MEng Project 4

Data-Driven Optimization of Synthetic-Jet Separation Control

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Project objective and research question. This project will develop a surrogate model for selecting synthetic-jet operating conditions that improve low-Reynolds-number airfoil performance. The research question is how actuation frequency, amplitude, duty cycle, waveform, and operating condition should be combined to delay separation or reduce drag while limiting actuator power.

Engineering-science foundation. The work integrates boundary-layer separation, lift and drag, unsteady forcing, nondimensional parameters, experimental design, regression, uncertainty quantification, and constrained optimization. It connects fluid-mechanical interpretation with machine-learning predictions rather than treating the model as a black box.

Methodology, data, and scope. Archived experimental or numerical datasets will be assembled into a consistent database of operating conditions, actuation inputs, and aerodynamic responses. After exploratory scaling and feature analysis, the student will compare Gaussian-process, tree-based, and neural-network surrogates. The selected model will be used for multi-objective optimization of aerodynamic benefit and actuation cost, with uncertainty bounds and leave-one-condition-out validation. Flow-field quantities or reduced-order coefficients will be included when available to test whether they improve prediction and interpretability. Python, scikit-learn, and optional PyTorch tools will be used.

Success metrics and contingency. Prediction error on withheld conditions; calibration of uncertainty bounds; improvement relative to the best measured baseline; sensitivity and feature-importance consistency with fluid mechanics; and Pareto tradeoffs between performance and actuation cost. If the dataset is too sparse for broad optimization, the fallback is Bayesian interpolation and optimization within one airfoil/angle-of-attack family.

Two-Term Work Plan and Deliverables

Term	Planned productive work	Deliverable due by the last day of lectures
1	Literature review and problem definition (18 h); data inventory, cleaning, and nondimensionalization (37 h); baseline statistical analysis (25 h); implement and compare initial surrogates (45 h); document validation plan (15 h). Total: 140 h.	Interim report, curated database, baseline models, and reproducible training/validation workflow.
2	Refine surrogate and uncertainty model (35 h); conduct constrained multi-objective optimization (35 h); validate recommendations and study robustness (35 h); interpret flow-control physics (20 h); finalize report, repository, and presentation (25 h). Total: 150 h.	Optimization tool, ranked operating strategies with uncertainty, final report, and presentation.

Expected outcome. A transparent decision tool for selecting promising synthetic-jet control settings and identifying the most valuable next experiment or simulation.