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Simulation Testing Methods for Improved Vehicle Dynamics

tECHNICAL cOMMUNICATION

**DRAFT**

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Abstract

# Executive Summary

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# Problem Analysis

## Overview of problem and its significance

The basic goal of motorsport is for one driver and vehicle to negotiate a fixed distance faster than any other competitor (Smith, 1978). Drivers must manage varying track surface conditions, weather, traffic, the weight of fuel burning. Typically racing events are a combination of practice, qualifying, and racing sessions. The purpose of practice sessions is for drivers and teams to become acclimated with the new track and fine tune the vehicle’s setup package. Practice sessions are extremely valuable to racing teams as these are usually the only times that teams are willing to experiment. For series like Formula 1, teams are only granted two extra testing days throughout the entire season. Qualifying sessions see race cars outfitted in their fastest setup package, as their fastest lap time will designate in what place it will begin the race. Usually, race durations can vary from 15 minute sprints to 24 hour endurance formats. Either way, the race setup will be such that the vehicle is consistently drivable, has minimal tire wear, and is fuel efficient.

As testing time is limited, the methods used to dial in a vehicles’ setup has become increasingly important. Racecar Engineering magazine suggests that for teams to be competitive they have to take advantage of simulation tools. Improvements in technology have allowed the race car to be analyzed before it ever touches pavement. Suspension setup, in particular, is hypersensitive to specific drivers and tracks.

## STEM fundamentals of problem

Framework:

1. Simple explanation of vehicle dynamics to provide background for testing. Tires receive all road inputs and generate all tractive forces. There are two modes in which tires interact with the vehicle to produce traction – mechanically and aerodynamically. Mechanical grip is result of kinematic design of vehicle and setup of suspension components. Aerodynamic grip which is produced by wings and bodywork takes affect at higher speeds and is dependent on vehicle ride height and attitude.
2. What do dynamic tests yield for results? How are cars fine-tuned?0

## Lessons from prior responses to the problem

Dynamic vehicle testing was first introduced to the laboratory environment in the 1950’s, with a focus on overall vehicle comfort and durability (Dodds & Plummer, 2001). Early testing apparatuses were designed using two-stage servo-valves and four linear actuators or posts, which were concurrently being developed by Moog (Dodds & Plummer, 2001). To operate the testing rig, a vehicle was suspended in the air in which each post supported one of the vehicle’s wheels. The posts were actuated vertically in accordance to a testing cycle which aimed to statistically replicate a vehicle’s wheel travel (Dodds & Plummer, 2001). While subjective results reported good comfort, users noted potential error from the test setup lacking lateral and for/aft forces as well as inertial forces associated with rolling tires. Furthermore, some unresolved dynamics issue with hydraulics systems used throughout the 1960’s muddied the results from “excitement simulations” (Dodds & Plummer, 2001).

The next breakthrough in dynamic vehicle testing was “Response Simulation”. GM Truck and Bus conceived that by using a vehicle as the transducer, road inputs at the tire contact patch could be determined while driving at the proving grounds. The measured wheel response could then be used to drive closed loop control of the servo-hydraulic system (Dodds & Plummer, 2001). Implementing this system improved relevance of test results and lead to the creation of multiple testing software.

In order to increase accuracy of simulations, contemporary testing rigs have been configured to allow forces and motion in multiple directions. Triaxial systems have the ability to generate vertical, lateral, and longitudinal forces, and yaw and pitch moments at each wheel (Dodds & Plummer, 2001). These more complex setups allows analysis of vehicle characteristics such as self-aligning torque and braking, which would be possible on previous four-post rigs. However, the setup for these tests are significantly more complex and require an extra actuator for every degree of motion (Dodds & Plummer, 2001).

An alternative method called “Body Restraint Testing” applies force and moment inputs through the chassis rather than wheels. The significance of this technique is that the inputs can be relatively small and output displacements in vertical, pitch, and roll can be large (Dodds & Plummer, 2001). Initial passive restraint setups were disadvantaged by changing the structural loading of the chassis, which skewed results. To eliminate this issue, later setups replaced fixed chassis restraints with actuators which could apply high frequency motions but respond to low frequency loads (Dodds & Plummer, 2001). These systems proved to have versatile control of the vehicle’s body and could introduce external forces such as aerodynamics in motorsports.

A common configuration found today is called the “7-Post Rig”, in which four of the posts support the wheels and three posts support the chassis. The unique characteristic of this setup is that the wheels are supported by flat plates which allows road inputs to be generated without impeding the natural motion of the wheels. The remaining three posts, often referred to as “aeroloaders” can be used to generate aerodynamic forces seen above roughly 100mph (“Seven-Post Rigs,” n.d.). Unfortunately, aeroloaders have a tendency to dampen the vehicle’s natural response to road inputs by the wheel plates. To mitigate this, a compliant linkage can be arranged between the aeroloaders and chassis to allow loading with a sufficient amount of compliance to let the vehicle move unimpeded (“Seven-Post Rigs,” n.d.). This solution has it’s own issue, being that the added compliance does not allow the large downforce loads to be generated in the simulation. By using “velocity feed-forward” algorithms to predict the motion of the chassis in addition to a compliant link, a workable result emerges for downforce to be simulated on a seven post shaker rig (“Seven-Post Rigs,” n.d.).

## Project objectives and constraints

The goal of this project is to analyze existing forms of dynamic vehicle testing and suggest methods that will yield the most effective improvements to vehicle performance.

The goal of this project is to improve the shaker rig simulations used in motorsports by evaluating the configuration and type of actuators used. To improve the quality of useable information extracted from simulations, shaker rig posts will be compared. The data collected by a shaker rig is based off the motions imparted on the vehicle during the simulation. If the apparatus is unable to replicate forces as they happen in real time, resulting data will not be relevant for analyzing vehicle performance.

Shaker rig posts operate by moving platforms or attachment points along a linear axis at high frequencies and with great force. Typical shaker rigs use servo-valve hydraulic linear actuators. Other applications have shown that pneumatic or electrical actuators could provide similar results with different cost/benefits.

The overarching goal is to improve the ability to optimize a racecar. The target audience would be racing teams and/or motorsports testing facilities. By developing more effective shaker rig testing apparatus, teams can extract more precise and reliable data and subsequently use that data to generate more competitive suspension setups. The responsibility of a shaker rig is to replicate the forces imparted on a vehicle by driving conditions. Each component used in a shaker rig contributes a certain amount of error in replicating these motions and forces. Post actuators and control mechanisms will be analyzed to find improvements in the accuracy in which they help replicate driving conditions.

Ultimately, the level of precision and accuracy the shaker rig can replicate driving conditions is based on the simulation model generated to run the rig. The primary method for generating simulation parameters is by collecting data using sensors placed on an actual vehicle driving around the subject racing circuit (Boggs, 2009). This places a contingency on the quality of data pulled from driving and the ability to process the data into a functional testing “drive file” (Boggs, 2009).

A high performance actuation system is one that has wide bandwidth frequency response, low resolution and high stiffness. Additionally, systems may call for intense duty cycles and small form factors (Rydberg, 2008).

# Candidate Solutions

## Scope of solutions considered

### Track testing

### Vehicle simulation

An alternative to testing the actual vehicle is using software to simulate performance.

### Shock dynamometer

### Shaker rig

### Kinematics and compliance testing

## Explanation of candidate solutions

### Candidate solution 1

### Candidate solution 2

### Candidate solution 3

A race car on a track

Description automatically generated

Figure 1. Ayrton Senna racing for McLaren

## Comparative assessment of candidate solutions

Blah blah blah

Table 2 - Comparison of Candidate Solutions

|  |  |  |  |
| --- | --- | --- | --- |
| Criteria |  |  |  |
| Costs |  |  |  |
| Collection time |  |  |  |
| Processing time |  |  |  |
| Key data points |  |  |  |
| Setup requirements |  |  |  |
| Data vulnerability |  |  |  |
|  |  |  |  |
|  |  |  |  |

# Project Recommendations

## Proposed solution

## Design and implementation challenges

## Anticipated project outcomes and impacts

# Glossary

# References

## Additional sources consulted

Boggs, C. M. (2009). *The Use of Simulation to Expedite Experimental Investigations of the Effect of High-Performance Shock Absorbers*. https://vtechworks.lib.vt.edu/handle/10919/26108

Dodds, C. J., & Plummer, A. R. (2001). *Laboratory Road Simulation for Full Vehicle Testing: A Review*. 2001-26–0047. https://doi.org/10.4271/2001-26-0047

Rydberg, K.-E. (2008). Hydraulic Servo Systems. *Hydraulic Servo Systems*.

Seven-post Rigs. (n.d.). *Racecar Engineering*.

Smith, C. (1978). *Tune to Win*.