Multifidelity Modeling and Analysis of Multidisciplinary Systems
Mehdi Ghommem & Muhammad R. Hajj
Department of Engineering Science and Mechanics, Virginia Tech

This work was supported in part by Institute for Critical Technology and Applied Science (ICTAS)

Motivation & Background

Equations governing the performance of the multidisciplinary systems comprise nonlinear partial differential equations. Recent advances in computer hardware and software in terms of speed and storage capacity have enabled the use of direct numerical simulations wherein the aforementioned equations are discretized and resolved with robust numerical approaches to enhance both the design and performance of these systems. Besides, the extensive computational resources and time associated with the use of these tools could limit the capability to simulate a large number of configurations. In such a case, there is a need for the development of novel methods that provide cost-effective tools in the simulation of these complex systems.

1. A low-dimensional tool for predicting force coefficients under varying inflow conditions

Research significance and needs

Unsteady flows are an integral part of natural flows and technological applications. Incorporating unsteadiness into CFD approaches yields a realistic assessment of load coefficients and increases significantly the computational cost. Hence, it is crucial to develop a low-dimensional model that can handle the complexity of flow fields while preserving the essential physics.

Approach

Use Proper Orthogonal Decomposition (POD) to derive a reduced-order model of the velocity field.

Use Linear Stochastic Estimator (LiSE) to relate the pressure field to the velocity field.

Results


equations

The reduced order model yields accurate predictions of lift and drag coefficients under varying inflow conditions.

**References**


A multidisciplinary analysis for micro air vehicle applications

2. a. Task 1: Effects of varying gust loads on a fixed wing

Aerodynamic modeling: 2-D UVLM

The boundary layer is treated as a set of discrete vortices. The wake vorticity is introduced by shedding point vortices from the trailing edge. The aerodynamic loads are computed using the anisotropy Bernoulli equation.

Gust modeling: Vice Kernel spectra (full military handbook)

Technical approach: Physical Expansion (PEC)

Objectives

- Quantify the uncertainty in lift coefficient of a rigid flat plate due to impressed in the upstream gust.
- Determine the sensitivity of the lift coefficient to variations in the incoming gust.

2. b. Task 2: Kinematic optimization of a two-dimensional hovering wing

Aerodynamic tool: 2-D UVLM

Wing kinematics

Global optimum: VStright

Objectives

- Model hover flight
- Find suitable kinematics that maximizes the lift generation

2. c. Task 3: Robust-based design of flapping wings

In forward flight

Aerodynamic tool: 2-D UVLM

Main assumptions

1. The flow is incompressible and inviscid (high Reynolds number)
2. The flow separates only from the sharp edges of the lifting surface
3. Boundary layers at the lower and upper surfaces are merged into a single vortex sheet
4. The wake is formed by connecting the vortices at the sharp edges

 Validation through comparisons with UVLM-based model and Euler solver

Objectives

- Simulate the aerodynamic response of flapping wings
- Introduce active shape morphing (prescribed wing deformation)
- Perform kinematic optimization
- Maximize the propulsion efficiency under lift and thrust constraints
- Conduct sensitivity analysis

References


Characterization of LCD response of aerelastic systems

3. a. Task 1: Uncertainty quantification and control of a two-dimensional aerelastic system

Governing equations

Low-dimensional representation: normal form

Objective: use the normal form to:
- Characterize the type of instability
- Perform sensitivity analysis of system's response to variations in its parameters

Sensitivity of flutter speed to variations in the structural stiffness: normal form vs. numerical integration

Effect of non-linear stiffness coefficients on the system's stability

References


In collaboration with Prof. D. T. Mook, Prof. L. T. Snyder, and Dr. P. S. Beno.