

Development and Implementation of a Warp Chassis Model

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ABSTRACT

Vehicle dynamics models often assume that the suspension attachment locations on the chassis are fixed and do not deform. However, this is not always a good assumption as the chassis can deform causing the suspension-to-chassis attachment locations to move in response to the forces transmitted through the suspension. When the suspension attachment points move, the kinematic and compliance properties of the suspensions can be affected. This can create a feedback situation where the chassis deformation affects the suspension response which affects the chassis loading.

When developing a vehicle dynamics model, the chassis is usually modeled as either a rigid member, as a series of lumped masses, or as a multi-body structure. The progression from rigid body to lumped mass to multi-body chassis models generally improves the resulting simulations as the estimation of suspension behavior improves. However, the increases in the quality of the simulations require additional chassis data and the simulation costs increase with the complexity of the chassis model.

The warp model is a fourth chassis modeling option where the vehicle chassis is modeled as a pair of parallel frames with a cross member that can deform torsionally. The single degree of freedom in the model allows one frame rail to rotate relative to the other such that the deformation shape resembles a helix albeit with minimal twist. This results in a chassis deformation shape that is similar to the deformations seen in an actual vehicle chassis. This modeling approach is relatively inexpensive and can be reasonably accurate in describing the true chassis deformation. The location of the cross member in the model is not constrained and there need not be a physical cross member at the location of the modeled cross member.

In this paper a new procedure for developing the warp model and its implementation in a vehicle dynamics simulation is outlined. The warp model development presented here differs from prior methods in an attempt to better show the requirements for implementing the model.

INTRODUCTION

In the field of vehicle dynamics, there are generally three methods used to model the chassis of a torsionally compliant vehicle. The first is a multiple degree of freedom multi-body model [1], the second is a lumped mass series model [2, 3], and the third is a warp chassis model [4]. While multi-body models are theoretically more accurate, they require a significant amount of data on the chassis design and more computational time to manage the extra degrees of freedom. Lumped mass models can be significantly cheaper to develop and solve with just a few degrees of freedom. However, lumped mass models require estimations of segment-to-segment torsional stiffness which may be difficult to obtain. They also limit the assessment of chassis roll to discrete segments.

The warp model addresses this compromise between computational cost and discretization of the chassis by introducing a single degree of freedom model that linearizes the deformation along the chassis length. While the warp model is a single degree of freedom model and cannot account for all potential chassis deformations, the torsional deformation mode produced by the warp model is usually not too dissimilar from what is seen in actual vehicles [4].

While multi-body and lumped mass models are generally well understood, the warp model is usually not understood as well and can be difficult to set up properly [5, 6]. The objective of the warp model presentation here is to document the warp model's development and to define the

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implementation requirements so that the reader can correctly incorporate the warp model into a vehicle simulation.

Once the limitations and requirements of the warp model are understood, the model is relatively easy to implement and the chassis data needed to implement the model is relatively easy to measure.

The warp model is intended to mimic the behavior of a typical commercial vehicle chassis by replicating the actual deformation of the chassis under torsion [4]. The model permits the chassis suspension attachment points to move in a vertical motion much as a real vehicle chassis would deform when exposed to asymmetrical suspension loads. This is accomplished by allowing the longitudinal frame rails, which are treated as rigid members, to pivot about a cross member as shown in [Figure 1](#). The cross member about which the frame rails rotate is a fictitious member representing the torsional axis of the chassis. There need not be an actual cross member at this location in the vehicle.

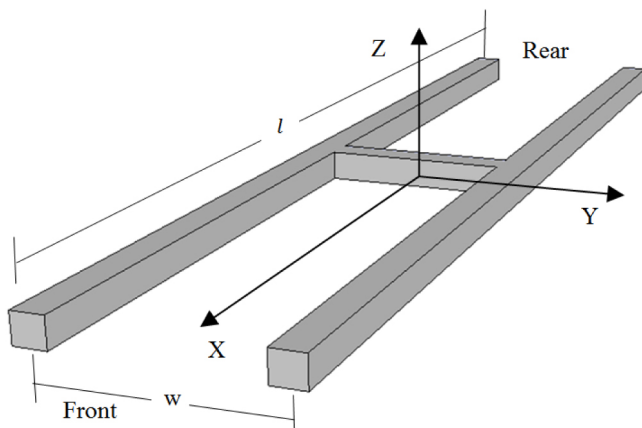


Figure 1. Simplified Chassis Frame

For the warp model development presented here, “ l ” represents the chassis frame length from the front axle to the rear axle and “ w ” represents the frame width. The suspensions are presumed to be attached to the frame at the frame ends and the frame rails are treated as being parallel and rigid. Finally, all deformation occurs through the twisting of the cross member which represents the effective torsional spring of the chassis.

MODEL GEOMETRY

The premise behind the warp model is that the two frame rails of the chassis are permitted to rotate (or warp) about a cross member as shown in [Figure 2](#). In this development of the warp model, the cross member's longitudinal location in the frame is termed the node location and is arbitrarily defined as being a distance “ n ” from the front of the frame. In [Figure 2](#), the “ h ” values represent the vertical deformation of

the chassis and the “ ϕ ” terms denote the resulting angular deformations.

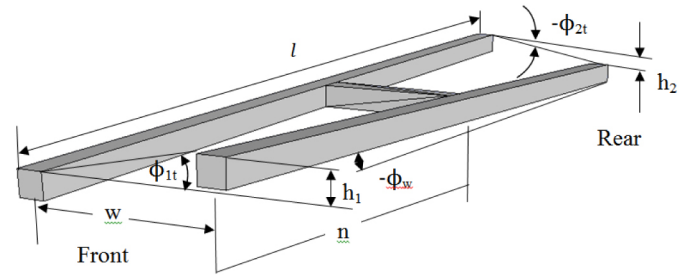


Figure 2. Warp Chassis Geometry

DEFORMATION DEFINITIONS

Based on the chassis deformations shown in [Figure 2](#), the relationships between the various deformation parameters can be defined as shown in [Equations \(1\), \(2\), \(3\), \(4\), \(5\), \(6\)](#). Here [Equation \(1\)](#) represents the total deformation observed in the chassis. [Equations \(2\)](#) and [\(3\)](#) denote the angular deformations observed at each end of the chassis and are functions of the vertical deformations and the frame width. [Equation \(5\)](#) defines the warp angle of the chassis and [Equation \(6\)](#) defines the geometrical relationship between the torsion and warp angles. As can be observed, the torsion and warp deformations are actually the same chassis deformation viewed from two different perspectives (longitudinal and lateral axis reference points). Note that the sign change between torsion and warp angles in [Equation \(6\)](#) is simply a product of the coordinate system selected ([Figure 1](#)) and does not have any bearing on the analysis.

$$h = h_1 + h_2 \quad (1)$$

$$\phi_{1t} = \tan^{-1} \left(\frac{h_1}{w} \right) \approx \frac{h_1}{w} \quad (2)$$

$$-\phi_{2t} = \tan^{-1} \left(\frac{h_2}{w} \right) \approx \frac{h_2}{w} \quad (3)$$

$$\phi_t = \phi_{1t} - \phi_{2t} \approx \frac{h_1}{w} + \frac{h_2}{w} = \frac{h}{w} \quad (4)$$

$$-\phi_w = \tan^{-1} \left(\frac{h}{l} \right) \approx \frac{h}{l} \quad (5)$$

$$-\phi_w = \frac{w}{l} * \phi_t \quad (6)$$

Finally, as the chassis length is generally much greater than the width, the warp angle will usually have a smaller magnitude than the torsion angle.

GEOMETRIC DEFINITIONS

A closer review of [Figure 2](#) also reveals that the deformation at the front of the chassis is proportional to the deformation at the rear of the chassis since the frame pivots around the node location. The rigid frame rails require that the deformation at the front and rear of the chassis be proportional to the distance from the frame end to the node location. It is easier to see this effect when viewing the chassis from the side (warp deformation) where the warp angle can be defined in terms of the chassis length and the node location ([Equation \[7\]](#)).

$$-\phi_w \approx \frac{h}{l} = \frac{h_1}{n} = \frac{h_2}{l-n} \quad (7)$$

Rewriting [Equation \(7\)](#) so that the deformation relationship is easier to see ([Equation \[8\]](#)) also provides a useful definition for the location of the node ([Equation \[9\]](#)). This equation states that there is one unique node location for any given ratio between the front and rear deformations.

$$h_1 = h_2 * \frac{n}{l-n} \quad (8)$$

$$n = \frac{l * \phi_{1t}}{\phi_{1t} - \phi_{2t}} = \frac{l * \phi_{1t}}{\phi_t} = \frac{l * h_1}{h} \quad (9)$$

ROLL AND TORSION SUPERPOSITION

At this point it is important to note that the chassis deformation illustrated in [Figures 1](#) and [2](#) represents only the torsional deformation of the chassis and does not necessarily represent the deformation seen by a suspension. To obtain the suspension deformations, the roll of the chassis needs to be superimposed upon the chassis torsional deformation as shown in [Figure 3](#). Physically, this indicates that while both suspensions are resisting chassis roll, the front suspension is rolling more than the rear suspension (asymmetrical suspension deflection assuming a level ground). I.e., the chassis is experiencing both roll and torsion at the same time.

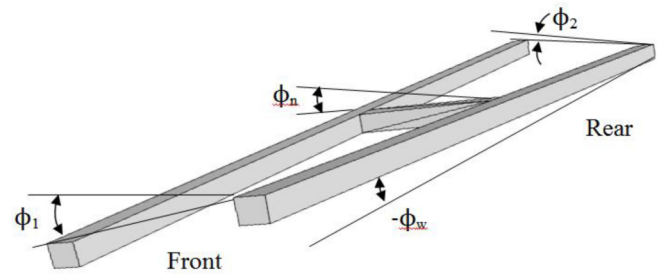


Figure 3. Warp and Roll

The resulting suspension roll angles ([Equations \[10\]](#) and [\[11\]](#)) are thus the sum of the roll of the entire chassis and the torsional deformation. Note that the body roll, ϕ_n , is defined at the node location because the node, by definition, has no torsional deformation. In other words, any rotation at the node location is due to chassis roll only. Lastly, the superposition of roll has no effect on the chassis torsional deformation ([Equation \[12\]](#)).

$$\phi_1 = \phi_n + \phi_{1t} \quad (10)$$

$$\phi_2 = \phi_n + \phi_{2t} \quad (11)$$

$$\phi_t = \phi_{1t} - \phi_{2t} = \phi_1 - \phi_2 \quad (12)$$

MOMENTS AND EQUILIBRIUM

As the warp model's purpose is to predict the torsional deformation of the chassis, an analysis of the moments acting on the chassis and the resulting chassis reaction to those moments is needed. For reasons of brevity, the analysis presented here was limited to a steady state case but the reader can easily incorporate inertial terms into the model if needed without negatively affecting the conclusions.

SUSPENSION REACTIONS

A review of a simple free body diagram of the loaded chassis ([Figure 4](#)) indicates that the reaction forces generated by the suspensions counter the forces and overturning moments generated when the vehicle's sprung mass is exposed to lateral accelerations and gravity ([Equations \[13\]](#), [\[14\]](#), [\[15\]](#)).