Proper Modeling of Integrated Vehicle Systems

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Modeling of Vehicle Driveline Systems for an Integrated Environment

Project team - Driveline Systems:

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UM, UM, UM, NAVISTAR, UM
Outline

- Motivation for integrated simulation tool - VESIM
- Integrated simulation environment
- Subsystem model implementation tools
- Description of powertrain module models
- Simulation results
- Future work
Motivation

• Integrated Ground Vehicle Simulation:
  - Facilitates concurrent engineering of military, passenger and commercial vehicles
  - Enables rapid study of alternate vehicle configurations
    » system design and optimization studies
    • driveability, fuel economy, emissions, etc.

• Modular environment ensures long-term relevance of simulation tool
Goal: Integration of Variable Complexity Models

ENGINE

EMPIRICAL

SIMPLIFIED

THERMODYNAMIC

HIGH-FIDELITY

VEHICLE DYNAMICS

POINT-MASS

MULTI-BODY

Automotive Research Center

Modeling of Integrated Vehicle Powertrain Systems
Background and Current State-of-the-Art

- Integrated simulation packages have been developed to:
  - Study transient operation of engines and vehicles
  - Predict dynamic response
  - Assess alternate system configurations

- Existing software packages allow building-block model construction

- Models have been developed for each subsystem, but integration effort is fairly new

We have yet to fully tap the potential of such a tool.
Integrated Modeling Tools

MATLAB-SIMULINK

• Block diagram graphical user interface
  - Simulink block libraries
  - Matlab programming language
  - C or Fortran source code

• Common solver used for engine, driveline, vehicle
Integrated Modeling Tools

$20S_{IM}$

- Bond graph model graphical user interface
- Common formalism for different energy domains
  - Systematic generation of state equations
- Bond graph and block diagram elements can be integrated
- Generates source code for Matlab C-MEX files
MODULAR STRUCTURE

• flexibility in choosing vehicle configuration
Torque Converter

• 3 element torque converter (pump, turbine & stator)

• Static or dynamic model?

(J.C. WHITE/FORD MOTOR CO.)
Torque Converter Model

• **Static Model Methodology** (e.g., Salaani and Heydinger, 1998)

![Torque Converter Diagram]

- 
  - Engine Speed
  - Torque Ratio
  - Speed Ratio
  - Capacity Factor
  - Engine Speed
  - Capacity Factor

- **Implementation**
  - 20SIM -> C code -> Matlab/Simulink
  - Direct block diagram entry to Matlab/Simulink
• **Modeling Strategies**
  - Input-output model based on experimental data
  - Physical component-level model
Input-Output Transmission Model

- Based on experimental measurement of input and output effective inertias, stiffnesses, and damping
- Implemented as discrete components (e.g. Bond Graph)
  - 20SIM -> C-MEX files -> Matlab/Simulink
- Incorporates losses
  - Gear inefficiency
  - Fluid pumping
Empirical blending functions are used for shifting.
Alternative Transmission Model

- Physical-Based Model (Cho and Hedrick, 1989)
- Model considers inertias of gears and compliances of shafts
- Clutches engage/disengage during shift event
  - Torque phase
  - Speed phase
- Model can switch between bond graphs for different phases
Shift Logic

• Decision to shift based on
  - Transmission output shaft speed
  - Throttle position

• Implementation
  - C-MEX function
    » Accepts inputs from transmission and driver
    » Outputs gear number, torque multiplication and speed reduction ratios
**Differential/Driveshaft Models**

- **Differentials**
  - Bond graph representations
    - Conventional bevel-gear
    - Worm-gear

- **Propshafts and Driveshafts**
  - Compliance, inertia, damping
  - Axle cooler churning losses

- **Implementation**
  - 20SIM -> C-MEX files
Vehicle Specifications

Engine

- V8 DI Diesel
- Turbocharged, Intercooled
- Rated Power: 210 HP @ 2400 rpm

Vehicle/Driveline

- GVWR: 7950 Kg
- 4 Speed Automatic Transmission
- Rear Wheel Drive - 4x2

NAVISTAR 4700 Series
• Vehicle launch performance validation
  - “0-60 mph” full throttle acceleration from idle
  - Engine and vehicle speed compared to experimental data

• Torque converter stall test validation
  - Compare torque converter stall speed with test data

• Shift quality parametric study
  - Shift duration nominally 0.8 seconds
  - Vary duration +/- 0.4 seconds
  - Compare vehicle forward jerk
Model Validation (0-60 MPH)

ENGINE SPEED [RPM]

VEHICLE SPEED [MPH]

Test
VESIM

TIME [SEC]
Torque Converter Stall Test

ENG. SPEED [RPM]

TIME [SEC]

Test
VESIM
- Consider trade-off between ride quality and:
  - Acceleration
  - Clutch wear
Summary

- An inventory of models for different powertrain components has been implemented.
- Driveline models have been integrated with engine and vehicle (VESIM).
- Models have been partially validated with test data.
- Potential utility of simulation tool has been explored through example design studies.
Conclusions

• Vehicle/engine integration of varying fidelity is possible

• Engine/vehicle interactions appear to be important to vehicle mobility design and evaluation

• Additional work on driveline models is necessary
Future Work

- Extend usefulness of VESIM as predictive design tool by expanding component model inventory
- Continue data collection effort for validation