Multi-Physics Simulation of Race Car Aerodynamics

Dr Abdel Fiala

July 7th, 2015
Introduction

AcuSolve and HyperWorks capabilities

- Transient solver
- Mesh Motion
- Fluid-Structure Interaction (FSI)
- Optimisation
- CFD-MBD coupling
- Tyre effect

Some example cases

Conclusion
Introduction

• **Objective of presentation**

  - An appetiser
  - Describe key HyperWorks technologies applicable to racecar aero
  - Illustrative examples of these key technologies
  - Some example cases applied to racecar.
Introduction

• **Classical aerodynamics simulation & design**
  - Mostly steady-state
  - Incremental design iterations is the norm, however long and repetitive
  - A wide range of freestream and car configurations => **Aero map**

• **Advanced / Next-generation aerodynamics simulation**
  - Optimisation becomes a necessity
  - Full transient simulations of important track sequences
  - Coupling between aerodynamics, dynamics and tyres
    - Dynamics; ride height, pitch, roll, yaw, steer
    - Tyres; shape, deformation, ground contact patch
  - Coupling between fluid and structure.
AcuSolve/HyperWorks

Key Technologies
AcuSolve – Transient Solver Capability

- AcuSolve core solver is independent of element quality, it only requires positive Jacobian elements.
- Accuracy is dependent on node resolution and distribution
- Main competition solvers require good element/cell quality which is crucial for stability, convergence and accuracy.
AcuSolve – Transient Solver Capability

- AcuSolve has a fast and unconditionally stable 2nd order implicit transient solver; No CFL stability condition
- Timestep size only constrained by time scales present in the flow
- Inherently unsteady problems on complex geometries, changing configurations, and complex physics become more easily accessible, including high fidelity turbulence (DES/LES)
**AcuSolve – Mesh Motion**

- **Powerful & versatile mesh motion capability**
  - User-Specified mesh motion: very fast computationally
  - Interpolated mesh motion: very fast computationally
  - Arbitrary Lagrangian-Eulerian (ALE) mesh motion using hyper-elasticity equation
  - Non-conformal mesh sliding interfaces

- **All technologies can be combined.**
**AcuSolve – Mesh Motion**

- **AcuSolve** is very robust with complex mesh motions and potential deterioration of element quality

- Mesh motion is pushed much further in AcuSolve compared to FVM-based technology, which is highly dependent on cell quality

- This is crucial for advanced transient simulations where geometry can move/deform due to significant aerodynamic effects.
Multi-Physics : Fluid-Structure Interaction

- AcuSolve incorporates a fast “Practical” FSI solver (P-FSI), based on modal analysis (conducted in a structural solver)

- ~50 to 100% increase in runtime vs fluid-only simulation (ALE approach)

- P-FSI is valid for small and linear structural displacements

- FSI can be critical for highly flexible devices on a racecar, e.g., front or rear wings, floor.
Multi-Physics: Parametric Optimisation (DOE)

- AcuSolve can be coupled with HyperStudy for parametric optimisation or Design of Experiments (DoE)

- The model mesh is morphed part of the problem spec where the user specifies the parameters of change and key results to be evaluated.

- Ideal for repetitive procedures with small incremental design changes.
Multi-Physics : Parametric Optimisation

- AcuSolve built-in design optimisation
- Post v14.0.
Multi-Physics : CFD-MBD Coupling

- A racecar is a complex machine where its aerodynamics and dynamics are highly coupled:
  - Continuous change in ride height, pitch, yaw, roll, and steer
  - Dynamic DRS evaluation of its effect on aerodynamics
Multi-Physics : CFD-MBD Coupling

- AcuSolve CFD solver with MotionSolve MBD solver can be used to simulate the coupled effect in one co-simulation
- AcuSolve-MotionSolve communication via code coupling interface
- Suitable for complex interactions; not possible with AcuSolve’s internal 6-DOF solver
- Currently rigid bodies only.
Multi-Physics : MBD-Tyre Dynamics Coupling

- FTire coupled with MotionSolve MBD to resolve full vehicle dynamics including tyre behaviour on a specific road layout,

- Future: Feedback tyre deformation to AcuSolve to account for its aerodynamic effect.
Example Cases

1. Simulation of a Racecar Cornering Sequence
Problem Description – Transient Cornering Sequence

• Simulation of flow around an open-wheel racecar through a simplified corner sequence.
  - Deceleration as the vehicle approaches the corner
  - Constant velocity during cornering with yaw only
  - Acceleration out of the corner

• Proof of concept that can be modified for more realistic racecar model with pre-defined conditions.
Problem Description – Boundary Conditions

- Far Field
  - Top modelled as Slip
  - Ground velocity is a function of vehicle speed

- Mesh Motion – Ten degree yaw

- Nodal velocity prescribed on wheels
Problem Description – Mesh

- Number of nodes/elements: 9.1M / 51.4M respectively
Problem Description – Mesh Motion

- A fully specified mesh was defined (less computational time vs ALE)
- The mesh motion is defined at the center of the vehicle
  - At radius $0 \leq r \leq 10m$; the motion is constant
  - At $10 < r \leq 40m$; the motion is scaled linearly as a function of distance
  - At $r > 40m$; the motion is reduced to 0.0
Results

- **DDES Turbulence**
  - Timestep size = 0.1ms;
  - 5500 timesteps (0.55 seconds)
Results

• Transient simulation was run on 144 cores of Intel Xeon E5649 2.53GHz
  
  □ Average timestep required 45 seconds of CPU time
  
  □ Total runtime ~ 71.5 hours for 5500 steps (~360K elements/core)

• For this case, overly resolved CFL (room to improve performance).
Summary – Transient Cornering Sequence

- Freestream condition and model configuration can be easily modified to reflect actual telemetry data.
Example Cases

2. Simulation of a Racecar DRS
Problem Description

- A transient simulation of a racecar rear wing DRS (Drag Reduction System) to obtain dynamic response
Example Cases

3. Simulation of an Elastic Rear Wing (P-FSI)
Simulation of an Elastic Rear Wing

- P-FSI analysis of a generic racecar rear wing
  - 20 & 100 Eigenmodes computed with OptiStruct

**Displacement of monitor point**

**Downforce for rigid and elastic**

4%
Example Cases

4. Simulation of Racecars Drafting
Simulation of Racecars Drafting

- Massively parallel application
- Largest model to date is open wheel racecar drafting simulation
- About 1 Billion elements
- Transient DDES.
Example Cases

5. Simulation of a Sedan Race Car

Aero + Break Cooling
AcuSolve for Aero + Thermal at GRM Australia

- **35M nodes / 195M elements**
  - Residual on mass conservation 0.0001 within 150 iterations; Drag in <50 iterations
    - Runtime 50 hours on 16 cores
    - Workstation with 2 Intel Sandybridge Xeon

Suspension surface mesh
AcuSolve for Aero + Thermal at GRM Australia

• Brake modelling resulted in improved performance;

  “ 7 percent increase in air mass flow rate, which translated to average brake temperatures dropping 27°C and a reduction of peak temperature observed under intense braking of up to 60°C ”
• Example Rotating Disk with Brake Pad

• Thermal transient simulation showing heating of the rotor by the pad.
Conclusion

- Altair’s AcuSolve and HyperWorks product suite have many multi-physics capabilities

- Their applications to advanced external aerodynamics simulation of racecar were illustrated

- A number of example cases applied to racecars were shown

- Next generation simulation of racecars is multi-physics and multi-disciplinary based.
Questions?

Background Image courtesy of David Wilson Photography