידוק רבים בסמוכת עוקת אגזוז (Turbine Exhaust Case Strut – TEC) אשר חרגו ממגבלות אורך הרשומות בספרות אחזקת המנוע. הממצאים גרמו להסרות רבות של מנועים. תהליך התיקון הקיים בספרות אחזקה לא התבצע מעולם ע"י מתפעלים אחרים.

עקב ירידה בזמינות האגזוזים ועלייה בכמות הממצאים, נדרש לבצע חקירה הנדסית אשר תבחן את מרווח הביטחון לכישלון מכאני של סמוכת האגזוז עקב נוכחות סדק החורג ממגבלות יצרן.

העומסים על הסמוכה (כוחות אוירודינמיים עקב זרימת הגז במנוע, וכן טמפרטורות גבוהות) חושבו בצורה אנליטית. מרווח הביטחון חושב כתלות בגודל הסדק באמצעות שלוש שיטות שונות: 1. תורת אלסטיות קלאסית – חישוב המתבסס על מאמצי כפיפה וגזירה בחתך העניין. חתך זה מאבד מן הקשיחות הגיאומטרית שלו כתוצאה מקיומו של סדק ועל כן המאמצים בו גדלים. 2. מכניקת השבר – חישוב באמצעות מקדם עוצמת מאמץ בסדק. שיטה 3 – שיטה נומרית – אלמנטים סופיים. חישוב מאמצים באמצעות תוכנה, מידול סמוכה, חישוב מטריצת קשיחות, מטריצת הזזות ומטריצת מאמצים.

E1

Improvements in Cooling of Gas Turbines

שיפור בקירור של טורבינות גז.

Dr. david Lior,

R-Jet Engineering

בתכן טורבינות גז נעשה שימוש באויר המדחס לקירור חלקים חמים וקריטים של המנוע כגון להבי סטטור הטורבינה, דפנות פנימיות של תא השריפה דיסקות הטורבינה וכו ' וזאת במטרה למנוע מאמצים תרמים ועוותים של חלקים חמים אלו. שיטה זו גורמת לאובדן אנרגיה הודות

למפלי הלחץ והטמפרטורה של זרימת האויר אשר מגיעה לספיקות של עד 15% בטורבינות גז מודרניות.

קירור מעטפות חיצוניות של המנוע בעזרת זרימה אויר או נוזל חיצוני גורם גם הוא לאובדן אנרגיה המושקעת במשאבות או מאוררים .פתרון אלטרנטיבי הוא לבודד אותם מבחוץ—אולם פתרון זה גורם למאמצים ומעוותים תרמים שעשויים לפגוע בשלמות הגיאומטרית ובחלקים עמוסים גם בהורדת מקדמי הביטחון ואורך חיים.

מוצג בזה תכן שונה לקירור הישים במיוחד לטורבינות גז עם רקופרטור (מחליף חום פנימי)., לפיו החלקים החמים מקוררים בעזרת אויר המדחס מבלי לפגוע בנצילות המחזור. העיקרון הוא השימוש באויר שנלקח מהמדחס עוקף את מחליף החום ומקרר ישירות את החלקים החמים. תוך כדי קירורו הוא מתחמם קרוב לטמפרטורות החלקים המקוררים ומתערבב בזרימה הראשית. בדרכו אל הטורבינה.

עקיפת מחליף החום יוצרת הגדלת היעילות האפקטיבית שלו הודות להגדלת יחסי הספיקות של הזרימה החמה לקרה. הגדלת היעילות האפקטיבית משפרת את נצילות מחליף החום ומפצה על ההפסדים הנגרמים עקב השימוש באויר הקירור.

מתואר תכן ספציפי של קירור שבלול טורבינה בשיטה הנ"ל כולל חישובי CFD.חישוב מתמטי מראה את הערך האופטימלי של הקירור ל נצילות מחזור אופטימלית.

Station	W kg/s	T K	P kPa	WRstd kg/s				
amb		288.00	101.350		PWSD	=	40.1	kW
1	0.307	288.00	101.350		PSFC	=	0.2260	kg/(kW*h)
2	0.307	288.00	99.323	0.314	Heat Rate=		11242.6	kJ/(kW*h)
3	0.298	420.73	293.003	0.125	Therm Eff=		0.3202	
31	0.298	420.73	293.003		WF	=	0.00252	kg/s
35	0.298	947.54	288.608		P35/P3	=	0.98500	
4	0.301	1277.00	277.063	0.233	P7/P6	=	0.98000	
41	0.301	1277.00	277.063	0.233	s NOx	=	0.81730	
49	0.301	1051.51	106.230		incidence=		0.00000	°
5	0.301	1051.51	106.230	0.550	XM8	=	-0.9580	
6	0.301	1051.51	105.487		A8	=	5.756E-4	m²
7	0.301	551.26	103.377					
8	0.301	551.26	103.377	0.410	P8/Ps8	=	0.50495	
Bleed	0.009	288.00	99.323		WBld/W2	=	0.03000	
Ps0-P2=	2.027	Ps8-Ps0=	103.377		P2/P1	=	0.98000	
					Ps8	=	204.727	kPa
Efficiencies:	isentr	polytr	RNI	P/P	W_NGV/W2	=	0.00000	
Compressor	0.7800	0.8103	0.981	2.950	WCL/W2	=	0.00000	
Burner	0.9900			0.960	Loading	=	100.00	%
Turbine	0.8550	0.8398	0.479	2.608	e45 th	=	0.85500	
Heat Exch.	0.8300							
Generator	0.0000				PW_gen	=	0.0	kW
Spool mech Eff	0.9850	Nom Spd		0 rpm	P6/P5	=	0.9930	

hum [%]	war0	FHV	Fuel
60.0	0.00644	49.736	Natural Gas

טבלה א :

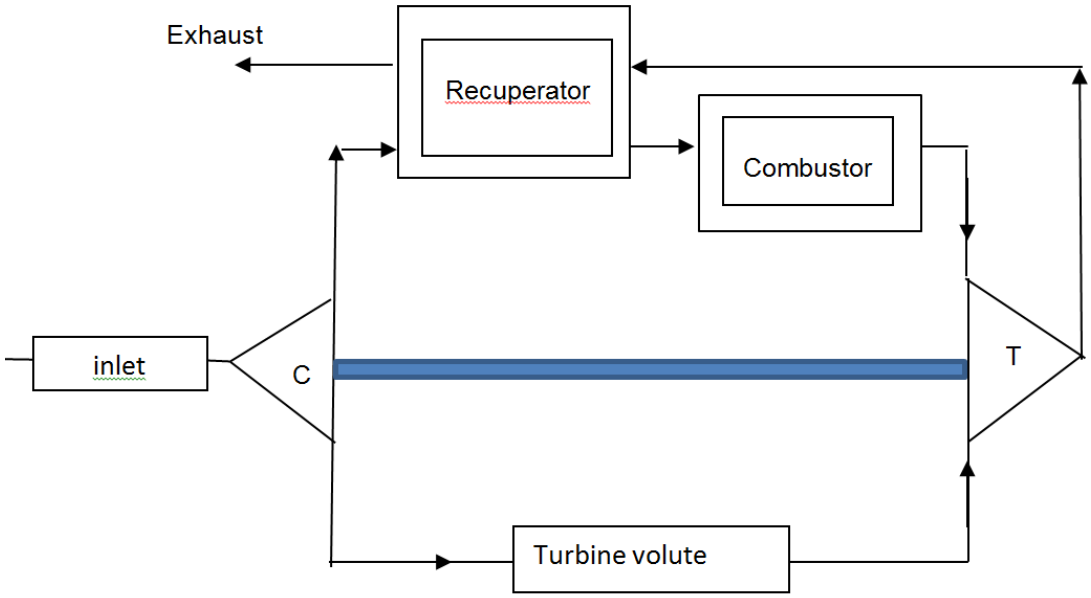
מחזור טורבינת גז 40 קוו"ט - ללא קירור, יעילות מחליף חום 83% , נצילות תרמית 32%.

טבלה ב :

מחזור טורבינת גז 40 קוו"ט - עם קירור עוקף 10% של מחליף החום, יעילות מחליף החום עולה ל-88%

Station	W kg/s	T K	P kPa	WRstd kg/s				
amb		288.00	101.350					
1	0.307	288.00	101.350		PSFC	=	0.2059	kg/(kW*h)
2	0.307	288.00	99.323	0.314	Heat Rate	=	10242.0	kJ/(kW*h)
3	0.298	420.73	293.003	0.125	Therm Eff	=	0.3515	
31	0.298	420.73	293.003		WF	=	0.00229	kg/s
35	0.267	978.99	288.608		P35/P3	=	0.98500	
4	0.270	1310.00	277.063	0.211	P7/P6	=	0.98000	
41	0.300	1277.43	277.063	0.232	s NOx	=	0.96085	
49	0.300	1051.59	106.230		incidence	=	0.00000	°
5	0.300	1051.59	106.230	0.550	XM8	=	-0.9556	
6	0.300	1051.59	105.487		A8	=	5.573E-4	m²
7	0.300	516.59	103.377					
8	0.300	516.59	103.377	0.396	P8/Ps8	=	0.50495	
Bleed	0.009	288.00	99.323		WBld/W2	=	0.03000	
					P2/P1	=	0.98000	
Ps0-P2=	2.027	Ps8-Ps0=	103.377		Ps8	=	204.727	kPa
Efficiencies:		isentr	polytr	RNI / P/P	W_NGV/W2	=	0.10000	
Compressor		0.7800	0.8103	0.981 / 2.950	WCL/W2	=	0.00000	
Burner		0.9900		0.960	Loading	=	100.00	%
Turbine		0.8550	0.8397	0.479 / 2.608	e45 th	=	0.85232	
Heat Exch.		0.8800						
Generator		0.0000			PW_gen	=	0.0	kW
Spool mech Eff		0.9850	Nom Spd	0 rpm	P6/P5	=	0.9930	

hum [%]	war0	FHV	Fuel
60.0	0.00644	49.736	Natural Gas



ציור 1- מחזור עם מחליף חום וקירור = TURBINE VOLUTE

E2.

A View of the Future of Civil Transport Aircraft Propulsion Systems

Ilan Berlowitz
Israel Aerospace Industries
Bedek Aviation Group/Aircraft Programs Division

Civil transport aircraft are designed to meet the requirements of airlines that operate them, in particular; performance and operating costs. However, the environmental impacts, particular the global warning, and the huge increase of fuel cost, have substantial effects on passenger aircraft design.

Modern propulsion systems have reached a high level of performance and efficiency. However, it is clear that both turbine entry temperature (TET) and overall pressure ratio (OPR) of aircraft gas turbine engines will keep increasing, leading to a further improvement of specific fuel consumption (SFC) and specific thrust. Consequently, there will be an increased use of bleeds, variable stator vanes and turbine clearance. This in turn will result in increased control systems complexity and enhanced safety schemes to prevent turbine overheat and rotor over-speed.

Beside the propulsive efficiency, which is in direct correlation to specific thrust or bypass ratio of an engine, the second main contributor to reduced fuel consumption and emission is the thermodynamic efficiency.

The presentation outlines the new technologies expected to be incorporated in futuristic civil transport aircraft propulsion systems contributing to low emissions products and fuel efficiency.

E3

Twin Spool Engine Control Using Partial Engine Model

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Two strategies are usually used for gas turbine engines control:

1) Referred fuel flow versus referred speed limitation,
2) Referred rate of change of speed (NDOT) versus referred speed limitation.

For twin spool engines, these control strategies are complex, and do not provide precise and optimal control as result of reciprocal influence of the two spools in transient.
Most gas turbine engines employ the modern computers for digital control systems. Using the fast computers, it is possible to solve the "partial engine model" equations in real time. For precise control, we don't include the compressor maps and don't use the measured high temperatures in the partial engine model. This idea with use of N_L or combustor temperature as controlled parameter (instead of N_H), enable to create precise and fast control systems.

The following ten principles for precise and fast control of twin spool engines are presented in the lecture:

1. To use effective control algorithms including the partial engine models corresponding to modern computers.
2. Do not to use compressor maps (HPC, LPC, IPC) in the partial engine models because the maps are vary from engine to engine.
3. In the control algorithms, do not use functions calculated from simulations or tests on an individual engine

(functions as $G_{f,cor} = f(N_{cor})$ or $\frac{dN}{dt}|_{cor} = f(N_{cor})$).

4. In the control algorithms, do not use measured high temperatures (T_4, T_5) because the sensors lag and temperature distortion.
5. To use the corrected control parameters ($K_{P,cor}, K_{I,cor}, \tau_{filter,cor}$) for adaptive control which is less dependent on flight conditions.
6. Do not use low pass filters for controlled parameters (PLA). This practice increases settling time.
7. To determine the order of priorities for danger protection (LPC, IPC, HPC stalls or maximal combustor temperature…). The controlled parameter (PLA) is chosen according to the dominant danger.

8. For example, combustor temperature has to chosen as controlled parameter for following order of priorities:

a) maximal combustor temperature,
b) LPC stall,
c) IPC stall,
d) HPC stall.

9. For optimal time control, a command (PLA) has to be maximal at acceleration and minimal at deceleration (bang-bang), the combustor temperature has to be close to maximal, stall margins – close to minimal at acceleration.

10. To represent the controller model in the discrete form (z-transform).

11. A control has to include protection from sensor failures.

Examples for twin spool engine control are presented in the lecture. The control is based on the formulated principles. In the 1st example, the controlled parameter (PLA) is N_L, in the 2nd example it is combustor temperature. In these controls the settling time is 35-40% of the conventional one. The closed loop engine simulations of the twin spool engine are executed in real time using code Simulink.