IITB-Monash Research Academy

Indian Institute of Technology Bombay | MONASH University

An Indian-Australian research partnership

Project Title:	Active Flutter Mitigation in Aircraft with Highly Flexible Wings	
Project Number	**IMURA1182**	
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Research Clusters: | Research Themes:

Highlight which of the Academy's CLUSTERS this project will address? *(Please nominate JUST* ***one.*** *For more information, see www.iitbmonash.org)*		**Highlight which of the Academy's Theme(s) this project will address?** ***(****Feel free to nominate more than one. For more information, see www.iitbmonash.org)*	
1	*Material Science/Engineering (including Nano, Metallurgy)*	***1***	*Artificial Intelligence and Advanced Computational Modelling*
2	*Energy, Green Chem, Chemistry, Catalysis, Reaction Eng*	2	*Circular Economy*
3	*Math, CFD, Modelling, Manufacturing*	3	*Clean Energy*
4	*CSE, IT, Optimisation, Data, Sensors, Systems, Signal Processing, Control*	4	*Health Sciences*
5	*Earth Sciences and Civil Engineering (Geo, Water, Climate)*	5	*Smart Materials*
6	*Bio, Stem Cells, Bio Chem, Pharma, Food*	6	*Sustainable Societies*
7	*Semi-Conductors, Optics, Photonics, Networks, Telecomm, Power Eng*	7	*Infrastructure*
8	*HSS, Design, Management*		

The research problem

Flutter mitigation has traditionally been viewed as a wing design problem and aircraft designers have generally sought to avoid flutter altogether. However, over the years, the importance of active flutter control has increased as the wings have become slenderer, lighter and consequently more flexible and susceptible to flutter. Active control provides an attractive alternative to traditional design-based solutions in that it entails, in principle, no increase in the mass of the wing. However, active flutter mitigation has proved to be a challenging problem in practice and there is no standard control framework or schema for flutter mitigation.

We propose to develop a first-principles based approach to flutter control which will directly employ the partial differential equations governing the wing dynamics instead of the traditional approach that uses a (typically high order) finite-dimensional approximation of the dynamics.

Our work is based on preliminary results which show that there exist output variables (e.g., the integral of the twist angle) for which the input-output transfer function of the aeroelastic dynamics has a finite relative degree. It is then possible to derive rigorous guarantees on the stability and the robustness provided by the controller. The controller has a compact form and relies on physically-intuitive feedback signals rather than the abstract modal coefficients that arise when finite-dimensional approximate models are used.

While our preliminary work has demonstrated how the controller design works on an isolated, linear flexible wing, several important open problems remain to be addressed. First, the robustness of the controller to unmodeled nonlinear dynamics and time delays needs to be established formally. Second, the control strategy needs to be extended to an integrated wing-body system wherein non-trivial modifications might be necessitated by the rigid body modes of the vehicle.

In the proposed project, we will address the two aforementioned challenges using a combination of theoretical analysis and high-performance computation. Subject to the availability of additional funding, we will investigate how well the controller performs in wind tunnel experiments.

Project aims

Define the aims of the project

1. Identify models for flexible wings which can be converted into an equivalent PDE-ODE form. Realistic flexible wings are usually modeled using finite element methods and we will identify a model that balances accuracy with tractability.
2. Design a control law, starting with the PIs' prior work, that can achieve stabilization and robustness to unmodeled dynamics and time delays.
3. Prove the system theoretic properties of the closed-loop system as rigorously as possible; in particular, identify bounds on the operating envelope in the process.
4. Integrate the controller with the longitudinal flight dynamics of a representative aircraft and investigate the degree of stabilization and robustness.
5. If resources permit: fabricate a representative wing and test in a wind tunnel.

What is expected of the student when at IITB and when at Monash?

Highlight how the project will gain from the students stay at IITB and at Monash

At IITB: In addition to completing the requisite courses, the student is expected to work on modeling and control design. They will work, additionally, on theoretical aspects of control design, notably the proofs of stability and robustness.

At Monash: They will focus on the implementation of the control law to realistic wing-only and wing-body models. If the funding permits, they would be expected to work on wind tunnel testing of the proposed control law in a wing-only setting.

Expected outcomes

Highlight the expected outcomes of the project

The proposed project will lead to the following outcomes.

Research outcomes:
(1) Novel methods for converting a class of large, distributed lumped-mass models into equivalent PDEs, potentially simplifying further analysis and control design, and
(2) Output-feedback control design techniques which bring together guaranteed closed-loop stability and robustness on the one hand, and compact formulation with minimal sensing requirements on the other.

Technology outcomes:
We will aim to create openly available tools for implementing the new control paradigm. Crucially, we aim to raise the technology readiness level of the PDE-based control technique, from a concept with proven principles to one which can be tested in a laboratory environment on a representative platform (e.g., wind tunnel and limited flight tests on a small aircraft testbed).

Educational outcomes:
The students will learn to write journal papers and present at reputed conferences. They will be exposed to interdisciplinary research which would prepare them for a career in a broad range of technical areas, including as specialists in vibration control, flight control, and infinite-dimensional systems depending on their preference.

How will the project address the Goals of the above Themes?

Describe how the project will address the goals of one or more of the 6 Themes listed above.

The themes that this project is most aligned with are `Artificial Intelligence and Advanced Computational Modelling’ and `Infrastructure’.

The proposed work will lead to novel computational models for simulating the aeroelasticity in the context of highly flexible aircraft wings. In particular, the existing models in the literature use finite-dimensional approximations for the wing dynamics. In contrast, we will develop compact aeroelastic models in the form of coupled PDE-ODE systems. Relevant physics can be incorporated in these models more naturally and these models are better suited for controller design.

The common approach to avoid flutter is to make the wing heavier by making it thicker or adding ballast. The main thrust of the project is on developing controllers that can mitigate flutter and enable the use of more aerodynamically efficient and lighter wings in aircraft. Flutter mitigation can reduce fatigue loads and enhance the longevity of the wings, leading to further collateral improvements in the maintenance cycles.

Potential RPCs from IITB and Monash

Provide names of the potential research progress committee members (RPCs) and describe why they are most suited for the proposed project

IIT Bombay: Prof. Abhijit Gogulapati (expertise in aeroelasticity), Prof. Srikant Sukumar (expertise in nonlinear control)

Monash: Prof. Mark Thompson (expertise in fluid dynamics and stability), Dr. Hoam Chung (expertise in control systems)

Capabilities and Degrees Required

List the ideal set of capabilities that a student should have for this project. Feel free to be as specific or as general as you like. These capabilities will be input into the online application form and students who opt for this project will be required to show that they can demonstrate these capabilities.

Bachelor's and/or Master's degrees in either of the following:

- Aerospace/Aeronautical/Mechanical Engineering
- Systems and Control
- Electrical Engineering, with preferably a minor in Aerospace/Mechanical Engineering

Preference will be given to students who can demonstrate prior exposure (through academic courses and/or quality research projects) in the following areas

- Flight dynamics and/or aeroelasticity
- Modeling and/or control of infinite dimensional systems (fluids, structures or thermal)
- Nonlinear systems and control

Necessary Courses

Name three tentative courses relevant to the project that the student should complete during his/her coursework at IITB (the student will require to secure 8 point in these courses)

- Systems Theory (SC625)
- Control of Nonlinear Dynamical Systems (SC602)
- Aircraft Flight Dynamics (AE717)
- Mathematical Methods for Mechanics and Dynamics (ME621)
- Linear Systems Theory for PDEs (SC702)
- Aeroelasticity (AE678)

Potential Collaborators

Please visit the IITB website www.iitb.ac.in OR Monash Website www.monash.edu to highlight some potential collaborators that would be best suited for the area of research you are intending to float.

TBD

Keywords relating to this project to make it easier for the students to apply.

Aeroelasticity, Continuum Systems Modeling, Flight Control, Control theory