MEng Project 3

Reduced-Order Modeling of Synthetic Jets in Crossflow

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Project objective and research question. This project will construct a compact, interpretable model of how a synthetic-jet actuator interacts with an external crossflow and boundary layer. The principal question is which flow structures and nondimensional parameters govern jet penetration, vortex formation, and momentum transfer, and whether those responses can be predicted from a small number of modes or state variables.

Engineering-science foundation. The work applies unsteady jets, vortex dynamics, boundary layers, momentum and energy transport, nondimensional analysis, turbulence statistics, and linear-algebra-based modal decomposition. It also introduces reduced-order modeling and data-driven system identification.

Methodology, data, and scope. The student will organize archived phase-resolved PIV or numerical data for synthetic jets in quiescent flow and crossflow. Conventional measures such as centerline velocity, jet width, circulation, penetration height, and momentum coefficient will be extracted. Proper orthogonal decomposition, spectral POD, or dynamic mode decomposition will then identify coherent structures and their dependence on actuation phase, frequency, velocity ratio, and boundary-layer conditions. A regression or sparse state-space model will predict selected flow metrics from actuation and crossflow inputs. Python, NumPy/SciPy, and established modal analysis tools will be used; no new experiment is required for the core project.

Success metrics and contingency. Energy captured by retained modes; reconstruction error; prediction error on withheld operating conditions; physical interpretability of modes; and robustness to spatial resolution and noise. If the available operating matrix is limited, the fallback is a detailed reduced-order analysis of one well-resolved condition with cross-validation across actuation phase.

Two-Term Work Plan and Deliverables

Term	Planned productive work	Deliverable due by the last day of lectures
1	Literature review and data audit (20 h); standardize and validate datasets (30 h); compute baseline jet and crossflow metrics (35 h); implement initial POD/DMD analysis (40 h); document results (15 h). Total: 140 h.	Interim report, organized dataset, baseline flow metrics, and reproducible modal-analysis code.
2	Compare modal methods and select model order (35 h); develop predictive reduced-order model (40 h); validate on withheld cases (30 h); interpret governing structures and scaling (20 h); finalize repository, report, and presentation (25 h). Total: 150 h.	Validated reduced-order model, complete computational package, final report, and presentation.

Expected outcome. An efficient model that links actuator inputs to the dominant synthetic-jet/crossflow structures and can support later design or control studies.