Validating Vehicle Dynamics Simulation Models

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Overview

1. Objective
2. Introduction to dynamics simulation and validation
3. Validation fundamentals:
   - Vehicle testing
   - Model matching sequence
   - When is a model "validated"?
4. Conclusions

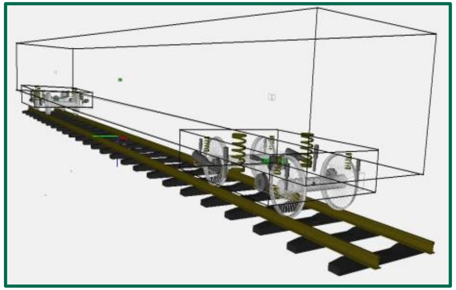
Objective

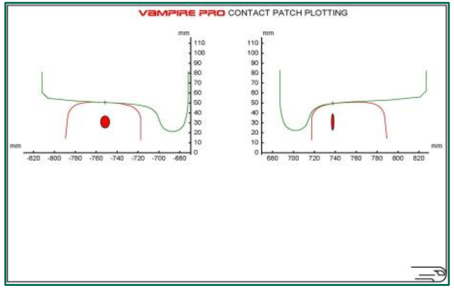
Present a structured process to guide model validation task

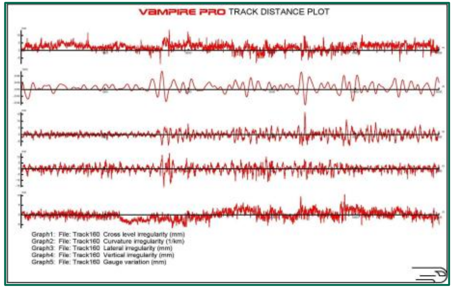
Principles applicable to all types of rail vehicle:

- Passenger (heavy rail, light rail, streetcar, transit...)
- Freight
- Locomotive
- Maintenance Of Way

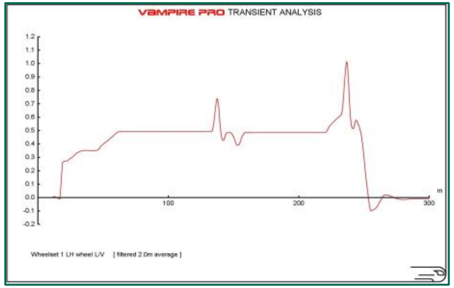
Vehicle Dynamics Simulation







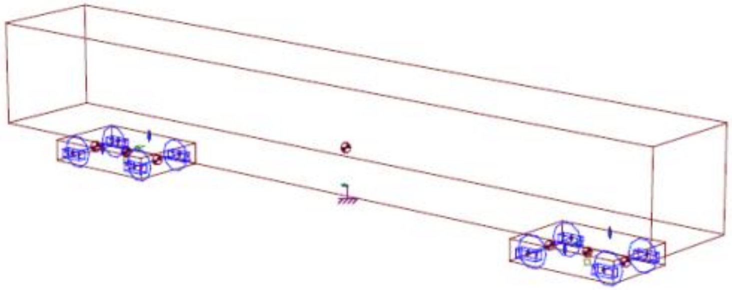
vehicle model + **wheel-rail contact** + **track**



= **outputs**

Simulation Software

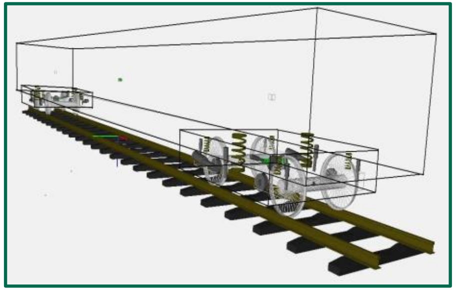
- Multibody simulation software for rail vehicle applications
- Detailed representation of wheel-rail contact mechanics
- Examples:
  - NUCARS
  - SIMPACK
  - VAMPIRE
  - UNIVERSAL MECHANISM

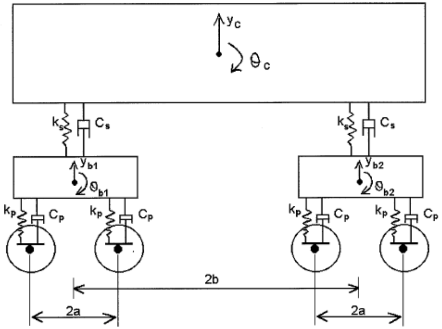


Why Simulation?

- Aid design of new vehicles / modifications
- Vehicle qualification (where required / permitted as complement to physical testing)
- Trouble-shoot in-service performance issues
- Explore changes to vehicle operation, e.g. increased speed or cant deficiency, change of deployment
- Studies to inform track design / maintenance / asset management
- Derailment investigations, etc.

Vehicle Model





- Typically 100+ parameters (geometry, inertias, suspension data…)
- Model variants (as required):
  - Tare and laden conditions
  - Inflated and deflated air springs (if fitted)
  - Static and dynamic stiffnesses (rubber)
  - New and worn components

Why Validation?

- Design-stage vehicle model typically contains uncertainties:
  - Inertias
  - Center of gravity position(s)
  - Parasitic stiffnesses
  - All design values
- This raises the question of whether the design-stage simulation model reliably represents the behavior of the as-built vehicle
- Validation necessary when simulation results are to be relied upon
- Model validated for intended use (type of analysis, input range)
- Enables assessment where direct test/measurement is impractical

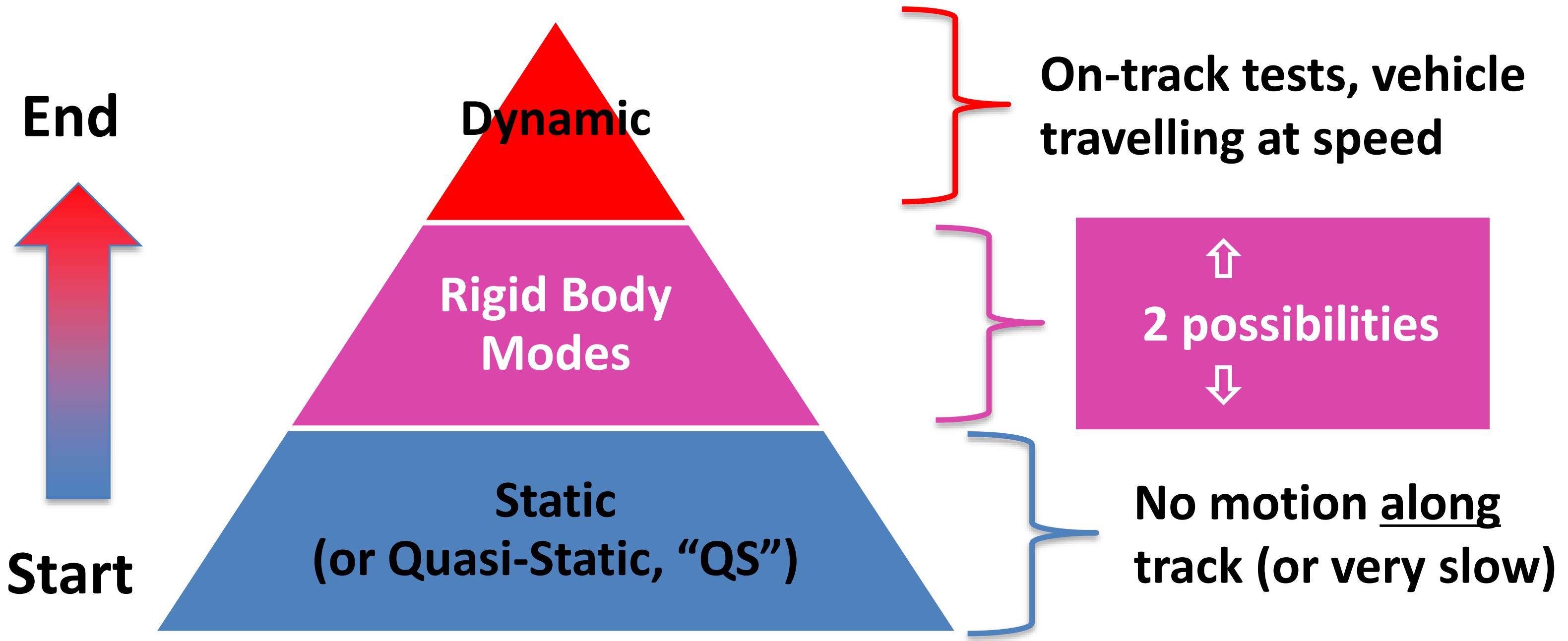
Basis Of Validation

- Software should be validated by its supplier (and report available)
- Simulate actual physical tests carried out on test vehicle
- Compare predicted vs. measured results, fine-tune vehicle model parameters as required (“model matching”)
- Iterative process
- Challenge to match to each test without spoiling match to others!

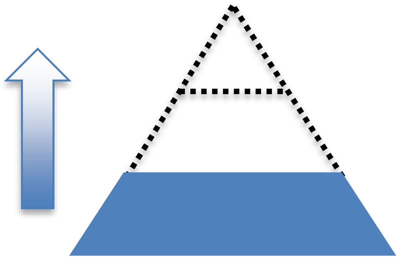
Testing for Validation Purposes

- New vehicle designs are generally required to undergo a range of static and dynamic tests for qualification purposes
- These tests are useful for model validation, but some enhancements are desirable to maximize their value for the model validation task
- Typical vehicle qualification tests (for N.A.) are outlined in later slides, in suggested order of consideration for validation task
- Where applicable, enhancements are suggested to aid validation
- If available, results from additional types of tests may be useful for validation (e.g. truck rotational resistance, component tests, etc.)

Model Matching Sequence



Why Static Results?



- Foundational ⇨ If match to vehicle's static behavior is poor, reliability of predicted dynamic response is doubtful
- Vehicle response is less complex than dynamic
- Measured outputs are steady / stable
- Starting with static tests allows model parameters to be 'locked in' progressively as confidence is gained (reduces unknowns, simplifying match to other tests)

1

Weight Test

Validation of:

- Overall vehicle mass
- Center of gravity position:
  - Longitudinal
  - Lateral

1

Weight Test – Tips

- Preferable to measure loads at all wheel positions simultaneously (both sides of both trucks)
- Otherwise, measure all wheel loads on one truck simultaneously, then repeat for other truck
- As a minimum, measure both wheel loads on one axle simultaneously, then repeat for each remaining axle
- Repeat entire test 2-3 times, roll vehicle along track between each weighing to work suspension / break out hysteresis
- Test each load condition used in R.B. modes / dynamic ride tests

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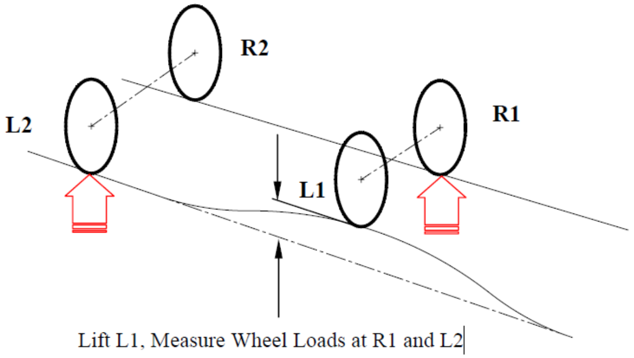
Static Wheel Load EQ Test



(Source: APTA SS-M-014-06)

Validation of:

– QS primary vertical stiffness
– Relative stiffness of pri. and sec. roll suspension

And, where applicable:

– Truck frame torsional compliance
– Body torsional compliance

2

Wheel Load EQ Test – Tips

– Apply (and remove) twist in incremental stages, taking care to avoid overshooting the target input at each stage

– Measure wheel loads and all vertical suspension displacements (primary and secondary) at all stages

– Also measure sidebearer vertical gaps at all stages (if applicable)

– Applying twist to diag. opposite corners of one truck, then to diag. opposite corners of whole vehicle, enables pri. and sec. suspension to be tested independently ⇨ useful additional info, particularly for vehicles where torsional compliance of truck / body are influential

3

Static Lean Test

Validation of:

- Center of gravity height
- QS suspension stiffness characteristics:
  - Vertical
  - Lateral (incl. bumpstop)
  - Roll

3

Static Lean Test – Tips

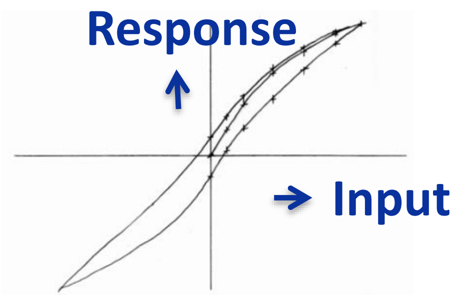
– Extend input range beyond minimum required for qualification

– Apply (and remove) cant in incremental stages, taking care to avoid overshooting the target input at each stage

– Measure body roll, truck roll and all suspension displacements (primary and secondary, vertical and lateral) at all stages

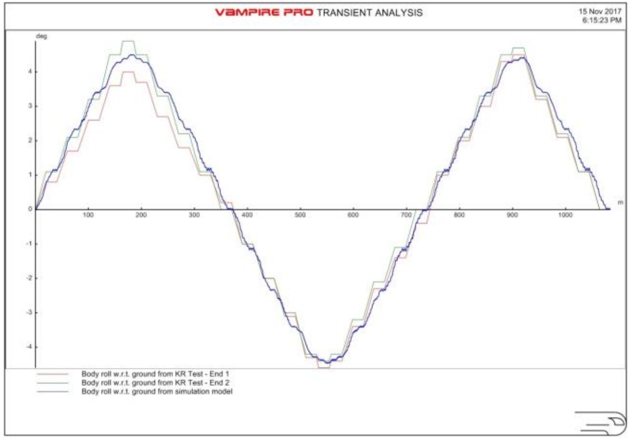
– Ideally, also measure wheel loads

– Obtain a full hysteresis loop



3 Example – Static Lean Test

Freight Car (3-Piece Trucks)



- Friction damping elements removed to enable ‘clean’ response
- Simulation outputs for body roll generally agreed with measured roll within 0.5 degree
- Additional measurements made for spring vert. and lat. displacements showed good agreement with model

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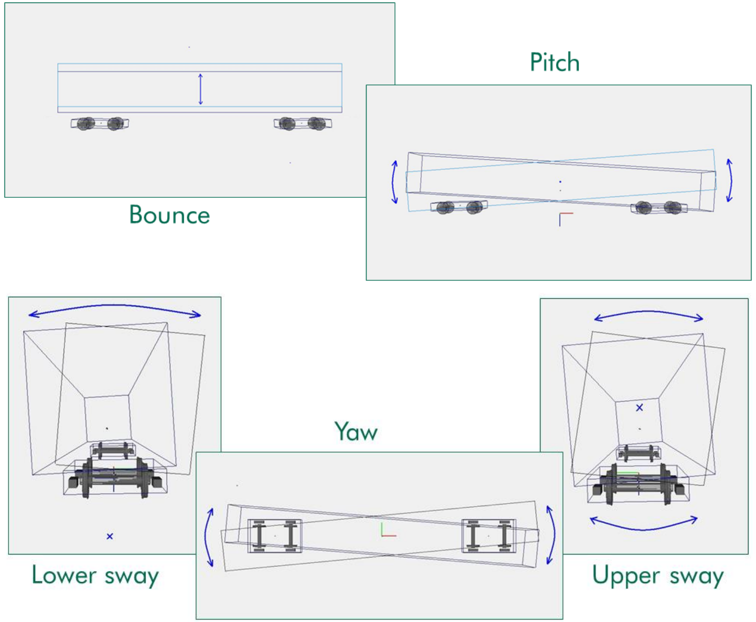
Rigid Body Modes



Validation of:

- **Body inertias (from sway, pitch, and yaw mode freqs.)**
- **Overall vertical dynamic stiffness (from bounce and pitch mode freqs.)**
- **Secondary lat. dynamic stiffness (from yaw mode freq.)**

Rigid Body Modes

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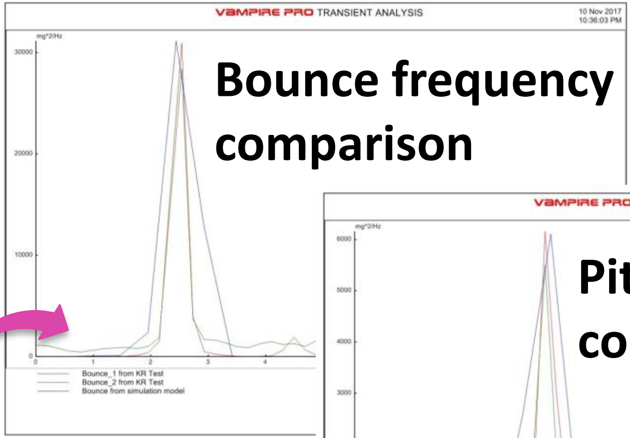
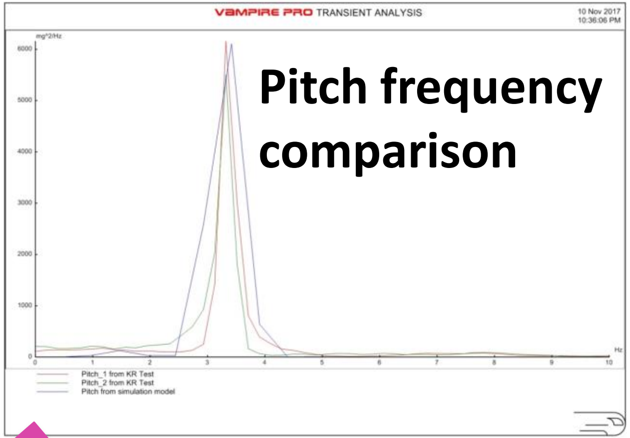


Bounce frequency comparison



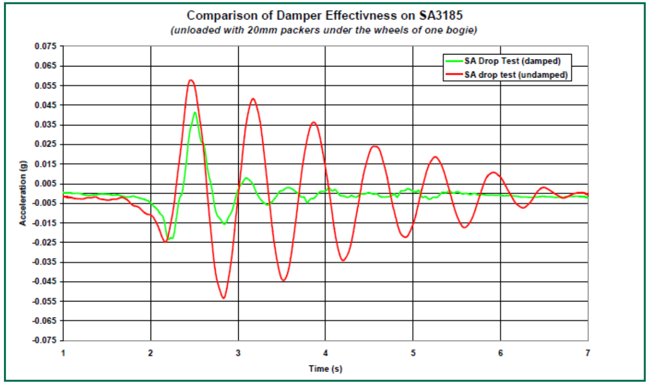
Pitch frequency comparison

Power Spectral Density (PSD) plots

- Dynamic ride test is (usually) preferred method
- Other methods possible (e.g. drop test, shaker table) but may need to remove damping elements
- Measure body accelerations
- Process data to isolate each mode, then make PSD plots

4 Example – Rigid Body Modes

Passenger Cars with Hydraulic Dampers



- **With vertical dampers removed, drop tests gave good results for some modes**
- **However, input was insufficient to provide ‘typical’ displacements, which affected results**
- **Results from track tests provided much better data for validation (incl. effects from damper parasitic stiffness)**

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Dynamic Ride Test

Validation of:

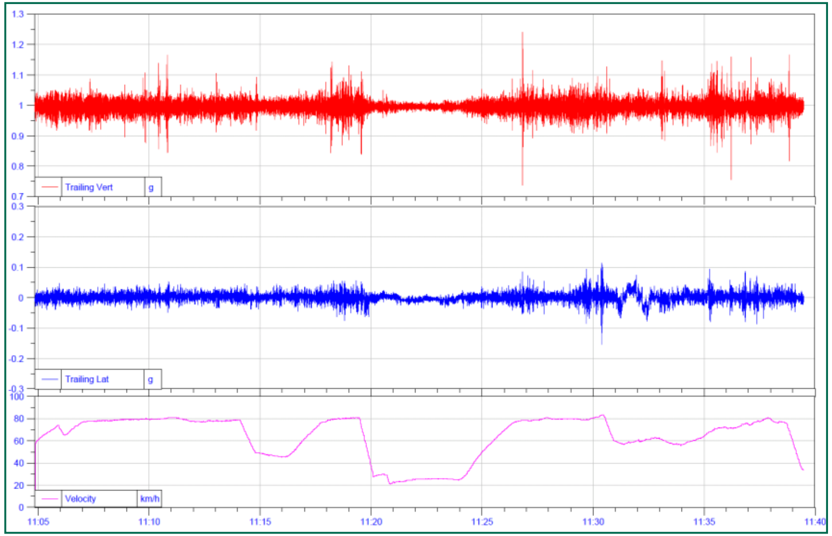
- **Overall vertical damping**
- **Secondary lateral damping**
- **Other parameters as described above for rigid body modes**

And, where applicable:

- **Wheel-rail contact forces**

5

Dynamic Ride Test



- Ride test validation is based on acceleration measurements (as described above for rigid body modes)
- Validation of WR contact forces requires necessary instrumentation and accurate knowledge of test track input

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Dynamic Ride Test – Tips

- Body vertical acceleration at each truck position
- Body lateral acceleration at each truck position, plus one at roof level
- If available, outputs from additional instrumentation (e.g. truck frame accelerations) may be useful to validation task
- Test in tare and laden conditions
- Test in inflated and deflated conditions for vehicles with air springs

When Is A Model "Validated"?

- Guidance regarding the level of agreement expected for North American vehicles remains to be fully developed / clarified
- FRA draft report DOT/FRA/ORD-06-XX "Validation of Dynamic Rail Vehicle Models" provides a useful reference for matching to dynamic test results (static tests are not covered)
- In Europe, Appendix K of UIC 518 provides useful reference material on validation, including % match limits for the load distribution comparison and examples of good and poor agreement
- A level of judgement is ultimately required

Conclusions

1. A structured approach is necessary to achieve aims of validation
2. A validated vehicle model enables confidence in assessing dynamic behavior in situations that are impractical to test/measure directly
3. Vehicle model must be validated for the type of analysis and input range used in simulations
4. Some thought needs to be given to the measurements required to be taken and methodology to be used for vehicle testing
5. A validated model permits options for vehicle / infrastructure mods or operational changes to be examined with confidence

Questions?