MEng Project 6

Reduced-Order Modeling and Optimization of Active Flow Control for High-Speed Trains

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Project objective and research question. This project will build a data-driven model linking active-flow-control inputs to the aerodynamic forces and wake response of a high-speed train. The research question is whether a small set of flow descriptors can predict drag, side force, or yawing moment across operating and control conditions well enough to guide actuator selection.

Engineering-science foundation. The work applies bluff-body and vehicle aerodynamics, boundary-layer separation, wake dynamics, pressure forces, crosswind effects, nondimensional scaling, turbulence statistics, modal decomposition, regression, and constrained optimization. It emphasizes physically interpretable features and validation.

Methodology, data, and scope. The student will organize available numerical or experimental train-aerodynamics datasets containing baseline and controlled cases. Surface-pressure, force, and flow-field outputs will be reduced using engineering features and, where appropriate, POD or SPOD coefficients. Gaussian-process, sparse-regression, or tree-based models will predict aerodynamic responses from speed, yaw angle, actuator location, and control parameters. The model will support constrained optimization and identify where additional simulations would most reduce uncertainty. If proprietary or ongoing datasets are restricted, an approved idealized vehicle dataset will be used. Python-based analysis is central; no new wind-tunnel test is required.

Success metrics and contingency. Force and pressure prediction error on withheld cases; reconstruction error of flow descriptors; uncertainty calibration; aerodynamic improvement relative to baseline; consistency with known wake physics; and computational efficiency. If the available control matrix is small, the fallback is a reduced-order analysis and surrogate for one speed/yaw family with a prioritized next-case recommendation.

Two-Term Work Plan and Deliverables

Term	Planned productive work	Deliverable due by the last day of lectures
1	Literature review and data-access audit (18 h); curate and nondimensionalize datasets (32 h); baseline force, pressure, and wake analysis (35 h); implement reduced descriptors and initial surrogate (40 h); document validation protocol (15 h). Total: 140 h.	Interim report, curated dataset, baseline aerodynamics, and reproducible reduced-order workflow.
2	Refine and compare predictive models (35 h); validate on withheld cases (30 h); perform constrained control optimization (35 h); interpret wake and force mechanisms (25 h); finalize repository, report, and presentation (25 h). Total: 150 h.	Validated predictive/optimization tool, design recommendations, final report, and presentation.

Expected outcome. A compact model that translates expensive train-flow datasets into actionable control recommendations and a rational plan for further simulations or experiments.