To: ENGR 132 Project Teams
From: Rowan Harper; Lead Control Systems Engineer
Date: March 24, 2025
Re: Data analysis of autonomous cruise controls systems

CruiseAuto specializes in the design and implementation of autonomous and semi-autonomous driving technologies for a variety of passenger and commercial automotive applications. We provide these systems to major car manufacturers around the world and our customers rely on us to ensure that our systems are cost-effective, operate as intended in a variety of driving conditions, and maintain occupant safety as a guiding principle in our designs.

Autonomous cruise control (ACC) in passenger vehicles is becoming more common. ACC uses some combination of cameras, lasers, and radar to adjust the speed of the vehicle based on traffic and road conditions without additional input from the driver. Some newer systems can allow a vehicle to come to a complete stop when necessary and then return to its set speed once the traffic in front has cleared [link]. To use cruise control, a driver brings the vehicle up to a desired speed and then activates the system to maintain that speed. ACC differs from standard cruise control, where the vehicle maintains the set speed regardless of any obstacles that may be in the vehicle's path.

One of our automotive partners is anticipating a change in the materials used in the tires supplied with their vehicles. Their tire supplier plans to move to a greener material in all of their tires and has stated that there will be subtle differences in the friction coefficients of the new tires. Our automotive partner needs us to examine how this change may affect the performance of the autonomous cruise control (ACC) system installed in several of their vehicles. *For additional information, view Addendum 1: Experimental Information*.

Our testing and reliability team have completed a set of performance tests and have provided you with the relevant data sets. We would like your team to analyze the performance of the ACC's controlled build-up of speed for each vehicle. We plan to incorporate your analysis alongside our other testing metrics and data related to the ACC performance. Over the next few weeks, we will need you to complete the following:

→ Construct a MATLAB algorithm to analyze several ACC test data sets we provide to you. Then, create a detailed description of your analysis of the data. This analysis should include clear and easy-to-understand graphics that summarize the data.
→ Provide an error analysis that characterizes the accuracy of your approach to determining the time constant and other performance characteristics of the system.
→ Draft a recommendation about what our company can honestly and ethically claim to our automotive partner about the performance of the ACC using the new tires.
→ List any further steps you would recommend after completing your analysis.

Our automotive partner needs to make a decision about the tires before the next model year vehicles start production. We will need your final technical brief by the end of the semester and have worked with your ENGR 132 instructors to develop a milestone schedule that will help you pace your progress toward your final deliverable *(see Addendum 2: Project Logistics and Schedule)*. These milestones are detailed in the project documents available to you on Brightspace. We expect to periodically supply updates as you work on the milestones.

We look forward to the results of your analysis.

Rowan Harper
Cruise Auto, Lead Control Systems Engineer

Addendum 1: Experimental Information

CruiseAuto's Process

CruiseAuto installs ACC systems in passenger cars and sport utility vehicles (SUVs) for a global auto manufacturer. The manufacturer's tire supplier has switched to eco-friendly materials, altering the tires' friction and has asked CruiseAuto to test how this affects the ACC system and whether updates are needed.

The automaker provided CruiseAuto with three vehicles for testing: a compact hatchback, a midsize four-door sedan, and a midsize SUV. Each vehicle is in a different weight class. The vehicles need to be tested with three types of tires: summer tires, all-season tires, and winter tires each with low, medium, and high frictional properties, respectively.

CruiseAuto tested the ACC in each vehicle with each type of tire. They used a "stop-and go test" where the drive set the ACC to 55 miles per hour, allowed the vehicle to stop, and then ramped it back up autonomously under a constant engine load. In this experiment, they ignored wheel inertia and assumed negligible wind resistance.

The test collected speed data while the car accelerated by using an onboard monitoring system. However, vibrations from the test track and engine noise affect the measurements. Additionally, the sensors used to record speed were not directly connected to the speedometer, leading to variability between the reported speeds and the actual sensor data. And lastly, the data were not collected to assess the ability of the ACC to speed up within a set time, so the starting point of the vehicle's acceleration varies. These challenges make it difficult to identify the parameters, especially when dealing with noisy data. CruiseAuto also identified that there are some faulty sensor readings in the experimental data provided to you. You may encounter random data dropouts, frozen data, or incorrect readings.

The ACC had been thoroughly tested and certified for the experiment vehicles using the original tires. CruiseAuto has performance boundaries in which the ACC must perform. The performance boundaries assume that the vehicle starts to speed up at t = 5 seconds. Plotting these two boundaries on the same set of axes will show two first-order responses (similar to Figure 1 below) with a gap between them; inside this gap is the acceptable performance of the ACC. The parameters for the boundaries are below, in Table 1.

	Left Bound	*Right Bound*
t_s, Time when ACC starts acceleration [s]	4.50	6.00
τ, Time constant [s]	1.26	3.89
y_L, Initial speed [m/s]	1.10	-0.90
y_h, Final speed [m/s]	25.82	23.36

Table 1. Parameters for boundaries of CruiseAuto's ACC system.

CruiseAuto must tell the auto manufacturer if the change in tire material affects the performance of the ACC in a meaningful way. CruiseAuto would like to claim that the ACC maintains similar performance between the old and new tires, so that no change would be needed to the ACC to accommodate the new tire material. Right now, CruiseAuto is unsure if their data support such a claim. Part of your task will be to help them decide what claims they can make based on the available data.

Background on Non-Linear First-Order Systems

Engineers in all disciplines commonly work with models (i.e., physical, virtual, mathematical) that represent real-world systems, structures, and processes. One of the most important functions that engineers perform is parameter identification: the process of identifying a best estimate of the value of one or more characteristic features of a model. This project provides an opportunity to gain practical experience in working with first-order systems, including identifying parameters from their time histories and utilizing these parameters to predict system requirements for specific performance objectives.

A first-order system is a type of dynamic system that displays how system performance varies with time, as shown in Figure 1. This reaction is called a "step response" because it shows how the system responds to a sudden change, or step change, in the external stimulus.

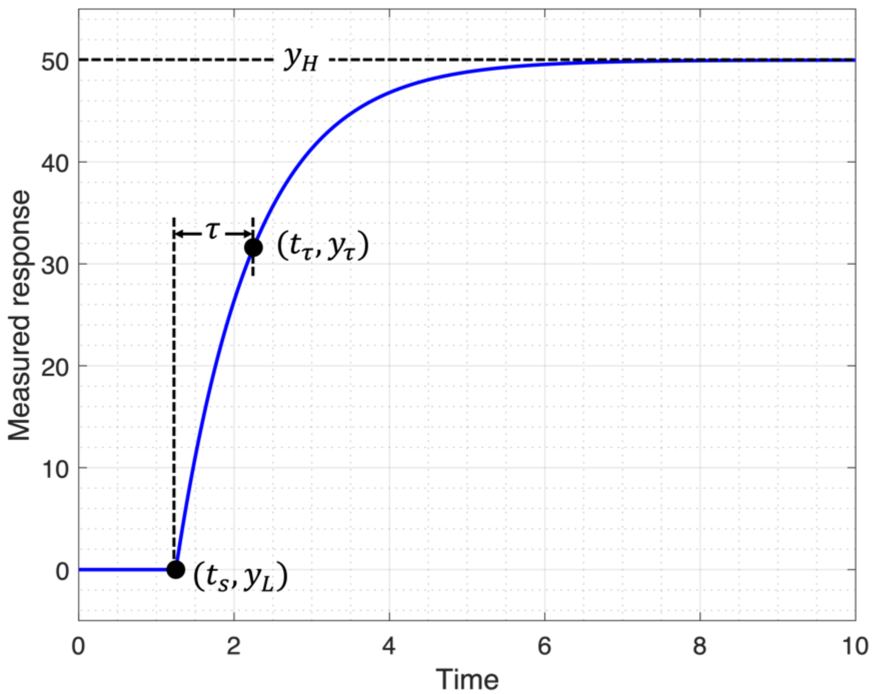

Figure 1. Generic first-order system response.

Key parameters characterizing this step response are labeled on the figure and are all defined in terms of the curve:

- (t_s, y_L) – the starting point
    - t_s – the time at which the step change is applied.
    - y_L – the initial 'low' value for the dependent variable. From a time of 0 (t_0) to the time at which the step change is applied (t_s), the value for y_L remains relatively constant. Note that this parameter is not always equal to 0.
- y_H – the 'high' value for the dependent variable. As $t \to \infty$, the value for the dependent variable approaches this asymptotic value.
- τ – the time constant for the system. This parameter characterizes how fast the dependent variable responds to changes in external stimuli.

Physically, τ (measured in seconds) represents the time it takes for the dependent variable to achieve a value of $y_\tau = y_L + 0.632(y_H - y_L)$. The 0.632 mutliplier in front of the quantity $(y_H - y_L)$, or y_{step}, is mathematically related to the exponential form of Equation 1, shown below. Equation 1 is the solution to the first-order differential equation describing this dynamic system.

$$y(t) = \begin{cases} y_L, \ 0 \le t < t_s \\ y_L + \left[1 - \exp\left(-\frac{t-t_s}{\tau}\right)\right](y_H - y_L), \ t \ge t_s \end{cases} \tag{1}$$

Equation 1 is a piecewise function, which is defined over intervals, or ranges, of the independent value. This particular function is defined for times where $0 \le t < t_s$ and $t \ge t_s$. Note that $y(t)$ is continuous, meaning that when $t = t_s$, both equations will provide the same value for $y(t)$.

Addendum 2: Project Logistics and Schedule

Deliverables

By the end of this project, your team will provide CruiseAuto with a 2-page technical brief containing both technical analysis and expert recommendations.

Milestone Schedule

You will work toward these final deliverables according to the following milestone breakdown. See the course assignment schedule for due dates.

Intro.	Problem Statement
M1.	Parameter Identification Brainstorming
M2.	Algorithm Development
M3.	Algorithm Evaluation and Improvements
M4.	Algorithm Refinement and Final Deliverable

Programmer Role Assignments

Every team member will be responsible for writing some of the code in this project. Being the primary programmer means that you must type the code yourself. All team members will aid in completion of the answer sheets for each milestone.

Programmer 1. Primary programmer on main function and data visualization.
Your code will:

→ Produce professionally formatted figures for the final report that clearly display the data and the analysis and its results.

→ Coordinate the subfunctions (below) so they are properly used in the main function.

Programmer 2. Primary programmer on managing data noise and errors. Your code will ensure that the data are usable and will be accurate for parameter identification.

Programmer 3. Primary programmer on finding the acceleration start time and the time constant. Your code will ensure proper identification of both time parameters.

Programmer 4. Primary programmer on finding the initial and final speeds.
Your code will ensure proper identification of both speed parameters.

Managing Data

Throughout the course of this project, you will be given several datasets. Each dataset will contain a multiple of 3 sets of data (1 for each car) but may include up multiples of 9 (1 for car and tire type). Your team's program should be designed such that it is flexible enough to handle various different sizes and produce outputs for each car type and/or season type. The goal of the experiment is to see how the mass of each vehicle and friction from the different types of tires affects each vehicles' ACC response. The result from each test can be modeled as first-order, open-loop response and the first-order system parameters can be found and used to describe the ACC's performance for each vehicle.