Turbomachinery Research Opportunities for Graduate Students

Asst. Prof Beni Cukurel

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Are you an ambitious, young scientist? Are you willing to learn multi-disciplinary research? Are you interested in turbomachinery applications? Do you like to be a part of establishing something new? Do you have a B.Sc. grade average above 85? Then we want **YOU**.

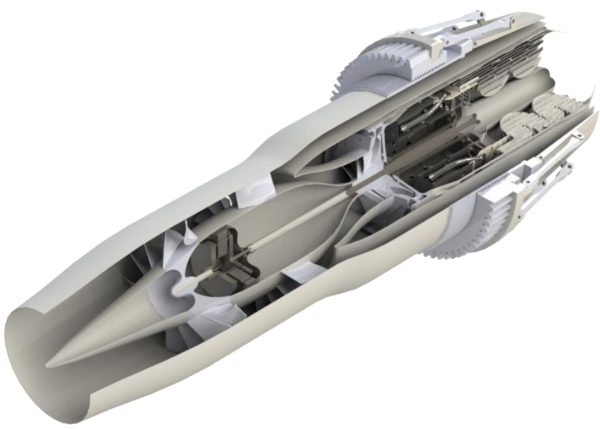
Looking for M.Sc. and Ph.D. students interested in:

- Experimental Aero-Thermal Dynamics and Heat Transfer
- Non-Intrusive Optical Measurement Technique Development
- Mechanical Design and Analytical Modeling

For further details, contact Asst. Prof. Beni Cukurel (beni@cukurel.org) or visit our website (http://bcukurel.net.technion.ac.il/) and you could become involved in projects such as:

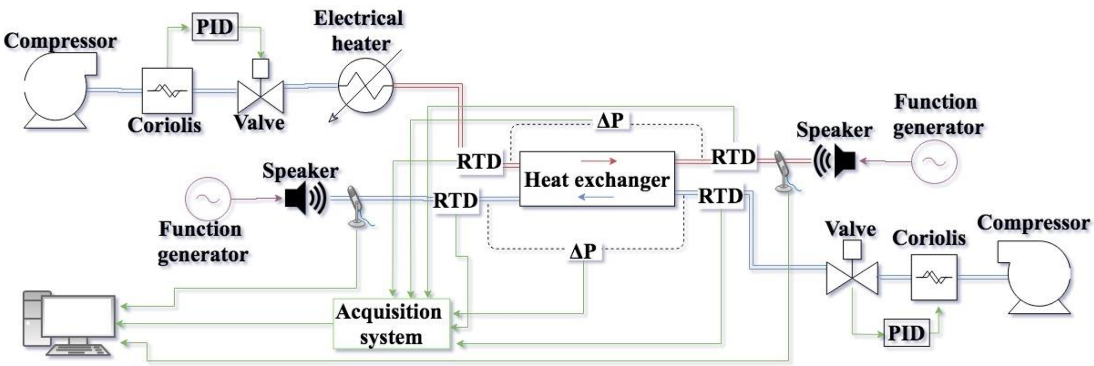
Adaptive Cycle Micro-Turbofan Engine

As the operational envelope of unmanned air vehicles expands into the high sub-sonic and transonic speed range, the engine design process requires compromises in thrust, weight, fuel consumption, size, reliability, and manufacturing cost. Moreover, the engine requirements for multiple operating points, consisting of loitering during reconnaissance and high-speed flight during cruise, are conflicting as design criteria for an efficient propulsion system. In general, micro-turbojet engines may offer a simple design capable of providing high levels of thrust, but are marked by poor fuel consumption, hindering range. In contrast, larger platforms utilize turbofan engine architectures due to their greater propulsive efficiency at low flight velocities. The goal of our project is the development of a variable cycle micro gas turbine engine, which operates via integration of a fan by a continuously variable transmission into an existing micro-turbojet with an adaptive bypass nozzle. The developed solution significantly improves maximum thrust, reduces fuel consumption by maintaining the core independently running at its optimum, and enables a wider operational range, all the meanwhile preserving a simple single spool configuration. Moreover, the introduction of a variable fan coupling allows real-time optimization for both "fly-fast" and "loiter" modes.



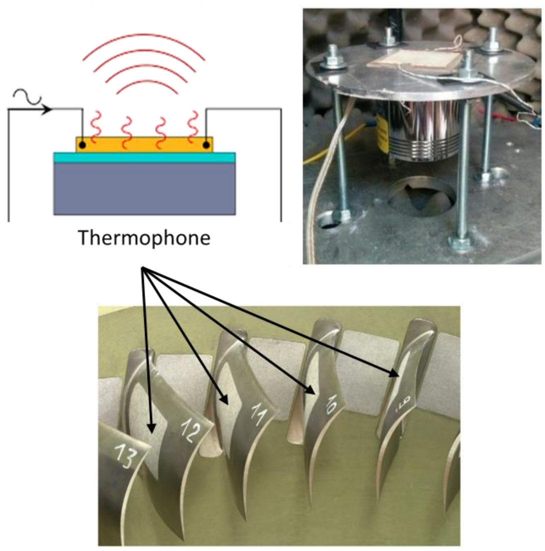
Acoustically Enhanced Forced Convection in Compact Heat Exchangers

Towards enhancing the efficiency of gas turbines, most thermodynamic cycles require heat to be either added or dissipated by a heat exchanger, which operates by associating two streams of different thermal potential. Due to form factor limitations of many size restrained applications, the state of the art is advancing towards more compact designs. This forms the need towards higher performance and efficiency heat exchangers - enabling more heat transfer for the same size heat exchanger unit with an unchanged pressure drop. Therefore, we focus on studying the convective heat transfer ramifications of acoustically excited smooth and turbulated walls. Determined by the resistance of the thermal boundary layer, convective heat transfer is undoubtedly a surface phenomenon, only dependent on the near wall region. Therefore, by acoustic streaming of wall bound flow and formation of a coupled Stokes layer, a local influence on the fluid-solid interface can be achieved without simultaneously affecting the mainstream flow motion - increasing heat transfer performance. However, when the net heat exchange of the flat surface is still insufficient, pertubrators are used to promote transport phenomena by improved mixing with the free stream. In order to improve the efficiency of this periodically reattaching flow problem, we use acoustic resonance driven standing waves to trigger a complex instability dynamic. The instability initiates a process of wavelength conversion by Tolmien-Schlichting waves that are later amplified into Kelvin-Helmoltz instability mechanisms in the free shear layer. Globally, considering the closely confined internal air flow inside highly branched heat exchangers, the coupled resonance behavior of interconnected passages and cavities exert a strong influence on the internal convection heat transfer, absent of additional pressure penalty. Neither of these engineering problems has previously received much prior attention.



Active Turbomachinery Noise Cancellation via Thermo-Acoustic Transducer

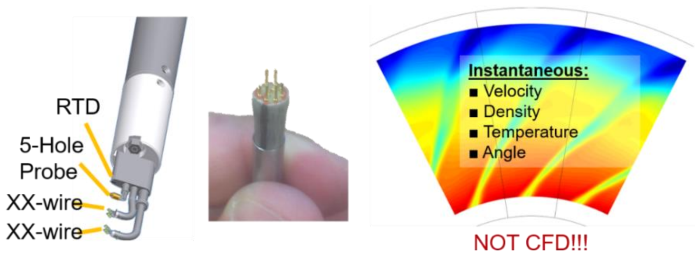
Majority of current investigations focus on attenuation of tonal frequencies by active and passive techniques, as well as local noise cancellation at the point of the recipient. However, the anticipated drastic progress on noise reduction can likely stem from sound cancellation at the source. Forming equal-amplitude and opposite-phase pressure waves to the noise, the sound emanating from the system can be negated. Thus far, the technological issue hindering the practical implementation of this approach has been absence of devices, which can be mounted on the entire noise generating surface without affecting the intended operation. Although the moving-coil loudspeaker has seen the most scientific development over the past 150 years, other forms of sound reproduction exist. In particular, thermophones utilize periodic Joule heating of an electrically conductive body to create surface temperature fluctuations, which are then converted into pressure waves by the thermo-acoustic effect. To date, a comprehensive model, which captures the exact mechanism of heat transfer in such devices, does not exist. Therefore, we have been working on a semi-analytical solution that couples the dual-phase-lag hyperbolic heat conduction problem with the ballistic transport on the surface. Considering the wave nature of conduction in



small time-scales, our model predicts the existence of thermal shocks, thermal resonances, and thermal interference patterns. Based on these estimates, we have engineered thin solid and epoxy media, stretched it between copper electrodes and excited with a combination of direct and alternating currents. Applying this formation on top of a conventional loudspeaker, our method has achieved acoustic cloaking by 500-fold reduction of the generated sound pressure levels. The next stage of the project focuses on reducing the aero-acoustic noise generated by the rotor-stator interaction in a small-scale ducted fan engine, where the thermophone will be deposited on the stators.

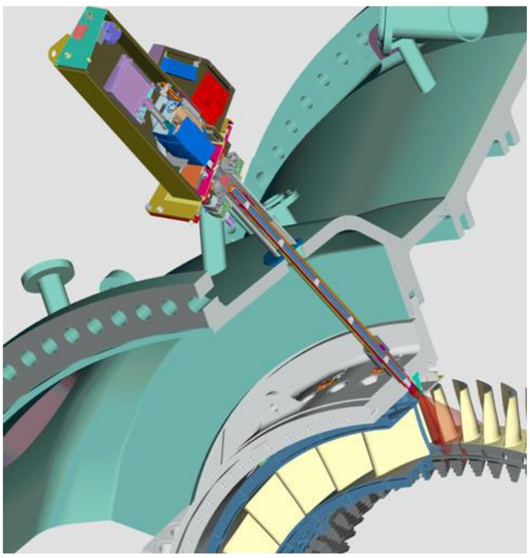
Advanced Multi-Hotwire Anemometry

In order to experimentally quantify aero-thermo-acoustic performance of work addition processes (such as fans), unique instrumentation is necessary to provide instantaneous velocity, density and temperature fields. Decoupling the effect of flow parameters on the sensor output signal is considered to be one of the historic challenges. In this regard, we are working on advanced 4-wire hot wire anemometry technique that is able to decouple such fluctuations from the mainstream flow processes. Experimentally characterizing the Nusselt-Reynolds relation over each wire in a simple calibration process, and accounting for the compressibility effects by semi-empirical Mach corrections, the heat transfer behavior of each thin heated filament can be accurately described. By deriving the sensitivity of each variable theoretically, we are able to attain a reasonably non-singular sensitivity matrix, formed by optimal selection of wire diameters and temperatures.



Advanced Multispectral Infrared Thermography

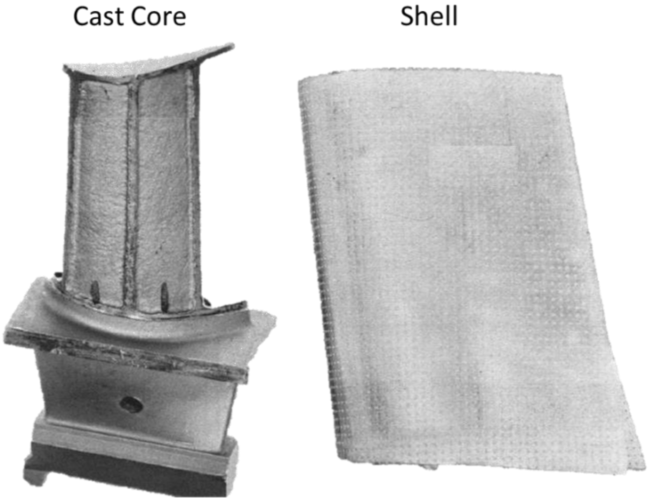
Gas turbine engines heavily rely on the durability of hot-section components to achieve the required levels of performance, reliability, and safety. While high pressure turbines are exposed to gas path temperatures approaching their melting points, features such as cooling systems and environmental coatings are used in combination to meet design goals. The performance of these parts is critically dependent on the temperatures, cycles, time, and stresses achieved during engine operation. Thermometry systems offer nonintrusive optical temperature monitoring for hot-section diagnostics. However, their potential is currently hindered by poor absolute temperature accuracy (large error bounds), as a result of ill-characterized uncertainty sources. Modern applications attempt to circumvent this issue by empirical corrections (target specific calibration), which is particularly problematic for surfaces with low and varying emissivity, as encountered in most metals. Unlike most common monochromatic pyrometers, we are focusing our efforts on multi-spectral thermography of unknown emissivity surfaces. Although the emissivity is typically a function of both



wavelength and temperature, on sufficiently close spectral bands, per-scenario assumptions (such as graybody, linear change with wavelength, etc.) are valid, and provide direct solution to the system matrix. By acquiring multi-integration time images and conducting quantitative image fusion considering total exposure non-linearity compensation, the currently developing optimized multispectral radiation thermography technique is geared towards accurate 2-D temperature measurement of hot target objects, absent of any repeated calibration. Thereby, directly decoupling surface temperature could contribute to significant advances in online monitoring of gas turbines.

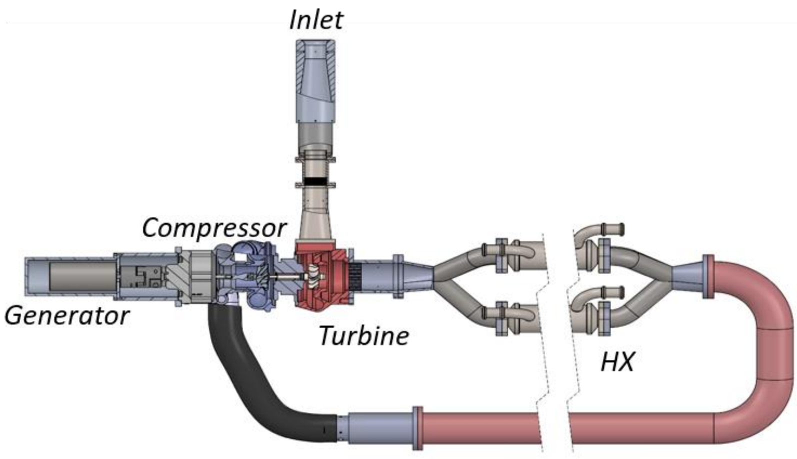
Effusion and Skin Cooling for Micro Gas Turbines

As the power and thrust requirements from modern micro turbomachines increase, they pose new challenges on the thermal management of the units. As such, the turbines of these devices are operating in increasingly harsher thermal environments and as the micro turbine are currently mostly uncooled, new cooling paradigms have to be explored to further promote the state of the art. Therefore, we are using our turbine research facilities to develop effusion and skin cooling methods for micro gas turbines. Previously used only in their larger counterparts, the transition of these methods to smaller scales is not trivial and requires significant scientific and experimental inputs in order to provide viable cooling solution for micro turbines.



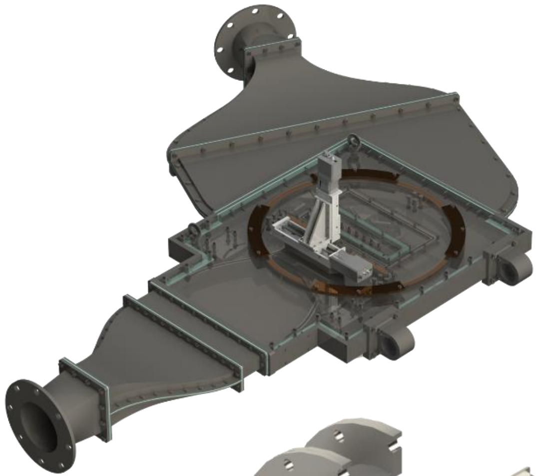
Inverted Brayton Bottoming Cycle for Hot Gas Energy Recovery

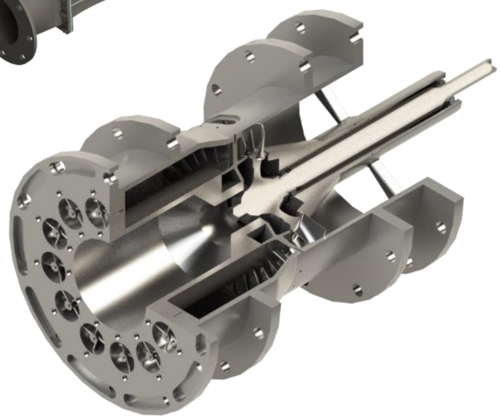
In numerous widely-used application (such as micro gas turbines, fuel cells and internal combustion engines) significant amount of thermal energy is expelled with hot waste gas. The inverted Brayton bottoming cycle (IBC) offers a way to utilize this expelled heat and boost the overall thermodynamic performance of the system. It makes use of high temperature exhaust gas in near-atmospheric conditions by expansion into vacuum. This avoids issues of backpressure and increases the potential energy recovery from exhaust heat. Our research project focuses on the design, development and validation of the IBC system concept in application-relevant conditions with the ultimate goal of assessing the actual impact on the system performance.



Linear and Rotational Micro-Turbine Research Facilities

Beyond the inherent design complexity, the physics associated with micro gas turbines are complicated by dimension-specific challenges. Hence, to obtain positive cycle efficiencies, the same design guidelines cannot be applied to large and miniaturized engines. Currently, among the main technological barriers of advanced micro gas turbine development is the lack of relevant scientific knowledge on the hot gas section, which is commercially confidential and export-controlled. In this light, we are building Israel's first turbine research facility, which will enable developmental projects to be structured around a versatile closed-loop pressurized high speed turbine facility. Incorporating an interchangeable test section to provide hot (~600K) transonic conditions for fixed blade cascade and rotating high/low pressure turbine stages of micro-engines, it is intended to provide unique research capabilities to the global research environment. The final specifications include maximum turbine diameter up to 350mm, closed loop turbine pressure ratio up to 6:1, maximum mass flow rate of 0.9 kg/sec, transonic Mach distribution on the blades, rotational rate of up to 90,000 rpm and flow to metal temperature ratio of up to 2:1. Matching all engine similarity conditions for high pressure turbine stages of micro-engines, the continuously running rig will enable full aero-thermal performance characterization of the turbine independent of other sub-components and contribute to advances in the areas of advanced thermal management, active tip clearance control and aerodynamic/thermal loss minimization.





Cold Flow Combustor Test Rig

Understanding the dissipation dynamics of the fluid inside the combustion chamber of a gas turbine is important from the stand point of flow mixing. Combustion efficiency could be improved by achieving effective mixing of air and fuel at a shorter distance. Fluid mixing could be studied easily through the dissipation rate of the scalars in a given region of investigation. In this experimental research, a non-reactive flow field inside the micro-combustor is resolved in a specially designed experimental facility, which includes a rectangular test section which simulates the flow inside an annular combustion chamber with multiple port of fuel injection at different directions. The flow field is dominated by the cross flow and the impinging flow/co-flow regimes. The research aims to study the dissipation rate of the introduced scalar from the fundamental level and to verify the periodicity boundary conditions used in the numerical modelling in such cases.