Multidisciplinary Design Exploration in Ground Vehicle Design

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Our Purpose

CD-adapco’s purpose is to facilitate innovation and to lower product development costs through the application of **multidisciplinary engineering simulation** and **design space exploration**.
CD-adapco’s purpose is to facilitate innovation and to lower product development costs through the application of multidisciplinary simulation and design space exploration.
Discover Better Designs, *Faster*

Virtual Prototype
(CAD - CAE – Costing Simulations)

- **Virtual Tests**
- **Design Variables**
- **Responses**
- **Design Modifications**

- **Build**
- **Test**
- **Improve**
- **Assess**

- **Process Automation**
- **Scalable Computation**
- **Efficient Exploration**
- **Sensitivity & Robustness**

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US Supertruck Program

Challenge
- Heavy duty vehicles constitute largest or second largest source of transport-sector carbon emissions.
- 2020 goals need to be developed during 2014-2015.
- DOE SuperTruck program cost-shared public/private for improving performance.
- Goal: Relative to 2010 technology:
  - 50% increase in freight efficiency
  - Timeline: 5 years to develop a new truck

Solution
- 1D & 3D Simulation used to test new concepts
  - 20% improvement on PowerTrain
  - 30% on Tractor/Trailer
- Scaled models, and subsystem testing done initially

Impact
- After 4 years, first physical prototype built.
- 50% BTE was achieved on the first prototype
Areas of Improvements

- Engine Downsizing
  - Increase compression ratio
- Optimize Piston Bowl
- Optimize ICE
- Decrease pressure loss: EGR recirculation
- Decrease friction losses
  - Oil type/Oil cooling
- Waste Heat Recovery (WHR)
- Improved turbocharger efficiency
- Reduced power coolant/fuel pumps
- Reduced friction gear train
- Improved aftertreatment system
Improving Powertrain Efficiency

- Optimization for Powertrain Applications
  - Webinar: December 2014
  - Piston Bowl Optimization
  - Port Flow Optimization
    - Adjoint/Heeds

- System Co-Simulation Analysis of Engine CHT & A Transient Oil Splash
  - SGC 2014: Jeff Schlautman, GM
  - Downsizing, and higher compression ratio have high impact on design
  - Simulation used to find better design, faster

- Meeting Future Emission Standards with Advanced Engine Simulation
  - 2013 webinar
  - Presented Piston Cooling Simulation
Customer Success: 
Piston Bowl Optimization

- **Challenge:**
  - Optimize shape of piston bowl and injection strategy to improve performance of DI Diesel Engine for performance and emissions

- **HEEDS Results:**

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<th>Parameters</th>
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- CATIA – updates CAD design
- Python – used to create screenshot of design generated in CATIA
- STAR-CCM+ - creates surface mesh
- es-ice – generates a moving computational mesh suitable for ICE applications
- pro-STAR – defines the physical set-up of the model
- STAR – solver that provides performance metrics
Discover Better Designs, Faster

- Design Space Exploration
  - Process Automation (Automate building of virtual prototype)
  - Scalable Computation (Accelerate testing of virtual prototype)
  - Design Optimization (Discover best design alternatives)
  - Sensitivity & Robustness (Ensure reliable product performance)

GEOMETRIC DESIGN
Auto-meshing
Simulation
Analysis

Optimized Design

1% increase in pump head
6.2% reduction in power

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In Vehicle PowerTrain Simulation

- Couple to 1D codes
  - GT Power, AMESIM, KULI, WAVE ...
- Direct CAD Export of PowerTrain
  - Full CHT model of engine, including gasket, and pressed fit inserts
- Surface of vehicle supplied by vehicle group (no CHT)
- Multi-Fluid Stream
  - Air Flow around Vehicle
  - Induction Air Flow
  - Exhaust Air Flow
  - Coolant Stream
  - Oil Flow Inside Engine
- Simulation
  - Steady State
  - Soak Study
  - Drive Cycle
Exhaust System Simulation

Key Components of Exhaust Simulation

**SCR**
- Included with nearly every diesel engine to improve emission
- Urea Spray mixing important
- Crystallization prediction important for long term performance

**DPF**
- Particle emission from diesels have been an issue
- Starting to be more common used with SCR system

**Catalysts**
- Important to have uniform flow for maximum performance
- Short catalysts light off timing important during heat up
  - Solution: Exhaust CHT to predict catalyst light off

**Turbochargers**
- Engine down sizing to improve mileage. Turbochargers help increase performance for small engines
- Water cooled turbochargers are at risk of boiling. Can cause lubrication failure

**EGR Cooler**
- Cooled EGR lowers NOx

**Waste Heat Recovery System**
- Looking at running exhaust gas around coolant to reduce engine warm up time. Want to minimize pressure loss in system while reducing warm up time. Important also with Hybrid Vehicles
  - Solution: Full CHT of Heat Recover System

**Oxygen Sensor/Catalyst Utilization and Exhaust Sensors**
- Location for best reading

**Webinar: March 31st**
Numerical Investigations of Deposit Formation in SCR systems
US Supertruck: Vehicle Freight Efficiency

Areas of Improvements

- **Optimized drive cycles**
  - Inertia and braking energy
- **Aerodynamics Improvements**
  - 16% improvement on aerodynamics with half coming from trailer
- **Weight Reduction**
- **Low-rolling resistance tires**
Vehicle Optimization: Morphing

- Control Points Definition
  - V9.06 includes tool to help define control points

- Morphing
  - Morphs Surface as well as volume.
  - Allows solution to continue from starting location

- Optimate
  - Conducts morphing study to determine surface sensitivities.
Vehicle Optimization: Multi Objective

Drive Conditions
- Highway speed, fan off
- Low speed, full engine power

Objectives
- Decrease drag
- Cool engine
- Reduce size of heat exchanger core

Variables
- Shroud design
- Grill/Bumper Openings
- Heat Exchanger core size

Looking to minimize energy used by vehicle
Vehicle Optimization: Adjoint

Adjoint Process
- Primal solution is the standard CFD aerodynamic calculation.
- Adjoint flow backs of flow sensitivity to the drag cost function.
- Mesh sensitivity calculates the sensitivity of the mesh to the cost function.
- Adjoint of the morpher helps create surface sensitivity from the solution.
- Can take sensitivity, feed directly into the morpher to move the surface.
  — Drag has been reduced!

V9.06 Improve stability allows adjoint for both trimmed and Polyhedral Grids
**Challenge:**
- Optimize British Touring Car set-up and driver strategy for optimal lap time performance at Gaudix circuit in Southern Spain
  - Minimize lap time
  - Minimize driver effort
- By modifying:
  - 39 suspension and driving parameters
- Through:
  - 5 load cases (static and dynamic), VI-Car RT

### HEEDS Results:
- Dramatic reduction in lap time from baseline
- Use curbs in first half of lap; avoid them after
- 4 pole positions, twelve 1st or 2nd place finishes
Digital Prototype becomes enabler for advance simulation

- Simulation for more advance analysis then just component design
- Simulation includes multi-physics.
- Simulation can involve motion as needed as well. Whatever best helps engineer design their product efficiently.
- In the past, these would not have been possible until hardware of the vehicle has been produced.
Key Technology Enablers

- Advanced Technology focus on MDX
  - Parts Based Meshing
  - Overset Grids
  - Co-Simulation
  - VOF <-> Wall Film <-> Lagrangian
  - Dispersed Multi-Phase
  - Eulerian Multiphase, Large Scale Interface

- Fall 2014 webinar concentrated on simulating systems from Mercedes-Benz
Vehicle Thermal Management Approach

Co-Simulation of a transient Solid Model (conduction and radiation) with a steady state Fluid Model (convection)

Solid Model (STAR-CCM+)

Detailed modelling of 4821 parts and 151 material properties.

Prediction of the heat transfer mechanisms taking place inside the vehicle structure based on the heat released inside the combustion chamber.
Transient Simulation vs. Measurement

Replicated Up-hill Drive

Temperature prediction of the turbocharger housing

*Referenced Temperature: $\Delta T = T - T_{test\_initial}$
Motion and Motion Modeling

- **Dispersed Multiphase (DMP)**
  - Lowers computational effort for modelling high droplet accounts during rain simulation

- **Overset Mesh**
  - Enabling complex motion of wiper on the curved glass surface
    - Full support for overset mesh with fluid film

- **Wall Film -> VOF**
  - Enable simulation of rain cutter filling with water.

**Water & Dirt Management**
Hybrid approach dramatically reduces computational cost & mesh count

Opens up applications that were not previously practical

VOF-Fluid Film phase interaction model locally chooses the most suitable model for the local flow regime and compute resources available

Applications
- Crankcase & gearbox sloshing
- Part dipping/coating
- Rainwater management
- Dishwashers

Part immersed in VOF bath
Picks up Fluid Film coating on leaving the bath
LMP droplets drip back into the VOF bath
Simulation took 12 hours on 10 cores
Aero-Vibro-Acoustics Simulation

Features
- Accurate predictions of pressure fluctuations on exterior
- Transmission of waves into the interior

Key Acoustic Applications
- Aero-Vibroacoustics
- Exhaust System
- HVAC Ducts
- Fans/Pumps
- Heavy equipment enclosure
- Lawn mower blade noise

Acoustic webinar: May 12th
Multidisciplinary Design Exploration in Ground Vehicle Design

- Impacting design today
- Environment of STAR-CCM+ leads to automation. Automation helps further reduce turn-around time, and allow engineers to concentrate on design.
- Focus on bringing in advanced physics to simulate reality

Development team still placing new features to help existing clients

- Overset Grids: Ease for grid motion
- Water Film model: Improved soiling
  - VOF -> Wall Film important
- Vibro Acoustics: noise inside the vehicle
- Optimization: design exploration to find better designs, faster
Thank You