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

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

ענף הנעה
מחלקת מטוסים
להק ציוד
חיל האויר

יום העיון האחד עשר
במנועי סילון וטורבינות גז

11th Israeli Symposium on Jet Engines and Gas Turbines

October 25 2012, Tehnion, Israel

BOOK OF ABSTRACTS

יום ה', ט' במר חשוון תשע"ג, 25/10/2012

8:00 – 16:45, אולם בטלר, בניין פורשהיימר, מוסד נאמן, הטכניון

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תודות
ACKNOWLEDGEMENTS

ברצוננו להודות לגופים ולמוסדות שתמכו בקיום יום העיון:

חיל האוויר

מפא"ת

טכניון – מכון טכנולוגי לישראל

רפא"ל

תודתינו לפרסום הכנס לאגודה
למדעי התעופה והחלל בישראל:

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חיל האויר

THE 11TH ISRAELI SYMPOSIUM ON JET ENGINES AND GAS TURBINES
Thursday, October 25, 2012 (9:00-17:00),
Butler Auditorium, Forchheimer Building, Neaman Institute (Building #260), Technion, Haifa

The 11th Israeli Symposium on Jet Engines and Gas Turbines will be held on Thursday, October 25, 2012 at the Butler Auditorium, Forchheimer Building, Neaman Institute (Building #260), Technion, Haifa
The last few years has seen a considerable expansion of activities in Israel in jet propulsion. This is in addition to the serial production of small engines, increased electricity generation using gas turbines and combined cycles, production of various engines' spare parts and maintenance work and more. 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 and technological innovations and new projects in Israel calls for continued professional meetings; for the exchange of information, cross-pollination and creating a fertile seedbed for cooperation. The ten previous symposia attended by about 100 scientists were a great success, wetting the appetite for more such meetings.
The 11th symposium will include 17 presentations including 5 invited introductory lectures on selected subjects from large jet engine manufacturers and experts. This will also be a good opportunity for professional meetings, exchange of ideas and presentation of models and products from various companies.

All presentations will be published in full or, as a "censored" version after the conference on the conference website. In addition there will be opportunity to present/display promotional material. Please contact the undersigned for this purpose.

Looking forward to seeing you at the symposium,

Professor Yeshayahou Levy
Chairman of the symposium

11th ISRAELI SYMPOSIUM ON JET ENGINES & GAS TURBINES
OCTOBER 25 2012
Butler Auditorium, Forchheimer Building, Neaman Institute (Building #260), Technion, Haifa

PROGRAM

08:00 - 09:15	**הרשמה (Registration)**
09:15 - 09:35	**Opening:**
	Prof. Yeshayahou Levy, Chairman, Head, Turbo and Jet Engine Laboratory, Faculty of Aerospace Engineering, Technion.
	Prof. Yoram Tambur , Dean, Faculty of Aerospace Engineering, Technion.
	Ltc. Roni Gordana, Head, Propulsion Systems Branch, Aeronautical Division, MOD.
	Lt.Col. Shlomi Konforty, Head of Propulsion Branch, IAF
09:35 - 13:00	**9:30 - 12:35 מושב ראשון (First Session, GUEST SPEAKERS, English) - Auditorium**
	Session Chairman: Moshe Levy, IAF
A1	Tom Johnson, United Technologies / Pratt & Whitney, F-35 Aircraft / F135 Propulsion System Design and Development Integration Challenges
A2	John Quinn General Manager. GE Military Propulsion Engineering, GE,, "Emerging Trends in Aviation Propulsion"
10:55 - 11:15	**הפסקה וכיבוד קל (Break and refreshments)**
A3	David Ogden and Susan Zubik, Southwest Research Institute® (SwRI®), Texas, USA, "A Multivariate Statistical Approach to Improved and Automated Engine Trending and Diagnostics (ET&D)"
A4	Boris Glezer, Optimized Turbine Solutions, USA, "Engine Thermal Transient Problems and Possible Solutions"
A5	Stefano Bianchi, Rolls-Royce plc, Derby, UK, "Tip Noise Passive Control in Low Mach Number Axial Fan"
13:00 - 14:00	**ארוחת צהריים (Lunch)**

PROGRAM (cont')

14:00 - 15:15	**Second Session- AERO-THERMODYNAMICS (English) - Auditorium**
	Session Chairman: Savely Khosid, Rafael
A6	***Louis M. Larosiliere, Concepts NREC, Vermont,USA***, " High-Efficiency, Wide-Operability, and Highly-Loaded Axial Compressors: Case History of Potential Impact of 3D Aerodynamic Inverse Design Technique "
A7	***Beni Cukurel, Technion,*** "Principle And Practice Of Hotwire Constant Temperature Anemometry In Turbomachinery Applications"
A8	***Andy Martin,Technical Support/Sales Manager, ZOK International Group Limited***, "Compressor Cleaning in Demanding Environments"
15:15 – 15:30	**הפסקה וכיבוד קל (Break and refreshments)**
15:30 - 16:45	**Third Session - CYCLES & OPERATION (Hebrew)**
	Session Chairman: Savely Khosid, Rafael
A9	***D. Lior, RJet***, "Turbocharging of microturbines"
A10	***Leitner Amiram and Zeev Shavit Rafael and Beker Engineering,*** "On the Development of Air Cycle Machine for Cooling Airborne Pods"
A11	***Ofer Weiss, Albert levy, Bet Shemesh Engines Ltd, Israel,*** "Influence of casting process on natural frequencies of turbine blades"

14:00 - 15:15	**Forth Session - SYSTEMS (Hebrew) – Side Hall**
	Session Chairman: Dr. Albert levy, Bet Shemesh Engines
A12	***Y. Hain, Dr. B. Chudnovsky, N. Rappoport, M. Reshef, Israel Electric Corporation (IEC) S. Baitel - DOR Chemicals, Haifa,*** "Methanol, as a low cost alternative fuel for emission reduction in gas turbines"
A13	***Ilan Berlowitz, Bedek Aviation Group, IAI,*** "Continued Airworthiness Aircraft Engine Interface"
A14	***Effie Mouzikansky, IAF*** "(Accelerated Mission Test) AMT בניית מנוע"
15:15 - 15:30	**הפסקה וכיבוד קל (Break and refreshments)**
15:30 - 16:45	**Fifth Session - MAINTANANCE (Hebrew)**
	Session Chairman: Yitzhak Hochmann, Edmatech
A15	***Eyal Aronson, IAF,*** "Investigation of JT3D's Nozzle Guide Vanes failure".
A16	***Yosi Kazas, IAI*** "מגמות בשוק MRO למנועים"
A17	***Prosper Dayan, Phase3 Technologies Ltd,*** "Maintenance system for rotating machines with electrical connection"

סיום ונעילת הכינוסSUMMARY -	16:45

Lecture #A1

F-35 Aircraft / F135 Propulsion System Design and Development Integration Challenges

Tom Johnson
Program Chief Engineer
Operational Military Engines
United Technologies / Pratt & Whitney
East Hartford, CT USA\
October 2012

ABSTRACT

The F135 Program is currently completing delivery of the fourth lot of production propulsion systems following a successful development and qualification program. The integration of the propulsion system into the aircraft provided significant technical challenge and opportunity to improve performance, cost, weight, interchangeability, and thermal management of the overall weapon system. The Propulsion Integration teams met these technical challenges and created unique and long lasting highly integrated solutions. These integrated solutions and accomplishments are presented to provide awareness and perspective on the system evolution.

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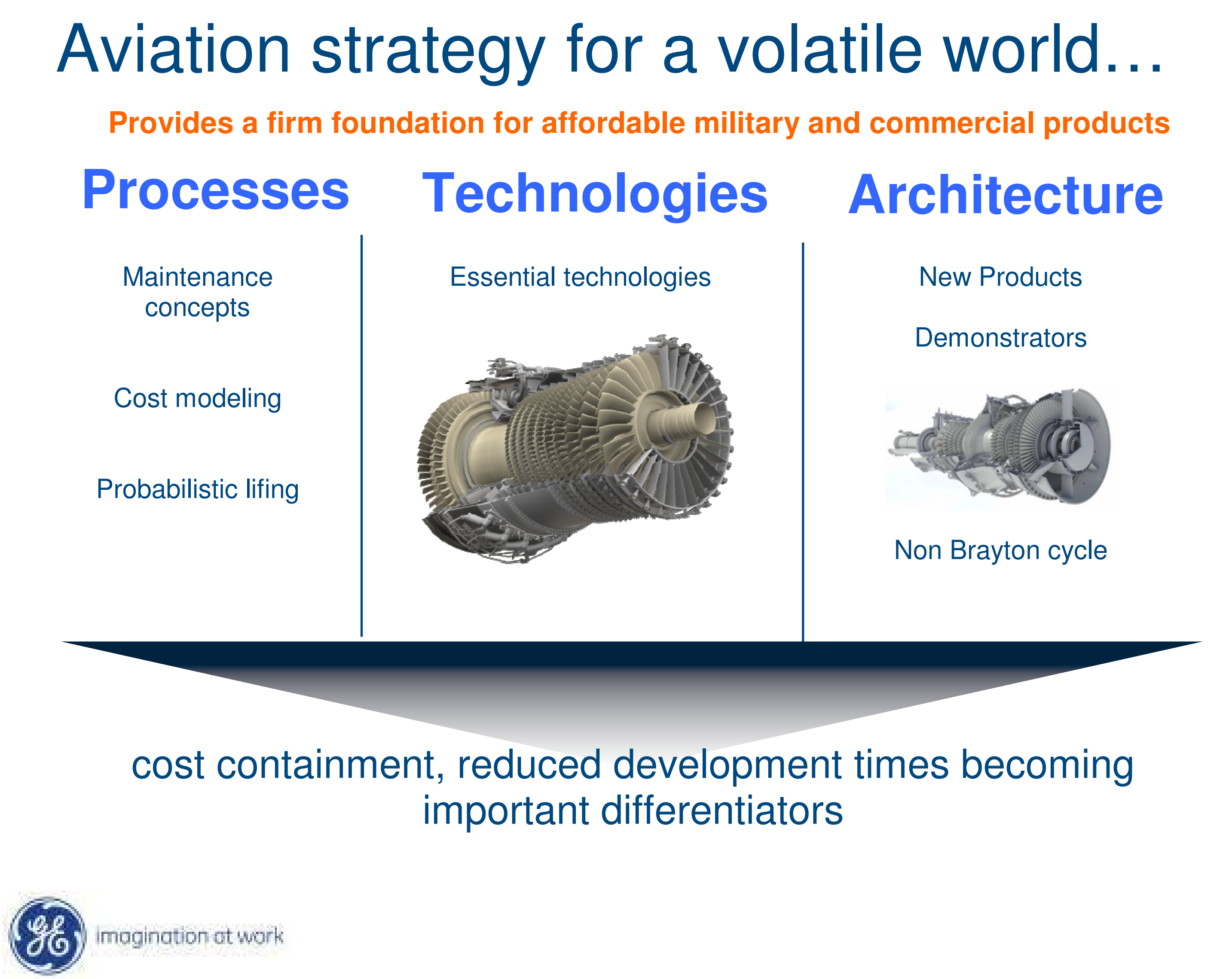
Lecture #A2

Emerging Trends in Aviation Propulsion

John Quinn
General Manager. GE Military Propulsion Engineering,
1000 Western Ave., M.S. 24501, Lynn, MA 01910, USA

Aviation propulsion is approaching a generational inflection point in both the military and the commercial worlds. Over the next decade, new products, technologies, and maintenance concepts have the potential to provide our customers with greatly increased capabilities and reduced operating costs which could transform our industry. These issues will be discussed in the context of emerging trends such as revolutionary metallic and non metallic materials, advanced cycles, more sophisticated design methods, services strategies, and alternative fuels. Taken in the aggregate, these and other technologies, demonstration programs, and systems integration methods have the potential to revolutionize propulsion system cost of ownership, weight, and performance.



Lecture # A3

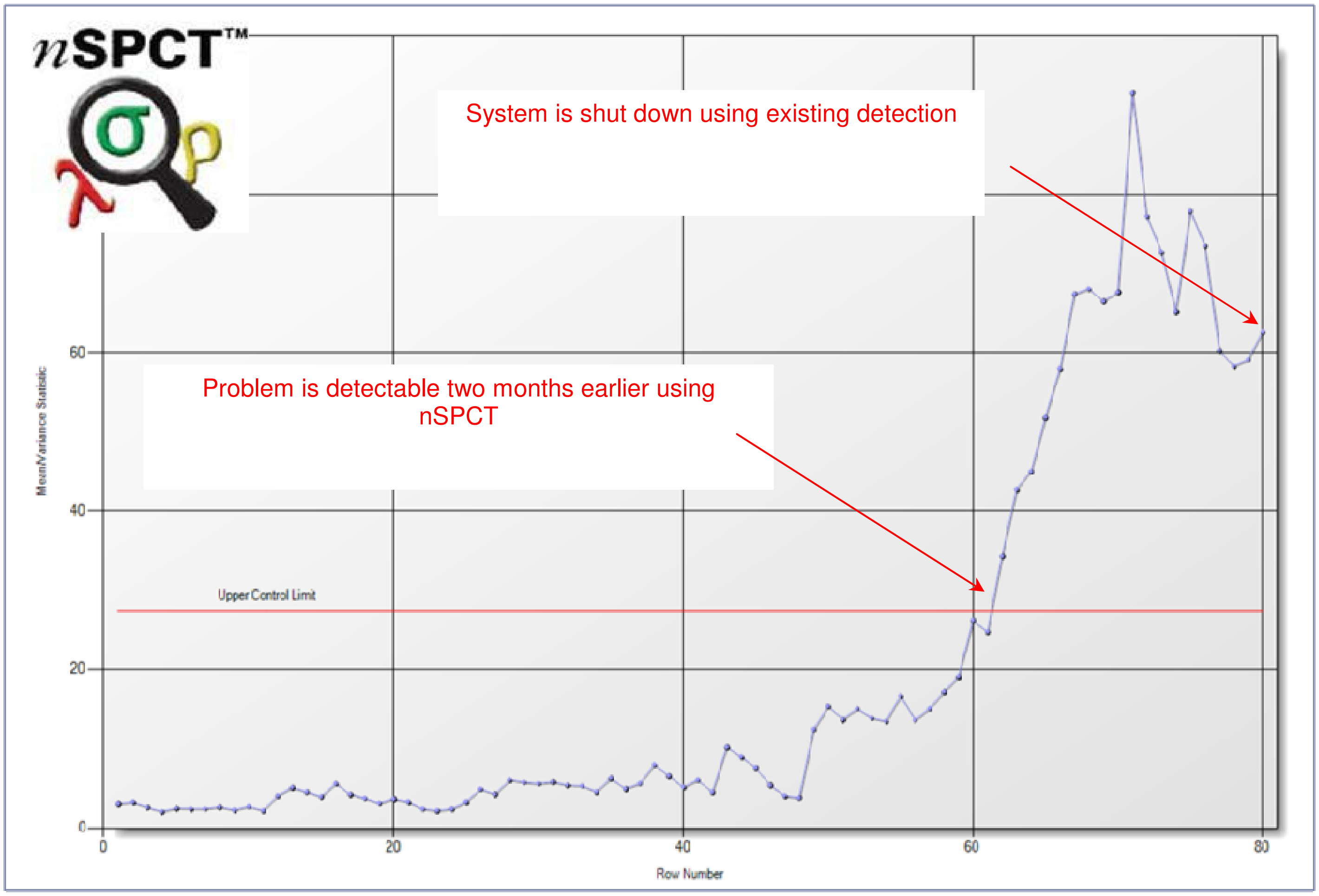
A Multivariate Statistical Approach to Improved and Automated Engine Trending and Diagnostics (ET&D)

David Ogden, Director
Susan Zubik, Manager
Southwest Research Institute® (SwRI®),
6220 Culebra Road, San Antonio, Texas 78248, USA

The effectiveness of engine health trending can be improved through automation using newly developed analytical tools. Challenges in engine performance data analysis include significant expertise and training, combined with a high level of manual effort. Engines are measured against population statistics that can mask important performance changes of an individual engine. Common approaches to engine trending only employ univariate or bi-variate analysis on a limited predefined set of relationships in gas path performance. Many older systems have few sensors or limited data collection systems. Engine system and subsystem efficiencies are very difficult to assess since there are no direct measures. Southwest Research Institute has developed tools and techniques that can overcome these challenges and are implementing many of them with the United State Air Force.

SwRI has developed the Jet Engine Trending Tool (JETT) to provide engine performance information that can be summarized at various levels including: Fleet, Major Command, Base, Aircraft, and Engine. This information can be used to determine current aircraft/engine status, trend engine performance, and provide alerts to users of abnormal engine performance. JETT can accept raw data, correct/standardize the data and trend it, or can use existing corrected data for display. The dashboard provides users with a compelling and consistent view of the data and enforces operational definitions of the "health" of the engine. Other sources of data, such as maintenance records, can be overlaid on the trend charts to assist users in root cause analysis of step changes in performance data for the selected engine serial number.

To improve the detection of performance shifts or system degradation, SwRI has advanced the state of the art in multivariate statistical analysis and has automated those new techniques in the n-Variable Statistical Process Control Tool (nSPCT™). This tool has been demonstrated on many types of engines, including turbine engines.
Early detection capability has been shown on engine failures that were not detected using conventional techniques. Changes in performance can frequently be detected weeks and months earlier, reducing damage or risk of mission failure, and ultimately operating costs. Most conventional systems only detect failure modes that are pre-defined. The nSPCT tool has the additional advantage of not being constrained to only detecting pre-defined failures. nSPCT can be incorporated into JETT to identify anomalies in the data and report them when they occur.



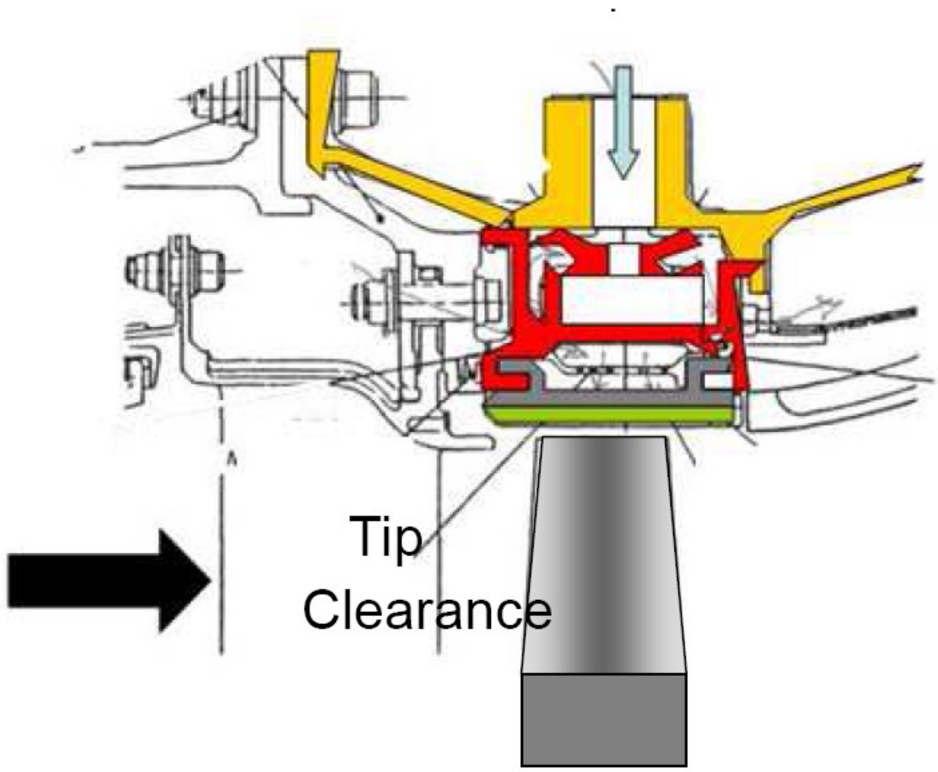
Example control chart produced by nSPCT

Assessing the system level performance on turbine engines is very difficult due to the complexity of interpreting the sensor data and the heavy computational load. SwRI has developed a unique approach to solving this problem using the combination of a physics-based engine model and a particle swarm optimization algorithm. Using this technique, equipment status can be determined in near real-time.

Lecture # A4

Engine Transient Thermal Behavior and Turbine Blade Tip Clearance Control

Dr. Boris Glezer, Optimized Turbine Solutions, USA



Many issues concerned with transient relative positioning of the rotor and stator components of the engine are often called "thermal management" of turbine design and are typically must be addressed starting with conceptual design of the engine.

One of the most challenging engine development objectives is to minimize and maintain tight turbine blade tip clearances over the life of the engine. This subject is a main focus of current presentation. The presentation addresses key factors affecting steady state and transient tip clearances with consideration of both thermal and inertial displacements. It discusses various techniques for controlling clearances, including passive tip clearance control that is based on close matching between transient growth of rotor and stator as well as active and semi-active clearance controlling techniques, which are usually based on modulation of the cooling air supply to the stationary structure during transient operation. Engine hot restart is shown to be the most critical for the blade tip rub and the most difficult to overcome in design. A number of non-traditional concepts which can be applied to address the tip clearance issues are analyzed.

Lecture # A5

Tip Noise Passive Control in Low Mach Number Axial Fan

Stefano Bianchi, Rolls-Royce plc, Derby, UK.

Engine noise at approach or take-off, is one of the most critical components of total aircraft noise. For modern large by-pass turbofan, the major noise contributor is that generated by the interaction of rotor wake with the stator vanes, known as fan noise. There are two major noise reduction techniques: active and passive. Active suppression, such as boundary layer suction, has been successful, however, it implies delicate and expensive control systems. Passive suppression are relatively simple since they are incorporated in the fan design. This extended abstract outlines new concepts for the design of blade tip end-plate in subsonic axial fan rotors based on the tip leakage vortex control.
The work was carried out between 2007 and 2009 at the University of Roma – Sapienza and at the semi-anechoic facility of Flakt Woods Ltd in Colchester.

INTRODUCTION

Aircraft noise is widely recognized to be one of the most objectionable impacts of aviation and an important environmental issue for those living close to airports as well as further a field under the main arrival and departure tracks. Therefore, taking effective measures to control and mitigate the effect of aircraft noise is fundamental to achieving the sustainable development of the aviation industry. In 2001, ICAO member states agreed to a balanced approach to controlling aircraft noise. The 'balanced approach' is supported in the EU by Directive 2002/30/EC. This is transposed through Statutory Instrument 2003 No.1742 [1], which applies the regulations to civil airports within the United Kingdom.

Concerning the fan noise, the major engine noise contributor [2], the interaction between the end wall boundary layer and the rotor tip is widely recognized as one of the most significant noise source. The fan tip noise is associated with the convection of turbulence over the tip edge of a rotating airfoil. Because of the role that organized structures in turbulent flow play in the noise generation process, controlling these eddies may be one of the keys to noise suppression. Experimental and numerical studies proved the pay-off resulting from the adoption of tip leakage flow control technologies [3, 4], and there was a speculation about the role of leakage vortex bursting phenomenon on the aeroacoustic performance of such a fan class. The vortex breakdown is an intriguing and practically important phenomenon occurring in swirling flows, and depending on the application, could be a productive or counter-productive flow feature.

VARIABLE THICKNESS END-PLATE DESIGN CONCEPT

The Variable Thickness End-plate design concept accomplishes the control on vortex breakdown onset advocating the use of a chordwise variation, in particular diminution, of the end-plate thickness. To suppress the tip-leakage vortex-bursting phenomenon, new end-plate design concepts were introduced [5]. The proposed configuration controls vortex breakdown by means of an end-plate of variable chord-wise thickness. The aim is to enhance near-axis swirl by reconfiguring the end-plate at the tip with a view to influencing the momentum transfer from the leakage flow and to force some waviness into the leakage-vortex trajectory. The rationale was combining a simplified law for the tip-gap pressure drop with a stability criterion of tip leakage vortex prescribed by the vortex rotation chordwise distribution i.e. the Rossby number. In accordance with the background experience, this end-plate design criterion, named Multiple Vortex Breakdown, advocates the linkage between the end-plate geometry and the modulation of tip leakage vortex near-axis swirl.

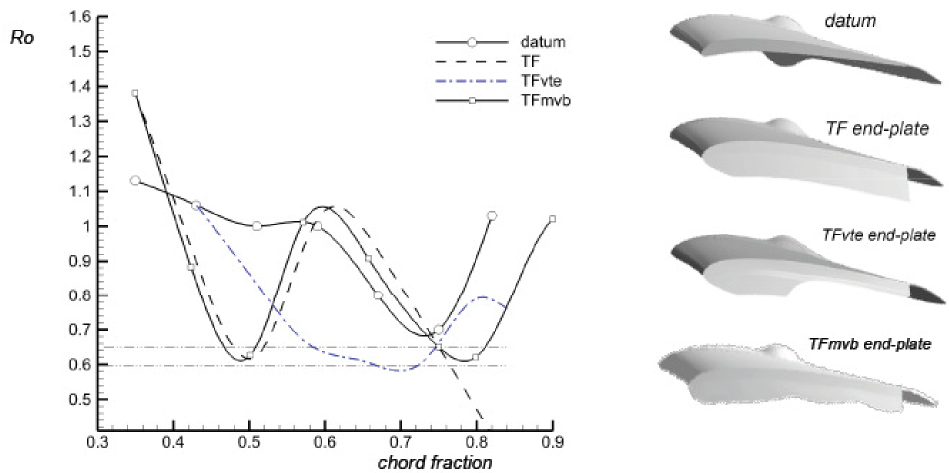


Figure 1 Background on improved tip concepts, chordwise evolution of tip leakage vortex, Rossby number (left), and end-plate geometries (right).

The key is to control the leaked flow in order to induce a sequence of subtraction of momentum transfer to the tip vortex up to a near-critical condition, followed by an addition of near-axis momentum [6]. As such, the new end-plate design concept exploits a passive control of tip vortex swirl level based on a succession of breakdown or bursting conditions able to enhance the mixing of coherent tip vortical structures with a favorable modulation of the correlated sound field. The Rossby number is the key metric to
resolve this problem.

Figure 1 shows the chordwise distribution of the tip leakage vortex swirl level at design condition. According to the interpretive criterion on vortex breakdown, the Rossby number (Ro) is simply a swirl metric. The figure gives the evolution of the Rossby number on the chord fraction for two different end-plate configurations and the MVB end-plate design plotted against the datum one. Moreover, Figure 1.b shows a sketch of the blade tips for the class of fan under investigation.

CONCLUSIVE REMARKS

The noise and performance parameters were measured in the Fläkt Woods test rig at Colchester (UK). Figure 2 shows the pay-off in the MVB's noise emission when compared with the datum and the TF rotor. The datum fan features a unique behaviour entailing, when increasing the power, a reduction of the specific noise level and an augmented sound power level OLw(A). This evidence suggests that the increased aerodynamic share in the sound generating mechanism, due to the actual fan operations, radiates more efficiently to the far-field and enhance the emitted noise in the audible frequency range [7]. In contrast, both the fan blades fitted with end-plates show a difference in the sound power-specific power levels. In particular, the MVB speeds-up the reduction in sound levels featuring a nearly linear distribution of exponent n = 1 and shows that the reduction of specific noise level with aerodynamic power is correlated to an attenuation of the emitted noise [8] according to a power law Ks $\propto$ OLw(A)n with n = 1. While n = 0.5 for the TF geometry

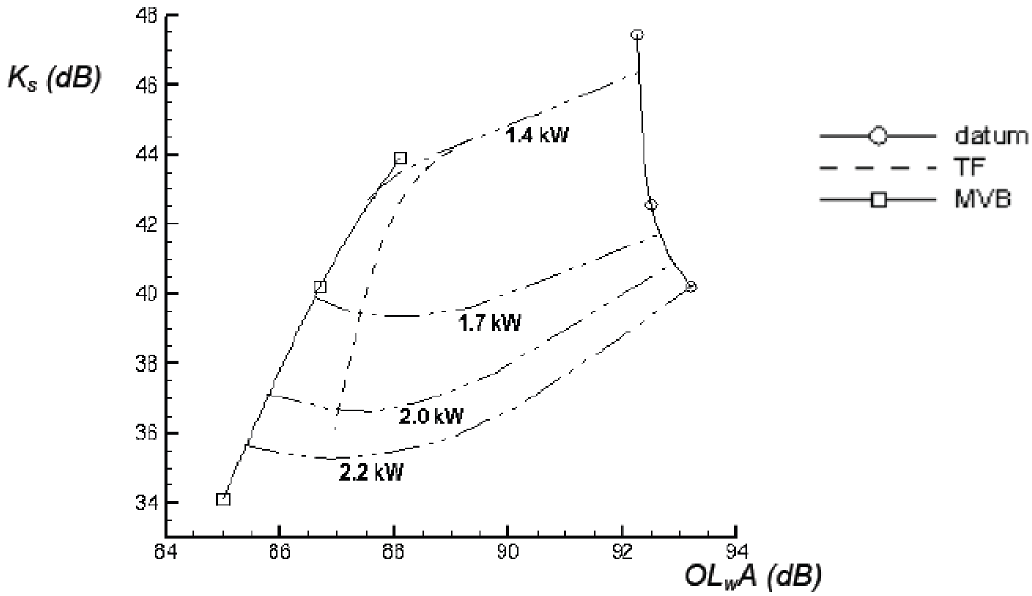


Figure 2: Comparison of A-filtered overall sound power level (OLw(A)) – specific noise level (Ks) polar plot.

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[1] http://www.legislation.gov.uk/uksi/1969

[2] Cumpsty, N., A., "Review: a critical review of turbomachinery noise," Journal of Fluids Engineering, vol. 99, no. 2, pp. 278–293, 1977.

[3] Bianchi, S., Corsini, A., Rispoli, F. & Sheard, A.G., "Experimental aeroacoustic studies on improved tip geometries for passive noise signature control in low-speed axial fan," Transactions of the ASME, Journal of Vibration & Acoustics, vol. 131, Article ID 061007, 2009.

[4] Corsini, A., Rispoli, F. & Sheard, A.G., "Shaping of tip endplate to control leakage vortex swirl in axial flow fans", Transactions of ASME, Journal of Turbomachinery, vol. 132, Article ID 031005, pp. 1–9, 2010.

[5] Corsini, A., Rispoli, F. & Sheard, A.G., "A Meridional Fan," 2008, Patent No. GB 0800582.9.

[6] Corsini, A., Rispoli, F. & Sheard, A.G., "Aerodynamic Performance of Blade Tip End-plates Designed for Low-noise Operation in Axial Flow Fans", Journal of Fluids Engineering, vol. 131, pp 1–13, Paper No. 081101, 2009.

[7] Bianchi, S., Corsini, A., Rispoli, F. & Sheard, A.G., 'Farfield Radiation of Tip Aerodynamic Sound Sources in Axial Fans Fitted with Passive Noise Control Features',

Transactions of the ASME, Journal of Vibration & Acoustics, vol. 133, Paper 051001, pp 1–11, 2011.

[8] Bianchi, S., Corsini, A. & Sheard, A.G., 'Experimental Characterisation of the Far-field Noise in Axial Fans Fitted with Shaped Tip End-plates', ISRN Mechanical Engineering, Volume 2012, Article ID 212358, 9 pages, doi: 10.5402/2012/212358, 2012.

Lecture # A6

High-Efficiency, Wide-Operability, and Highly-Loaded Axial Compressors: Case History of Potential Impact of 3D Aerodynamic Inverse Design Technique

Louis M. Larosiliere, Concepts NREC

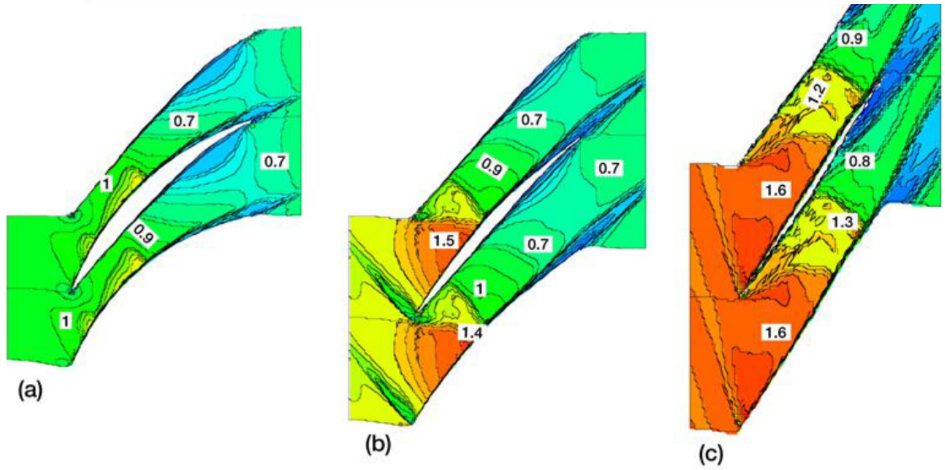
217 Billings Farm Road, Wilder, Vermont 05059, USA

As a direct response to the need for further performance gains from current multistage axial compressors, investigations of advanced aerodynamic design concepts that will lead to compact, highly-loaded, high-efficiency, and wide-operability configurations have been pursued. This presentation will describe the projected level of technical advancement relative to the state of the art and quantifies it in terms of basic aerodynamic technology elements of current design systems. A rational enhancement of these elements is shown to lead to a substantial expansion of the design and operability space. Aerodynamic design considerations for a four-stage core compressor intended to serve as a vehicle to develop, integrate, and demonstrate aero-technology advancements will be discussed.

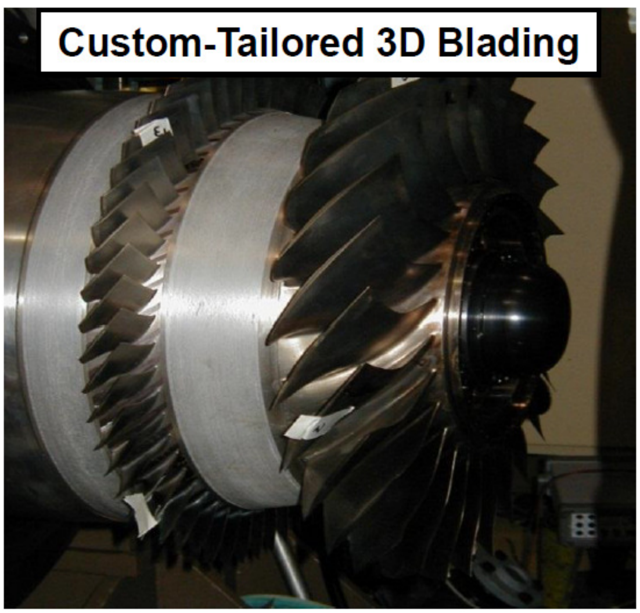
The benefits of a 3D inverse design method are illustrated by developing an appropriate pressure-loading strategy for transonic blading and applying it to re-blade the rotors in the front two stages of the four-stage configuration. The proposed method allows improvement of design point blade row matching by direct regulation of the circulation capacity of the blading within a multistage environment.

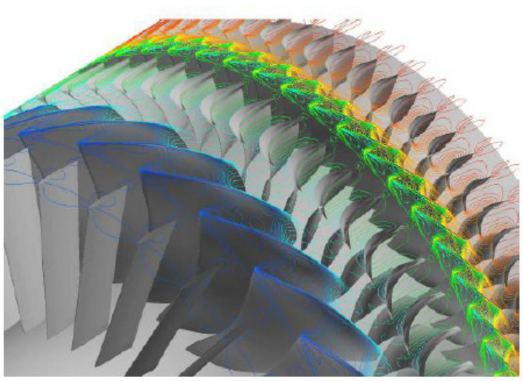
During the design calculation, blade shapes are adjusted to account for inflow and outflow conditions while producing a prescribed pressure loading. Thus, it is computationally ensured that the intended pressure-loading distribution is consistent with the derived blading geometry operating in a multi-blade row environment that accounts for certain blade row interactions. Multistage CFD simulations based on the average passage formulation indicated an overall efficiency potential far exceeding current practice for the front two stages. Results of the CFD simulation at the aerodynamic design point were interrogated to identify areas requiring additional development. In spite of the significantly higher aerodynamic loadings, advanced CFD-based tools, including 3D inverse design, were able to effectively guide the design of a very efficient axial compressor under state-of-the-art aeromechanical constraints.

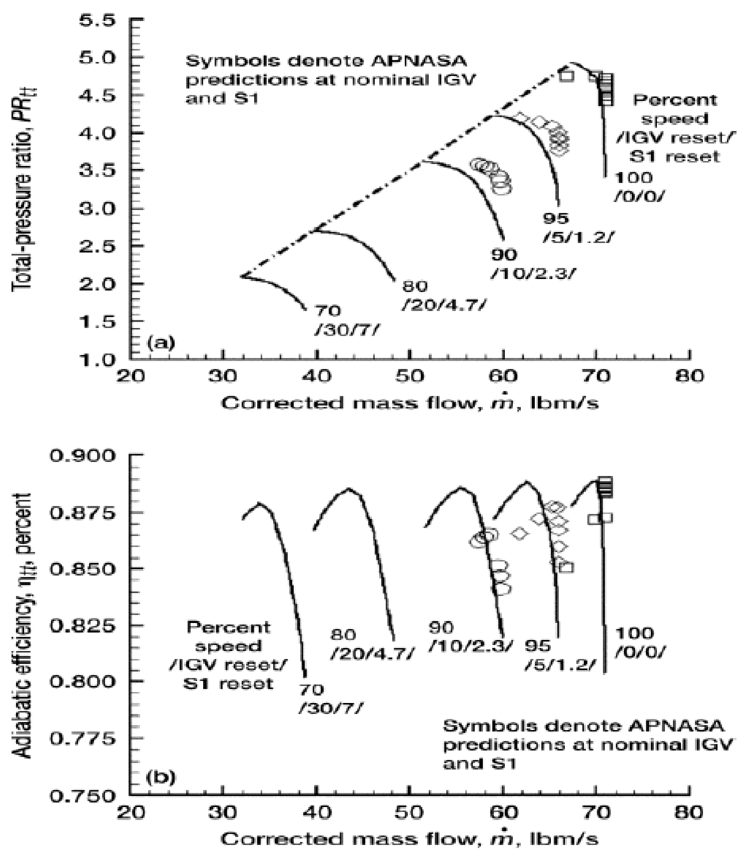
Advanced Technology Demonstrator: 4.65:1 Pressure Ratio Utip = 1,477 ft/s in Two Stages



Relative Mach number distributions at design point for rotor 1.
(a) 9-percent span. (b) 50-percent span. (c) 95-percent span.







Predicted overall performance characteristics.
(a) Total-pressure ratio. (b) Adiabatic efficiency.

Figure 1: High Mach number, High Stage Loading Compressor Designed Using 3D Inverse Blading Design Technique

Principle And Practice Of Hotwire Constant Temperature Anemometry In Turbomachinery Applications

Dr. Cukurel Beni,

Turbo and jet Engine Laboratory, The Faculty of Aerospace Engineering,

Technion-Israel Institute of Technology, Haifa, Israel.

One of the principal means to measure instantaneous turbulent flow quantities at high frequency is hot-wire anemometry (HWA), a technique which relates heated thin wire convection to the consumed electrical power. The wire temperature, and equivalently resistance, is fixed at a value higher than the surrounding fluid (overheating) by a fast response feedback amplifier, which corrects the bridge voltage unbalance by modifying the circuit top voltage. By maintaining a constant wire resistance with respect to the other internal arms of the bridge, Constant Temperature Anemometry (CTA) eliminates thermal inertia issues, and thus the wire heat transfer can be directly related to the bridge top voltage.

Historically, data reduction for flow conditions of $0.4<M<1.2$ is regarded as problematic, even in the simplified case of flow normal mounted wires, measuring 1-D flow. Thus, in comparison to the incompressible and supersonic conditions, the literature addressing these flow regimes is quite limited, since the wire voltage is a function of flow density, velocity, temperature and angle, Figure 1.

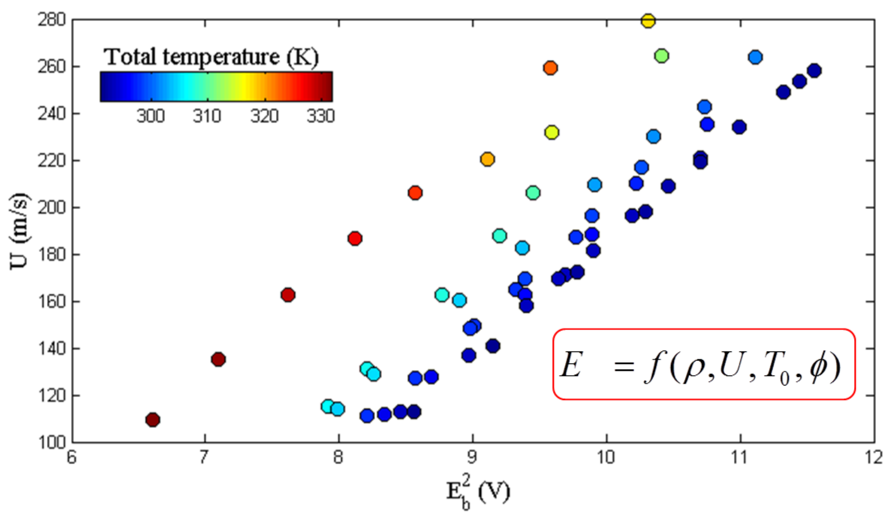


Figure 1: Dependency of Wire Voltage on Dimensional Flow Quantities

This, in part, restricted wide quantitative application of this measurement technique to modern turbomachinery flows, where transonic multidimensional flow features with large independent fluctuating components are typical. In other words, the flow phenomena generating fluctuations of density, velocity, temperature and angle is coupled but not necessarily correlated.

Consequentially, so long as the mean (or if possible instantaneous) total temperature and local mean Mach number are supplied along with the wire voltages, the instantaneous mass flux and flow angle can be obtained via probe-specific calibrations consisting of a single compressibility corrected Nusselt - Reynolds relationship and a directional calibration curve, Figure 2.

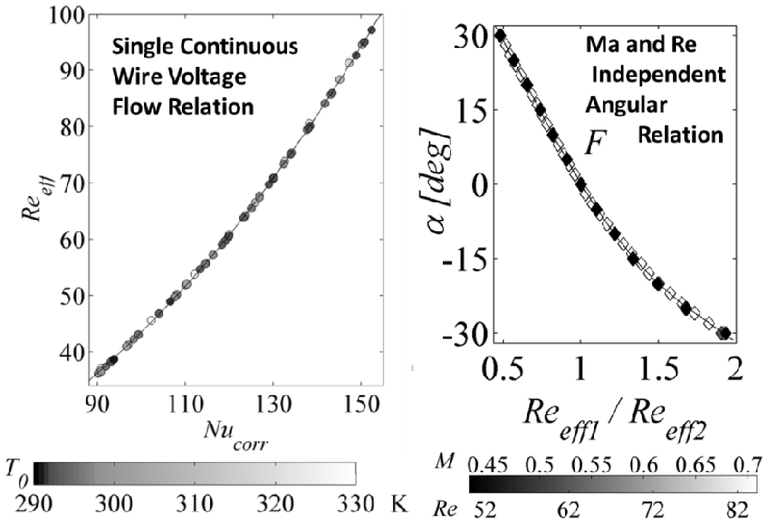


Figure 2: Compressibility corrected Nusselt - Reynolds and Directional Relation

Therefore, a short and robust calibration can be performed in an unheated free jet facility with applicability towards a broad range of planar flow conditions, Figure 3. This disposes the need for typical closed loop calibration wind tunnels which vary flow velocity, density and temperature independently to parameterize the voltage dependency in a purely empirical manner. Moreover, without any additional effort, sensitivities at local flow conditions can be calculated resulting in independent temperature and density fluctuation quantities.

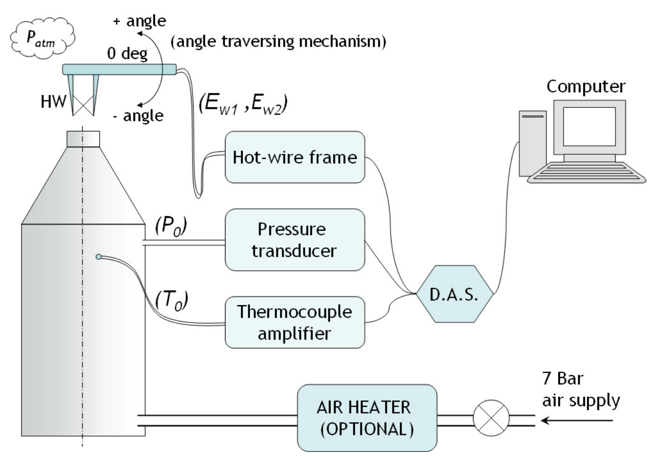


Figure 3: Typical Calibration Setup

In conclusion, the new hot wire data reduction methodology offers a high speed calibration scheme over a wide range of Reynolds and Mach numbers with an effort equivalent to that of a cross-hot-wire calibration under isothermal low speed flows. As nondimensional parameters and widely accepted correlations are used, there is no need for closed loop wind tunnels which vary each flow variable independently. Such advances in hotwire anemometry measurements allow for wide-spread, quantitative, reliable and robust application of the technique to highly complex flow environments with large fluctuations in flow angle, velocity, temperature and pressure; common examples of which can be found in fan, compressor and turbine flows.

Cukurel, B., Acarer, S., Arts T., “A Novel Perspective to High Speed Cross-Hotwire Calibration Methodology”, *Experiments in Fluids,* Vol. 53, pp. 1073-1085, 2012.

Lecture # A8

Compressor Cleaning in Demanding Environments

Andy Martin

Technical Support/Sales Manager

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Maintaining an engine in accordance with the engine maintenance manual (EMM) has been proven to keep an engine on wing longer and the longer an engine is on wing reduces the overall acquisition and repair costs. Performing preventative maintenance practices will ensure the integrity of the engine and ensuring it will always be available to fly at a moment's notice. Compressor washing is a crucial part of a maintenance program.

Engine manufactures recommend regular gas path washing, particularly for engines that operate in harsh environments where quality of air with the presence of salt, sand, industrial pollution and to a lesser degree but significantly volcanic ash is present.

There are two types of washing desalination and performance recovery washing. The desalination wash is done to remove salt deposits from the compressor section. The performance recovery wash is a more thorough wash of the compressor that will ensure optimum operation of the engine.

Clean and efficient gas turbines help to ensure:

- The safety and responsiveness demanded by operators.
- Avoidance of the build-up of engine contamination, resulting in a boost of engine performance, lower operating temperatures, reduction in fuel consumption and increased the time on wing.

This can be achieved by the use of ZOK products because:

- ZOK 27 with its unique formulation and corrosion inhibiting qualities ensures to keep gas compressors working efficiently and reliably throughout the engines life.
- ZOK cleaning products are biodegradable and water based. Specifically designed for use in ecological sensitive environments and are approved by all leading engine manufacturers.
- At ZOK's manufacturing plant in the UK is a modern well-equipped laboratory staffed by qualified chemists who constantly ensure that all products produced and dispatched to customers meet all the stringent OEM specifications.

ZOK International has over 30 years, specialized in the development, manufacture and worldwide distribution of compressor cleaning fluids for gas turbines.

Turbocharging of microturbines.

R-Jet Engineering Ltd, Israel
Dr. David Lior

A turbocharged cycle is presented for micro-turbines, in which the turbocharger compressor boosts the micro turbine compressor inlet instead of boosting the piston suction inlet as practiced in piston engines. The basic microturbine core configuration is maintained if the corrected pressure values are maintained by properly choosing a turbocharger with a proper matching of air mass flow a, air pressure and temperature at compressor and turbine inlets. Intercooling boosts the airflow but results in heavier gas turbine effective solution for commercial microturbines.

Matching a 40kw microturbine to an automotive turbocharger is presented in which the power is increased to 200kw, and the thermal efficiency is 36% using a recuperated intercooled cycle.
The mechanical integration is simple if the combustor is located externally to the gas turbine turbo-compressor subassembly –this allows installing simple ducts between combustor and recuperator resulting in low pressure drops within the system.

The combined cycle is presented and analyzed for different configurations. In which the power is extracted from the core engine shaft, from the turbocharger shaft or from both shafts

Preliminary design and cost/effectiveness analysis result in ex-factory /cost of 500$/kw competitive with similar power gas piston engines.

Aerospace configuration of a 150kw turboprop / turboshaft is presented. The cycle is a none inter-cooled recuperated gas turbine in which the recuperator is compact—optimized for high altitude performance. The aerospaceturbocharged design performance is competitive to aerospace piston engines –its power/ weight ratio is less than 1kw/k and its thermal efficiency is 38% at an altitude of 10000 m-allowing a high flight endurance time. Output power to the load is transmitted to the propeller through a planetary transmission connected to the free turbocharger turbine. An electric alternator may be an alternate solution to be integrated with an aircraft electric propulsion design.

APU-Auxiliary Power Unit –is another application which will use a non recuperated cycle supplying electric energy or pressurized air or both. APUs may be installed in the aircraft or in ground aircraft service carts.

The core engine is in final development stage-scheduled to be tested by end 2012. The first turbocharged version will use an existing automotive turbocharger, to be later replaced by improved variant-with higher compressor and turbine efficiencies.

On the Development of an ACM Cooling System for Airborne Pods

A. Leitner and Z. Shavit, Rafael

Electronic warfare (EW), Electro-Optical (E/O) Targeting and Navigation pods are externally installed on an aircraft, either using existing ordnance hanging stations retrofitted to receive those pods, or through designated pylons.

The electronic and optical equipment in the pod requires controlled temperature conditions in order to operate properly, and therefore requires an active cooling system. Most pods are cooled by vapor-cycle systems (VCS), which due to the strict demands on volume and weights, and high recovery temperature, have coefficient of performance (COP) around one unit, a much lower than that of a household air-conditioner or home refrigerator, thus requiring an electricity supply of the same order of magnitude as the electronic cooling itself. A household VCS occupies hundreds of liters in volume. An airborne cooling system would have to fit into a 50-liter niche, and would still have to have similar cooling power.

In most types of fighter jets, pods are supplied with a limited amount of electric power from the aircraft. Typically, this limit would be approximately 3.5 to 4.5kVA of power. A rise in operational requirements from the electronic systems increases the pod's consumption of electric power from the aircraft, thus requiring more cooling power, and leaving less electric power to invest in cooling.

Air Cycle Machine (ACM) systems use ram air around the aircraft to produce cooling or heat disposal power, with only a pump or fan that requires electric power to operate. This would normally account for less than 10% of the VCS's overall power requirement. More explicitly, the system utilizes the dynamic pressure difference between the total pressure of the incoming air and the static atmospheric pressure of the surrounding air.

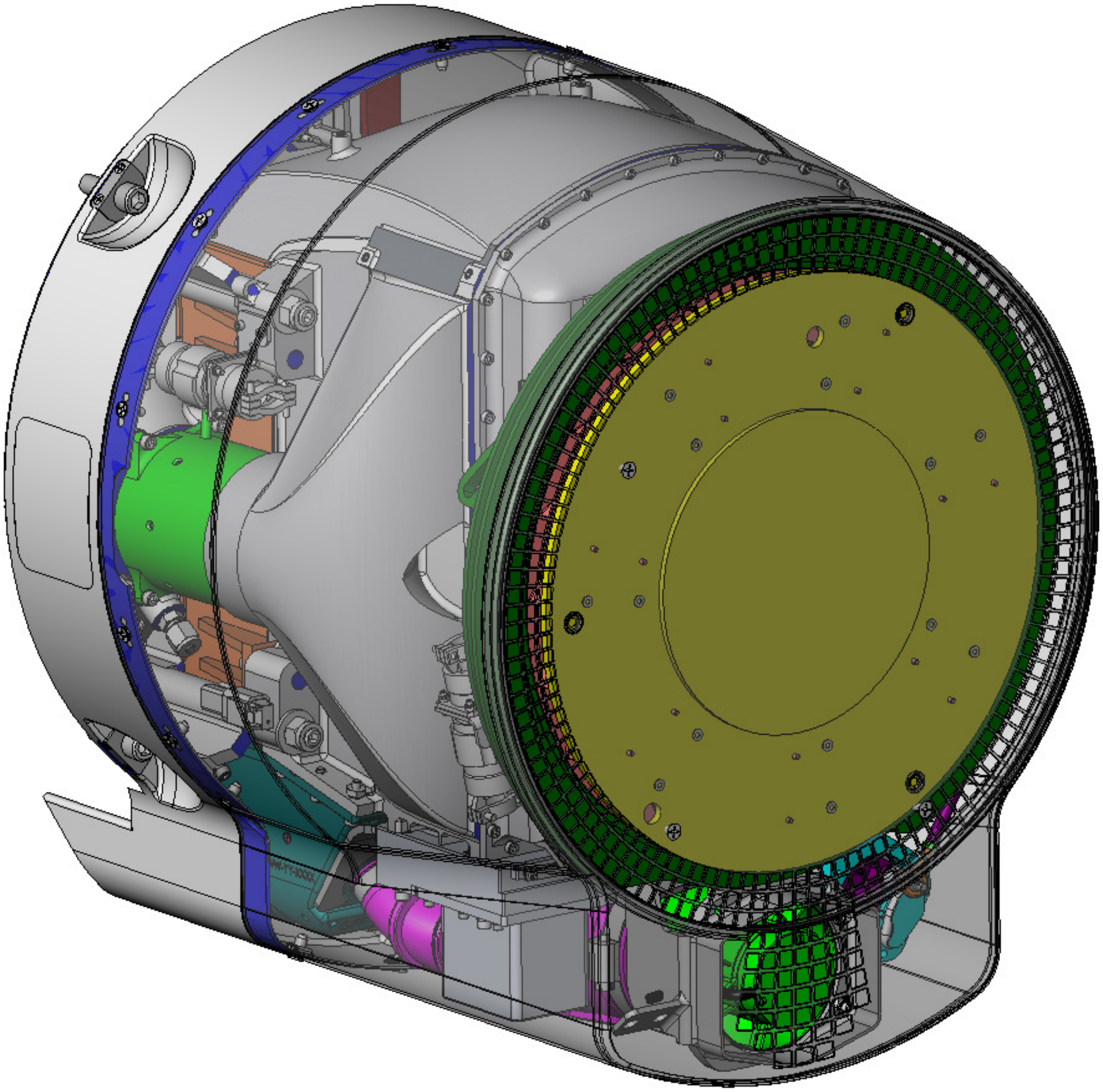
ACM systems can be fitted to any type of pod installed on a jet aircraft, commonly but not necessarily a fighter jet. ACM systems do not use high-pressure vessels and do not require any coolant other than the surrounding air, and therefore are not prone to cause environmental pollution. Additionally, ACM systems are characterized by lower vibration amplitude at higher frequencies, causing fewer disturbances to the pod's electronic or optic equipment than VCS that incorporate a high-pressure electric pump.

A designated ACM system was developed by Rafael and Becker Engineering to replace the existing VCS in the Rafael Litening pod. The ACM was tested in a ground "connected pipe" facility that simulates aerodynamic heat load due to flight Mach number in addition to heat load produced by the pod electronics.

Performance was compared with the VCS, and the results show an improved performance at the nominal condition and a wider Mach range performance with zero power consumption.

Flight tests were performed, and prove the simulation tests results are valid.

The new ACM is designed to be FFF (Form, Fit, Function) with the VCS it replaces. Several advantages of the ACM include power consumption of only 0.4kw compared to 2.5kw in the VCS, cooling capacity of up to 3.5kw compared to 2.4kw, and a larger flight envelope.



The ACM Cooling System for Airborne Pods

Lecture # A11

תקציר - השפעת תהליך היציקה על התדרים העצמיים של להבי טורבינה

Influence of casting process on natural frequencies of turbine blades

עופר וייס, אלברט לוי, מנועי בית שמש בע"מ

Ofer Weiss, Albert levy, Bet Shemesh Engines Ltd

כללי

במסגרת אנליזה של תכן שבוצעה עבור לקוח זר, נבדקו חומרים שונים שהיו מועמדים עבור להב טורבינה של הפרויקט.

סקירה

אחד הנושאים שנבחנו הוא התדרים העצמיים של הלהב, כאשר המטרה לוודא שאין סכנה של רזוננס בעת פעולת מנוע.

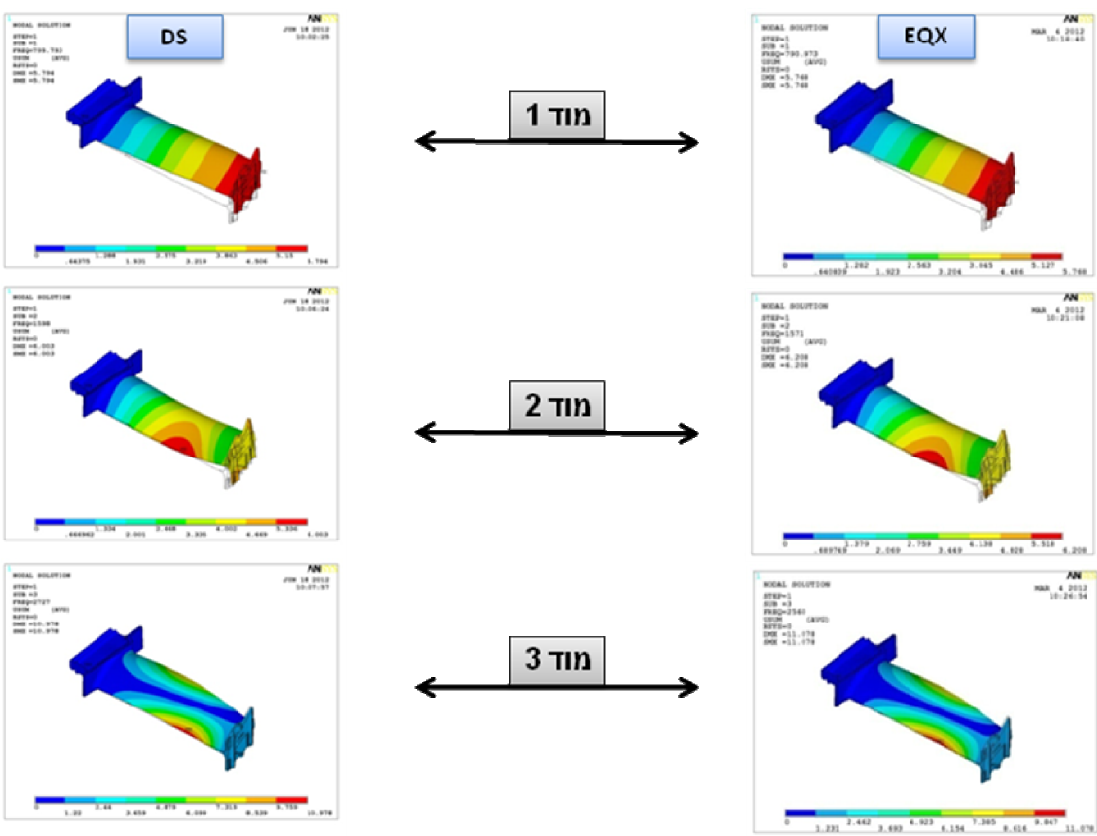
יציקת הלהב היא מסוג DS, כלומר הגרעינים מוארכים בכיוון הציר הרדיאלי של הלהב במטרה להאריך את אורך חיי הלהב בזחילה. חישוב התדרים העצמיים מתבצעים כמקובל בהנחה של חומר אלסטי-לינארי עם מודול ינג התלוי בטמפרטורה המשתנה לאורך הלהב. הניסיון מראה שבחומר היצוק בצורה כיוונית (DS), יש הבדל במודול ינג בכיוון האורכי ובשני הכיוונים הניצבים לו. נעשה שימוש במודל של חומר אלסטי אורתוטרופי המצוי בתוכנת ANSYS עם מודול ינג שונה בכיוון אחד $\left(E_Z \neq E_X = E_Y\right)$ על-מנת להעריך השפעת האנאיזוטרופיות.

בתמונה המצורפת ניתן לראות ששלושת המודים הראשונים בחישוב DS דומים מאד למודים במצב EQX.

נערכו חישובים הן בשיטה הקונבנציונלית והן בהתחשבות באניזוטרופיות של החומר.

במסגרת ההרצאה יוצגו ההבדלים בתוצאות שאינם גדולים, אך יכולים להיות קריטיים.

השוואת המודים



Lecture # A12

Methanol, as a low cost alternative fuel for emission reduction in gas turbines

1 Y. Hain, 1 B. Chudnovsky, 2 N. Rappoport, 2 M. Reshef, 3 S. Baitel
1 - Israel Electric Corporation (IEC) Engineering Division,
2 - Israel Electric Corporation (IEC), Generation Division,
P.O.B 10, Haifa, Israel, 31000,
3 - DOR Chemicals
POB 10036 Haifa, Israel, 26110

Over the past years there has been a dramatic increase in the regulatory requirements for low emissions from both new and existing utility boilers and gas turbines. Traditional methods of reducing NOx emissions, such as: modification of the firing system (DLN – Dry Low NOx), addition of water into the firing system (WLN – Wet Low NOx), and/or post combustion treatment of the flue gas to remove NOx are very expensive.
One of the attractive alternative fuels for combustion in the utility boilers and in stationary gas turbines may be Methanol. Using Methanol has become an important solution for emissions compliance due to its unique constituents and combustion characteristics. Methanol may be referred to as an ***enviro fuel***. The clean burning characteristics of methanol are expected to lead, on top of low emissions, to clean pressure parts, turbine blades and lower maintenance than with fuel oil.

Here, we shall focus on presenting results of a basic test run by a joint venture of IEC - Israel Electric Corporation and Dor Chemicals, of burning Methanol in a jet Gas Turbine - **FT4C TWIN-PAC 50 MWe** designed and produced by **Pratt & Whitney**. The test was run in an IEC site at **Caesarea** and it was conducted in a way where the GT was started with no. 2 fuel oil (gas oil) and later Methanol was introduced into the machine gradually while the no. 2 oil flow was closed until the engine was running using methanol firing only

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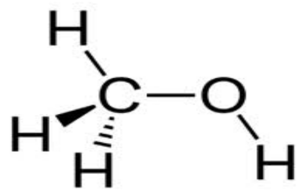
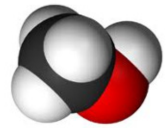
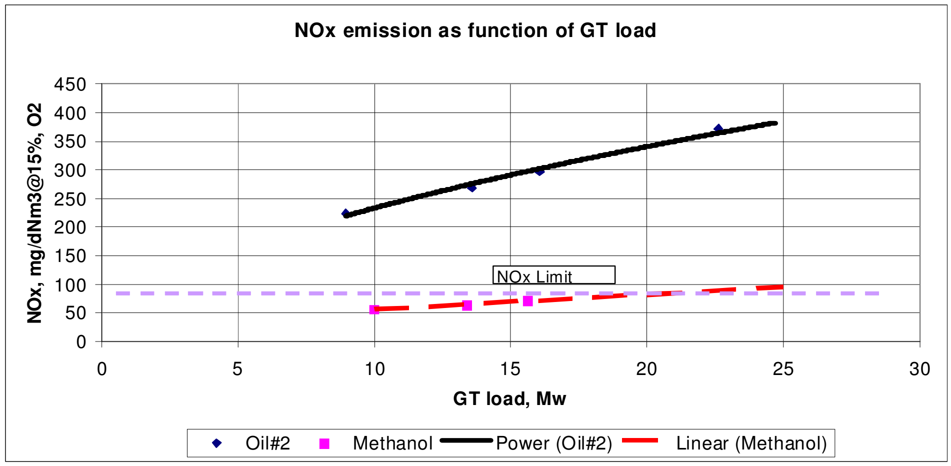
METHANOL CH_3OH

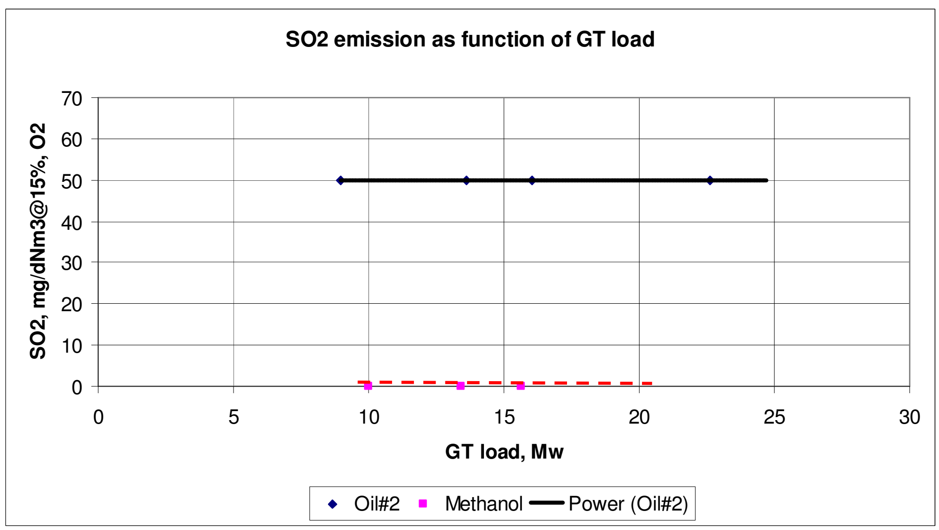




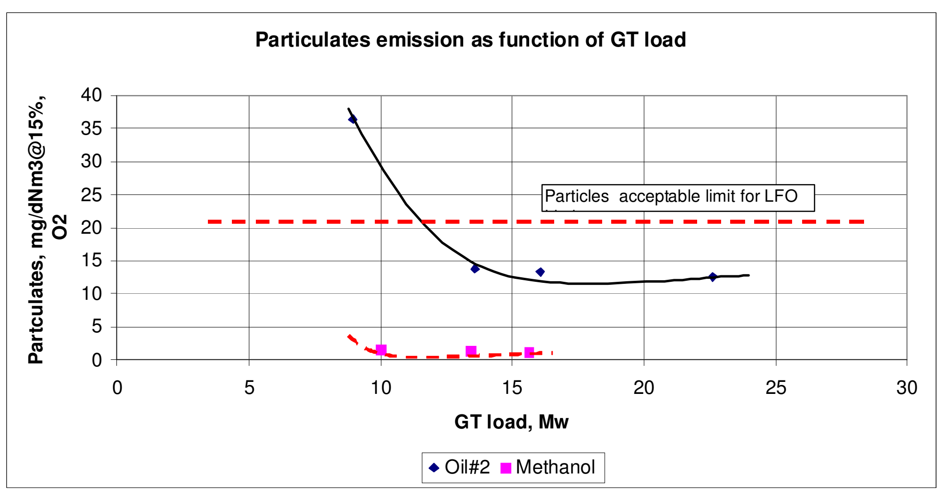
Methanol connection



Measuring equipment



Methanol Tank



Emissions improvement while firing Methanol compared to Fuel oil

Lecture # A13

Continued Airworthiness of Airframe Engine Interfaces

Ilan Berlowitz
Israel Aerospace Industries
BEDEK Aviation Group, Aircraft Programs Division

Although covered by relatively well established continued airworthiness management procedures, the interface between engine and airframe is an area that deserves more consideration as engines are the primary source for aircraft thrust and power. The requirements in terms of continued airworthiness are indeed common for both engines and airframes.

The airframe / engine interface is a complex interface that has to be designed under very intensive restrictions due to its specific location & geometry and also due to the various systems it has to deal with. Design and manufacturing requirements have to be managed so that the different designers and manufacturers involved ensure perfect match between engine and airframe.

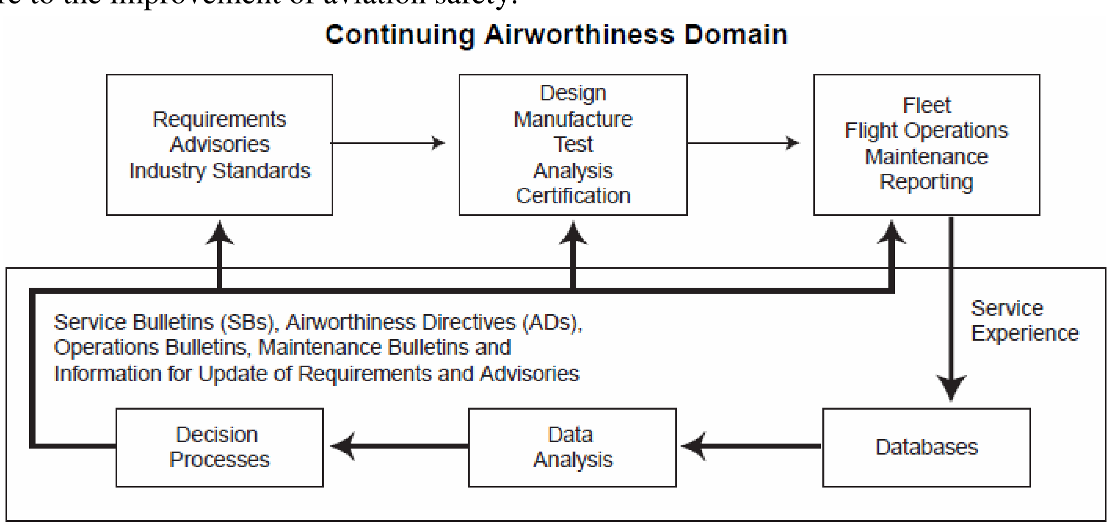
Aircraft in service are constantly exposed to the occurrence of incidents or accidents that are comparatively easy to be caused by failure of the mechanical/electrical/hydraulic/fuel interfaces or by the impact of a potential engines failure on the airframe.

A study on the continued airworthiness of engine / airframe interfaces was built on an investigation mode of operation. The objectives and expected results of the study were chosen to guarantee significant conclusions that may affect tomorrow's continued airworthiness management:

- To conclude lessons by analyzing some related air accidents/incidents;
- To advise amendments to relevant clauses in airworthiness regulations on civil transport aircraft and engine through research;
- To bring out some continued airworthiness management structure recommendations

Seven relevant incident/accident cases have been chosen to be re-explored. All the chosen incidents/accidents were investigated and detailed investigation reports were published by the American National Transportation Safety Board (NTSB) or equivalent organizations. In some cases, the NTSB's recommendations were adopted by the Federal Aviation Administration (FAA) to ensure continued airworthiness is maximized.

The study re-analyzed these incidents/incidents to get new findings on the behaviors of related participants in continued airworthiness. Related clauses in continued airworthiness regulations were analyzed. On the basis of the case studies, several lessons and suggestions on regulation revisions are proposed to potentially contribute to the improvement of the continued airworthiness processes and therefore to the improvement of aviation safety.



Lecture # A14

בניית מנוע ל AMT (Accelerated Mission Test)

Effie Mouzikansky, IAF

תקציר

עקב קשיים ברכש חלפים וצמצום תקציבי החל פיתוח של תהליכים לשיקום/שיפוץ של חלקי מנוע T64 (מנוע של מסוק היסעור).

בעקבות כך הועלה הצורך בבניית מנוע AMT (Accelerated Mission Test) לבחינת החלקים המשוקמים/משופצים במתאר ההרצה המדמה את מתאר התפעול של מסוקי היסעור.

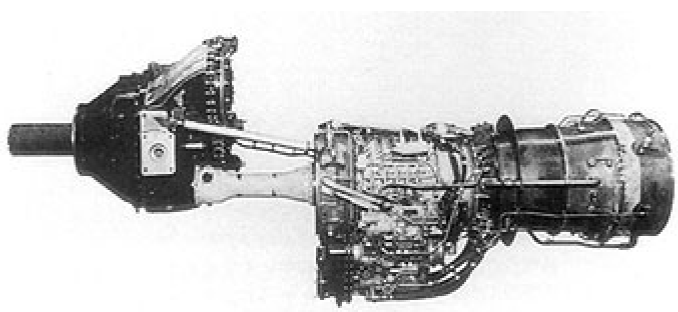
העיקרון מאחוריו עומדת הרצת מנוע AMT הוא אימוץ (מאמץ) הרכיב הנבחן למקסימום במשך תקופת זמן קצרה יחסית כאשר בתקופת זמן זו יושם הדגש על תפעול המנוע בנקודות קיצון מבחינת מאמצים, טמפ', מהירויות וכו, לעומת זאת, תפעול המנוע במעטפת התחתונה של המאמצים תוגבל עד למינימום.

העבודה מציגה את אופן בניית מתאר התפעול של מנוע ה-AMT ואת השיקולים שנלקחו כדי לדמות באופן אמיתי את אינטרוול אורך החיים הנדרש של 800 ש"פ.

תהליכי התיקון שנבדקו היו : שיקום להבי סטטור ועמידות שגמים בתאי שריפה.

פירוק המנוע ובדיקת ממצאי רכיבי המנוע הראו שתהליכי שיקום/שיפוץ שנבדקו הוכיחו את עצמם.

שימוש בכלי של מנוע AMT הוכיח את עצמו בפיתוח תהליכי שיקום/שיפוץ ויכול להוות כלי הנדסי בפיתוח ואחזקה של מנועים.



Lecture # A15

כשל להבי NGV במנועי הJT3D-

איל אהרונסון – ח״א

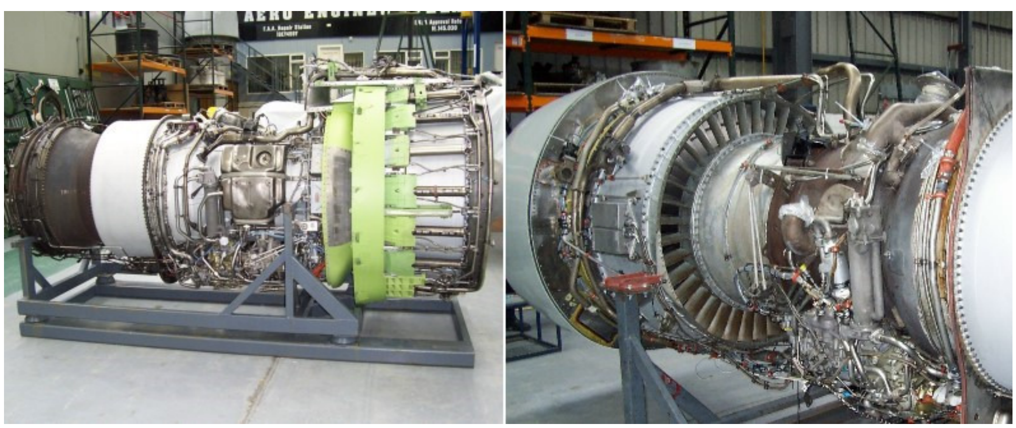
במהלך שנת 2009, בעקבות התרחשות כישלונות חמורים בשלושה מנועי JT3D בפרק זמן קצר מאוד, בוצעה חקירת כשל מקיפה. בפירוק שני המנועים הראשונים התגלו ממצאי נזק חמורים בלהבי NGV של הטורבינה. זמן קצר לאחר מכן התרחש אירוע חמור נוסף שבו, במהלך טיסה ובעת טיפוס לגובה 2500 רגל, הורגשה מכה מאחד המנועים, הסל״ד דע, לחץ השמן ירד והמנוע כבה באוויר. גם בפירוק מנוע זה התגלו נזקים חמורים בלהבי NGV. בנוסף, לאחד הלהבים הייתה חסרה תושבת ושאר דרגות הטורבינה נמצאו גרוסות.

מראה הנזקים בלהבי ה-NGV של המנוע האחרון היה שונה ביחס לשני המנועים הראשונים. בעוד שבשני המנועים הראשונים פרופיל הלהבים התעוות והתנפח בצורה אופיינית וידועה המכונה ״bow״ ונגרמה כתוצאה מזחילה, במנוע האחרון הובחן מראה דמוי איכול שהעלה חשד לסוגיות ייצור לקוי של הלהבים. עם זאת, החקירה התמקדה במנגנוני כשל האופייניים לטמפרטורות גבוהות בשל סמיכות שלושת האירועים ודמיון במאפייניהם הכלליים כגון מיקומם של הלהבים בהיקף הדרגה, כמות הלהבים שניזוקו וממצאי נזקים כלליים שנראו כתוצאה משריפה של הלהבים או חשיפתם לטמפרטורה חריגה.

נבחנו מנגנונים שונים כגון ״HOTSPOT״ (כתוצאה מהזרקת דלק לא טובה), אוקסידציה, זחילה, התעייפות תרמית ועוד. בהתאמה נבחנו גורמי כשל שונים כגון סוגיות ייצור לקוי או שיפוץ לקוי של להבים, היכולים להסביר את רגישותם לטמפרטורות עבודה תקינות ותהליכי אחזקה לקויים אשר יכלו לגרום לחשיפת הלהבים לטמפרטורות גבוהות ו/או לסיום אורך חיים סופי של הלהבים.

ממצאי החקירה לימדו על קשר ישיר בין חומר הגלם ממנו עשויים הלהבים לבין מאפייני הכישלון שלהם- מראה מאוכל או התנפחות. שונות זו השפיעה גם על אפקטיביות בדיקות האל-הרס שהתבססו עד לשלב זה רק על זיהוי העיוות של הלהבים ולא אפשרו איתור להבים בעלי מראה מאוכל.

JT3D Engine



1st Blade and 1st Vane Front and Back

Lecture # A16

נושא ההרצאה: <u>מגמות בשוק MRO למנועים</u>

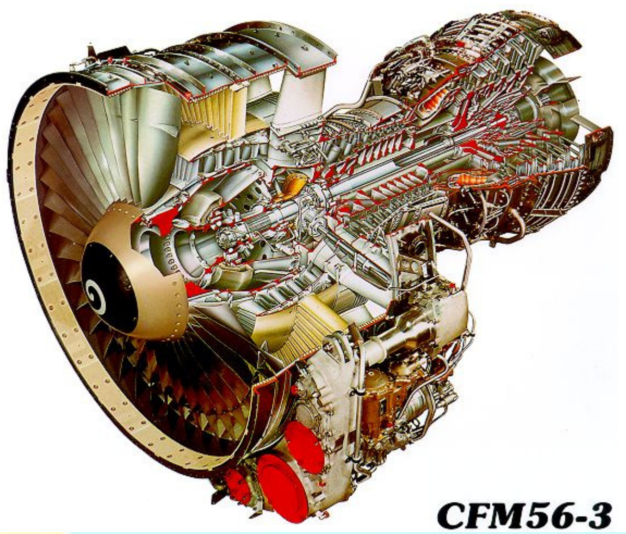
יוסי קזס,

מנהל מפעל מנועים – התע"א

טכנולוגיות מודרניות וחדשניות גורמות למנועים להחזיק זמן רב על הכנף ללא צורך בתחזוקה. מנועים יורדים היום בשל מגבלת אורך חיים (LLP) ולא בשל בצועים (EGT) או סיבה אחרת. שינויים מהירים מתחוללים בשוק ה-MRO ושיפוץ מנועים הופך להיות עסק עם סיכון מורחב. ההשתלטות של יצרני המנועים על השווקים בשני העשורים האחרונים הביאה לכך שהיום השוק מוחזק ברובו על ידי יצרני המנועים ורק 15%-20% בידי האחרים. צפוי כי נתח זה ישמר בשל הצורך של Operators לשמור על התחרות בכדאי שעלויות התחזוקה לא יצמחו.

העלות של הכניסה למנועים חדשים היא גבוה מאוד בשל הטכנולוגיות הנדרשות וכן הרצון של ה-OEM להרים מחסומי כניסה על מנת לבקר ולשמור על נתח השוק שלהם.

כדי ליצור תחרותיות בשוק, מפעלים עצמאיים מרחיבים את היכולות הטכנולוגיות שלהם ומתמקדים בפתוח יכולת התיקון עצמית של חלקי מנועים, בביצוע Lean בכל התחומים כולל רכש ולוגיסטיקה על מנת לייעל את העבודה ולהוזיל עלויות למפעילים.



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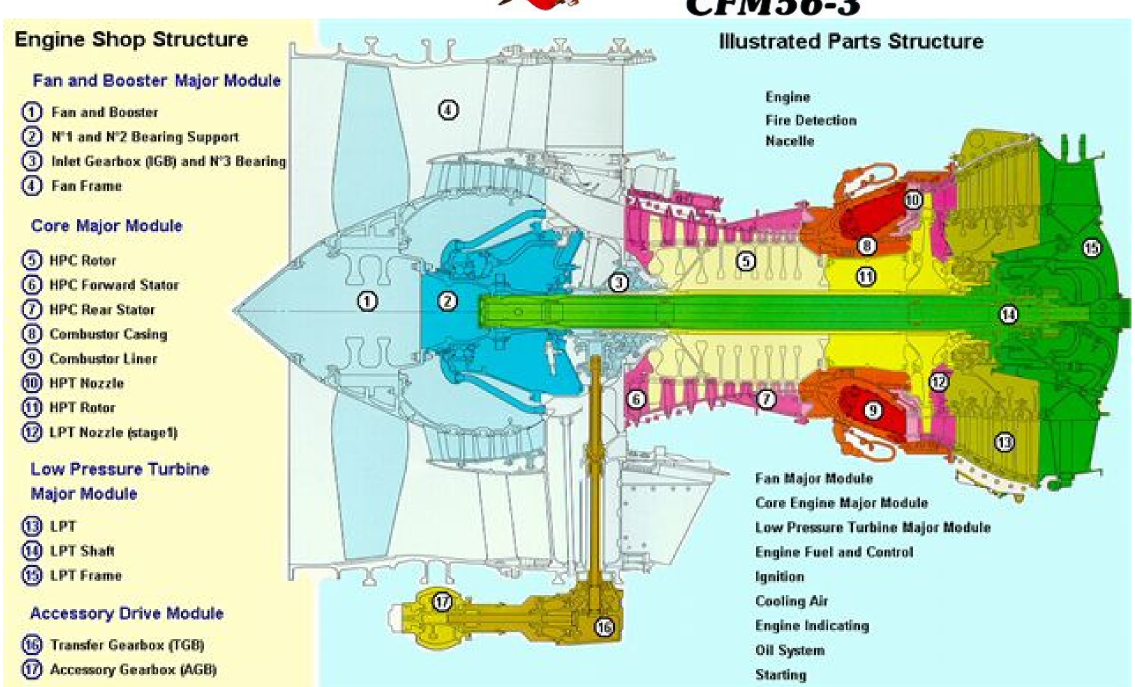

Lecture # A17

Maintenance system for rotating machines with electrical connection

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A method for monitoring a rotating machine having an electrical connection is presented. The connection has at least two phases and respective currents. The system is based on electrical sensors and dedicated algorithm that performs constant real-time monitoring condition and performance of electrical machines like motor, generator and turbines.

The system will diagnose usability and performance status of three-phase electric motors and generators, and to alarm about the development of a mechanical malfunction or failure of one component at an early stage may lead to machine damage or other systemic. Savings in providing early warning is significant. The system will be used for a wide range of electric machines: production lines of factories, pumps, blowers, power plants, turbines, generators and actually all mechanical equipment supplied by electricity. The system deals with real-time monitoring of the motor working condition. Also the system will be applicable for monitoring generators. The purposes of the system are:

a. improving the availability of the machines

b. prevent unexpected down time

c. cost savings in operation and maintenance of deficiencies in the existing maintenance policy.

The system consists of hardware equipment and a set of algorithms. The hardware includes electrical sensor which is current transformer and a dedicated card. All equipment will be planned by the startup and will be producing by subcontractors. Sensor is broadband, also works at frequencies of tens kHz and fit many other applications such as gas turbines generators, water and more. The algorithm will be mounted in the dedicated card and will operate in real time and without having an operating system and will be based on diagnostic experience over 15 years in the discovery and prediction problems.

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