NDnano
Notre Dame Nanoscience and Technology

# NDnano Summer Undergraduate Research
# 2024 Project Summary

1. Student name & home university:
Lyon Burns, Purdue University

2. ND faculty name & department:
Hirotaka Sakaue, Aerospace and Mechanical Engineering

3. Summer project title:
Pitching Airfoil Using Motion-capturing TSP Method

4. Briefly describe new skills you acquired during your summer research:
This summer, I gained essential knowledge about the research process—from understanding what you are looking for, to finding and reading relevant research papers, and applying the findings to support your own research. I have started to familiarize myself with luminescent chemistry and have developed a deep understanding of fluid dynamics. Additionally, I have worked on the skill of discussing and presenting my work to various groups with different backgrounds, requiring me to tailor my presentations and messages according to each group's level of knowledge and experience.

5. Briefly share a practical application/end use of your research:
One practical application of Pressure/Temperature Sensitive Paint (PSP/TSP) is in studying dynamic stall, a type of stall phenomenon where the pitch rate of the airfoil is considered. Traditionally, pressure transducers are placed along the airfoil to collect pressure measurements. However, this method has limitations and cannot provide continuous measurements. TSP is useful in this scenario because it allows us to visualize the temperature field, thereby determining where the flow transitions from laminar to turbulent.

6. 50- to 75-word abstract of your project:
Pressure/Temperature Sensitive Paint (PSP/TSP) are chemical sensors used to measure the pressure and temperature of a surface, respectively. They have numerous applications in research, including wind tunnel tests on various test sections. In my project, I studied two-color TSP to enhance our understanding of dynamic stall. Additionally, I created a prototype to change the angle of attack, mimicking dynamic stall conditions.

7. References for papers, posters, or presentations of your research:
A. Neal Watkins,1 Gregory M. Buck,2 Bradley D. Leighty,3 and William E. Lipford,4 NASA Langley Research Center, Hampton, VA 23681, USA (N.d.). Retrieved from https://ntrs.nasa.gov/api/citations/20080008344/downloads/20080008344.pdf

Dussling, J. J. (n.d.). Development of an improved temperature sensitive paint system for the Boeing/AFOSR Mach-6 Quiet Tunnel. Retrieved from https://docs.lib.purdue.edu/dissertations/AAI1510071/

Kenneth W. McAlister, Lawrence W. Carr, and William J. McCroskey (N.d.). Retrieved from https://ntrs.nasa.gov/api/citations/19780009057/downloads/19780009057.pdf

R.R. Leknys, M. Arjomandi, R.M. Kelso and C. Birzer (N.d.). Retrieved from https://people.eng.unimelb.edu.au/imarusic/proceedings/20/641%20Paper.pdf

Dynamic stall is a complex and not well-understood phenomenon due to the difficulties in testing it experimentally. Understanding the transition point can help prevent dynamic stall. The goal of this project is to contribute to the understanding of dynamic stall by accurately measuring the transition point using chemical techniques.

Pressure and temperature are critical factors in analyzing an airfoil's performance. Pressure can be mapped along the airfoil's chord to calculate the total lift and drag. Temperature analysis helps evaluate the airfoil and material at different speeds and angles. Wind tunnel tests aid in preventing failures during flight. However, common measurement techniques like pressure taps and temperature probes are limited by the number of probes that can be used. Increasing the number of probes raises the cost and complexity of data collection.

Pressure Sensitive Paint (PSP) is a luminescent paint that measures air pressure on a surface using oxygen quenching of luminescence. PSP overcomes the limitations of conventional techniques as it can be applied over the entire wing area, providing a visual pressure field.

PSP formulation is complex, involving a luminophore dye, a polymer binder, and a solvent. The dye emits light when illuminated, which excites the PSP to quench oxygen because oxygen provides a non-radiative energy transfer. By illuminating the PSP with light (usually UV) and running air over it, the oxygen molecules in the PSP correlate with the surface pressure. TSP works similarly but is oxygen-impermeable, correlating temperature with luminescence.

Two-color TSP is studied and employed when an additional variable needs to be considered. In this case, model vibrations and instability can be accounted for using two-color TSP. Luminescent molecules are selected for maximum temperature sensitivity and are dispersed in an oxygen-impermeable binder to limit quenching by oxygen. As a result, all quenching occurs through non-radiative temperature effects.

Fluid dynamic testing using a two-color TSP was designed. The wind tunnel test setup features a NACA 0012 airfoil painted with a two-color TSP. The airfoil is attached to a wire shaft at the mid-chord, allowing it to pitch freely. An ultraviolet (UV) light is used to excite the luminophores in the TSP. A CMOS sensor captures the luminescence or fluorescence emitted by the TSP coatings applied to the test model's surface. The high-speed camera collects numerous images and creates a mean image for more accurate results.

Understanding PSP/TSP's functionality is crucial for studying dynamic stall. Static stall occurs when an airfoil pitches at too high an angle of attack, tested by slowly increasing the angle until reaching the critical angle. Dynamic stall happens when the airfoil pitches too quickly, allowing a higher angle of attack before stalling compared to static stall. However, dynamic stall is unpredictable and violent. After a strong lift increase, the airfoil must lower significantly to reattach the boundary layer, a phenomenon known as hysteresis.