

Abstract of the proposed project for public

This project aims to improve the safety and reliability of compression systems by developing a new method to analyze dangerous flow instability without risking damage to the machinery. Compressors are widely used in aircraft engines, industrial systems, and power generation. However, one of the most critical and least understood challenges in their operation is *surge*—a violent instability in which the airflow reverses direction. Surge can lead to severe vibrations, loud noise, mechanical failure, and even complete system shutdown. Because testing this phenomenon in real machines is risky and potentially destructive, engineers often lack reliable data to understand how and when it occurs.

What makes this approach unique is its hybrid nature. We combine a well-known analytical model, the surge Greitzer model with CFD simulations. Instead of simulating the entire compressor, we simulate just the plenum section with variable volume, while treating the compressor and throttle using boundary conditions based on mathematical equations. This allows us to examine how changes in volume affect the dynamic response of the entire system, with much lower computational cost and reduced numerical instability. This methodology enables the investigation of how specific features of the plenum—such as its volume, shape, and internal layout—affect the global dynamic behavior of the compressor system, particularly in relation to the onset of surge and the growth of oscillations. By varying plenum geometries and boundary conditions systematically, we can observe the resulting pressure fluctuations, wave propagation, and feedback effects in the system.

The expected outcomes of the project include a validated hybrid surge prediction model capable of accurately identifying the surge boundary across different system configurations. Moreover, it will quantify how the plenum's physical features influence system stability, providing engineers with a tool for optimizing design for surge resistance. If successful, the model can reduce the need for extensive full-scale CFD simulations in early design stages and offer a reliable way to assess instability risk using a faster and more manageable approach. This project thus directly contributes to safer and more energy-efficient compressor operations, bridging the gap between theory and practical application in the field of turbomachinery.

Moreover, this approach is highly relevant to the design of turbomachinery systems in aerospace, automotive, and energy sectors, where understanding the onset of instability can significantly improve safety margins and control strategies. The oscillations triggered by sudden changes in plenum volume are analyzed to reveal resonance-like behavior that can mimic actual surge cycles, thus providing a surrogate for surge frequency estimation under stable conditions. Hence, the research not only enhances theoretical understanding but also offers pragmatic resolutions to real-world engineering obstacles. The rationale for this research arises from the substantial impact that nonlinear flow dynamics and pressure oscillations have on the stability and reliability of centrifugal compressor systems, particularly during surge conditions.

The main objective of this project is to connect theoretical modeling with practical implementation, thereby offering meaningful insights into the stability and dynamic behavior of centrifugal compressor systems. Such systems are prevalent in various industrial applications where flow instabilities must be understood and utilized to enhance performance and safety.