I. Project Title

A “Big Data” approach to measurement for real-world, real-time automotive aerodynamics

II. Abstract

The research described in this proposal represents a multi-disciplinary aerodynamics project featuring a connection between Cal Poly and Tesla Motors. We will undertake a novel means of live surface pressure measurement on a road-going vehicle across a range of conditions. A unique new “big-data” approach will be taken to establish the feasibility of creating a prediction tool for aerodynamic behavior in certain on-road scenarios. Bringing together mechanical, aerospace, statistics and computer science skillsets, our team will investigate how complex real-world aerodynamic flows can be embraced rather than avoided as in the more “perfect” realm of traditional wind tunnel testing. The hands-on project lives up to Cal Poly’s Learn By Doing philosophy, and provides opportunities to four undergraduates for a unique chance to apply our combined skills to a relevant problem for industry.

III. Introduction

The ever-changing, high-turbulence environment in which most road vehicles operate is very different to the conditions typically applied to the vehicle’s aerodynamic design phase. This is a limitation of the tools available; wind tunnels tend to be relatively low turbulence and there are physical restrictions on test conditions (cornering, gusts, traffic, etc.) (1); and computational fluid dynamics (CFD) simulations in industry are not complex or high-resolution enough to capture the full range of dynamic conditions or turbulent effects. Ultimately, on-road aerodynamic performance is what matters, and particularly in the modern era it is a standout concern for heavy (haulage) vehicles and electric cars. The latter industry faces a great challenge in overcoming “range anxiety”, identified as one of the biggest issues affecting the more widespread adoption of the technology with the public. **Improved aerodynamic efficiency in real-world conditions therefore has huge potential to reduce fuel consumption in vehicles of many types.**

Without tools for more effective prediction of real-world aerodynamic performance, these hindrances will continue to result in under-optimized designs, conservative range estimates, and an inability to properly maximize the potential of technologies like active flow control that otherwise appears to hold great promise yet can currently only be properly designed for a small handful of pre-determined conditions. Rather than continuing to modify wind tunnels which will always be relatively exact, generic and expensive to run (2), the present proposal involves a novel approach to continuous, low-resolution measurement of the flow at the rear of a real vehicle in real driving conditions, as a first step towards an efficient means to predict - with enhanced confidence - aerodynamic behavior (for both stability and energy-efficient performance) in a vast range of scenarios. Through a pre-existing connection through the coursework of the applicants, **Tesla Motors have invited us to demonstrate this idea to their aerodynamics team in Hawthorne, with potential for them to fund continued research on the topic at Cal Poly.**

IV. Objective(s)

By taking a “big data” approach - which we expect will generate several terabytes of aerodynamic and video data combined with crude vehicle telemetry - we expect to be able to derive trends which would not otherwise be evident, and to identify tendencies from measured aerodynamic behavior in response to certain conditions or events. Specific objectives are therefore:

1) demonstrate the feasibility of useful continuous on-car pressure and "event" measurements by instrumenting the rear of a test vehicle with distributed pressure ports synchronized with a separate probe measuring oncoming flow conditions, and an onboard camera.
2) investigate systematically how much data is required to be able to identify within a certain margin of certainty what measurable airflow a specific driving condition will produce, and evaluate the potential of grouping conditions and "events" together to define a critical "bandwidth" of predictable outcomes for a given scenario.
3) present results to industry – Tesla Motors, and at the SAE Automotive World Congress – to forge future collaborations for Cal Poly, and potential employment.

V. Methodology

We will have access to the existing industry-standard 64-port Scanivalve pressure transducer system in the Cal Poly Low Speed Wind Tunnel lab, which we will later use on the test vehicle (belonging to the applicants) under battery power, connected via Ethernet to an in-car laptop. Initially we will test running the transducers off the battery in the wind tunnel, testing their response to rapid changes in flow conditions, and testing the ability of the hardware setup to log large amounts of data for hours. Two of us (Andrew, Danny) are already familiar with the equipment from our coursework in AERO307 and AERO568/569 with Dr. Doig. We will then construct static pressure probe mounts that can securely attach to the rearward portions of the test vehicle using a carbon-fiber "false trunk" cover robust enough for field testing. After an initial test of the hardware we will meet with the aero team at Tesla for feedback on the kinds of outputs they would be most interested in seeing from a given test, and they have offered to provide us with a test vehicle for an initial 1-day demonstration of the technique with support and input from Dr. Westphal from ME as well as Dr. Doig. From this experience, we will then proceed to additional, more in-depth testing.

The main testing will involve the car's rear quarters being instrumented with pressure probes, combined with a 5 hole (angular velocity) probe mounted at the front of the vehicle to measure on-coming flow conditions and vehicle speed vector, and a forward-facing GoPro camera to continuously record visual data of surroundings and any "events" to correlate to GPS (these will be noted by the observer passenger). The car will be driven extensively to gather as much data as possible. Given the limited funding and timeline, we will concentrate on relatively controlled testing at the Allan Hancock Public Safety Training Complex, where (through experience with Formula SAE) we can have free access to their 1.3 mile track when it's not otherwise in use. This will allow us to rapidly build up a database of vehicle aerodynamic response lap after lap after lap, in both directions, in varying conditions of turbulence and wind, etc., and at different speeds. This is already a wealth of data, and thus we will be able to test the ability of our approach to pick out vehicle flow behavior in general driving, to which we will add one typical event – that of oncoming passing vehicles.

We will develop a basic algorithm to assist in sorting the data, eventually grouping them into a database of discrete moments that coincide with scenarios – for instance; call up all data on all instances of mild cornering at 40mph on a non-windy day with open terrain – *or* groups where we only analyze the flow patterns measured at the rear of the car, and bring up all the other measured data to evaluate whether there is a consistent factor or series of factors producing the flowfield. We stress that this is a preliminary study to assess whether sorting through this volume of data or level of complexity produces conclusive results, or requires more data even for simple conditions. Additional test data at the center will help us gather considerably more data for different atmospheric conditions, and allow us to correlate our crude initial predictions from the previous test with what is being measured in the new ones. As the dataset grows, we anticipate the predictive ability to grow also.

VI. Timeline

Initial wind-tunnel based development of the approach will occur during **summer into fall 2016**. We will also conduct our preliminary meeting/demonstration with Tesla Motors in fall. Full on-car integration of our proposed tools will occur in fall leading into winter, coinciding with developing a sorting algorithm and data presentation approach. Initial track testing will occur in early winter, with secondary runs later that quarter as the numerical approach is refined – correlation across data sets will span the project until spring break 2017 when we anticipate having enough data to present at the SAE Congress, and mop-up testing and data handling will round out the **spring 2017 quarter**.

VII. Final Products and Dissemination

By the end of the project we hope to have effectively built a preliminary aerodynamic prediction database that correlates driving conditions and "events" with measurements of the air flow at the vehicle surface. Though specific to the vehicle being used, this would be a significant step towards understanding how real-world aerodynamic performance of a vehicle can be classified into bandwidths which, in the future, could be used to predict aerodynamic response and fine-tune handling and flow control (3). We will produce visual demonstrations highlighting the link between events captured on video and the measured responses, and an HTML-based interface which would allow users to select moments in time or event types based on our categorization. We will present the findings to the aerodynamics team at Tesla Motors, and will also write a peer-reviewed conference paper for the SAE Automotive World Congress in Detroit in April 2017- the premier gathering for the automotive industry worldwide. Presenting this will ensure that the results are widely shared and distributed and industry professionals will get to see our work. We will also make this available through Cal Poly digital commons. In addition, we hope to be able to make a video feature using the media equipment available in the wind tunnel lab and from the Kennedy library, to share with the Cal Poly community.

VIII. Budget Justification

Budget is requested for travel, with the distinction that: *the main aspect of this project involves driving a vehicle extensively to take continuous real-time measurements*, and separate travel support is requested to allow 2 students to present their findings at the SAE Automotive World Congress in Detroit in April 2017. In-state travel breakdown, (Cal Poly mileage rates): $1120 - 2 return trips for students and faculty adviser to Tesla Motors design studio in Hawthorne (2 x 230), 4 return trips to Allan Hancock College test track in Lompoc (160), and approximately 200 miles of driving per test day (500). SAE World Congress trip breakdown of $1800 total – 2 x $450 flights, $600 4 nights accom., approx. $300 food/expenses. Equipment is requested as essential to the project's approach and completion: a portable battery ($350) to run the pressure transducers for a whole day, a GoPro Session camera to mount onto the vehicle ($200), 32GB of RAM to handle data post-processing on a local desktop machine ($150), 6TB of external hard drive for data storage and backup ($300), and a 32GB micro SD card for video capture ($20). The significant hardware and storage requirements are a function of our unique "big data" approach, and typical lab computers in Aero and ME are not up to specification.

References:

1) Keogh, J., Barber, T., Diasinos, S., & Doig, G. (2015). *Techniques for Aerodynamic Analysis of Cornering Vehicles* (No. 2015-01-0022). SAE Technical Paper.

2) Mankowski, O. A., Sims-Williams, D. B., & Dominy, R. G. (2014). A wind tunnel simulation facility for on-road transients. *SAE Int.J. of passenger cars. 7*(3), 1087-1095.

3)Barsotti, D. L., Divo, E. A., & Boetcher, S. K. (2015). Optimizing Jets for Active Control of Wake Refinement for Ground Vehicles. *Journal of Fluids Engineering*, *137*(12), 121108.

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Dear Baker and Koob Endowment Committee,

I'm writing in strong support of the application of Danny Stalters, Andrew Furmidge, Andrew Voorhees and Jacob Rickman, for their proposal to the Baker and Koob endowments' student project funds. Their project proposal on taking a "big data" approach to the messy real-world aerodynamics of vehicles is innovative and has the potential to attract attention from industry; the nature of the team and the proposal are an excellent match to the Endowment's mission to support multi-disciplinary, cross-college collaborative Learn by Doing activities.

Andrew and Danny have made significant contributions to the Cal Poly Low Speed Wind Tunnel lab – which I oversee - over the last year, including designing and constructing a new wind tunnel test section in addition to their work on the Formula SAE car in designing the aerodynamics package for this year. I nominated Andrew for Cal Poly's "Outstanding Student Employee of the Year" award as a result of his leading role in overhauling our wind tunnel. Both he and Danny are extremely dedicated to the field of aerodynamics, as evidenced by their undertaking of my "Aerodynamic Research and Development" course which is normally only open to seniors and grads – it is unique that these juniors were advanced enough in their aerodynamic testing and simulation abilities to be able to enrol and excel in this hands-on class. It is in this course that they also made a connection to Tesla Motors (who are sponsoring some of our work on wheel aerodynamics), where my colleague Rob Palin (head of aerodynamics) has been impressed enough with their work to invite them to demonstrate their ideas for the project being proposed for the Baker and Koob endowments.

From their project-based learning in my class, the existing Tesla connection, their clear interest in the field, and their determination to do innovative work to pursue careers in this area, they have been able to refine some very promising ideas for novel testing that they have proposed here, and they have assembled an impressive team that includes Andrew Vorhees and Jacob Rickman who bring computer science and statistics skillsets to the project – essential in tackling the side of the project that involves handling and analysing the terabytes of information the testing will yield – levels of data that are very atypical of aerodynamic testing. I have met Jacob and Andrew briefly and they forwarded some interesting ideas, I think they will add a lot to the table and the team as a whole appears formidable enough to tackle the challenge.

As a result of all this, I'm more than willing to let them use the capabilities of my lab to undertake aspects of the project and will be guiding them in the implementation and post-processing, as well as overseeing their plans to write a paper for the SAE Automotive World Congress (the world's top conference for this type of work, where they and Cal Poly are sure to get some attention from the major automotive manufacturers). They will have no-cost use of the wind tunnel to calibrate probes and test methodologies, as well as the probes themselves which I will loan to them and help them use to maximum effect – this is very expensive and sensitive equipment however Danny and Andrew have both made use of the equipment in a class setting and I trust them with it. I will also make sure they have access to suitable computing resources aside from those they are requesting in the grant.

The research plan is sound and, to the best of my extensive knowledge, an approach like this hasn't been attempted before – there's a lot of potential here to develop a new methodology that sits at the leading edge of aerodynamic and computer science, and I think it will be impressive research if they can take those first steps and continue to develop our Tesla Motors connection to further a partnership that can provide future opportunities for Cal Poly students to work on industry-relevant applied aerodynamic research.

Please don't hesitate to contact me should you require more information about the project or the team members!

Yours sincerely,

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