Project Description

Project 1: Flow Field Characterization of a Generic Rocket Nozzle

Mentor: Rajan Kumar

***Synopsis*:** Recent advances in commercial space transportation emphasize rocket engine reusability and its operation over a wide range of operating conditions. Rocket nozzles are designed for optimal performance at a certain design point in the rocket trajectory, which happens to be typically in the vacuous, upper atmosphere. Therefore, these rocket nozzles underperform at sea level conditions where they operate at highly over-expanded pressure conditions. Operation at highly over-expanded pressures lead to flow separation and flow entrainment from the ambient conditions (Fig. 2) that lower nozzle efficiency.

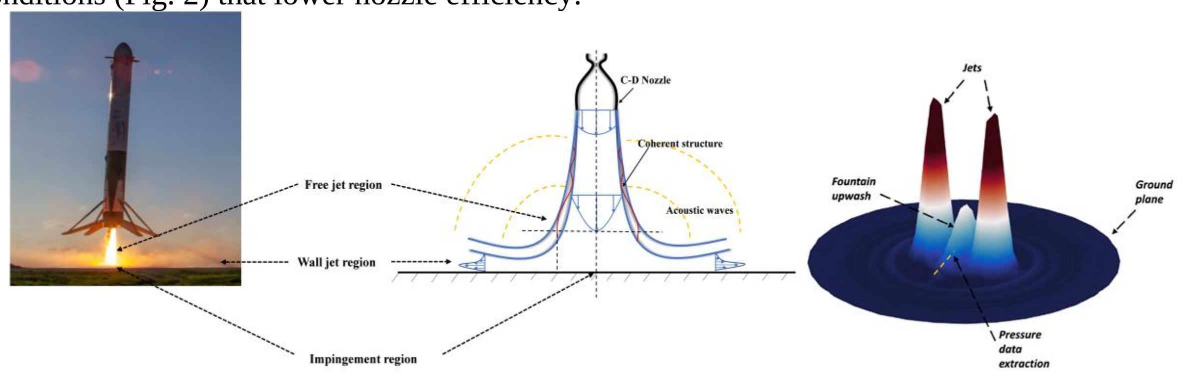

Figure 2. Single (main) and twin (booster) impinging jet characterization for a rocket nozzle

Summer Program: Students familiarize themselves with rocket nozzle design, gas dynamics, and microjet control. They perform pressure measurements to determine pressure distributions inside the nozzle, with and without, microjet control over a range of nozzle pressure ratios. They also characterize the flow-separation location as a function of the nozzle pressure ratio and implement microjet control to manipulate local separation while improving the rocket nozzle performance.

Project 2: Particle dynamics in a complex flow environment

Mentor: Huixuan Wu

Synopsis: The behavior of solid particles within complex flow environments is profoundly influenced by a diverse array of factors, including fluid velocity, turbulence levels, and the presence of obstacles or irregular geometries. Furthermore, the dynamics of these particles carry far-reaching implications that extend beyond disciplinary boundaries, spanning from environmental science to engineering. A comprehensive understanding of solid particle dynamics within complex flows serves as the cornerstone for advancing processes, refining transport systems, and addressing pressing environmental challenges, thereby underscoring its vital and wide-ranging impact.

Summer Program: Students will collaborate closely with graduate students and researchers to gain valuable knowledge on particle dynamics, multiphase flows, and advanced measurement technologies. Students will undertake the task of developing a computer program for calculating particle trajectories and subsequently validate these results through experimentation. During the summer program, participants will actively engage in designing an experimental platform tailored to observe particle motions within a rotating flow. Additionally, they will simulate particle dynamics employing software or an in-house program. This multifaceted approach will enable students to draw comparisons between the simulation and experimental outcomes, pinpoint potential sources of error, and enhance the consistency of their facilities and programs. This immersive process will equip students with a comprehensive understanding of scientific research methodology, encompassing the formulation of theoretical models and the refinement of experimental validation techniques.

Project 3: Evaluation of wake unsteadiness of slender bodies at a high angle of attack
Mentor: Unnikrishnan Sasidharan Nair/Rajan Kumar
Synopsis: Wakes of slender forebodies exhibit qualitatively different flow regimes depending on the flow and geometric parameters. In the proposed effort, we aim to understand the instability characteristics of these wakes under varying effects of compressibility, on a canonical axisymmetric slender forebody with a tangent-ogive nose section. The students will utilize stability solvers and a high-fidelity in-house CFD framework to evaluate wake dynamics at low-subsonic Mach numbers for a forebody at a 40-degree angle of attack.

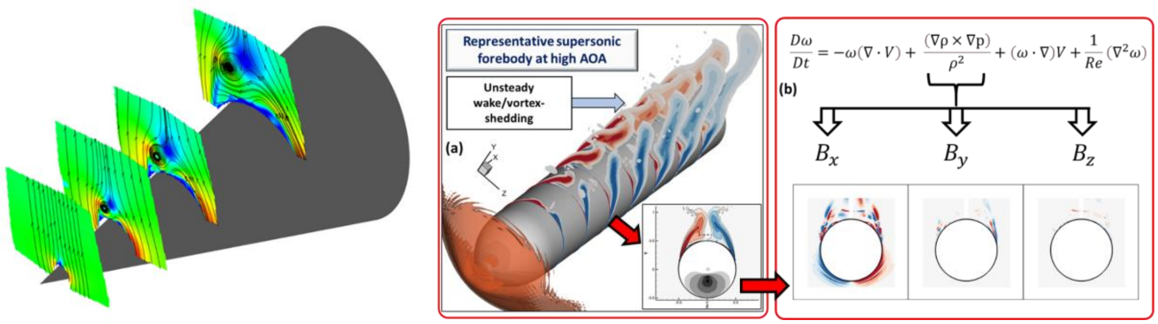

Figure 3. Vortex asymmetry on slender bodies at high angles of incidence

Summer program: One fellow will be trained on the basics of the numerical simulation framework, and modal/spectral analysis tools. They will first utilize the linear stability tool to obtain linear estimates of instability wavelengths and frequencies in the wake. Following this, they will analyze the high-fidelity simulations to understand the effects of turbulence in determining the real-world system response and loading. Comparisons with linear predictions will provide insights into potential reduced-order models for this complicated flowfield.

Project 4: Robot Terrain adaptation for multi-modal locomotion
Mentor: Jonathan Clark
***Synopsis*:** The goal of this project is to develop techniques to enable a quadrupedal robot to successfully navigate natural terrain in multiple modalities. To mimic animals' abilities to use their legs to run, climb, jump, swim, etc. robots will need to have appropriately designed appendages, control strategies, and the ability to adapt to different terrains.
Summer Program: Students engaged in this project will learn the fundamentals of animal and robot locomotion. They will help develop novel mechanisms for better attachment, increased endurance, and more efficient swimming gaits. They will help build experimental terrains for testing and develop test plans to quantify and improve the performance of the robot's appendages. They will take part in the design, test, and evaluation cycle for the robot limbs. Their designs will be incorporated into the robot's control and adaptation strategies to determine their effectiveness in both laboratory and real-world environments.

Project 5: Optimization of Projectile Maneuver Flight Control
Mentor: Rajan Kumar/Nair Unnikrishnan
Synopsis: To optimize a pre-existing baseline projectile model to provide enhanced aerodynamic characteristics while limiting any negative effects on existing baseline metrics. The baseline model is a missile model with only tail fins to control. In this process, students will be testing two different models: the addition of either a delta wing or split canards. The added delta wings will reduce the drag while increasing lift for higher payload capabilities.
Summer program: Two Fellows will be involved in the feasibility design analysis and preliminary wind tunnel testing of both models. Use the CFD Solver to predict the performance of models under the startup process of the supersonic wind tunnel to ascertain that they can withstand extremely high loads by the passage of the initial shock wave.

Project 6: Cyber-physical Adaptive Structures for High-Speed Flow Control
Mentor: William Oates
Synopsis: Adaptive structures are known for their ability to actuate and sense different stimuli in the environment using compact, solid-state systems and structures. These materials range from piezoelectric ceramics, magnetostrictive compounds, shape memory alloys, and a broad range of multifunctional polymers and composites. Piezoelectric ceramics exhibit the ability to both sense forces and actuate mechanisms across a broad bandwidth of frequencies. We will design and implement a pixelated array of self-sensory actuators for use in controlling supersonic flow across aircraft control surfaces (Fig. 4). Novel algorithms that use entropy dynamics (a generalized form of Bayesian uncertainty quantification (UQ)) will be used to create robust state estimators and nonlinear optimal control feedback with novel adaptation.

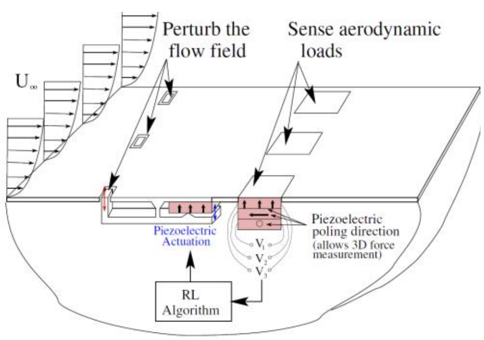

Figure 4. 3D schematic of the UQ state estimation and control algorithm using sensors and actuators.

Summer Program: It is expected this to be a project involving a cohort of REU students from multiple REU summers. Students will work with graduate students and postdocs to learn about piezoelectric materials and adaptive structure designs for flow control applications. He/she will also learn how Bayesian UQ applies to state estimation and optimal control for real-time experimental aerodynamic control problems. The student will create CAD designs and work with machinists within our research center to fabricate the adaptive structure for wind tunnel testing. The first summer's efforts will focus on design and open-loop control implementation. Data will be collected, and entropy dynamics (Bayesian UQ) algorithms will be implemented to create a system amenable to real-time state estimation. We will build upon this work in future summers by having students update the adaptive structure flow controller, and state estimator robustness, and extend the work to optimal feedback control. In the third and final summer, different control methods using hybrid feedforward and perturbation feedback will be explored by using robust Bayesian priors to mitigate larger feedback to enhance stability and controllability in highly nonlinear regimes.

Project 7: Next Generation Tribological Materials for Aerospace Applications
Mentor: Brandon Krick
Synopsis: Aerospace vehicles and devices have numerous mission-critical moving mechanical assemblies that depend on efficient and reliable actuation of sliding interfaces (Fig. 5). Traditional lubricants are precluded from use in these extreme environments because of extreme temperatures, differences in the local environment (*e.g.* ultrahigh vacuum in space, high altitude flight environment, or other harsh terrestrial environments), and in many cases the inability to retain traditional lubricants. This work studies 1) ***Polymer nanocomposites:*** design multifunctional, self-lubricating materials and 2) ***Next-generation coatings:*** leverage processing-structure-property relationships of traditional and emerging coating deposition techniques to create next-generation wear, corrosion, and thermal-barrier materials.

Summer Program: This project will immerse the student into synthesis, characterization, and experimentation for tribological applications. The student will be trained, with daily hands-on mentoring from a graduate student and faculty advisor. Depending upon the student's strengths and interests, the student will be able to choose one of two routes. *Route 1) materials synthesis, testing, and characterization:* here, the emphasis will be on the materials science, chemistry, and physics of the interactions between the materials and their environments. *Route 2) experimental development and materials testing*: the emphasis is on developing tribometer (friction and wear measurement apparatus) capabilities, including the ongoing design of an ultrahigh vacuum tribometer as well as a tribometer that will be deployed for automated operation on the international space station. Research requires the ability to design and control an experiment, analyze, and document results, and report discoveries for publications and patents.

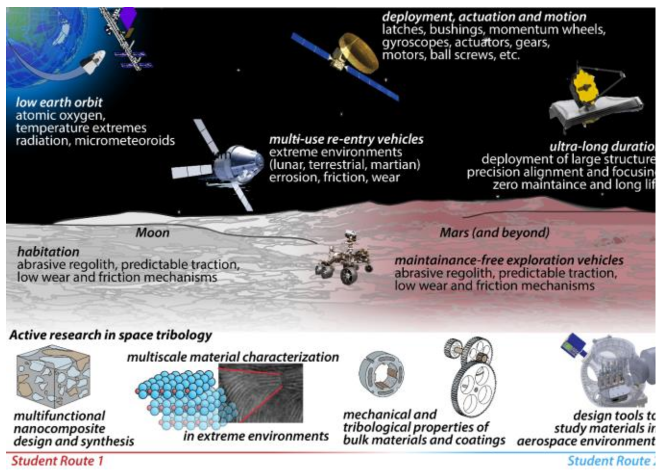

Figure 5. Challenges for space tribology including applications (top) and active research areas at FAMU-FSU COE (bottom). Student Routes highlighted in red and blue along the bottom of the active research areas.

Project 8: ***Design and Construction of Active Flow Control System for Reinforcement Learning***
Mentors: Kourosh Shoele
Synopsis: It is sometimes beneficial to use active control methods to study flow phenomena and improve their performance. This project consists of designing and constructing an apparatus required to use machine learning techniques to perform active flow control in a wind or water tunnel. The connection between hardware and software will allow using techniques such as reinforcement learning to perform adaptive flow control studies in the facility. The facility will be beneficial in studying many different problems that benefited from active flow control technology such as fluid-structure interaction.

Summer program: The Fellow will be involved in designing and building protocols to connect the wind tunnel hardware to the MATLAB machine learning toolbox. The apparatus is made of decks and consists of several major components: DYN2-series motor controllers, NI USB-6218 Data acquisition (DAQ) board, ATI sensors, and power sources. The apparatus will be tested for the active control of the flow over a cylinder using rotating bars placed near the leeward face of the cylinder for a range of flow velocities.

Project 9: Transition length scale characterization for simple axisymmetric models in the PSWT
Mentor: Alexandre Berger
Synopsis**:** The transition from laminar to turbulent flow significantly impacts vehicle performance. Aerodynamicists have dedicated decades of research to comprehending the transition mechanisms associated with flight conditions and vehicle geometry. This knowledge has practical applications in improving flight vehicle performance. Nevertheless, wind tunnel experiments introduce flow disturbances, often in the form of acoustic instabilities, leading to discrepancies between transition locations observed in the wind tunnel and those experienced in-flight. Researchers at the PolySonic Wind Tunnel (PSWT) aim to characterize transition lengths for common geometries. This project will provide a better understanding of results in relation to other facilities and in-flight conditions. Simultaneously, Focused Laser Differential Interferometry (FLDI), is a novel flow diagnostic method currently under development. This method will be used to measure the flow instabilities of interest. Thus, the objective of this project is to characterize the laminar to turbulent transition length scales for common models in supersonic flow conditions using FLDI and surface pressure measurements.
Summer program**:** This project offers students a comprehensive experience encompassing all phases of an experimental aerodynamic campaign, from planning and execution to data analysis and reporting, with straightforward and valuable objectives benefiting the entire facility. Daily guidance from both a graduate student and faculty member will provide continuous mentorship. Following the **development of the test matrix**, students will actively participate in **setting up optical diagnostics and installing models**. This hands-on involvement will familiarize them with rigorous laboratory safety protocols and methodologies. Upon completing the experiment, students will assume responsibility for basic **data analysis**. They will receive training in MATLAB or Python, if needed, enabling them to perform simple **signal analysis** of the surface pressure and FLDI data. The project will conclude with guidance and support in formatting and **presenting results** in a clear and accessible manner. In summary, students will acquire a diverse range of practical laboratory skills while gaining valuable exposure to a real-world supersonic wind tunnel experiment.