1 Abstract

Approved for Public Release

The goal of the proposed work is to establish a new field of **extreme aerodynamics** that describes the highly unsteady nature of turbulent flows around air vehicles in severe weather, urban canyons, and wakes of ships and complex terrains.

Motivation: Operating air vehicles, especially those that are smaller in size, in highly adverse atmospheric conditions is a major technological challenge with essentially no available theory. Currently, aircraft avoid operating in such extreme aerodynamic scenarios, leaving a void in the operational capability. This is due to the fact that traditional aerodynamics are largely based on linear analysis about a steady operating condition with nonlinear extensions for modest levels of perturbations. Understanding flight in extreme aerodynamic environments calls for innovative perspectives to analyze, model, predict, and control extreme levels of unsteadiness over lifting bodies. Recent advancements in computational hardware and data-science libraries present a unique opportunity to develop next-generation aircraft achieving air dominance in extreme weather.

Objectives: The ultimate objective here is to establish a novel framework to detect the approach of unknown large-scale perturbations in the atmosphere, determine how such disturbances affect the dynamics of the aircraft, and perform flow control or maneuvers to achieve stable flight. One of the major challenges is that turbulent disturbances in the atmosphere take various forms affecting the vehicle performance in strongly nonlinear manners. If these disturbance dynamics are naively considered, the investigation would require an astronomical number of parametric studies. For these reasons, the study of extreme aerodynamics requires a shift in our scientific perspective from traditional aerodynamics to an innovative approach to extracting the dominant extreme response of flying bodies from a massive collection of data. To achieve the goals of this proposal, we will utilize ultramodern concepts in dynamical systems, network science, and data science. In the present effort, we will (1) numerically simulate extreme aerodynamic model flows with large potential, vortical, and turbulent disturbances for 2D and 3D wings as well as a tailless UAV model; (2) reveal the universal extreme aerodynamic features through manifold identification using machine learning; (3) model extreme aerodynamics using cluster network analysis and identify key vortical features responsible for transient force generation; (4) assess control effectors for extreme aerodynamic conditions and develop control techniques based on generalized phased-based and model predictive control; (5) train graduate students and postdoctoral scholars in an interdisciplinary manner to be leading experts in extreme aerodynamics; and (6) disseminate findings through publications, conferences presentations, and workshop organizations to form a research community in the field of extreme aerodynamics.

Impact on DoD Capabilities: A focused research investment for this orchestrated work will establish the theoretical and computational framework for a new field of extreme aerodynamics and support the designs and operations of next-generation air vehicles in adverse atmospheric conditions. The novel approaches developed from this effort can also be extended to highly unsteady marine environments.