Optimum Complexity and Efficient Truck Models

Loucas Louca

Steve Riley

3-Axle Tractor with 3-Axle Semitrailer
M916A1/M870A2
Optimum Complexity Truck Models

Loucas Louca, Graduate Student UofM
Jeffrey Stein, Professor UofM
Gregory Hulbert, Associate Professor UofM
James Sprague, Failure Analysis Associates
Ashraf Zeid, General Dynamics
Outline

• Optimum Complexity Truck Models
  - Objective
  - Key Ideas
  - Theory & Reduction Algorithm
  - Quarter Car Example
  - M916A1 Case Study
  - Future Work

• Efficient Truck Models
  - Overview: The Problem of “Small” Inertias
  - Simple Quarter Car Example
  - Equation Formulation Issues
Objective

Apply power-based modeling metric to a “real-world” system
Key Ideas

• Use energy/power flow as an automated modeling metric

• Use energy level to rank the importance of elements
Energy-Based Metric: Motivation

- Power\( (t) = \) generalized Force $\bullet$ generalized Velocity

- Power can be defined for:
  - For all nonlinear elements
  - For all energy domains (Mechanical, Hydraulic, etc.)
    gives comparable measures

- Use the element power to calculate a metric in order to reduce the model complexity

- Power is time dependent !!!
Element Activity

• Time independent activity measure:

\[ \text{Activity} = \int_{t_1}^{t_2} |P(t)| \cdot dt \]

- where \( t_2 - t_1 = T \) (Basic Period)

• The element activity measures the total amount of energy that flows in and out of the element
Element Activity Index

• For a system with a total of $N_e$ ideal energy elements, for the $n^{th}$ element we define:
  - Element Activity as:
    \[
    \text{Activity}_n = \int_{t_1}^{t_2} |P_n(t)| \cdot dt
    \]
  - Non-dimensional Element Activity Index as:
    \[
    \text{EAI}_n = \frac{\text{Activity}_n}{\sum_{j=1}^{N_e} \text{Activity}_j}
    \]
A Model Reduction Algorithm

• Build a model (most complicated) of the system

• For a given input and system parameters, calculate for each element:
  - Power ---> Activity ---> Activity Index

• Sort the Activity Indices

• Keep the elements that account for a given activity level, e.g., set threshold to 90%
Elimination Procedure

- Element Number
- Activity Index
- Cumulative Index
- Sorted Index

Threshold
Removed Elements
Quarter Car Model

For a first implementation, a simple linear quarter car model is used.
Step Change in Road Height
Model Comparison

Tire Deformation [m]

Time [s]
M916 Case Study

- 33 rigid body DOF / 91 state variables
  - 1 Tractor: 6 DOF
  - 1 Trailer: 3 DOF (Rotational)
  - 6 Axles: 2 DOF (Roll and Jounce)
  - 12 Wheels: 1 DOF (Spin)

- Simulation conditions
  - 60 mph constant forward speed
  - Lane change maneuver steering input

126,000 lbf
GVW
Element Activity Indices

![Graph showing Element Activity Indices and Cumulative Activity Index against Element Number]
Element Importance

High

Low
Directional Importance

Wheel

Axle

High
Low

Optimum Complexity and Efficient Truck Models
Results: 20% element reduction

- Lateral Acceleration [g]
  - Time [sec]

- Yaw Rate [deg/s]
  - Time [sec]

Full

Reduced
Results: 23% element reduction

- Lateral Acceleration [g]

- Yaw Rate [deg/s]

**Graphs showing**

- Full
- Reduced
Results: Reduced Model Comparison

[Diagram showing Time [sec] vs. Front Suspension Damper Force [lbf] with two lines, one labeled 20% in green and the other labeled 23% in red.]
Results: 30% element reduction

- Lateral Acceleration [g]
- Yaw Rate [deg/s]

Time [sec]
Future Work

• Generate more reduced size models
  - Tractor and trailer pitch inertia
  - Tractor and trailer jounce inertial effects
  - ...

• Address modeling assumptions of model
Efficient Truck Models

Stephen Riley, Graduate Student UofM
Jeffrey Stein, Professor UofM
Mike Sayers, UMTRI
James Overholt, TARDEC
Rick Mousseau, Ford Motor Company
Overview

• The “generalized” force of inertia is often small

• Small inertias often give rise to high frequencies

• Small inertias can make it easier to formulate equations, but harder to solve them

• It would be very useful to remove the “generalized” force of inertia, but it is not easy
  - Proper models
  - Efficient models
    » 21 X 21 mass matrix ----> 9 X 9
    » Increase integration step size by a factor of 2
Simple Quarter Car Model

\[ \dot{X}_1 = V_1 \]
\[ \dot{X}_2 = V_2 \]
Quarter Car Equations of Motion

\[ \dot{X}_1 = V_1 \]

\[ \dot{X}_2 = V_2 \]

\[ k_s(X_2 - X_1) - b_s(V_2 - V_1) = m_s \ddot{V}_1 \]

\[ k_t(Z_r - X_2) - b_t(\ddot{Z}_r - V_2) - k_s(X_2 - X_1) + b_s(V_2 - V_1) = m_{us} \ddot{V}_2 \]

If \( m_{us} = 0 \),

\[ V_2 = \frac{1}{(b_s + b_t)} \left[ k_t(Z_r - X_2) - k_s(X_2 - X_1) - b_t \ddot{Z}_r - b_s V_1 \right] \]
Equation Formulation Issues

- Damping

\[ v_2 = \frac{1}{(b_s + b_t)} \left[ k_t (Z_r - X_2) - k_s (X_2 - X_1) - b_t \ddot{Z}_r - b_s V_1 \right] \]

\[ \text{If } b_s = b_t = 0 \]

\[ X_2 = \frac{k_t Z_r + k_s X_1}{k_t + k_s} \]

\[ \dot{X}_1 = V_1 \]

\[ \frac{k_t k_s}{k_t + k_s} Z_r + k_s X_1 \left( \frac{k_s}{k_t + k_s} - 1 \right) = m_s \ddot{V}_1 \]
Equation Formulation Issues (cont.)

• Quasi-static solution requires Newton-Raphson iteration

• Forces and moments must be differentiable

• Some inertias cannot be eliminated
  - Unusual forcing functions
  - “Projected” inertia
    » Open chains
    » Closed loops
The Efficiency Payoff (Hopefully)

- Bottom Line: Use larger time step

- Other benefits:
  - Model size reduced
  - Possibly avoid “stiff” integrators