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Gas Dynamics and Propulsion Laboratory (GDPL)

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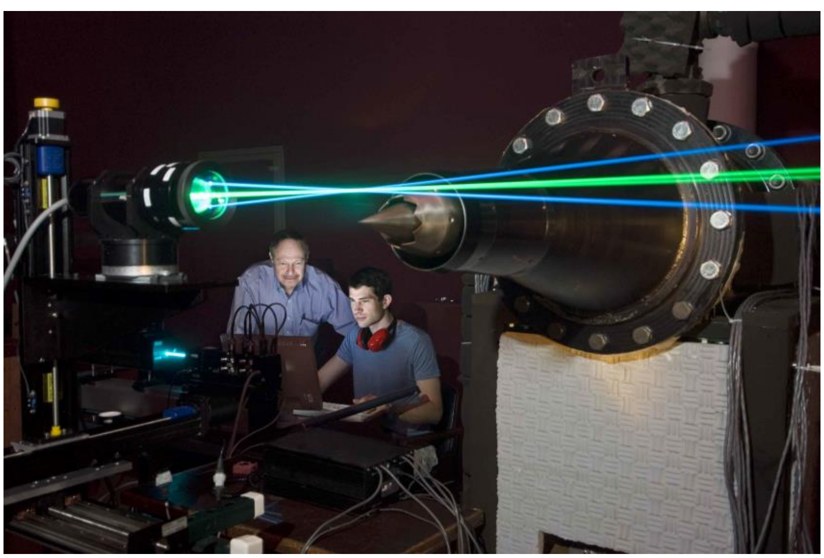
The Gas Dynamics and Propulsion Laboratory (GDPL) is located on campus, at a satellite research park, and in the Medical Sciences Building, and affords the researcher exceptional experimental and computational facilities. The laboratory occupies a high bay area with over 10,000 square feet of floor space. The most advanced flow and propulsion diagnostics are available, in addition to state-of-the-art computational capabilities. A brief description of the research topics performed at GDPL follows.

1. Jet Noise-Prediction and Reduction (Funded by GE Aviation, NASA, US Dept. of Defense, ONR, Sweden DoD)



The advent of jet engine as a power plant for military and civil aircraft and its unavoidable counterpart, jet engine noise, initiated substantial research on the sources and causes of jet noise, as well as methods and devices for its reduction. The noise level of jet engines, particularly during takeoff and climb, is often a concern for people living near airports or working near airplanes. Such high noise levels can limit future airport air traffic expansion, and force new airports to occupy remote sites. It also limits the ability of personnel to work for extended times near airplanes. New requirements for lower jet noise are a continued area of interest both by governmental agencies and by neighborhoods located in close proximity to airports, flight paths and to engine and flight vehicle manufacturers. Due to these concerns a need to further jet noise reduction technology is in demand.

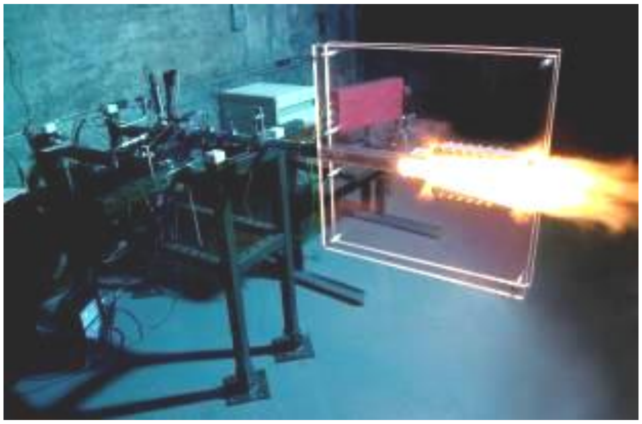
Various approaches have been proposed to overcome the noise issue. The optimal solution should be such that substantial noise suppression is achieved using a method that is easy to implement, low cost, reliable, and without substantial adverse effects on the engine performance. Development of such devise requires basic understanding of the noise generation mechanisms. The objectives of our research are to evaluate experimentally new concepts for jet noise reduction and to develop analytical or numerical tools for the prediction of jet noise and jet noise reduction techniques for commercial and military engines (subsonic and supersonic jets).

2. Combustion Control and Flameless Combustion (Funded by Office of Naval research, NASA, GE Aviation and UTC)

Considerable amount of work in the area of passive and active combustion control for gaseous and liquid fueled combustion has been reported during the last two decades. These studies have dealt mostly with bluff-body-stabilized combustor and dump combustors where the recirculation induced by a bluff-body or by a sudden expansion is used to stabilize the flame and were more recently extended to swirl stabilized combustors. Active control strategies have been used to suppress thermo-acoustic instabilities resulting from a coupling between the heat release and the acoustic modes in the combustor. These control strategies have generally relied on modulating the fuel injection and phase shifting it so as to decouple the pressure rise and heat release with respect to each other. Control strategies have also looked at improving fuel efficiency and reducing pollutants, and in extending flammability limits. Our research deals with the control of gas-turbine gaseous and liquid fuel combustors with swirlers, bluff body stabilizers and distributed fuel injection for rapid mixing and stabilization. It focuses on investigating the mixing patterns and flame structure in these combustors and developing control strategies for improved performance of gas-turbine combustors.

In addition, we are developing new technology of combustion, called "Flameless Combustion" for gas turbine engines. This technology provides low emissions and very stable combustion and has the potential of becoming the next generation of combustion systems for propulsion and power generation gas turbines.

3. Pulse Detonation Engines – PDE and Rotating Detonation Engines - RDE (Funded by NASA, and ISSI/Air Force Research Laboratories/DARPA, and GE Aviation/GEGR)



A pulse detonation engine (PDE) offers few moving parts, high efficiency, high thrust, low weight, low cost, and ease of scaling. These make the PDE an attractive alternative to jet turbine engines for small disposable engines. The near constant volume heat addition process, along with the lack of a compression cycle, lend to the high efficiency and specific impulse, simplicity, and low-cost of pulse detonation engines. Pulse detonation engines have the potential for operation at speeds ranging from static to hypersonic, with competitive efficiencies, enabling supersonic operation beyond conventional gas turbine engine technology. Currently, no single cycle engine exists which has such a broad range of operability. Computational and experimental program is conducted at UC to investigate the performance of an air breathing pulse detonation engine (PDE). This research effort involves investigating such critical issues as: detonation initiation and propagation; valving, timing and control; instrumentation and diagnostics; purging, heat transfer, and repetition rate; noise and multi-tube effects; detonation and deflagration to detonation transition modeling; and performance prediction and analysis. Our lab has a unique hybrid engine that includes an array of 6 PDEs integrated with an axial turbine. This system potentially can replace the entire high pressure core of a jet engine, including high pressure compressor and turbine and the combustor.

4. Novel Augmentor System Design (Funded by GE Aviation, AFRL)

A new and unique facility that simulates the flow conditions in an afterburner configuration is operating in our laboratory. The facility includes a combustor with an exhaust duct where innovative strategies of secondary fuel injection can be tested. It is also instrumented for advanced flow and combustion diagnostics. The facility is used to study secondary combustion dynamics in an augmentor configuration. The research emphasizes new concepts for flame stabilization, and investigation of combustion instabilities in augmentors and their prevention using passive control and acoustic liners. The research combines experimental and computational work.

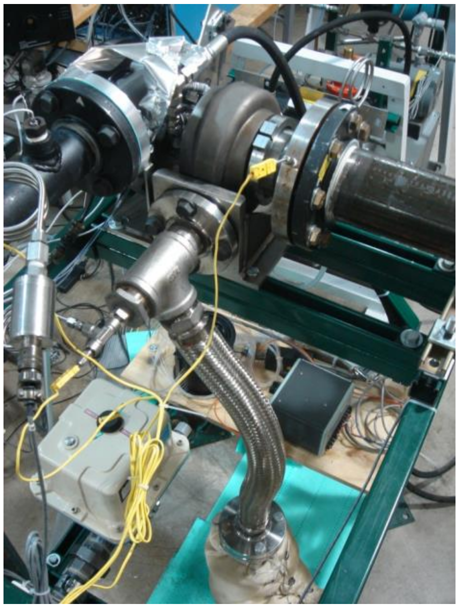
5. Flight Control of Modern Shaped Wings Using Vortex and Flapping Actuators (Air Force Research Laboratory)

Lift force on modern shaped wings at a high angle of attack relies on complex set of vortices that are formed at the leading edges, flaps, and tips of the wing. At high angle of attack these vortices loose gradually their coherence due to intrinsic flow instabilities. At these conditions, the lift produced by the vortices is reduced and the aerodynamic moments derivatives change from stable to unstable conditions causing loss of controllability and stall. Tests showed that small continuous, pulsating, or flapping microjets that are injected into the separated regions from certain locations on the wing surface could control the behavior of the flow over the wing. Depending on the orientation of the injected microjets, the flow pattern over the wing can be altered to achieve the desired controllability. The microjets injection can therefore be used for flight control without the conventional control surfaces. Controlled actuation of different combinations of microjets based on feedback from sensors distributed over the wing surface can yield the desired pitch, yaw, and roll moments. Moreover, this method incurs little or no drag penalty.

The control system relies on rational activation of pulsating jets. Static and dynamic modeling of the flow topology, aerodynamic responses and actuator characteristics are required for closed-loop control system design. Advanced external flow control and aircraft attitude control architectures and algorithms are needed to cope with the highly coupled, time-varying, uncertain and complex nonlinear aerodynamics that are dynamically and structurally unstable.

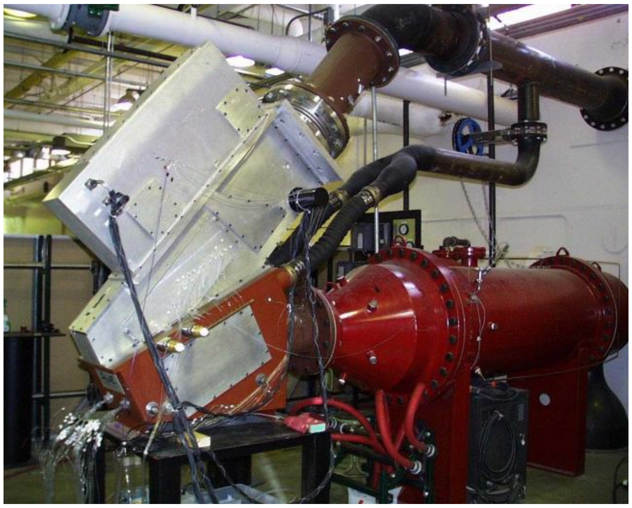
The present concept is applicable to attitude control of tailless fighters, reentry vehicles and UAVs, especially micro UAVs, without requiring control surfaces such as ailerons, rudder, elevator, or flaps. This type of controlled lift can also be used to enhance performance of lifting bodies. The advantage of such a system lies in its aerodynamic simplicity, reduced radar cross-section and ease of miniaturization.

6. Turbocharger Compressor Range Extension (Funded by Honeywell/Garrett)



The goal of the project is to develop better understanding of the flow processes in the compressor that affect stall and surge for different operating conditions, geometrical changes, and new design concept. We aim to be able to design a compressor with a wider flow range in order to satisfy engine manufacturers' demands. In particular, the surge line should be moved to the left on the compressor map. Ported shrouds yield improved range but the effect on efficiency are not clear. De-swirling vanes in the port channel yielded improved surge performance, but the mechanism remains unknown. Additional areas of interest include the use of the UC unsteady turbine flow facility to study pulsatile turbocharger flow in the turbine section. Such tests can include effects of unsteady inflow conditions, effects of compressible flow such as choking, unsteady flow dynamics, flow separation, acoustics and other instabilities.

7. Turbine Blade Cooling and Hot Streaks Secondary Reactions(Funded by NASA, AFRL, GE aviation, and Allison Rolls-Royce)



The performance and efficiency of gas-turbine engines can be significantly improved by increasing the combustion temperature. The major problems associated with increasing this temperature are the increased thermal stresses on the turbine blades that could lead to their failure. To allow higher combustion temperatures, blades of gas turbines have to be protected from the hot gases. One of the method to protect gas turbine blades are the film cooling techniques that have been investigated during the last four decays. Our research is performed in a unique facility at UC comprising of a transonic cascade in which cooling air is simulated by heavy gases and heat transfer efficiency and its effect on the blade aerodynamics is investigated in advanced blade geometries. We've recently constructed a special purpose facility to study the effectiveness of film cooling using gas sampling and Pressure Sensitive paint.

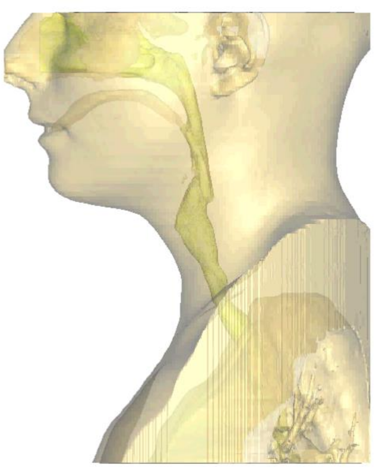
In another facility we study the cases in which secondary combustion occurs on the turbine guide vanes due to reactions between hot products of incomplete combustion with the fresh air injected for film cooling. Our unique facility allows simulation of these conditions by controlling the composition of the combustion products, the flow and temperature profiles entering the turbine section. The facility also includes a test section with an instrumented guide vane with film cooling provisions, on which secondary combustion can be studied.

8. New Concepts for Duct Noise Suppression by Acoustic Liners (Funded by NASA, GE Aviation)

Acoustic liners are used to reduce the noise radiated from aircraft engine nacelles. They are also applied in augmentors ducts to absorb acoustic energy to prevent combustion instabilities. The liner consists of honeycomb cavities covered with a perforated face sheet. There is no clear understanding of the liner sound absorption and dissipation mechanisms. Conventional Single Layer (SDOF) Acoustic Liners are constructed with honeycomb core with impervious cell-walls. This ensures that there is no acoustic transmission across the walls of honeycomb cells. It allows the liner to be treated as a uniform array of Helmholtz Resonators. The acoustic damping occurs due to viscous and rotational losses, as air particles oscillate through the porous face sheet.

The current research investigates the use of passively and actively adaptive liners design. These designs are expected to have acoustic suppression properties equal or greater than current liners. They will yield significant advantages in terms of effectiveness, weight, cost, ease of manufacture, and environmental impact.

9. Airway, Voice, Cardiovascular Research (Funded by NIH, UCCoM, CCHMC Foundation)



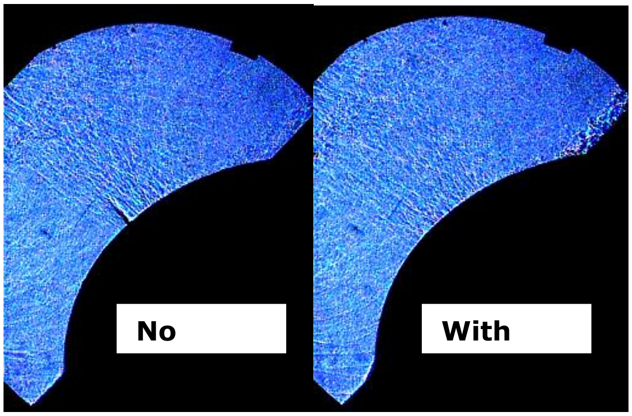
Mechanisms of voice production are not well understood. They involve interaction between flow and structural vibrations of the vocal folds within the larynx; this is the aeroelastic aspect of the mechanism. The interaction between the flow and vibrating folds modify the flow and produces highly vortical flow pattern. This flow includes organizes vortices and random turbulence generates sound via mechanisms described by aeroacoustic theory. The sound is amplified and filtered in the mouth cavity before exiting as voice. Our jet noise research described in section 1 above has many similarities to voice generation mechanisms. Our research investigates the relationship between the flow field and the noise produced by the jet and both experimental and computational tools are useful for the larynx applications. The voice research is a collaborative effort between our laboratory and the Otolaryngology Department at the UC School of Medicine. Our goal is to develop the physical understanding of voice production that will help in

developing new medical treatment and surgical procedures for patients with voice pathologies.
In addition to voice research we are collaborating with the Pulmonary and ENT Departments of CCHMC (Cincinnati Children's Hospital) in applying CFD to compute airway flow and pressure distribution for sleep apnea and airway reconstruction research.

10. Novel Hydraulic System for Oil Drilling and Extraction (Funded by Halliburton Inc., Texas)

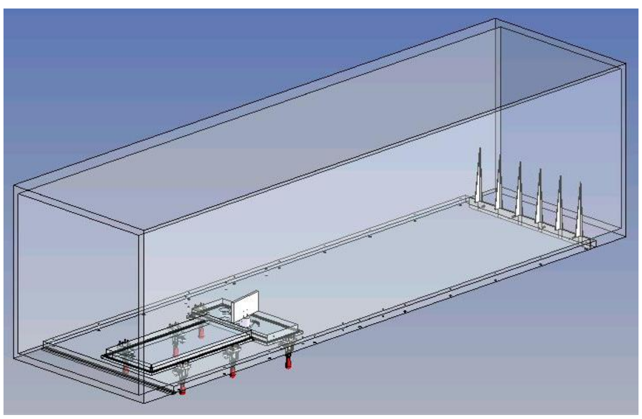
A new and unique facility that simulates the flow conditions at the bottom of an oil well is operating in our laboratory. The facility is used to study the hydrodynamics of Halliburton roller cone and PDC drill bits for oil explorations. The acquisition of the pressure map under the drill bit and the measurements and visualization of the flow field around the bit for different nozzles and for a wide range of operating conditions are the main objectives of the investigation. Improved hydrodynamic performance will be translated into tremendous savings in the cost of oil drilling operations.
The goal of the project is to test new nozzles in a realistic drilling environment including high flow rates used in drilling operations. The measurements show the influences of different nozzle geometries on drill bit performance in actual bottom hole environment. The tests include optimization of bit internal and nozzle geometry for predetermined pressure and momentum distribution with high discharge coefficient for low pressure-drop. Other measurements include the velocity field measured by PIV (Particle Image Velocimetry). In addition to the experimental component, Computational Fluid Dynamics (CFD) is used to study the flow in the nozzles and around the 12 ¼" modular roller cone bit.
Our lab has a simulator of downhole proppant injection for fracking operation and bi-stable valves to separate between oil and water or gas. Both facilities are fully instrumented with the goal of improving the understanding of their operation and optimize it. CFD is used to compare with experiments and assist with the optimization efforts.

11. Flow Control at High Speed Conditions (Funded by Boeing Inc., Seattle)



A hemispheric protrusion on an airframe at near sonic flight conditions suffers a tremendous degree of flow separation behind the unsteady shock that forms near its apex. Such condition can be alleviated by applying active flow control (AFC). However, due to the performance degradation occurring with standard AFC devices at high flight velocities combined with impractical weight requirements, a new system that was developed at the University of Cincinnati (UC) offers a lower weight alternative that can provide control authority at sonic to supersonic flow speeds. The simplicity and scalability of this device make it an attractive alternative to more conventional methodologies. UC has extensive experience and resources related to such technology and flow diagnostics.

12. Unsteady Aerodynamic Loading on Aircraft Fuselage (Funded by Boeing Inc., Seattle)



Experiments are performed in a subsonic wind tunnel with a special test section that is used to study unsteady flow separation behind generic protrusions to simulate flight conditions of an airplane with appendages installed on the fuselage (cameras, antennas, probes, etc). The experiments enable research of the correlation between the flow field, unsteady pressure, and vibrational modes induced on a fuselage panel. Special provisions were made to generate thick boundary layers relative to the protrusions to simulate the thick boundary layer at the aft end of the airplane. The experiments are also used to validate CFD results and to develop a robust design methodology.

13. Wing Tip Vortices and VBI of Rotating Blades (Funded by Boeing Inc., Seattle)

Experiments are performed in a subsonic wind tunnel to study wing tip vortices and develop passive and active methods to suppress them. Wing tip vortices adversely affect aircraft performance by causing induced drag. They also slow down the take-off and landing process because of the safety distance that airplanes have to keep between them to prevent unsteady loads caused by the trailing vortices of one airplane on another. In helicopters, unducted fans, propellers, or rotating blades the cause noise and deteriorated performance due to Vortex-Blade-Interaction (VBI). The experiments enable research of the mechanisms of tip vortex formation and their evolution, and of the methodology of mitigation.

14. Fuel Management and Mixing Control for Scramjet Propulsion (Air Force Research Laboratories and NASA)

Scramjet combustors are characterized by an extremely short residence time for the completion of fuel atomization, mixing and combustion. It is therefore desired to develop fuel injection schemes that will accelerate the mixing process by improving penetration, achieving small-dispersed fuel droplets, and enhancing mixing. In addition, during vehicle acceleration the location of heat release in the combustor has to shift to ensure optimal performance in the entire range of Mach numbers. This project addresses the aforementioned issues by investigating fuel injection flow control strategies. Specially designed injectors are designed and tested in quiescent, cold cross flow, and reacting conditions. The effect of fuel temperature, as the fuel is heat soaked for combustor cooling, would also be simulated to test the stability of the injectors. Emissions, which are a critical concern for commercial space applications, would also be used as a performance parameter in evaluating the injectors. In parallel with these experiments, numerical modeling is pursued to study the flow physics and effectiveness of the different injector configurations in cold and reacting flows.