Expanding virtual ride quality subjective assessment using VI-grade DiM250

2022 Zero Prototypes Summit

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Introduction

Multimatic is a supplier that delivers manufactured products and engineering services to the global automotive industry at any volume level. Headquartered in Toronto, Canada with facilities in North America, Europe and Asia.

Low Volume Production → **High Volume Production**

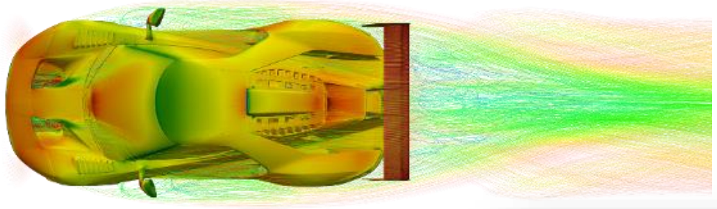
Suspension Products

Structural Products

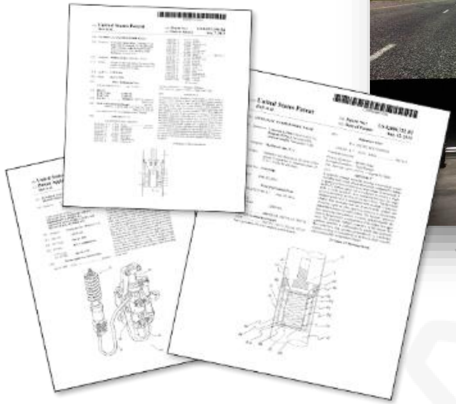
Mechanism Products

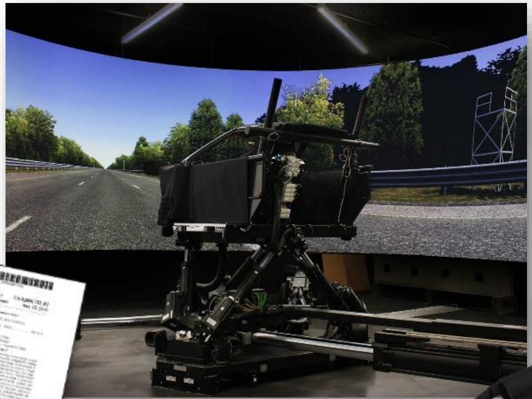
Multimatic Engineering

Multimatic Engineering delivers integrated design, analysis, prototyping, testing, validation and R&D activities for products ranging from individual components to complete vehicles



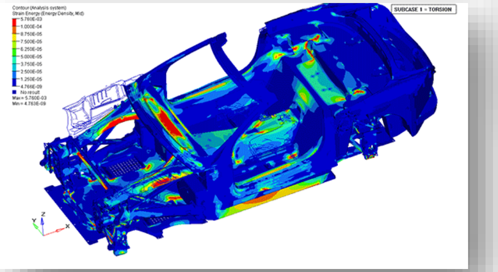
Research and Development





Vehicle Dynamics

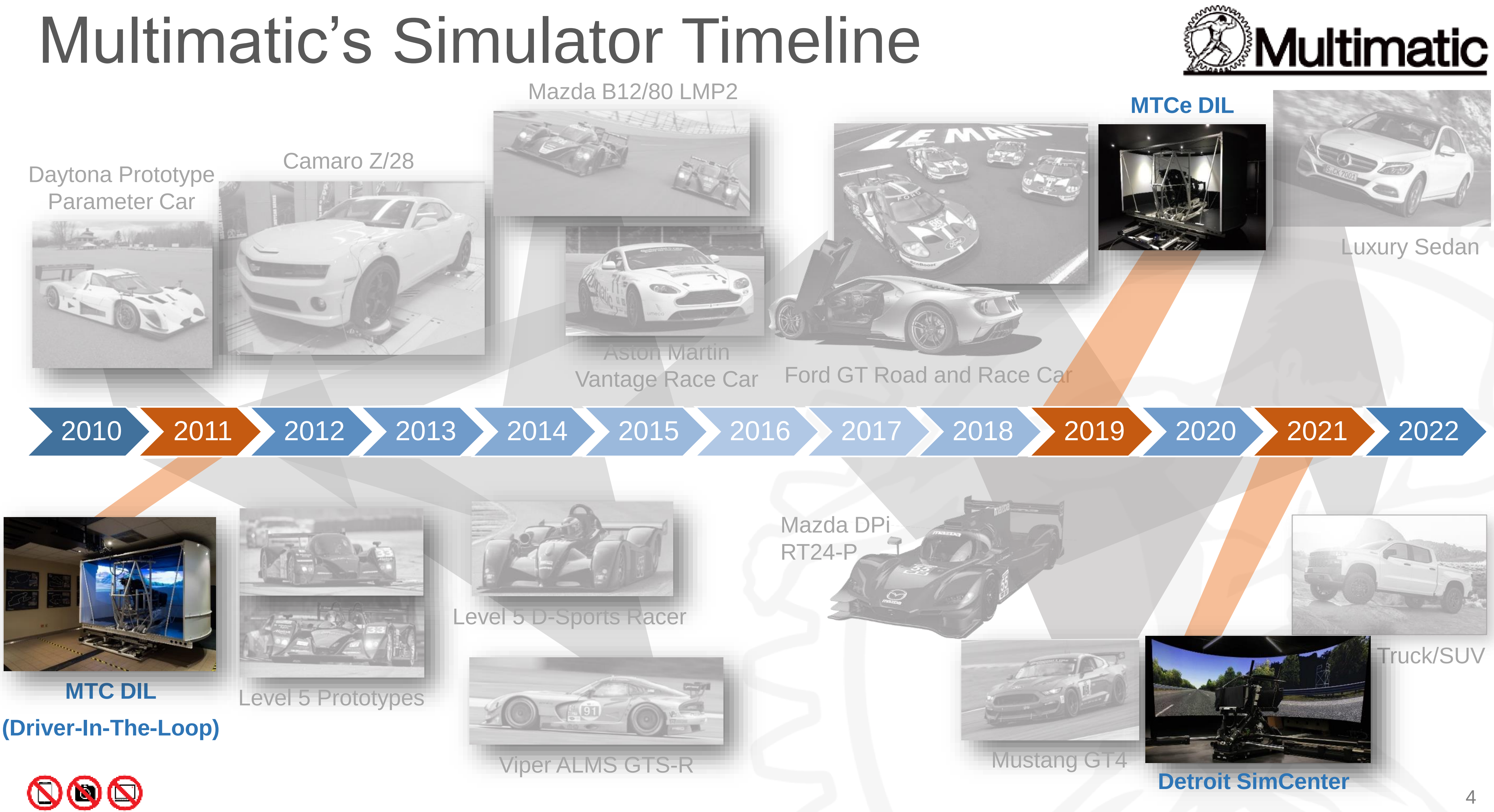
Testing



Advanced simulation

Component and system engineering

Multimatic's Simulator Timeline



An Integrated Development Approach

Multimatic

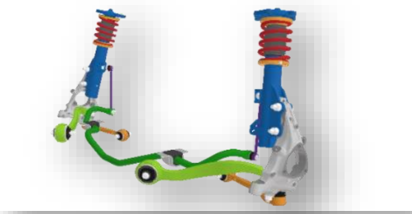
MISA is an approach applied throughout Multimatic. It allows for the translation of vehicle level design briefs into components that achieve those goals.

Our driving simulators are a critical part of this process. DIL validation bridges the gap between the analytical and the subjective and integrates the driver into the MISA process. This has allowed us to reduce total development timelines by over 50% in some cases.

Design Brief

Create the ultimate track-day vehicle with unprecedented performance on the track and on the road.

Vehicle Level Specification



System Level Specification

Component Level Specification & Verification

Correlation

Computer Virtual World

Multimatic Integrated Systems Analysis (MISA)

Cascading Product Development Process

Real Physical World

Vehicle Level Performance Verification

System Level Performance Verification

DiM Ride Project – Goals

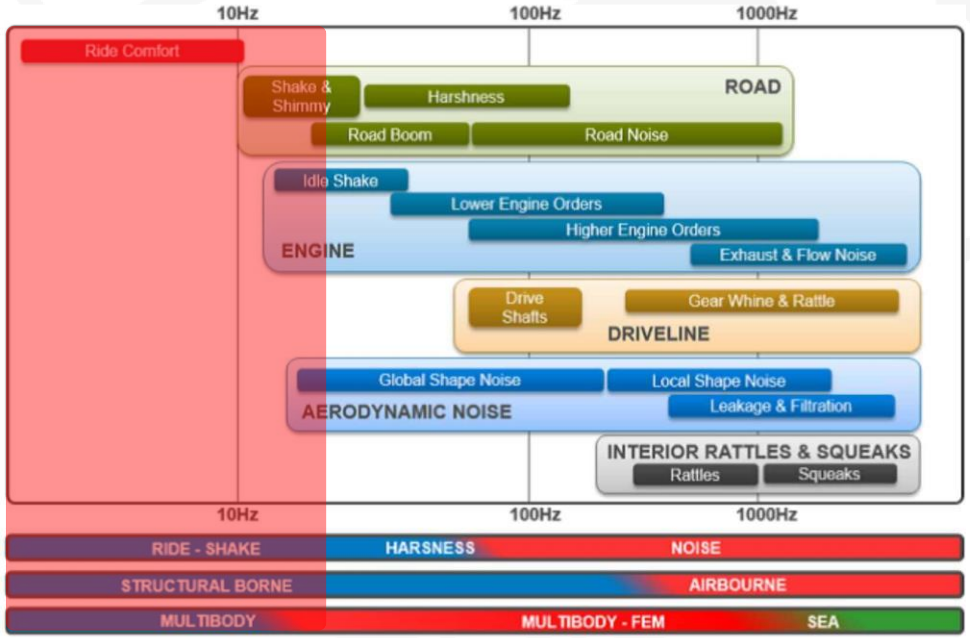
Expand virtual ride quality subjective assessment using VI-grade DiM 250

- Multimatic has **replicated real world subjective testing environments** through the implementation of high fidelity correlated vehicle/road models and simulator motion cueing analysis. These developments have **allowed for virtual assessment of vehicle subjective ride performance** saving development time and providing a link between objective metrics and subjective driver impressions.

Steering:
- The response of the vehicle to steering wheel inputs and the steering wheel forces involved in those maneuvers as perceived by the driver
- Typically grouped into ‘on-centre’ and ‘off-center’ operation

Handling:
- The vehicle directional responses to driver inputs and road inputs as perceived by driver and passengers
- Split into sub-limit and limit handling

Ride:
- **The response of the vehicle body to road disturbances (~1-30Hz)**
- Frequently grouped into smooth road and rough road categories
- Ride performance is closely related to NVH performance



DiM Ride Project – Achievements

Murray White (Technical Director & Test Driver, Vehicle Development)

Initially we were not able to feel the difference between the different damper settings on the DiM*, which in the real vehicle was obvious. We spend a lot of time working on correlating the models.*

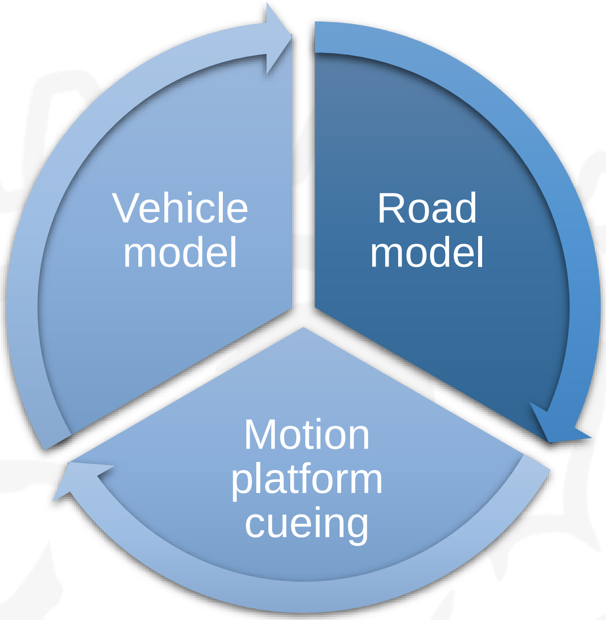
We got to the point where we were able to discern the different damper modes blindly*. We were able to start driving on the simulator and know which mode we were in (passive, active, sport, etc.)*

Currently, 100% of the changes we make on the DiM are directionally replicated on the real vehicle.

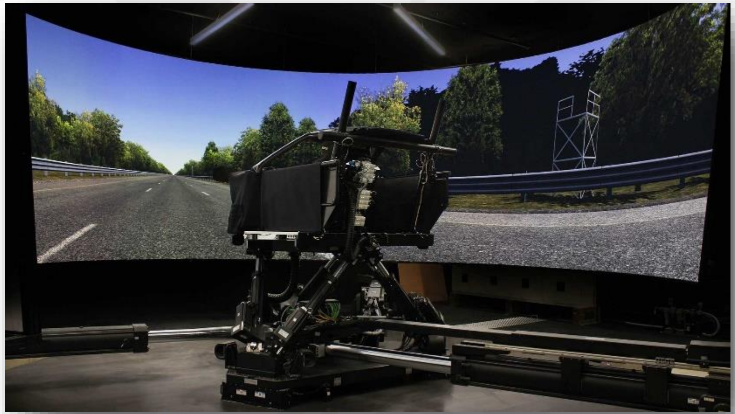
DiM Ride Development – Methodology

These achievements are not possible without three key elements that are critical to the program:

1. *Virtual vehicle model*
2. *Virtual road model*
3. *Motion platform cueing*



Accurately reproducing real world testing environments on the DiM requires correlated models and high fidelity simulator response



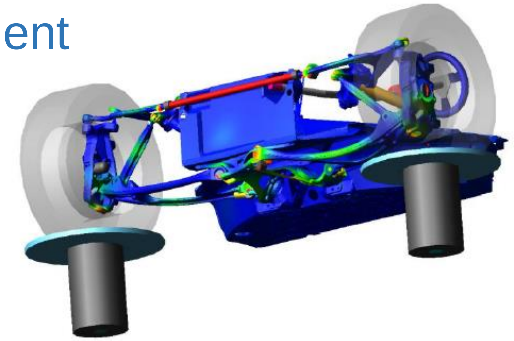
Virtual Vehicle Model

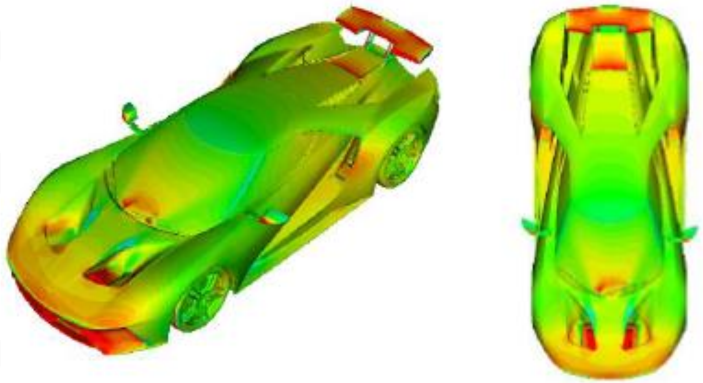
Analytical Simulation

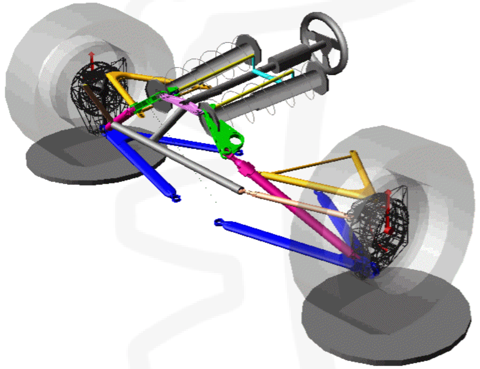
High fidelity virtual model creation is critical to the ride development program. Full vehicle model development is the first step in this process.

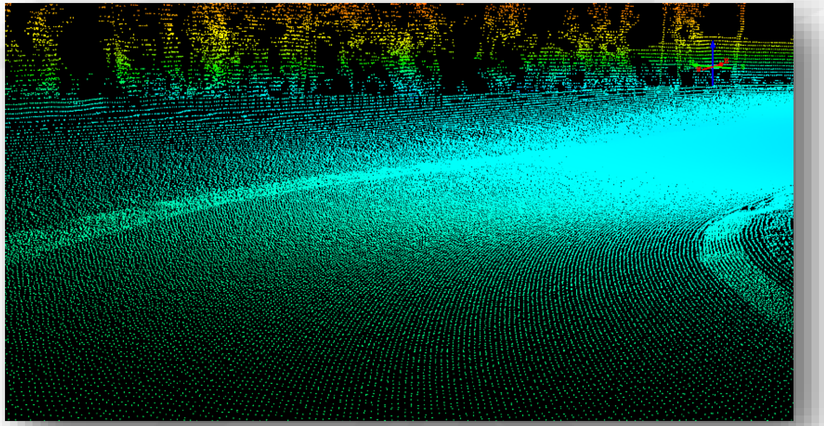
Core competencies include:

- Suspension kinematic and compliance development
- Aerodynamics development
- Tire model integration
- Control system integration
  - *ABS*
  - *TCS*
  - *Active Aerodynamics*
  - *Active Suspension*
  - *E-differentials*
  - *Etc…*









Objective Testing & Correlation

Ensuring the vehicle model is correlated is critical and objective test results are used in this process.

Objective testing methods used for correlation are:

- Multi-post rig vertical dynamics testing
- Kinematics and compliance (K&C) testing
- Road and track testing

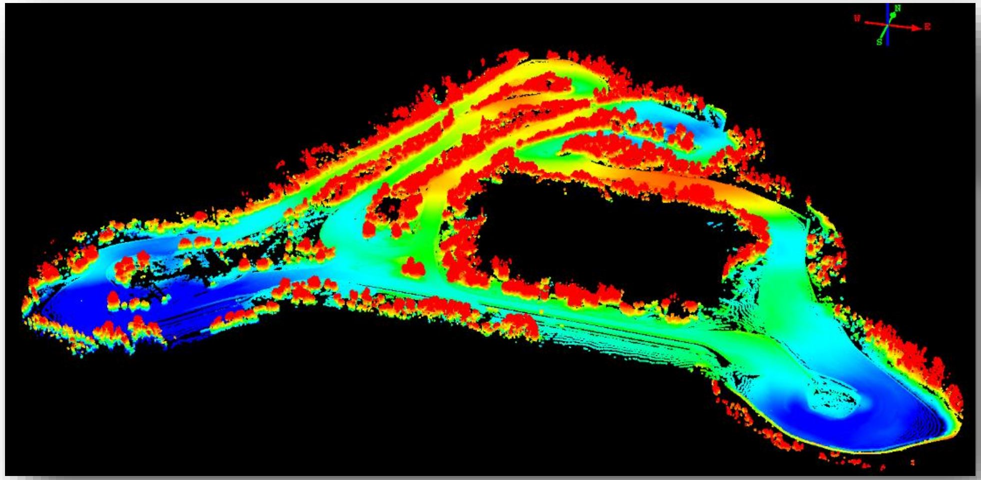
Virtual Road Model

Virtual Road Model Development

High fidelity virtual road models are critical to replicating accurate tire to road interaction in simulation. They also play a key role in subjective ride assessment on the DiM.

Multimatic has developed methods to process laser scanned point clouds of all types of surfaces:

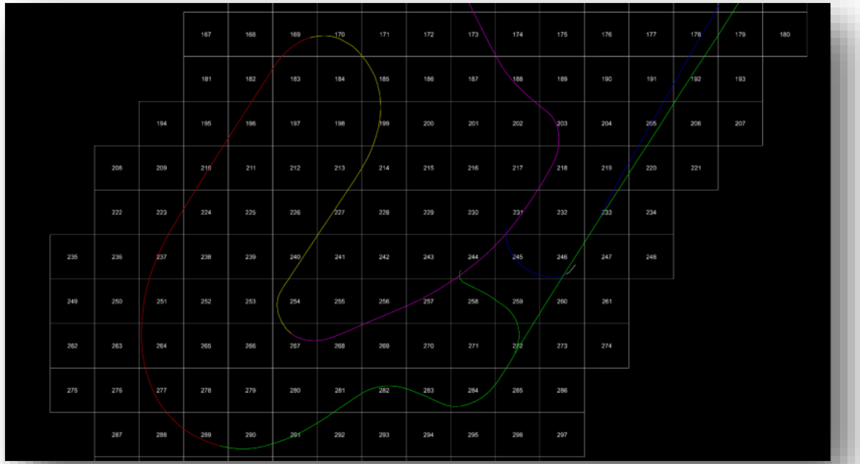
- Racetracks
- Public roads
- Proving grounds
- On/off road trail/obstacles

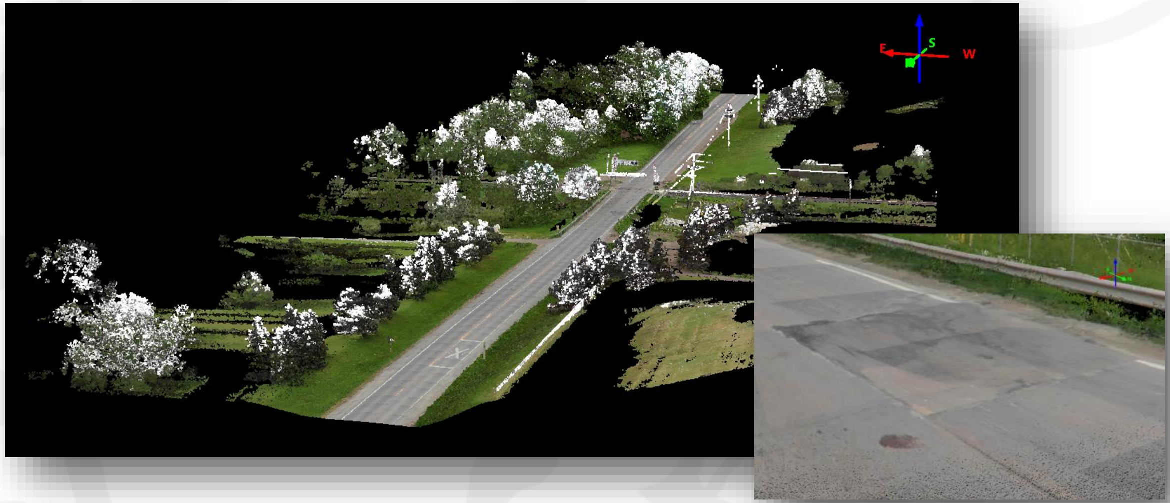


Laser Scanned Point Clouds

As laser scanning technologies have advanced, highly accurate surface scanning techniques that can measure 10 000+ points per square metre have become more accessible. Typically, more than 100 million points are generated.

Most modern point clouds are generated using a mobile mapping technique. This involves an instrumented vehicle that scans the target road surface and surrounding environment.

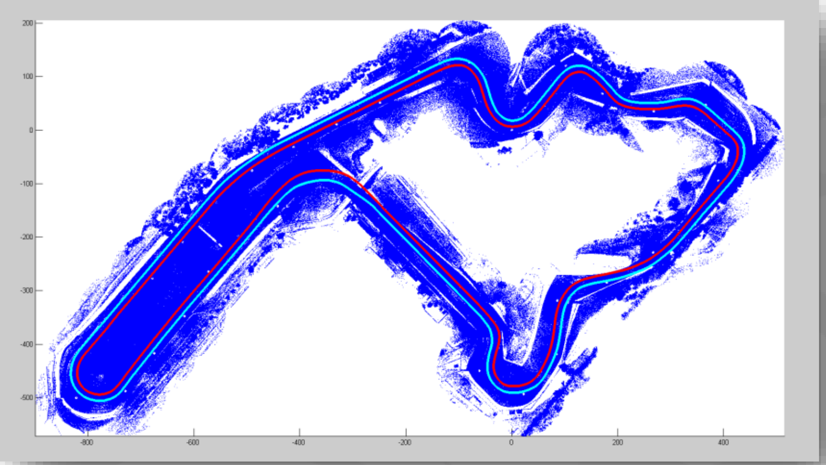


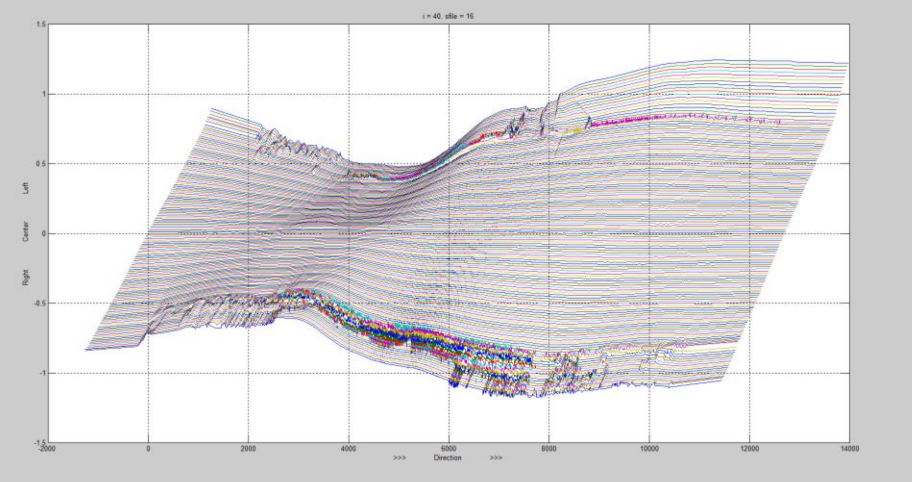


Virtual Road Generation Process

At a high level, the process used to take a raw point cloud and create a virtual road surface mesh are as follows:

- Process point cloud files and organize them in track/road running order
- Remove scenery points that are not relevant to the road surface to be modelled
- Remove any spurious/overhanging points above the road surface (power lines, trees, overpasses, etc.…)
- Create a uniformly spaced fine grid along the road
- Map grid z coordinates onto a surface generated using the remaining point cloud points
- Low pass filter the uniformly spaced grid
- Generate a continuous track surface ribbon mesh from the grid
- Write out in required format



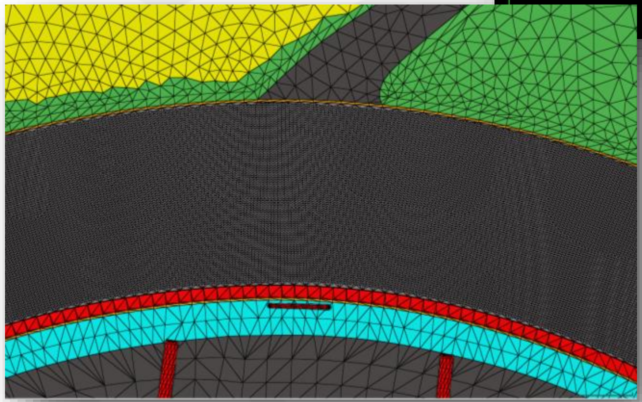


Virtual Road Generation Process

The final product is a uniformly spaced mesh of the road surface to be used in offline and DiL/DiM simulations.

In parallel to the analytical road surface model creation, the same point cloud is being used to generate a mesh of everything surrounding the road surface (grass, kerbing, service roads, medians,etc…).

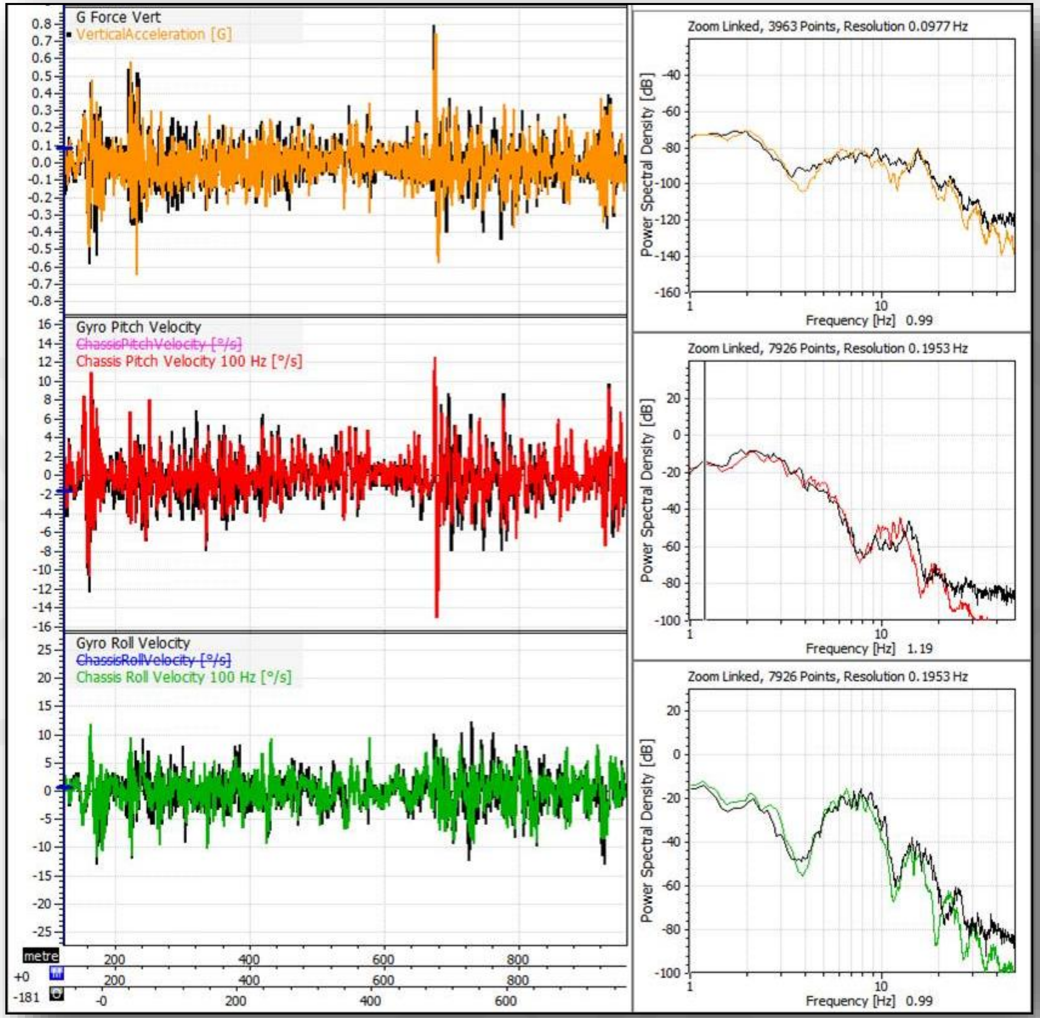
These two meshes are then combined to create the final virtual road model.



Virtual Road Validation

BLACK: Real data

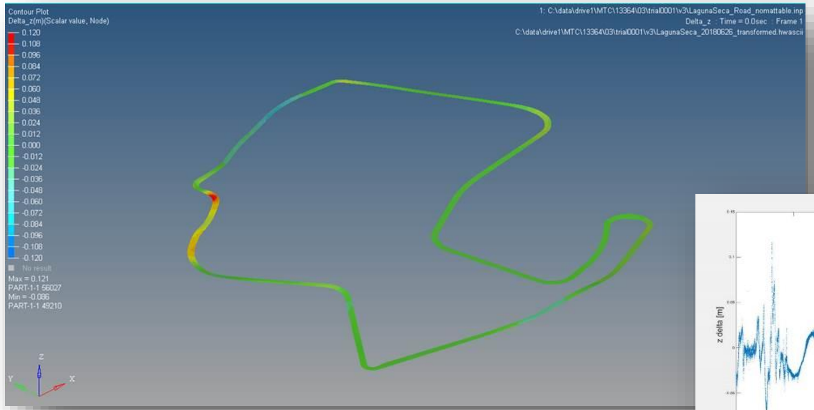
COLOURED: Virtual road

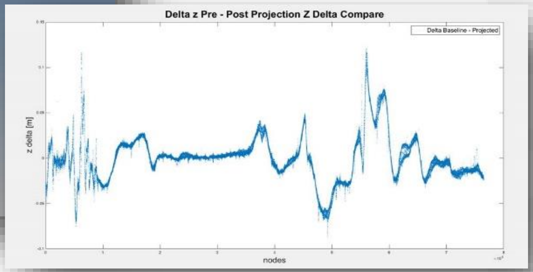


Ensuring the virtual road model has all the same content as the road it represents is critical to the ride development program.

Offline simulations are conducted with a correlated vehicle model driving over the generated road model. The same vehicle is driven over the road in the real world and the results are compared to assess the virtual road model's fidelity in both the time and frequency domains.

Subjective evaluations are also conducted on the DiM and compared to same evaluator's impressions while driving over the road surface in the real world.





Virtual Road Validation

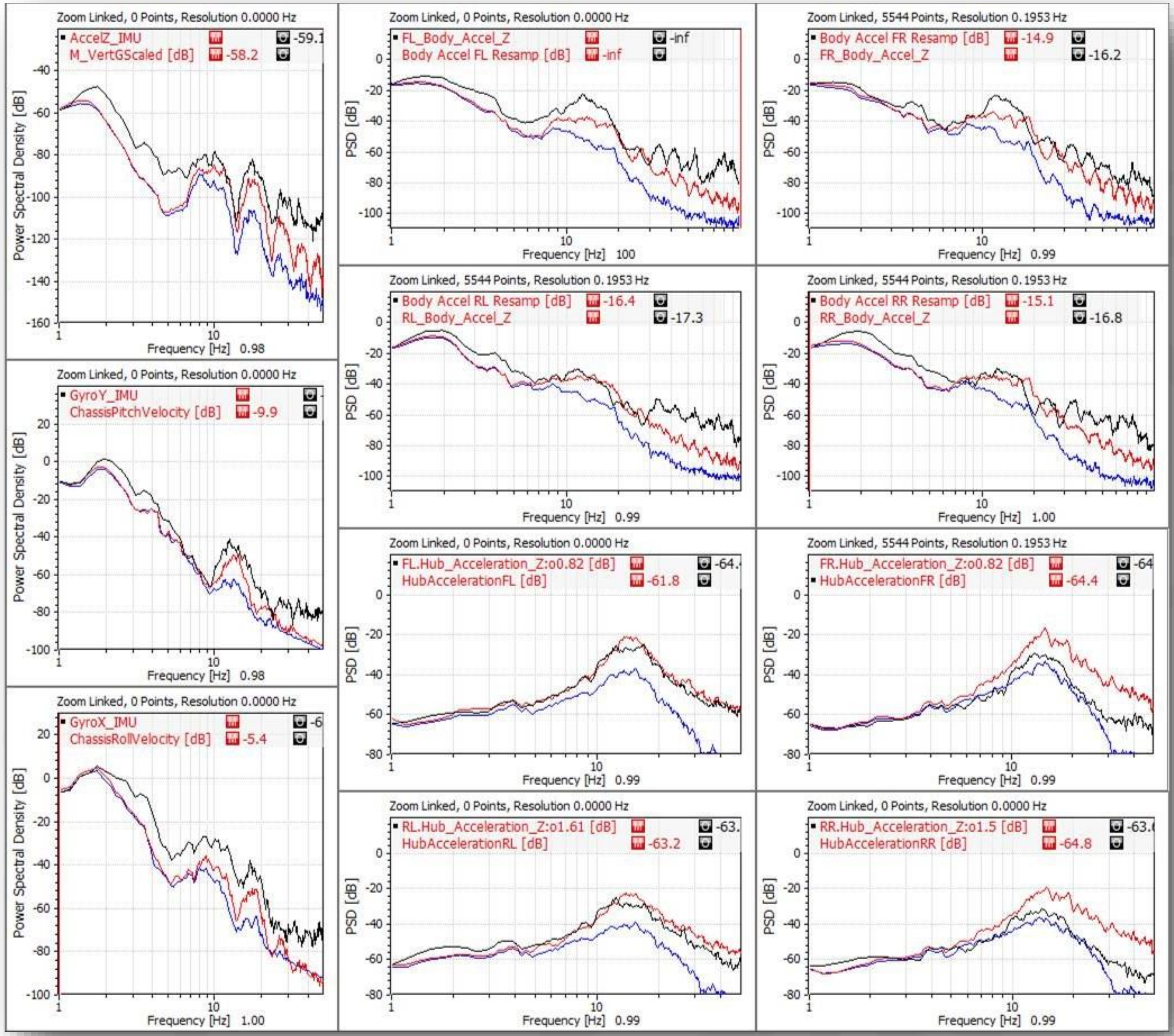
Road Model Development

Increasing element density/filter cutoff

BLACK: Real Data
BLUE: Baseline Road
RED: Updated road

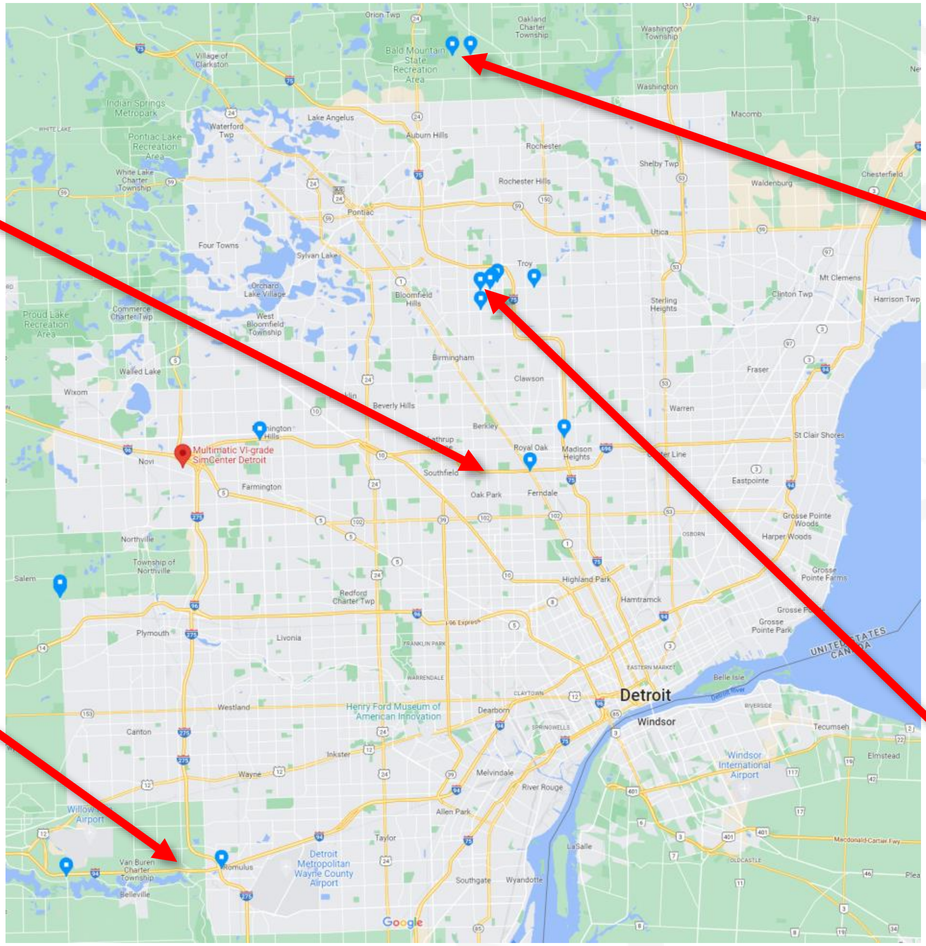
Increased high-frequency motion is visibly apparent with revised road, similar in nature to measured data:

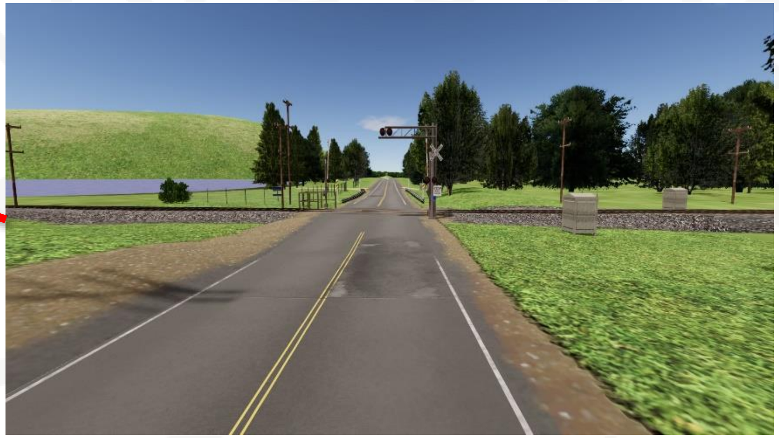
- Improved chassis heave, pitch roll 7-20 Hz but still lacking heave, pitch, roll content from 2-6 Hz
- 12-14 Hz pitch mode significantly increased
- Body corner acceleration improved above 7 Hz



Virtual Ride Roads (Michigan, US)

A series of roads in Michigan used for our subjective evaluation including smooth/rough roads, highways and obstacles (railroad crossing, speed bumps, etc.) have been scanned and rendered.

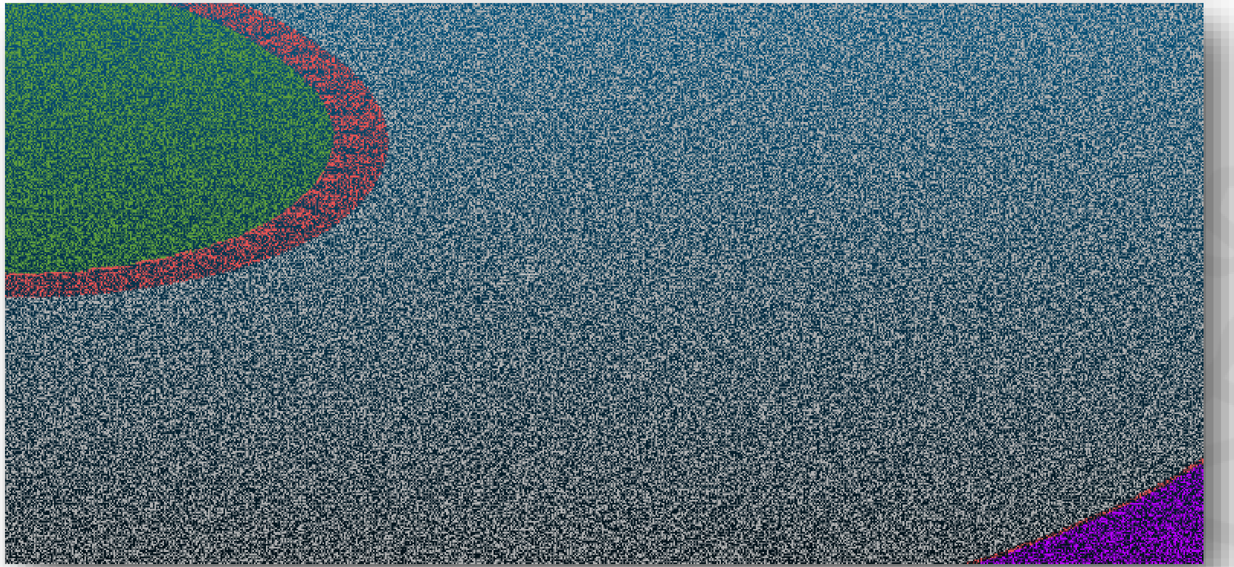


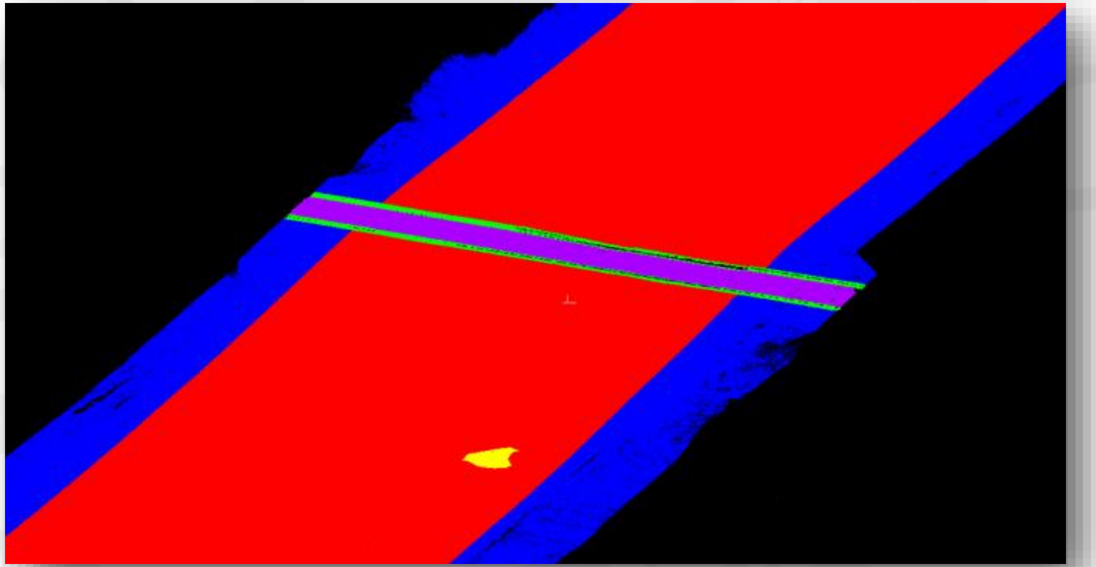


Next Steps

VI-grade GridMesh RDF road format integration:

- Eliminates road mesh element density limitations
- Allows for resolutions down to 1 cm
- Uses VI-Road point cloud toolkit for road generation from point cloud data
- Critical to capture small features (cracks, railroad tracks, etc.…) for ride evaluation
- Collector specific sound can be applied when driving over certain sections of road

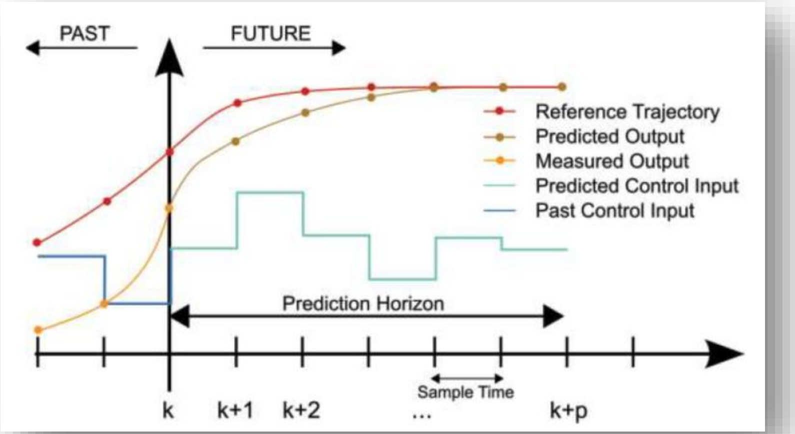


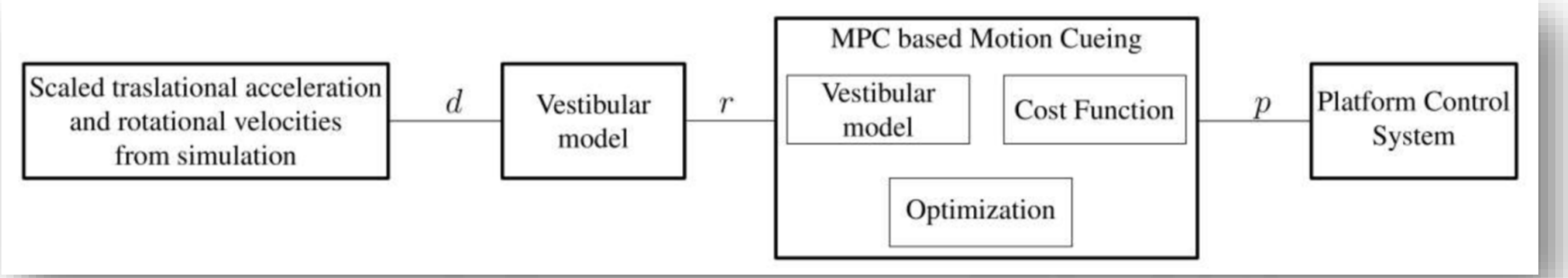


Motion Platform Cueing

Motion Platform Cueing (MPC)

- Crucial to accurately **reproduce driving feel** so that the driver can fully exploit the virtual driving experience
- One of the main difficulties in the design of efficient motion cueing algorithms is due to the **complex nature of the human perception system**
- VI-grade's motion cueing algorithm (MCA) developed is based on the **Model Predictive Control** (MPC)
  - Obtain the current **vehicle states** (translational acceleration and angular velocities), convert these signals into **perceived accelerations** from the driver vestibular system model, and **compute the displacement signals** passed to the platform control system

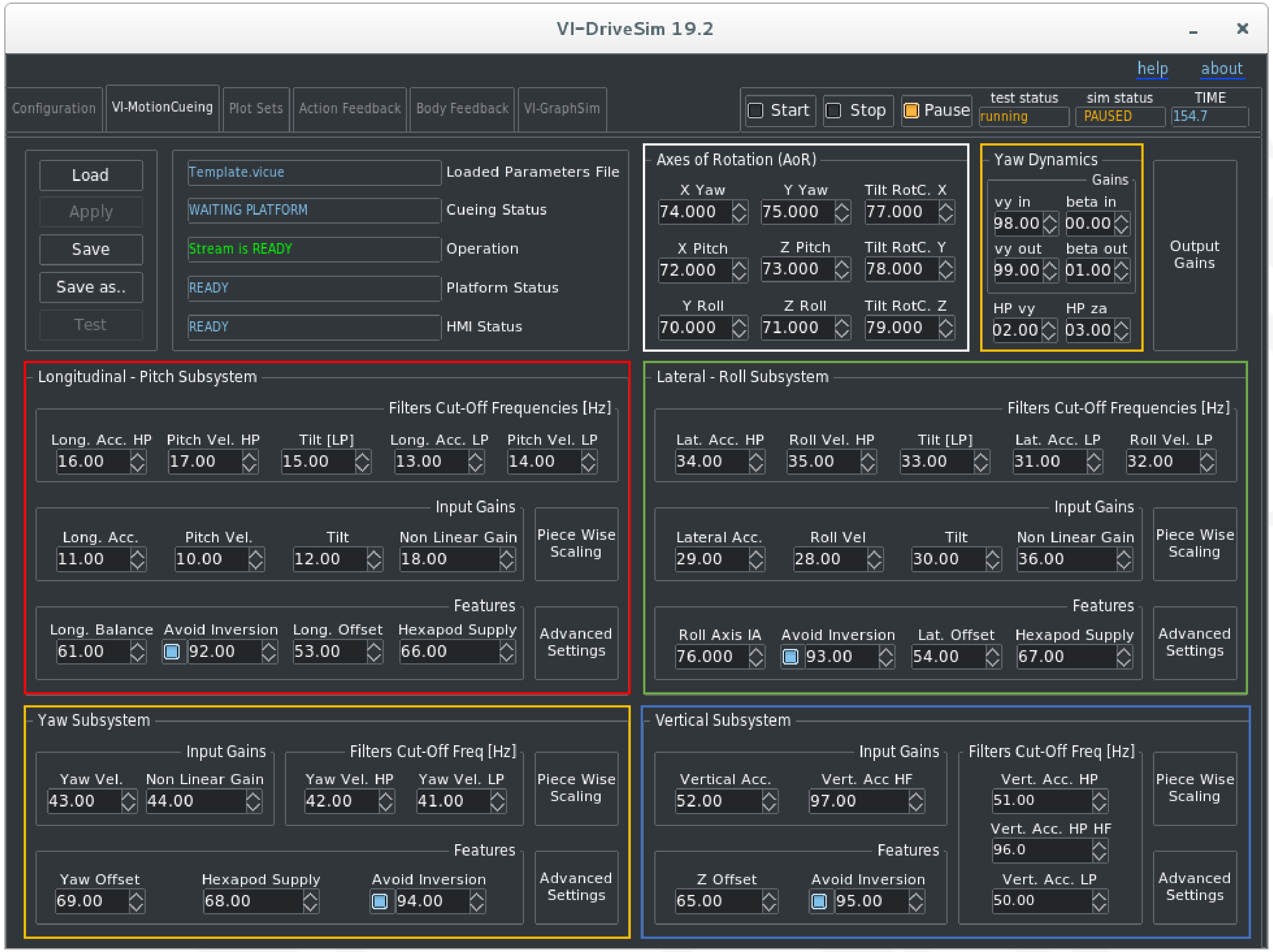




VI-DriveSim Software

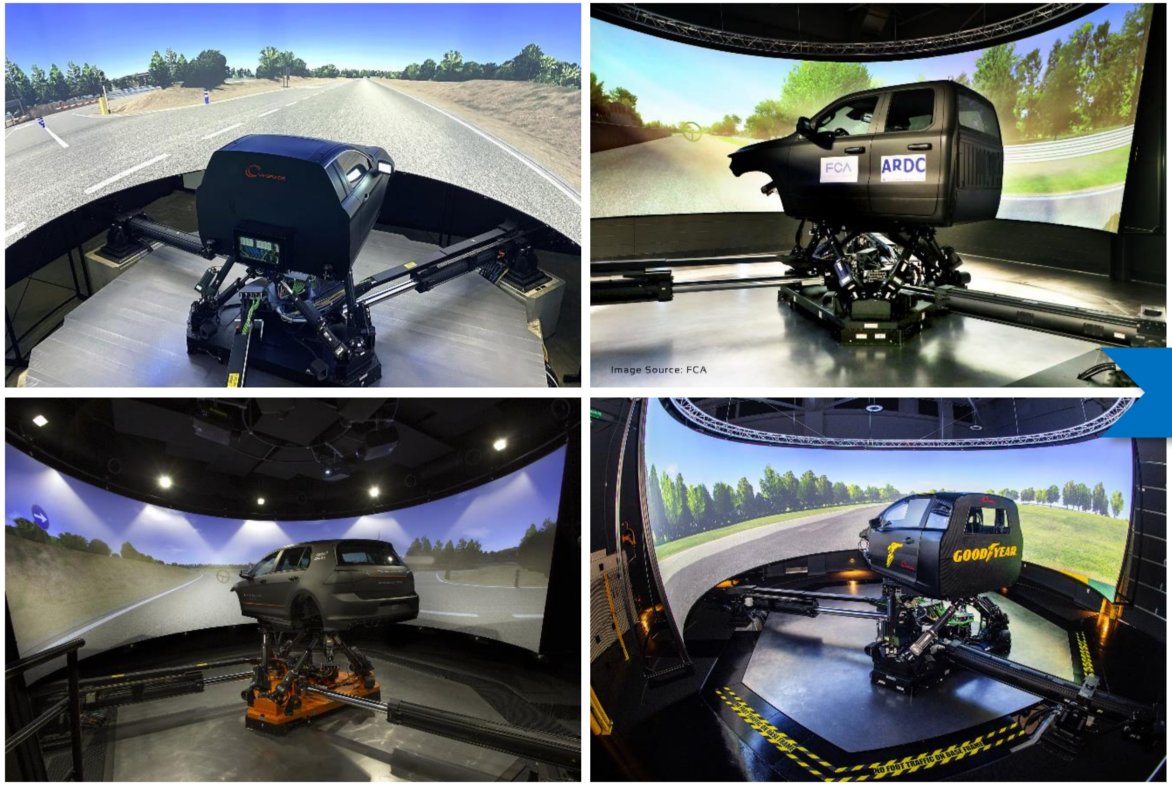
Multimatic

- **VI-DriveSim** software allows the user the adjust coefficients in real-time while the test is running
- **150 coefficients** acting on all individual subsystems:
  - Gains (linear and non-linear),
  - Filters (low and high pass)
  - Platform Weights
  - Inversion Constraints
  - Projection
- Each of these factors influencing the platform responses (both low and high frequency) differently.

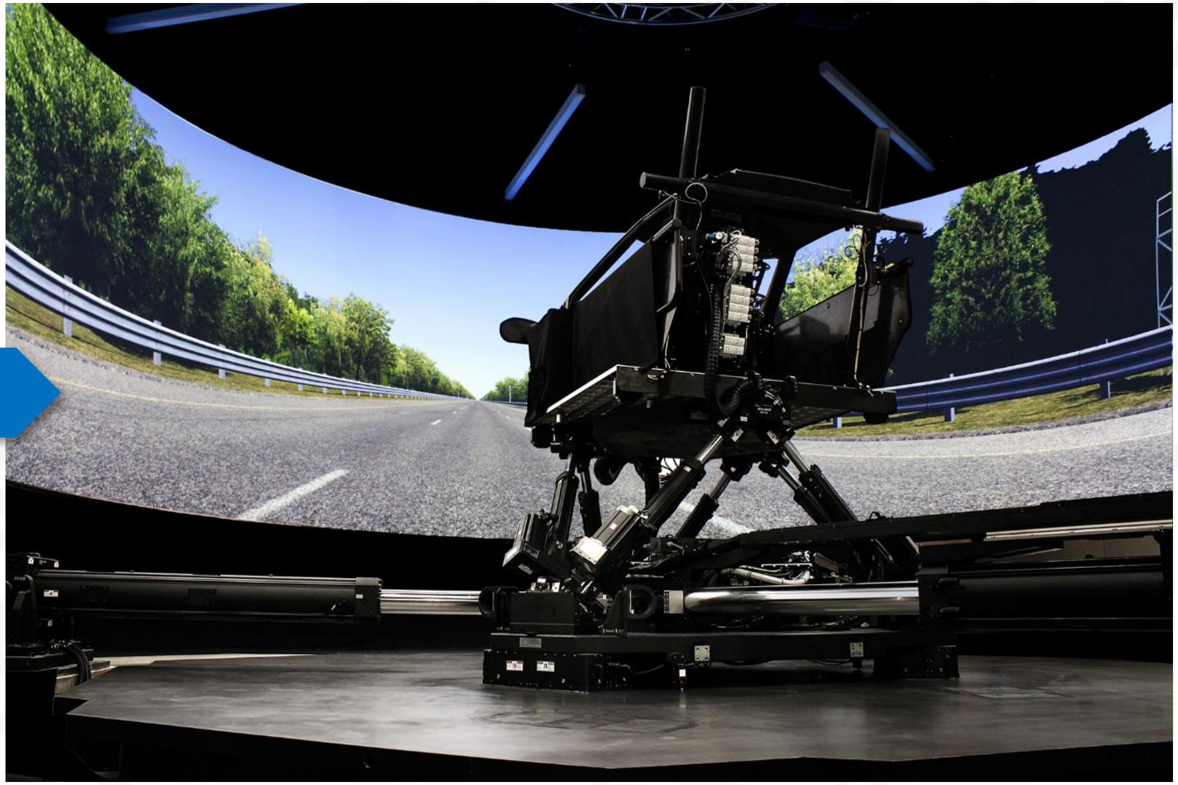


DiM250 Simulator – Modular Cockpit

- Due to the wide range of projects and vehicles Multimatic is involved with, **a fully reconfigurable cockpit** have been designed and built.



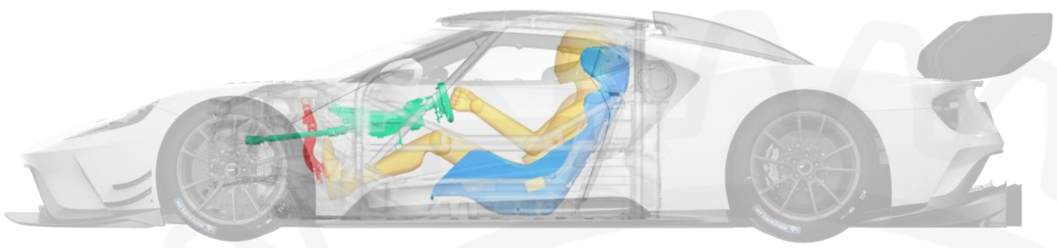
Example of road car shell from OEMs, tire manufacturers, etc.

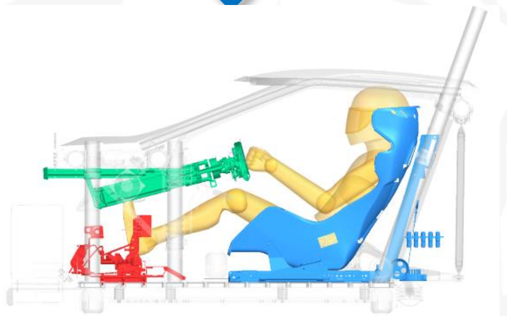


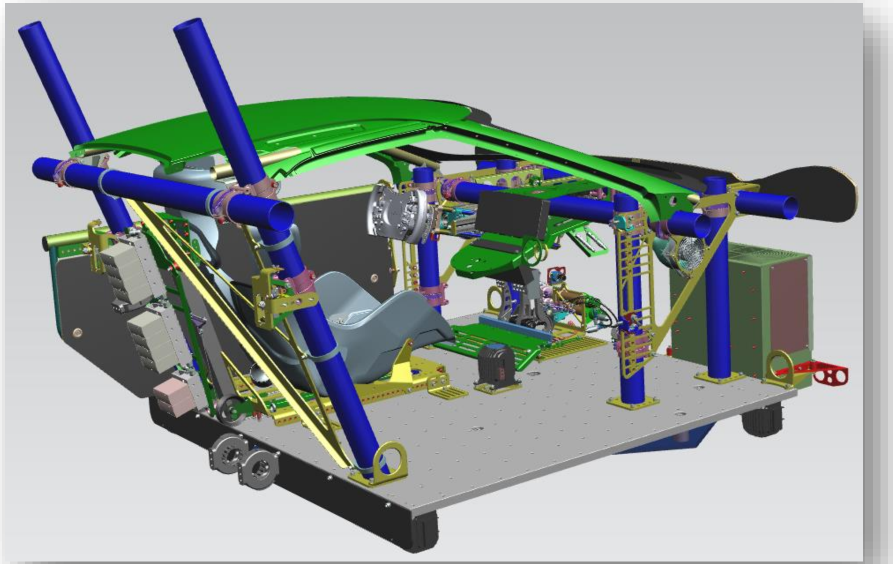
Multimatic's modular cockpit

DiM250 Simulator – Modular Cockpit

- Multimatic's configurable cockpit allows to:
  - **Replicate the real car driving position and viewpoint** with adjustable seat, pedals and steering
  - Minimize weight and inertia to maximize DiM actuators performance
- These are both critical in order to obtain good cueing fidelity





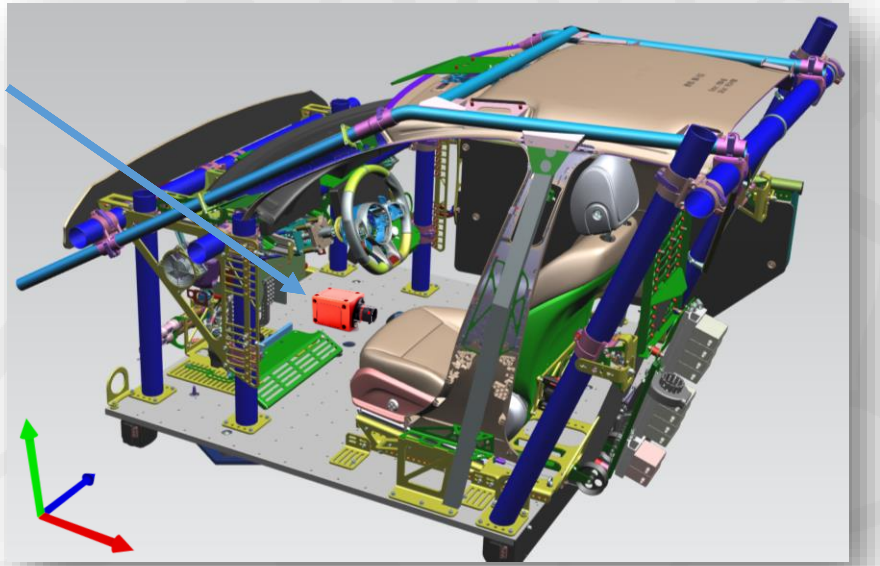


Ford GT (Racecar)

DiM250 Simulator – Modular Cockpit

- The cockpit has been **instrumented with a additional sensors** allowing:
  - The comparison of the requested and actual platform motions
  - The **comparison of real car, vehicle model and platform motions** (accelerations, velocities and displacements)

Inertia Measurement Unit (IMU)



Luxury Sedan

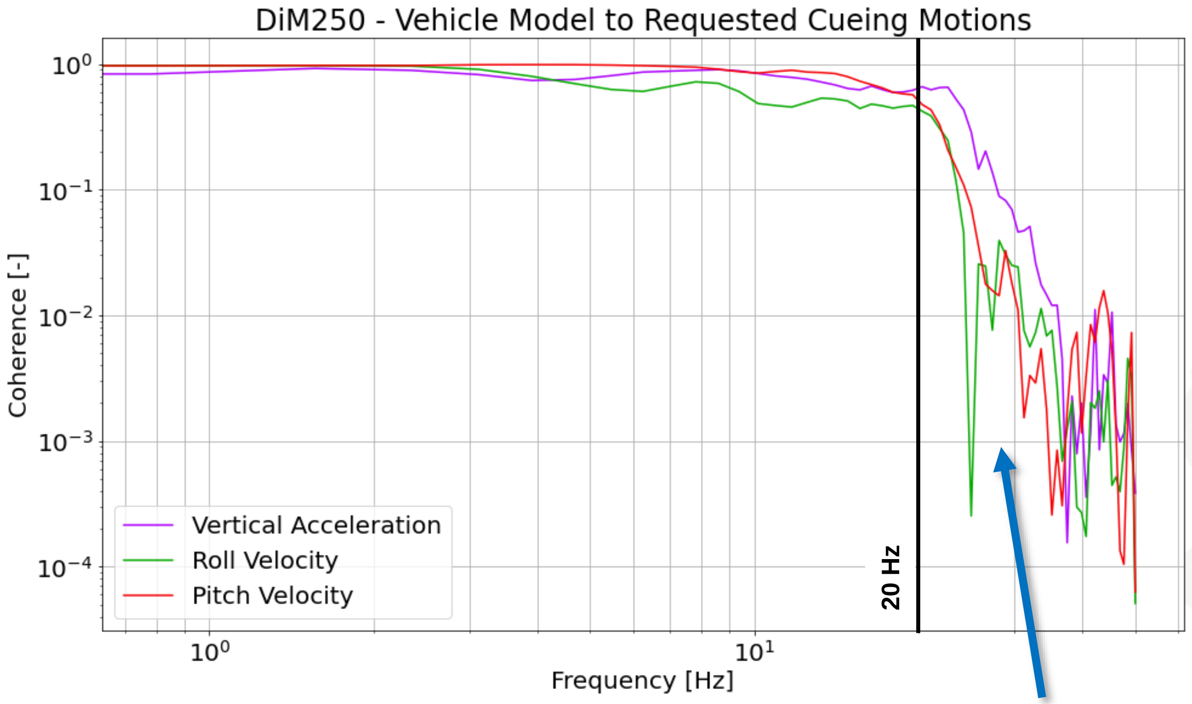
Real Car

Vehicle Model

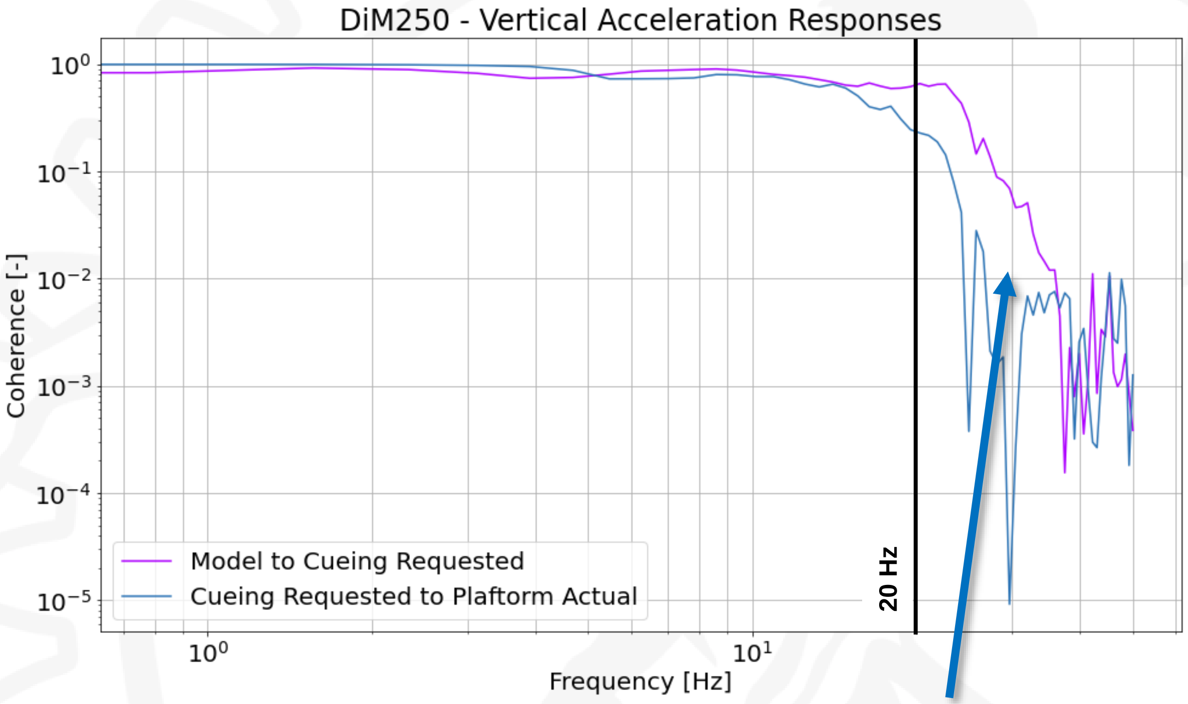
Motion Platform

Vehicle Model & Cueing Responses

- The combination of **high fidelity vehicle model** and **platform motion cueing response** is well suited for the performing **subjective evaluation of the vehicle body to road disturbances** is possible thanks to:
  - Accurate vehicle model: Multimatic's models validated up to 25-30 Hz
  - High fidelity simulator response: VI-grade DiM250 motion cueing consistent up to 20-25 Hz



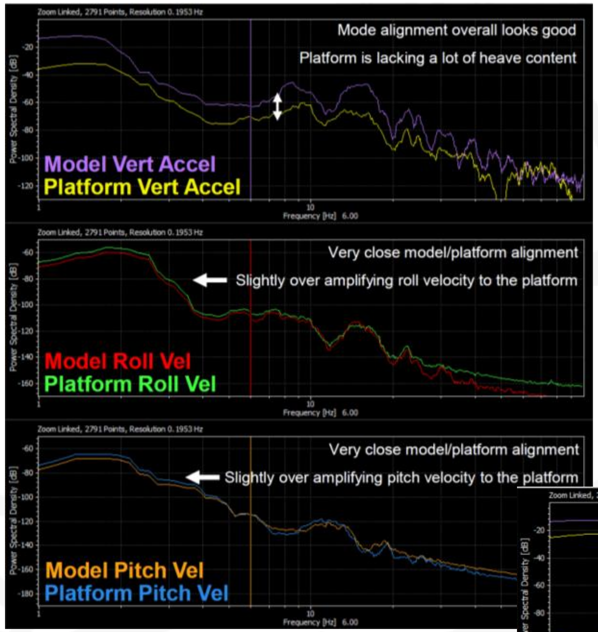
Vehicle Model Limitation



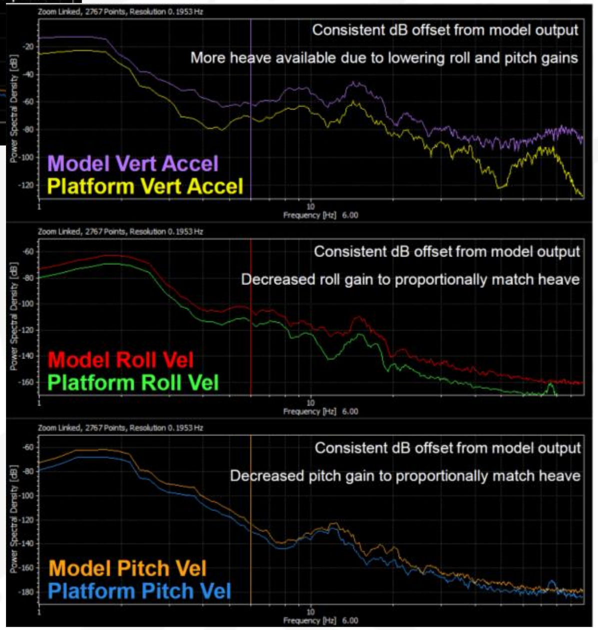
Motion Platform Limitation

Motion Platform Cueing – Tuning

- The challenge lays in understanding which parameters must be tune to achieved the desired change in platform response.
  - Often, it is necessary to **adjust more than just one coefficients**
  - Sometimes, a **compromise** must be found to ensure we **remain within platform limits**
- Different people/driver perceive different level of motions cueing as useful, however
  - Confirming that both the **vehicle motions** and **platform accelerations** are **well matched** throughout the **frequency range** (both amplitude and phase angle) is critical for providing faithful motion cueing.



Overlay of **vehicle model** and **platform vertical accelerations:** effect of updating the gains for the vertical, roll and pitch subsystems to better scale each of the vehicle motions.



Vertical Acceleration, Roll & Pitch Velocities shown for:

VEHICLE MODEL

SENSORS ON PLATFORM

Motion Platform Cueing – Tuning

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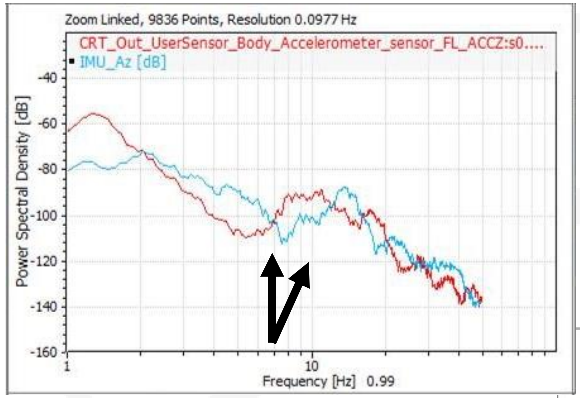
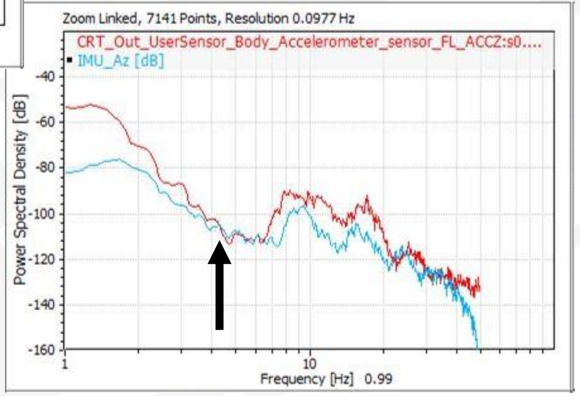


Vertical Acceleration shown for:

VEHICLE MODEL

SENSORS ON PLATFORM



Overlay of **vehicle model** and **platform vertical accelerations:** effect of updating the axis of rotation (equivalent of the driver hip point) and the cut-off frequency of the high pass filter for the vertical subsystem.

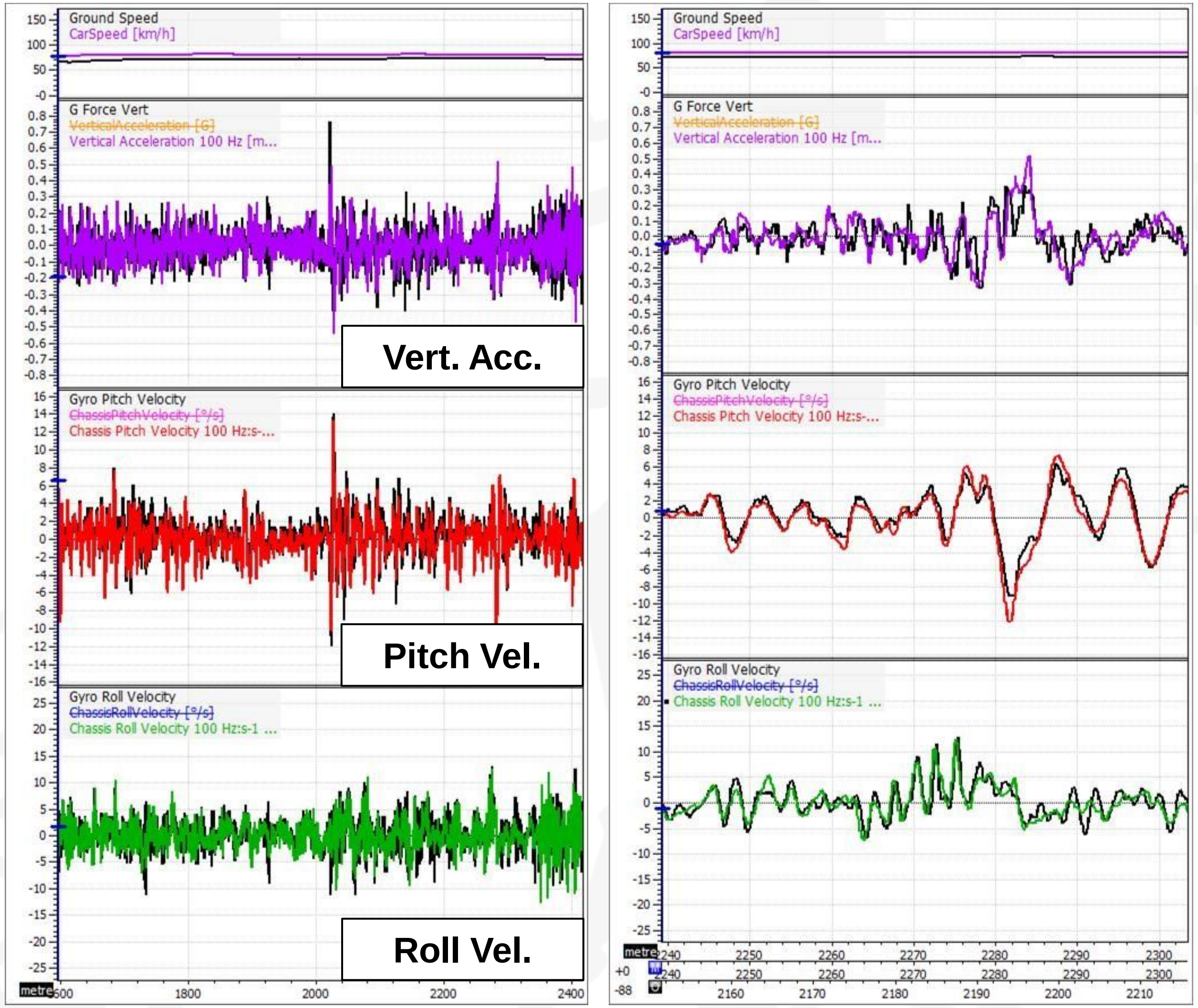
Motion Platform Cueing – Case Study

- Despite high vehicle model fidelity (vehicle, tires and roads), it is rarely possible to get an exact match between the real car and platform responses

- Ensuring a similar trend is critical as this allows the driver to **perceive setup changes** equally between the real car and the simulator thus allowing for a proper **assessment of ride performance**

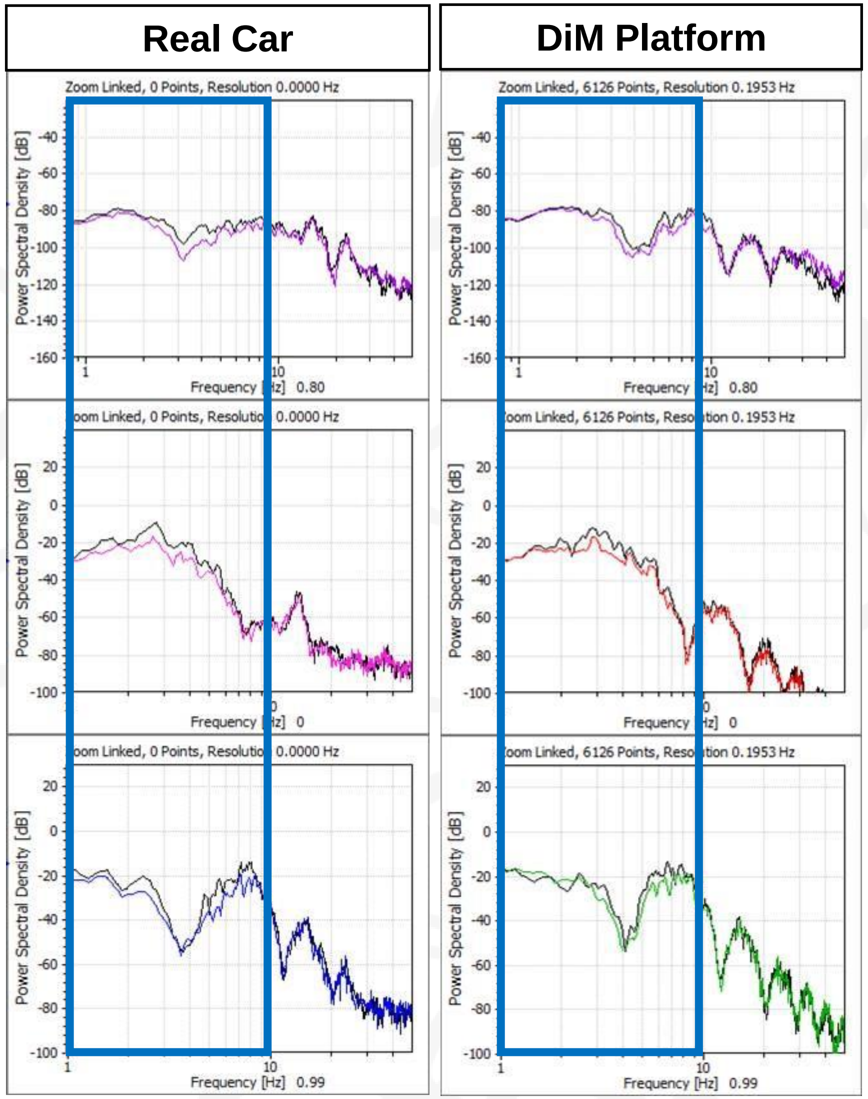
- Developing our active damper (eDSSV, TASV) technologies:
  - Test Driver: Murray White
  - Vehicle : Mercedes C200
  - Roads: Gunn Road (MI, USA)

BLACK: real car **COLOURED**: vehicle model



Motion Platform Cueing – Case Study

- Comparisons of the vertical accelerations, pitch velocity and roll velocity between **passive** and **active damper settings**
  - The active settings **reduces** both perceived **vertical accelerations** and **pitch velocity** around the heave mode of the vehicle (i.e. 2-4 Hz)
- Both effects noticeable on the real car logged data are **replicated accurately** on the motion platform, resulting in the **driver able to easily discern the behavior change**.

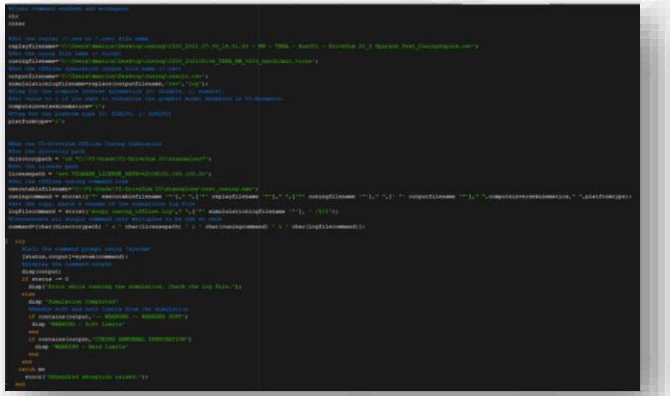


BLACK: passive damper settings

COLOURED: active damper settings

Motion Platform Cueing – Offline Simulation

- Use of the **offline cueing** tool to validate and optimize cueing parameters **before running a test** session:
  - Check motion cueing fidelity by comparing real data (when available) against vehicle model and simulator platform
  - **Maximizing range** usage while remaining within platform limits
- **Identical algorithm** to the one used when running real-time, vehicle model outputs (from offline simulation or real data) fed to the solver to estimate motion platform motions
  - Input file format can be a *.csv or *.res (from Vi-CarRealTime)
- Developed **Python/MATLAB scripts** to run large scale **DoEs and optimization studies**



DiM Ride Project – Next Steps

We have now **successfully** applied this work on **3 different vehicles equipped with our adaptive damping technology** (a Mercedes C200, a Ford GT and Chevrolet Silverado 1500 Trail Boss).

We are now working toward a **standardized methodology** that we can use as a starting point for any project/vehicle.

The primary ride, choppiness and even secondary ride shape (up to 20 Hz) are reproduced very realistically, we are now working toward **bridging the gap between the ride and NVH** (Noise, vibration, and harshness) through enhanced:

- **Road model and tire interaction** using
  - *Superior fidelity vehicle model*
  - *Higher road profile resolution (grid mesh)*
  - *Multi-contact point tire models*
- **Driver immersion** using
  - *More realistic graphics rendering*
  - *Additional sounds (structure-borne and airborne) for suspension/tire impact noise*
  - *Enhance motion platform cueing algorithms and tuning*

Presentation Information

Audience:	2022 Zero Prototypes Summit Attendees
Date:	May 18th-19th, 2022
Location:	Udine, Italy
Presenters:	Peter D'Urso, Kevin Marion
Title:	Expanding virtual ride quality subjective assessment using VI-grade DiM 250
Abstract:	Multimatic has replicated real world subjective testing environments through the implementation of high fidelity correlated vehicle/road models and simulator motion cueing analysis. These developments have allowed for virtual assessment of vehicle subjective ride performance saving development time and providing a link between objective metrics and subjective driver impressions.