Shell Eco marathon Simulink System Documentation V1

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System Overview

This document presents the development and implementation of a one-dimensional (1D) longitudinal vehicle dynamics and energy consumption model for a Shell Eco-Marathon prototype vehicle. The model is implemented in MATLAB/Simulink and is intended to support performance analysis, efficiency optimization, and design validation. The system computes vehicle velocity, position, cumulative energy consumption, and estimated fuel usage as functions of time, based on applied driving force and resistive loads.

Introduction

Energy efficiency is the primary performance metric in Shell Eco-Marathon competitions. Achieving competitive results requires careful optimization of vehicle mass, aerodynamics, drivetrain efficiency, and driving strategy. To support these goals, a physics-based simulation environment was developed to model the longitudinal motion and energy usage of the vehicle.

The present model represents the vehicle as a lumped-mass system moving in one dimension along a straight track. The system incorporates aerodynamic drag, rolling resistance, drivetrain efficiency, and fuel energy conversion. The model serves as a foundation for future extensions, including driver control, gear ratio optimization, and track-based simulations.

System Architecture

The simulation is organized into four primary subsystems:

1. Driver Strategy / Powertrain
2. Force Summation (F_Net)
3. Vehicle Dynamics
4. Energy Modeling

At the top level, the system receives a commanded driving force from the powertrain model. Resistive forces are subtracted to form the net longitudinal force, which is integrated to obtain velocity and position. Energy consumption is computed using the instantaneous mechanical power at the wheels.

The system operates in continuous time and is numerically integrated using Simulink solvers.

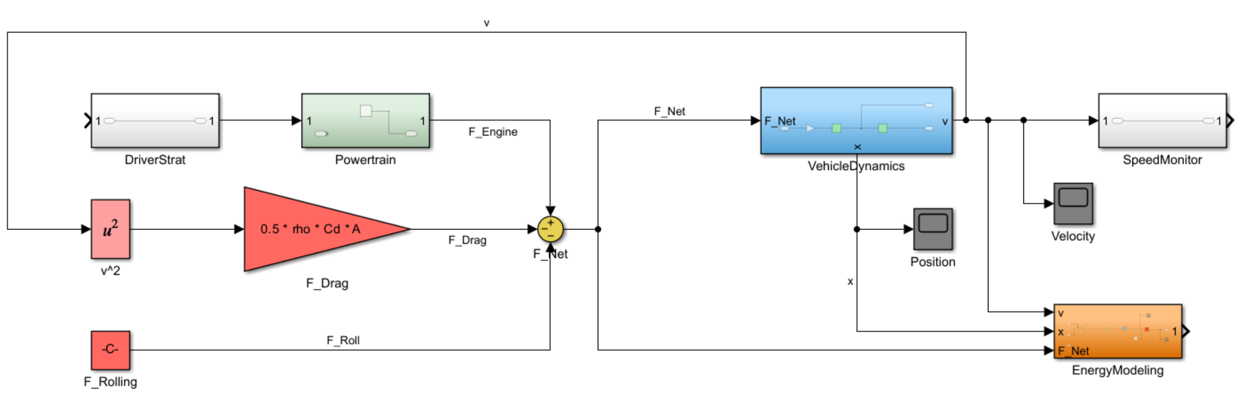


Figure 1: Version 01 of the Simulink System

Input Parameters and Initial Boundary Conditions

The Simulink relies on physical parameters defined in the MATLAB workspace.

An asterisk (*) represents a parameter currently using a temporary and hypothetical value until true values can be determined in simulation, analysis, and testing.

A. Vehicle Parameters

Parameter	Variable	Unit
Vehicle Mass *	m	kg
Drag Coefficient *	Cd	
Frontal Area *	A	m^2
Rolling Resistance Coefficient *	Crr	
Drivetrain Efficiency *	effic_drive	

B. Environmental Parameters

Parameter	Variable	Unit
Air Density	rho	$\frac{\mathrm{kg}}{\mathrm{m}^3}$
Gravitational Acceleration	g	$\frac{\mathrm{m}}{\mathrm{s}^2}$

C. Fuel Parameter

Parameter	Variable	Unit
Lower Heating Value	LHV	$\frac{\mathrm{J}}{\mathrm{kg}}$

D. Initial Conditions

Parameter	Variable	Unit
Initial Velocity	v0	$\frac{\mathrm{m}}{\mathrm{s}}$
Initial Position	x0	m
Initial Energy	E0	J

Longitudinal Force Modeling

Driving Force

The driving force is produced by the powertrain subsystem. In the current implementation this force is represented by a constant value for baseline testing. In future versions, this will be replaced by throttle or feedback-based model.

Aerodynamic Drag

Aerodynamic Drag is modeled as a function of velocity:

$$F_{drag} = \frac{1}{2}\rho C_d A v^2$$

In the system this force is supposed to be always opposing the direction of motion.

In the Simulink model you will notice a branch coming from the VehicleDynamics v output appear to circumvent back to feed into F_{drag} calculations. Part of the reason Simulink was so ideal is because the velocity is generated by a continuous-time integrator, Simulink solves all the equations simultaneously at each timestep. That lets velocity feed back into drag even though drag affects acceleration.

Rolling Resistance

Rolling Resistance is modeled as a constant force proportional to the vehicle's weight:

$$F_{roll} = mgC_{rr}$$

Net Force

The net longitudinal force acting on the vehicle is given by:

$$F_{net} = F_{engine} - F_{drag} - F_{roll}$$

This Net Force determines the acceleration of the vehicle.

Vehicle Dynamics Model

The vehicle is currently simply modeled as a point mass moving along a single dimension, hence a one-dimensional “road load” model.

Newton’s Second Law is applied:

$$m\frac{dv}{dt} = F_{net}$$

Rearranging for acceleration:

$$\frac{dv}{dt} = \frac{F_{net}}{m}$$

Velocity Calculation

Velocity is obtained by numerical integration:

$$v(t) = v_0 + \int_0^{\mathrm{t}} \frac{F_{net}(\tau)}{m} d\tau$$

This operation is implemented using a continuous-time integrator block in Simulink. This was referenced in Aerodynamic Drag calculations and is what makes Simulink ideal.

Position Calculation

Position is obtained by integrating velocity:

$$x(t) = x_0 + \int_0^{\mathrm{t}} v(\tau) d\tau$$

The resulting position is representative of distance traveled along the track.

Energy and Power Modeling

Instantaneous Power

Mechanical power at the wheels is computed from force and velocity:

$$P(t) = F_{net}(t)v(t)$$

This represents the rate of mechanical work applied to the vehicle.

Drivetrain Efficiency

Drivetrain losses are modeled using a constant efficiency term

$$P_{eff}(t) = \eta_{drive}P(t)$$

This term accounts for assembled drivetrain losses in the engine, transmission, and bearings.

Energy Consumption

Cumulative mechanical energy delivered to the wheels is computed by integrating effective power:

$$E(t) = \int_0^t P_{eff}(\tau)d\tau$$

This represents the total useful energy expended by the drivetrain.

Fuel Consumption Estimation

Fuel Energy Relationship

The chemical energy contained in consumed fuel is related to mechanical energy by:

$$E_{fuel} = \frac{E}{LHV}$$

Where E_{fuel} represents fuel mass since chosen calculation is in units $\frac{\mathrm{J}}{\mathrm{kg}}$.

Fuel Usage Calculation

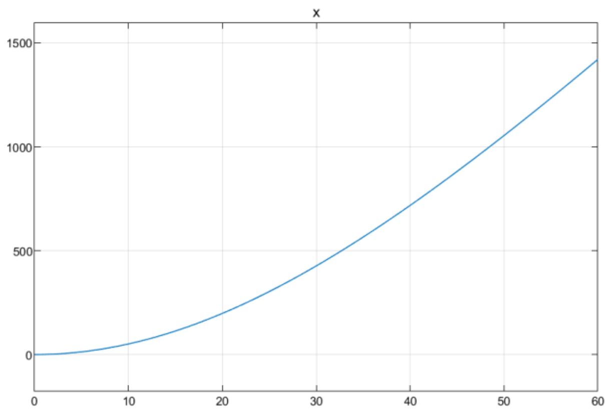
Cumulative fuel usage is computed as

$$\mathrm{Fuel}(t) = \frac{E(t)}{LHV}$$

This quantity provides a measure of efficiency over time and distance.

Simulation Outputs

The model currently produces the following outputs visualized here from Simulink scope blocks and logged for post-processing:



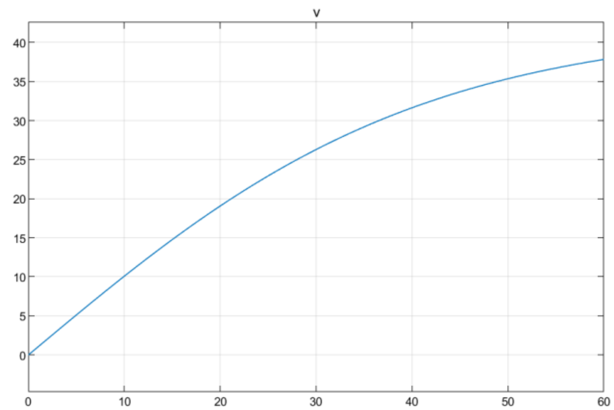
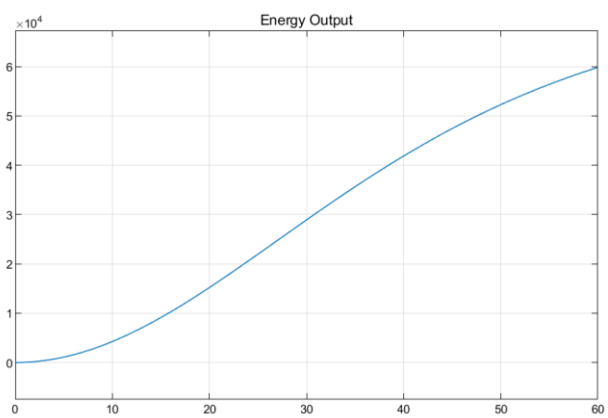


Figure 2 (Top Left): Vehicle Position x(t)

Figure 3 (Top Right): Vehicle Velocity v(t)



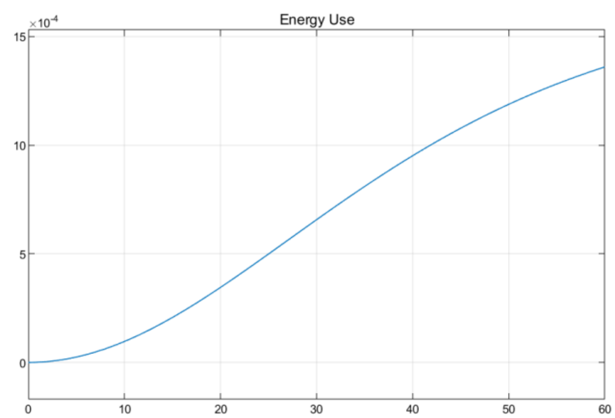


Figure 4 (Bottom Left): Cumulative Wheel Energy E(t)

Figure 5 (Bottom Right): Estimated Fuel Usage Fuel(t)

Model Limitations

The current implementation includes several simplifying assumptions. The model is restricted to one-dimensional motion and does not include lateral dynamics or cornering effects. Road grade and elevation changes are neglected. Engine dynamics, gear shifting, and throttle behavior are not yet modeled. Tire slip and braking are also excluded.

Despite these limitations, the model provides a solid foundation for preliminary energy and performance analysis.

Future Work

Planned extensions to the model include the implementation of closed-loop driver control, speed-profile optimization, gear ratio modeling, track-based elevation inputs, and experimental validation using measured test data. Integration with optimization algorithms is also planned to support automated efficiency studies.

MATLAB driving parameters will only get more defined as modeling continues in SOLIDWORKS, analysis in SOLIDWORKS Flow and ANSYS Flow. Mass and center of gravity will become defined with full car assembly and translation to CAD/CAE.

Conclusion

A modular 1D vehicle dynamics and energy consumption model has been developed in MATLAB/Simulink for Shell Eco-Marathon applications. The system integrates physical force modeling, vehicle kinematics, drivetrain efficiency, and fuel energy conversion. The model enables rapid evaluation of design and operational strategies and provides a strong foundation for future optimization and experimental validation.