COMMUNITY OF EXPERTS
OF DASSAULT SYSTÈMES SOLUTIONS

Founding Partner
DASSAULT SYSTEMES

COExperience

APR 16-19, 2023

Miami, FL | Hyatt Regency Miami

EXPERTS TOGETHER

COMMUNITY OF EXPERTS
OF DASSAULT SYSTÈMES SOLUTIONS

Founding Partner
DASSAULT SYSTEMES

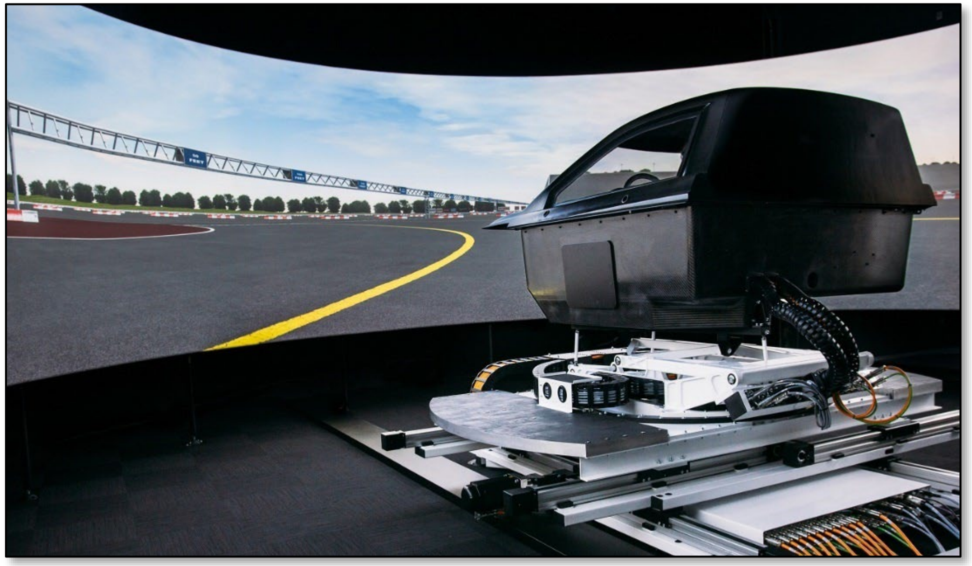
Virtual Twins in Motorsport: Deploying Dymola Models in the Field

By Claytex, a TECHNIA Company

Presentation Outline

CLAYTEX
TECHNIA COMPANY

- Claytex Background
- My Background
- Dymola and Modelica
- Virtual Twin - User Base
- Virtual Twins in Motorsport
- Deployments



Claytex Background

CLAYTEX
TECHNIA COMPANY

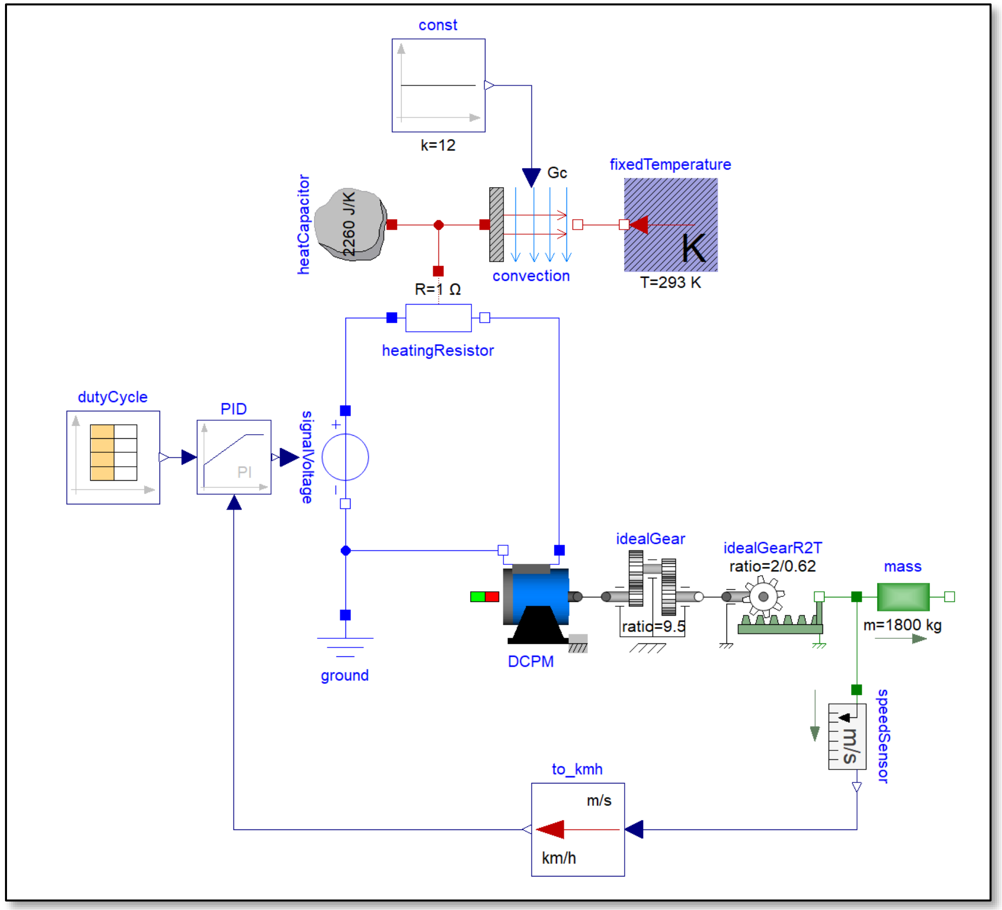
- Based in Leamington Spa, UK
  - Other offices in Cape Town, South Africa and Charlotte NC, USA
- Established in 1998
- Systems Engineering, Modelling and Simulation
  - Focused on physical modelling to support control system design and development
- Business Activities
  - Engineering consultancy
  - Software sales and support
  - Modelica library developers
  - Training services
- Global customer base
  - Europe, USA, India, South Korea, Japan
- Acquired by TECHNIA in Q1 - 2022

My Background

- University of Iowa (B.S. and M.S.) in Mechanical Engineering
- Boeing Commercial Airplanes for 2 years
- Worked at Red Bull for 5 years until the operation shut down in 2011
  - Opportunity to collaborate with the Red Bull F1 team
  - First NASCAR team to use Dymola / Modelica
  - Introduced to Mike Dempsey (Founder of Claytex)
- Worked for 5 years at Chip Ganassi Racing (NASCAR program)
  - Vehicle Dynamics Group Leader
    - Simulation
    - Software
    - 7 Post Testing
  - Performance Group Manager
    - Add Aerodynamics
- Started at Claytex in February of 2017
  - Start up the US office

DYMOLA - DYnamic MOdelling LAboratory

…is a component-based tool for modelling and simulation

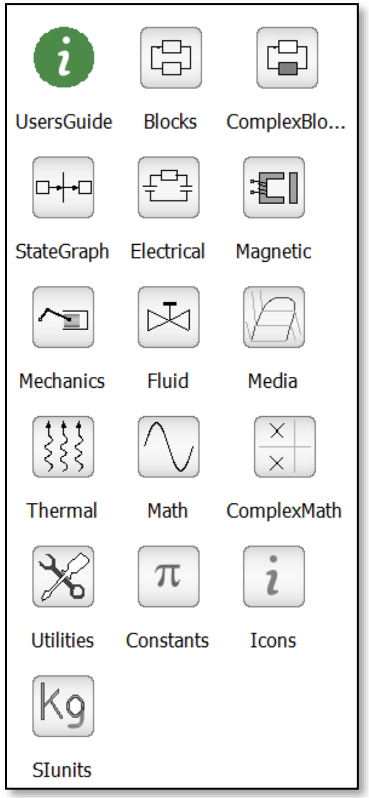


Dymola

Modelica…

Purpose-built modeling language for modeling physical systems interactions of all types.

Modelica Association



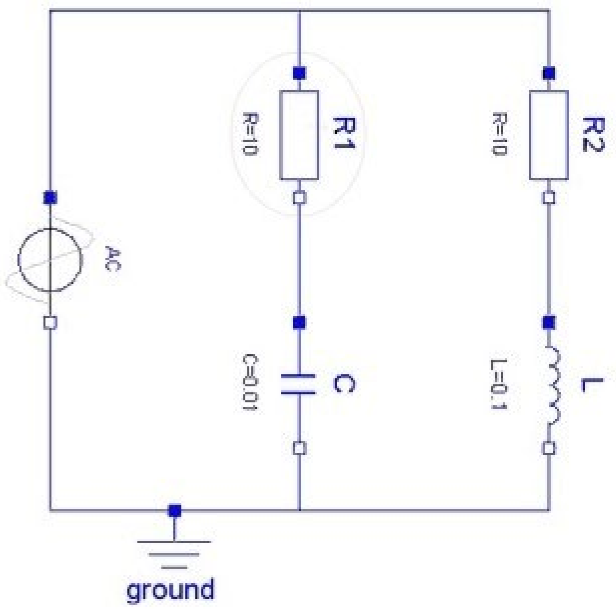

```
encapsulated model Enginel
  import ModelicaAdditions.MultiBody.CutJoints;
  import ModelicaAdditions.MultiBody.Parts;
  import ModelicaAdditions.MultiBody.Examples.Loops.Utilities;

  extends Utilities.Engine;
  Parts.ShapeBody rodBody(
    r={L,0,0},
    rCM={L/2,0,0},
    m=0.5,
    I33=0.0018,
    Width=0.02,
    Height=0.01) annotation (extent=[4, 20; -16, 40]);
  CutJoints.ConnectingRod2 rod(
    L=L,
    na={0,0,1},
    r_rela(start={-0.2,0,0}, each fixed=false))
    annotation (extent=[20, 0; 0, 20]);
equation
  connect(crank.frame_b, rod.frame_b) annotation (points=[-17.5, 10;
  connect(rod.frame_a, cyl.frame_b)
    annotation (points=[20.5, 10; 70, 10; 70, -70; 60.5, -70]);
  connect(rod.frame_c, rodBody.frame_a)
    annotation (points=[12.1, 12.1; 12, 30; 4.5, 30]);
  annotation (Documentation(info="Use the following settings:
experiment StopTime=0.2 Interval=0.002 Tolerance=1.E-8
Perform 'simulate' and then see animation in
Animation window.
  Plot the following variables:
  AngVelDegS: Angular velocity of motor shaft [rev/min]
  x         : position of cylinder [m]
  press     : pressure in cylinder [bar]
"),
       Commands(file="Enginel.mos" "Simulate and plot x and V"));
end Enginel;
```

Dymola and Modelica - Symbolic Math Engine

- The model equations are automatically transformed into the required form for simulation
- Advanced mathematical techniques are used to reduce the size of the problem without removing detail from the model
- Pre and post translation model statistics are provided to aide the developer in understanding the model complexity

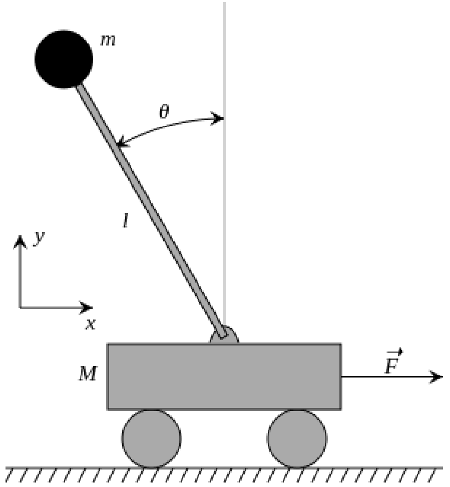
Dymola and Modelica - Symbolic Manipulation

DAE:



Dymola and Modelica - Symbolic Manipulation

What does this mean in practice?



- An Inverted Pendulum contains 659 equations
  - Using the Modelica modelling approach these are formed as a DAE
- Symbolic manipulation automatically reduces this to:
  - 7 continuous time states
  - 92 other time varying quantities
    - Including 1 linear system, originally containing 14 equations but reduced to a system containing just 2 equations
  - All the other equations relate to constants or variables that are exactly equal to these 99 variables
- Advantages of Symbolic Manipulation
  - Automate the often error prone process of rearranging equations into a solution
  - Apply advanced mathematical techniques to reduce the size of the problem
  - Can deliver real-time simulation performance of Vehicle Dynamics models with over 100,000 equations (1ms time step)

Dymola and Modelica - Post - Symbolic Manipulation

- The resulting simulation model is automatically exported as C code
- By default, this C code is compiled into an executable
- The user can choose to do other things with this code
  - *.fmu
  - *.dll
  - *.so
  - *.s19

Dymola and Modelica - Licensing and Deployment

- There are 3 Dymola licensing levels:
  - **Standard Configuration** - resulting binaries can only be run on machines with a valid Dymola license
  - **Binary Model Export** - resulting binaries can be run license free on any machine
  - **Source Code Export** - resulting C-code can be compiled into whatever the user desires… and run license-free on whatever target

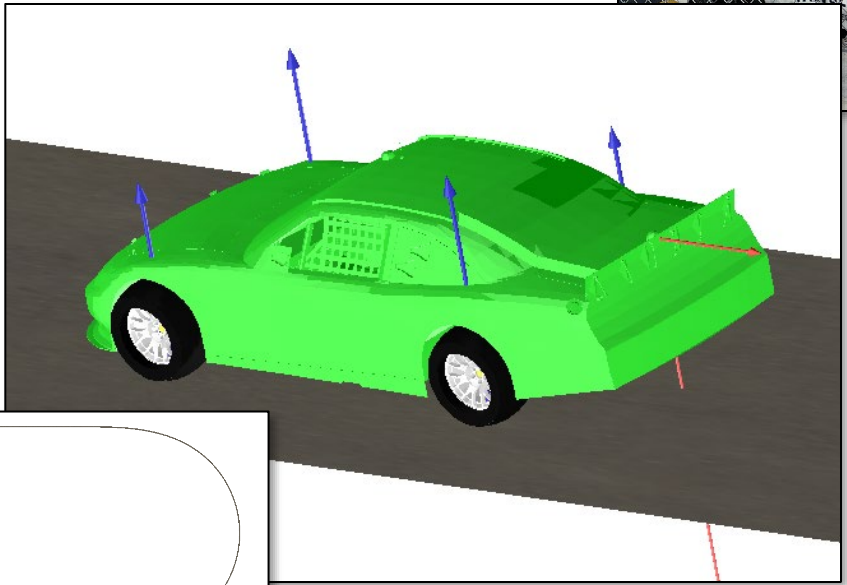
Virtual Twin - User Base

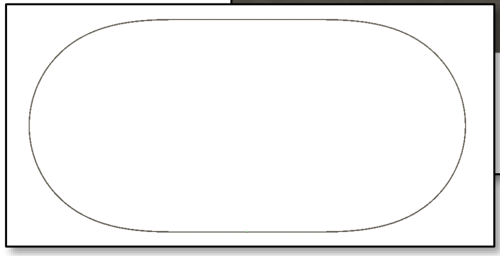
- Race Engineers
- Performance Engineers
- Engineering Managers
- Mechanics
- Quality Control Technicians
- Marketing Personnel?
- Sponsor Relations?
- Motorsport Fans?

- Optimize / adjust setups (during)
- Optimize setup (pre-event)
- Analyze development targets
- Streamline car build
- Verify components
- Attract sponsors / fans
- Sponsor Employee Engagement?
- Immersive fan experience?

Virtual Twins In Motorsport

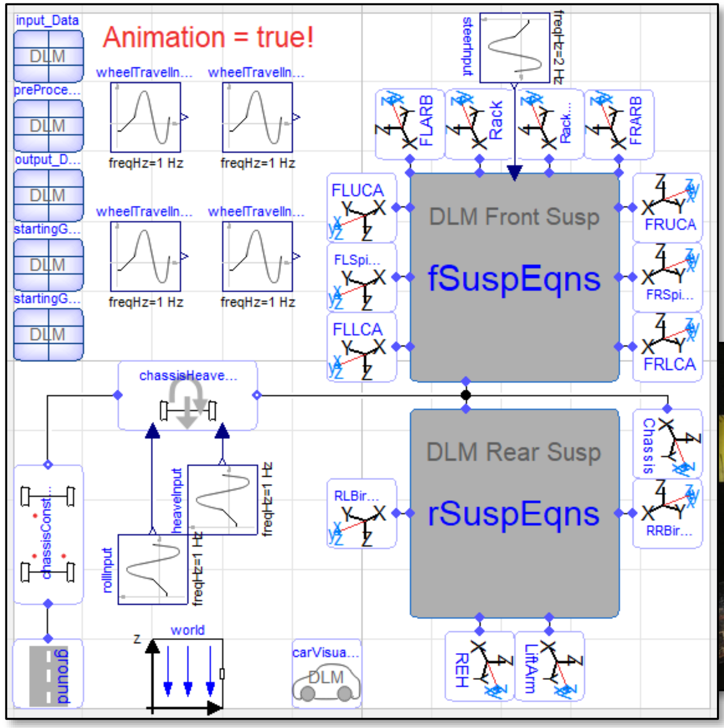
- Used in various applications
  - Kinematic Assembly
  - Setup Events
  - Mass Check
  - Pulldown Rig
  - 7 Post
  - Quasi Static
  - Lap Simulation
  - Static Platform (DiL)
  - Full Motion Platform DiL

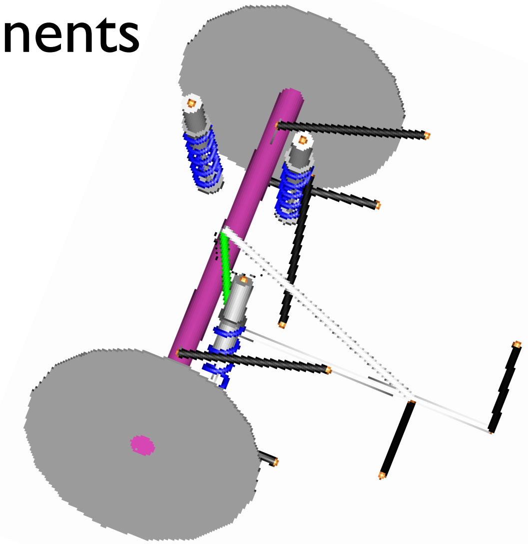


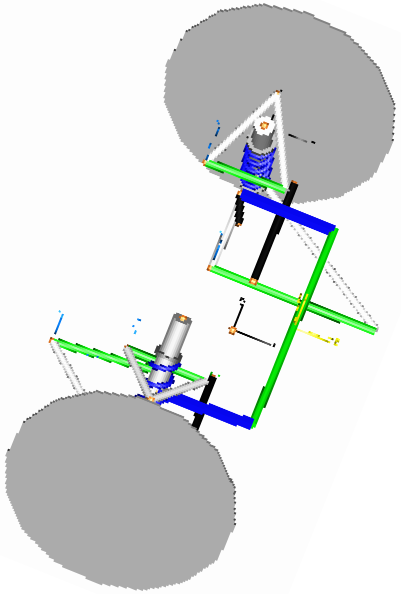


Virtual Twins In Motorsport - Kinematic Assembly

- Algebraic model to assemble components
  - Inputs in local part coordinates
  - Outputs in vehicle coordinates

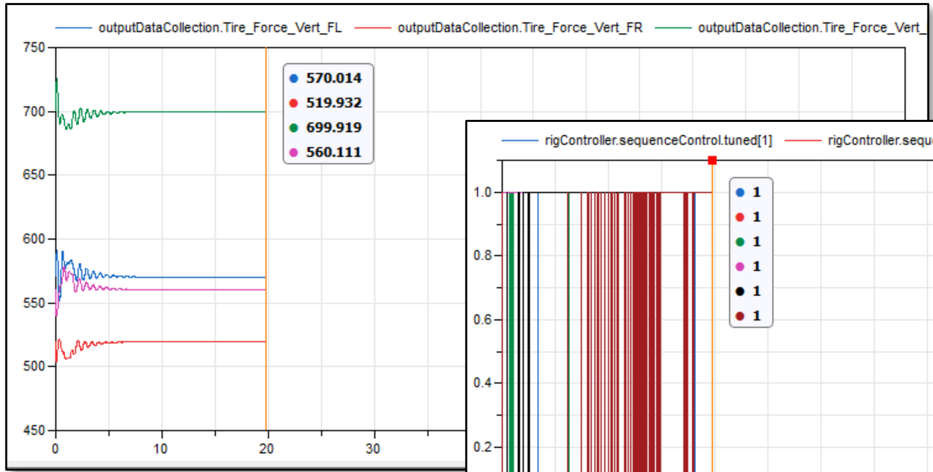


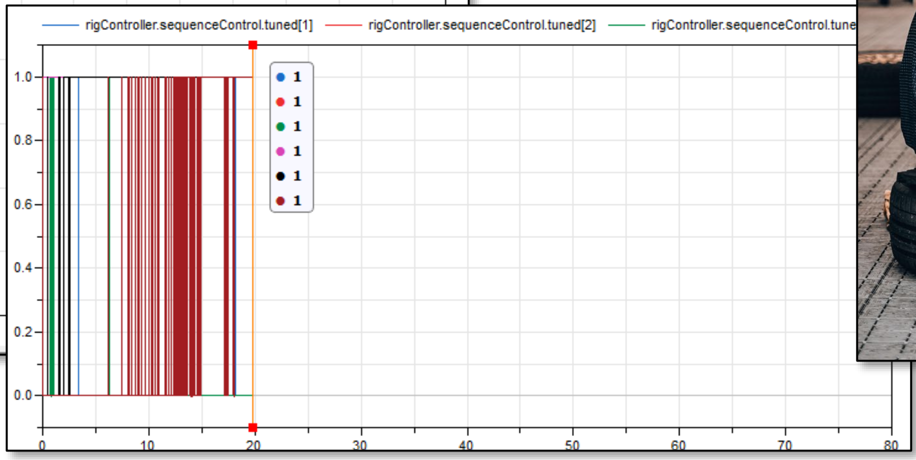


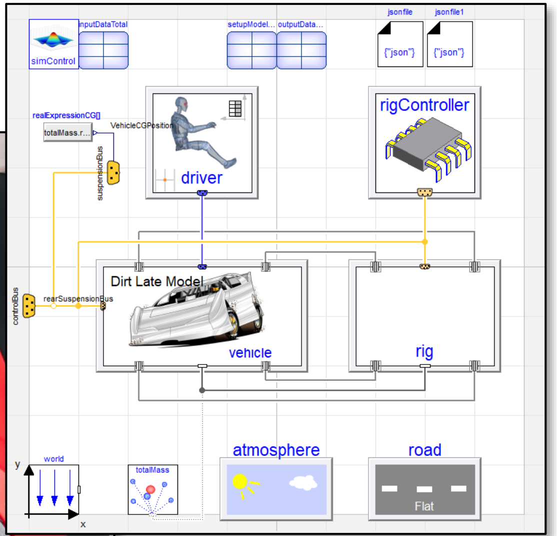


Virtual Twins In Motorsport - Setup Event

- Closed loop adjustment simulation
  - Adjusts camber shims (camber angles)
  - Adjusts tierod lengths (toe angles)
  - Adjusts body CG x and y position (front and left side weight %)
  - Adjusts spring preloads (ride height and cross weight %)
  - Adjusts ARB droplink length (ARB preload)

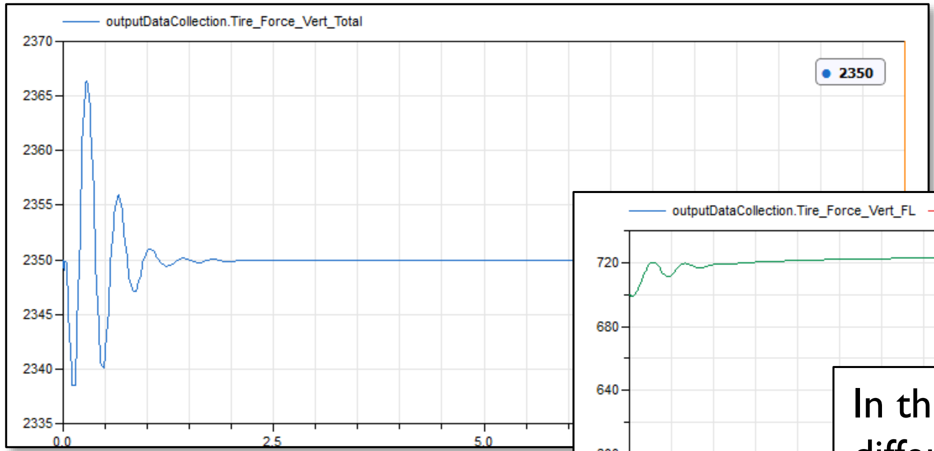


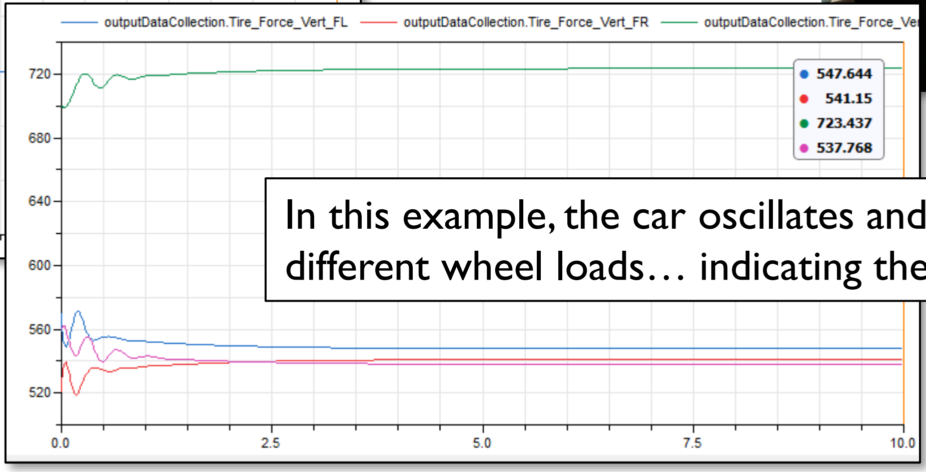




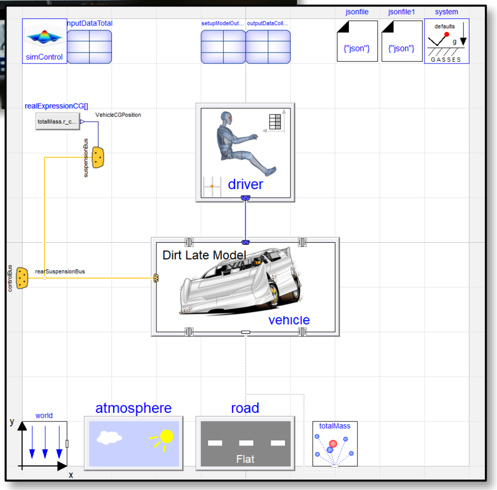
Virtual Twins In Motorsport - Mass Check

- Simple simulation to check the results of a Setup sim
  - If adjustments are properly applied to car it will remain static for the entire sim… if there are errors in transferring data across the car will oscillate



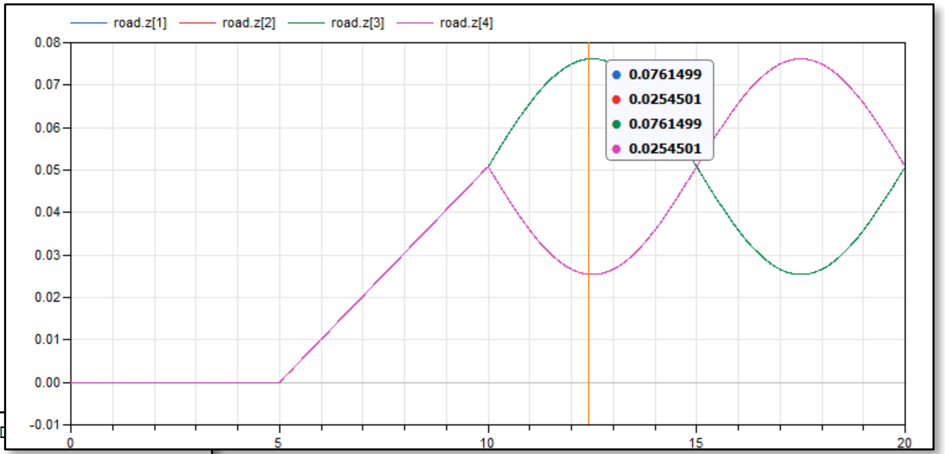


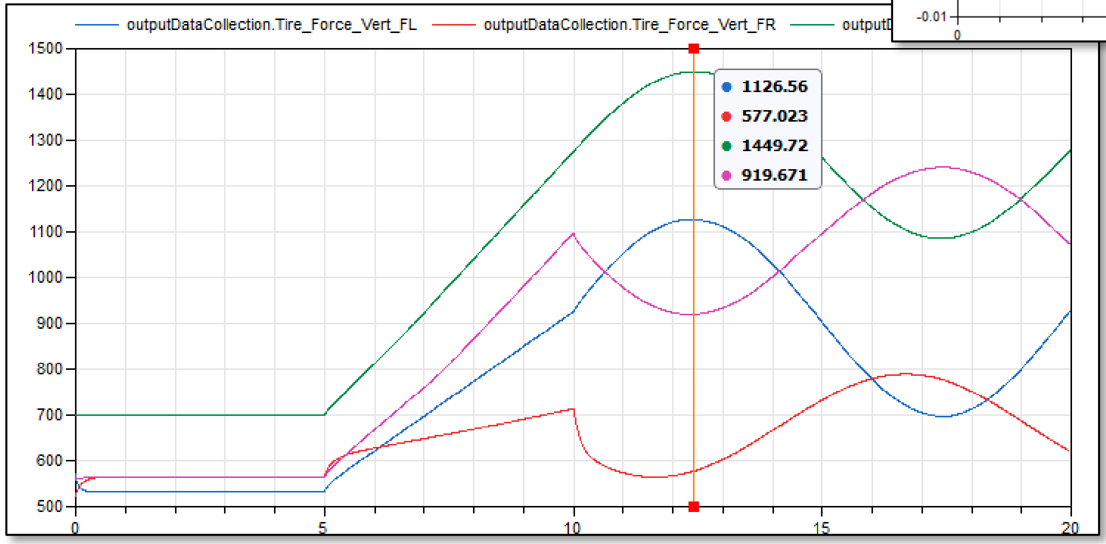
In this example, the car oscillates and settles with different wheel loads… indicating there is an issue

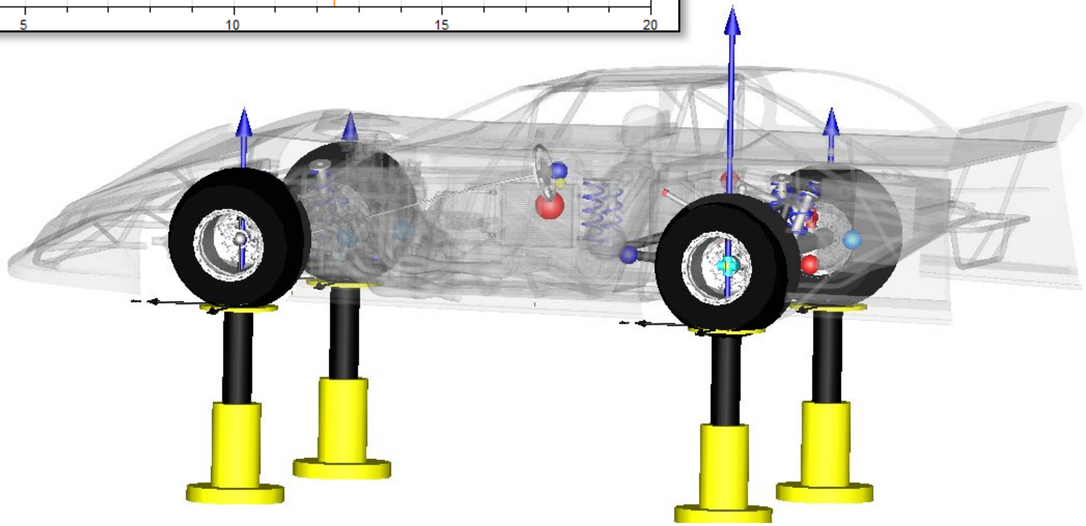


Virtual Twins In Motorsport - Pulldown Rig

- Pulldown rig ('pushup rig')
  - General low frequency analysis
  - Wheel rates
  - Roll rates
  - Camber gain
  - Damper to wheel motion ratios

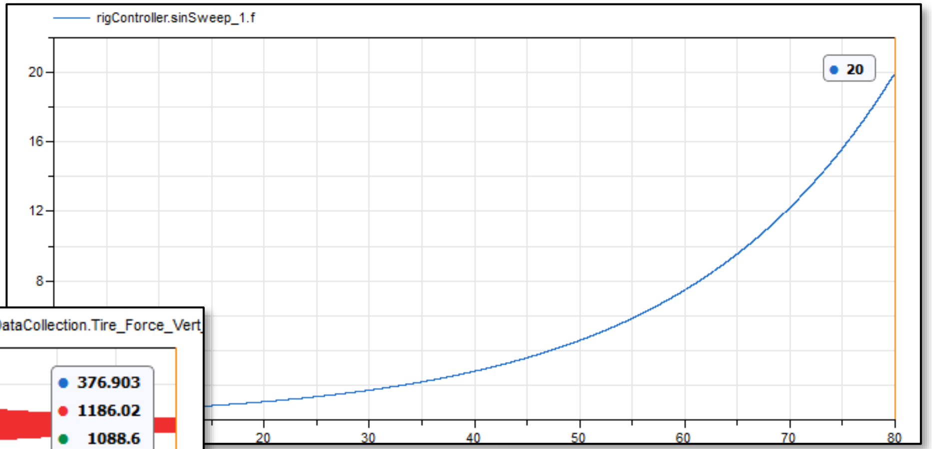


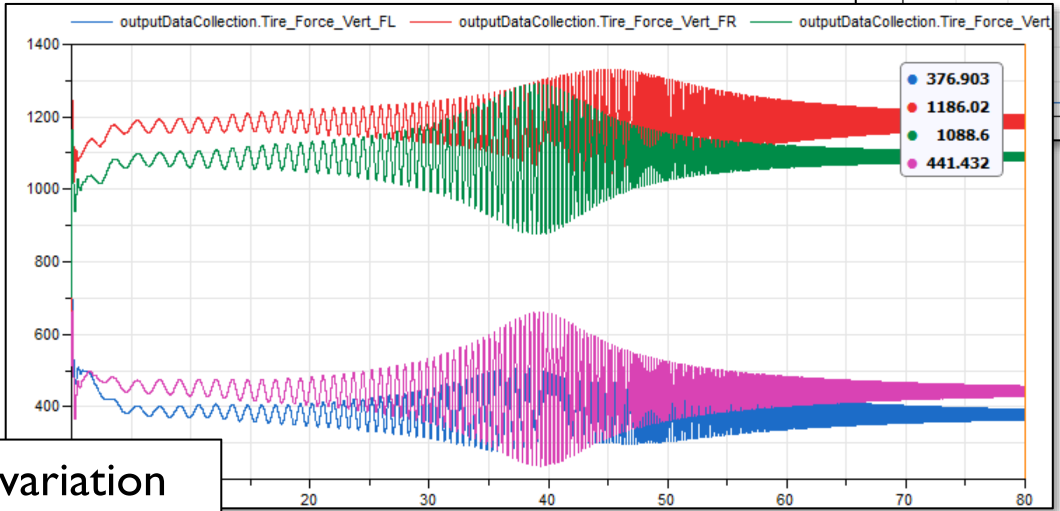


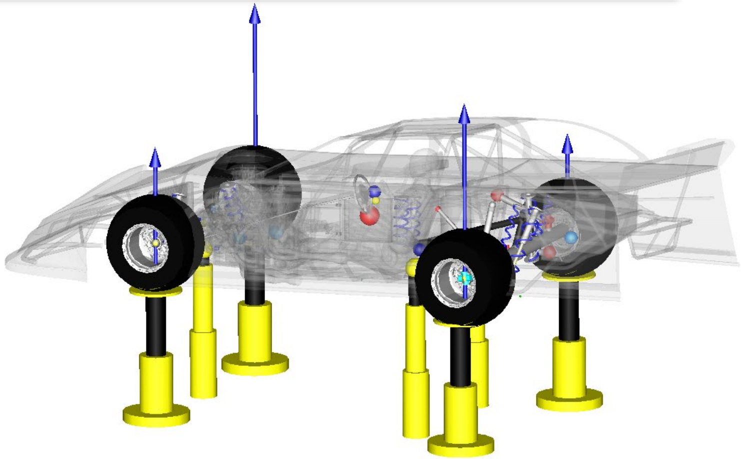


Virtual Twins In Motorsport - 7 Post Swept Sine

- Modal analysis on a 7-post rig
  - Extract Body modes
    - Heave
    - Pitch
    - Roll
    - Other?





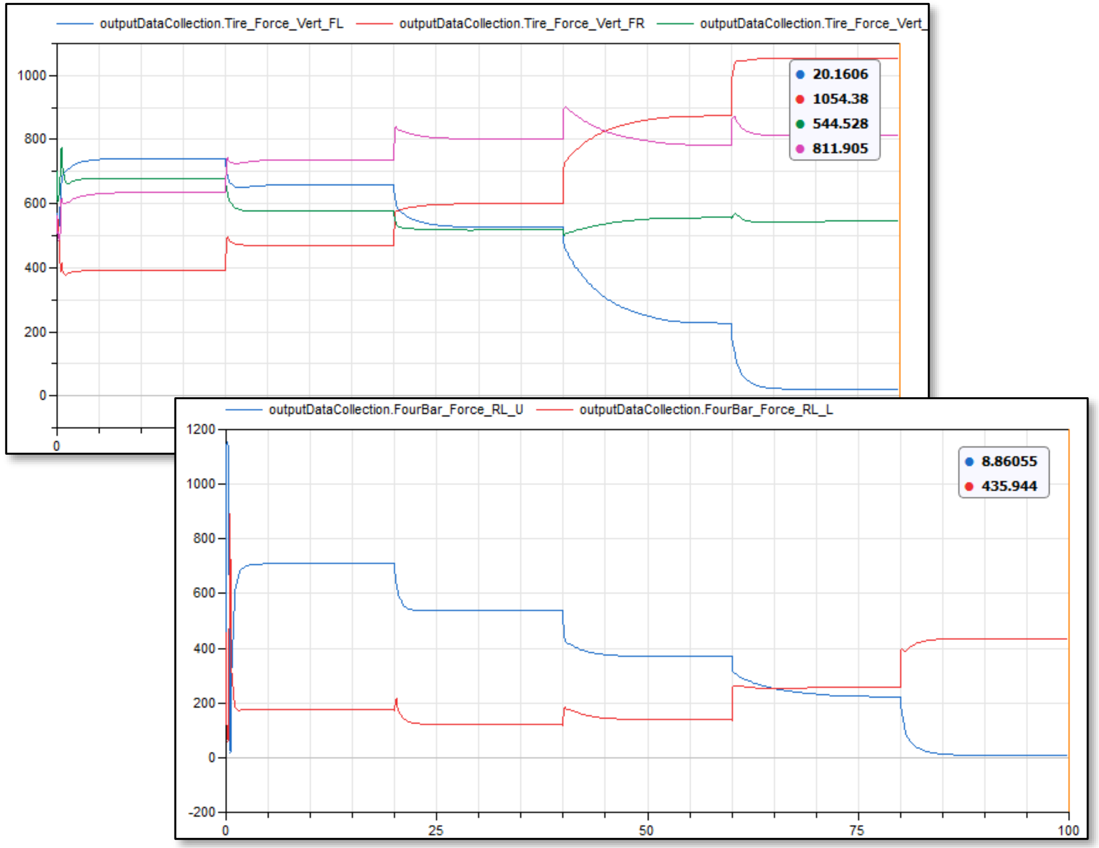


Tire vertical load variation

- Optimize Damping

Virtual Twins In Motorsport - Quasi Static

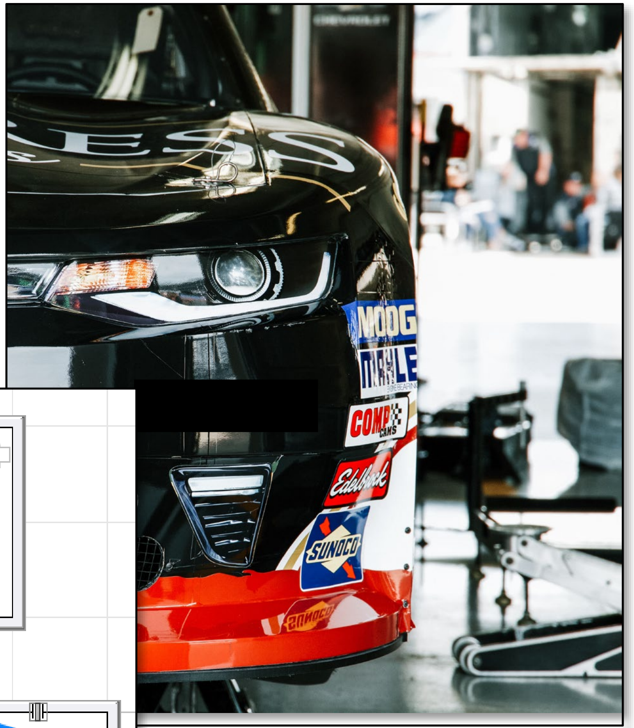
- Single State target… divided up into 5 steps
  - Note that the upper 'four bar' load is approaching zero at this point on the track

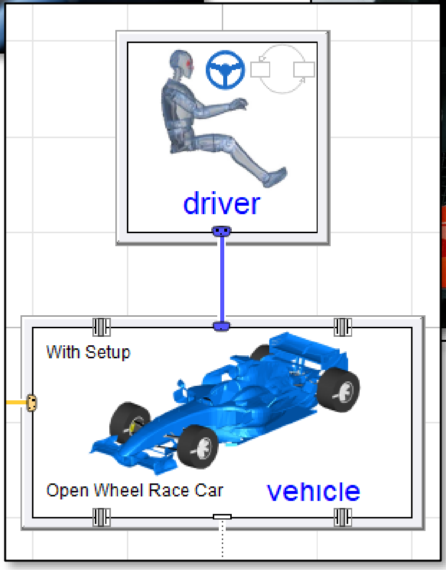


Virtual Twins In Motorsport - Lap Simulation

- Virtual Twin of the Driver
- Virtual Twin of the Vehicle

- Lap Simulations can be conducted in many ways
  - Fixed Line and Speed
  - Fixed line / variable speed
  - Variable line / variable speed





Virtual Twins In Motorsport - Static Simulator

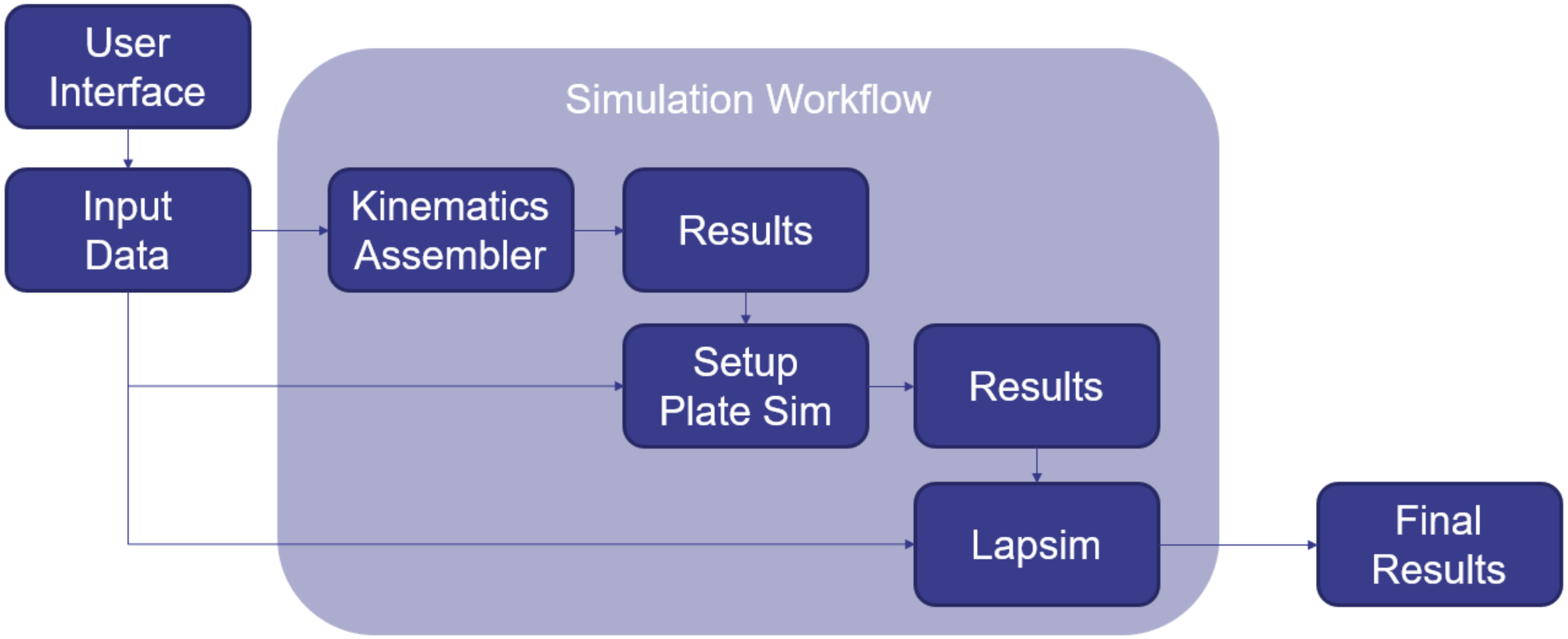
- Driver in the Loop (DiL)
- Static platform

Virtual Twins In Motorsport - Driving Simulator

- Full motion platform driving simulator

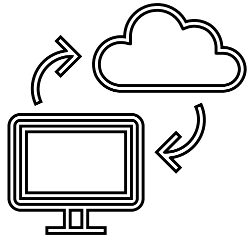
Motorsport Simulations - Workflow

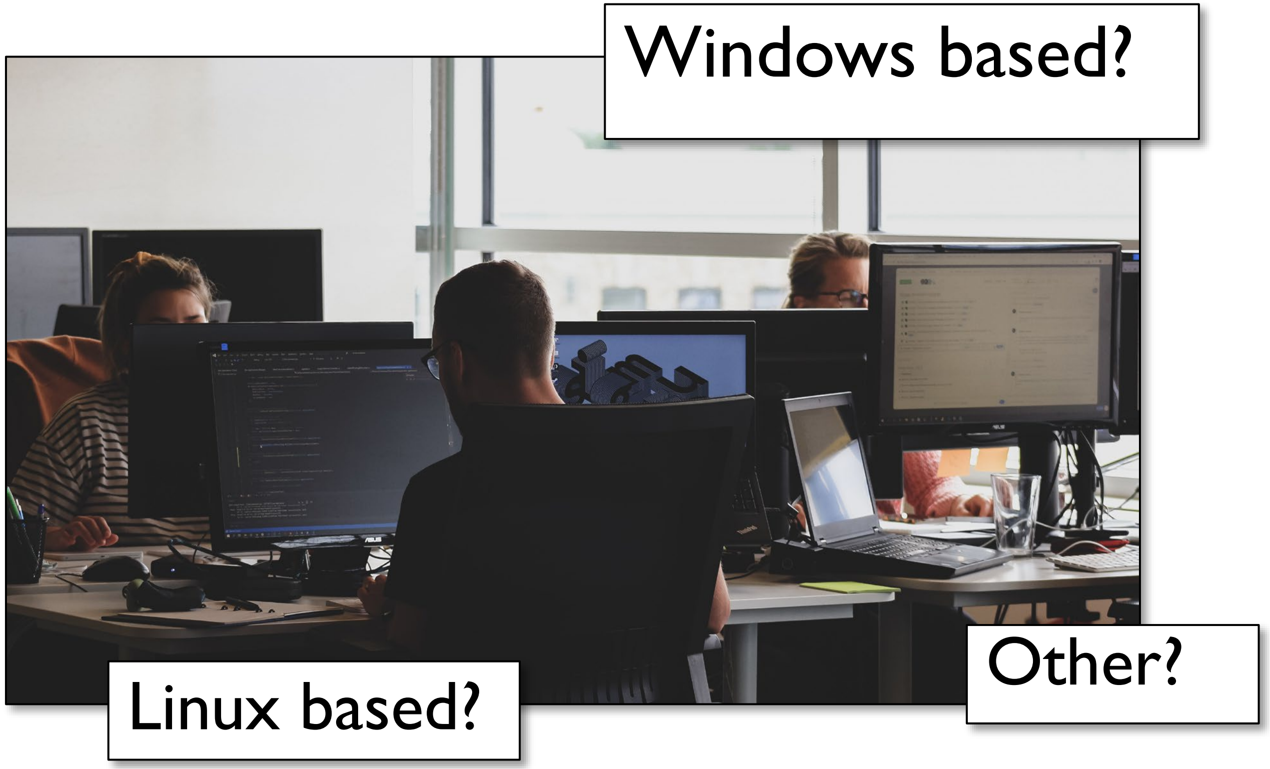
- Representative workflow for a Motorsport application



Virtual Twins In Motorsport - Workflow Deployment

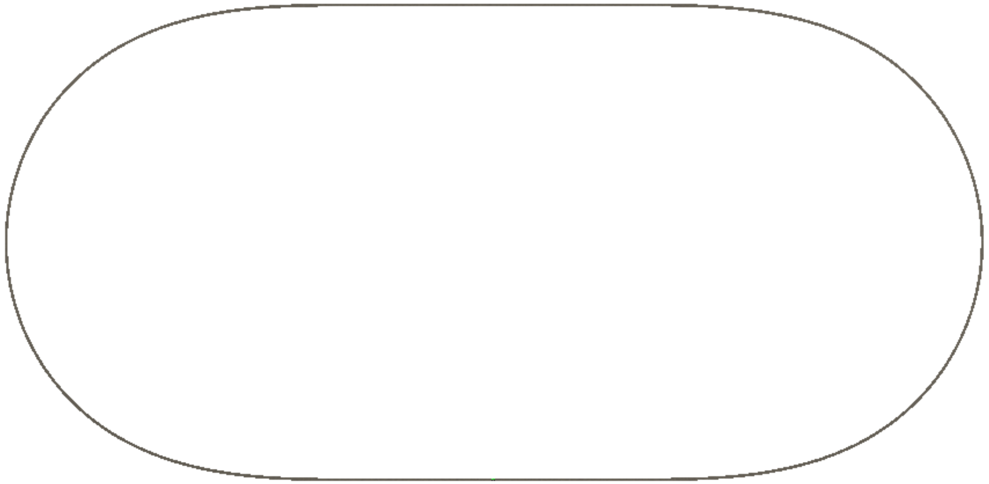
- Local
  - Machine
  - Server
  - Distributed Computing
- Remote
  - Server
  - Distributed Computing
- Cloud
  - Server
  - Serverless





Developments in Lap-time Predictive Simulations

- Challenges
  - Battery state of charge
  - Thermal state of various components
    - Tires
    - Batteries
    - Driveline
- Optimal Control approach to lap time predictive simulations



Summary

- There are a many types of Virtual Twins utilized in Motorsports
- To get useful results, multiple simulations are often necessary and thus a workflow with multiple Virtual Twins are required
- There are many different types of Virtual Twin users
- There are numerous platforms on which these Virtual Twins are used
- Advances in cloud computing have changed the way race teams prepare for events
- Optimal Control strategies can provide highly valuable information when applied to accurate Virtual Twins

COMMUNITY OF EXPERTS
OF DASSAULT SYSTÈMES SOLUTIONS

Founding Partner
DASSAULT SYSTEMES

Questions?