

FRAUNHOFER INSTITUTE FOR ALGORITHMS
AND SCIENTIFIC COMPUTING SCAI

WHY FLUID-STRUCTURE-INTERACTION MODELS ARE SO IMPORTANT TO WIN THE NEXT RACE



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1985 – CFD Engineer at
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1999 – Chief Project
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Dr. Ulrich Schiefer has an extended and practical experience in aerodynamics, racing sports, and engineering services. He is an expert in technology, innovation, product management, complete vehicle integration, composites, aerodynamics and engine development.

Situation

With Formula 1 being one of the most popular motorsports on the globe, there is always high pressure to provide excellent performance as a way to retain existing and attract new audiences.

To keep the races fair, challenging and exciting, the governing body of F1 is constantly adjusting the technical regulations. Additional to regulations which try to influence the performance of the racing cars, FIA – the regulation authority – has to ensure that maximum safety is guaranteed and the team expenditures stay within a reasonable amount. Only on very rare occasions, Formula 1 seasons start with lower performance like, for example, slower lap times than the year before.

In the 2017 season, the regulations were altered to shift the focus from technical to driver performance compared to the previous years. For this reason, a decision was made to widen

the tires. This gives the race cars a more aggressive look, which is important for the media presence, but also causes more mechanical grip and asks for more driver performance as it pushes them to their physical limits.

Targets

Irrespective of the budget of a Formula 1 racing team, money and manpower are always short. Therefore, every team is constantly looking for opportunities to achieve the best performance while keeping investments as small as possible.

Performance on the race track is an essential requirement! Starting and finishing in the rear part of the field result in very limited media exposure. Hence, it is unattractive for the team sponsors who want to sell success via competitiveness.

Passing the finish line with a 1 meter lead is good enough to win the race. Putting the meter in relation to the overall distance makes clear how tiny the differences between contenders really are, when it comes to distinguish between winning and losing the race.

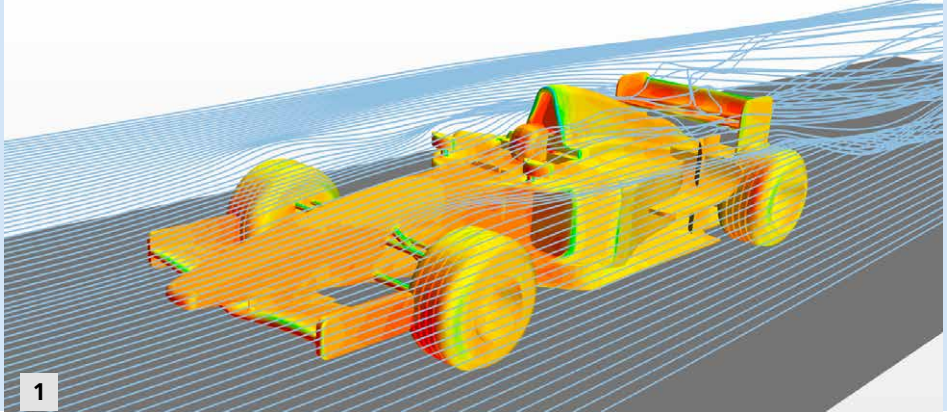
One meter in a 200 kilometer race – which is a typical distance for a Formula 1 race – typically means a difference of 0.0005 % of the overall race distance. And whenever the start lights swap to green, the battle for this meter begins.

1 VELOCITY FIELDS

Result of a CFD simulation of a Formula 1 racing car. Velocity magnitude plotted on car and symmetry plane.

2 PRESSURE FIELDS

Result of a CFD simulation of a Formula 1 racing car. Pressure plotted on car and symmetry plane.



1 STREAMLINES

Result of a CFD simulation of a Formula 1 racing car. Streamlines around and pressure contour on the car.

2 REAR SPOILER

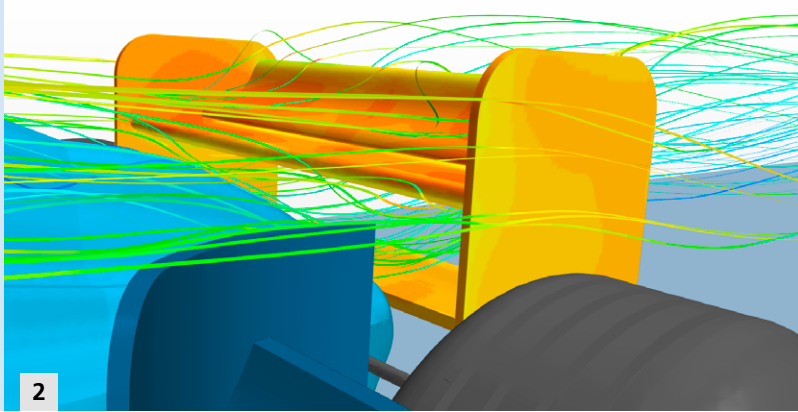
Close-up of rear spoiler (colored with pressure contour) and velocity-colored streamlines.

Technical Challenges

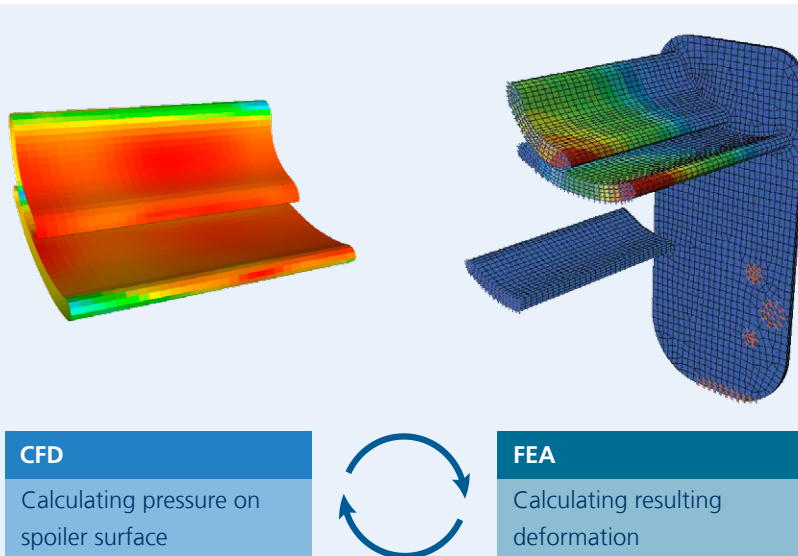
The importance of the different engineering aspects for the development of racing cars changed over time: in the past 20 years aerodynamics became more and more important. What led to this development?

FIA – the regulation authority – carefully constrained the design and layout of aerodynamic devices. This motivated the teams to heavily invest into this discipline. At the beginning, they built more and more sophisticated wind tunnels and then started to invest in simulation technology such as CFD and sensor technology to better understand the behavior of the car in real driving situation.

After starting with quite simple 2-dimensional simulations of the race car profile, CFD simulations became more detailed and complicated, leading to 3-dimensional simulations including vortices. This development has an impact on the layout of the components with a passive or active role in designing the aerodynamic flow pattern around the car: while the 2-dimensional approach just needs to make sure that aerodynamic pressures and the related forces do not bend or even destroy structures, the 3-dimensional approach focuses on the design and construction of vortex influencing structures.



These structures do not necessarily have to carry heavy aero-dynamical pressure loads on themselves, but still can be susceptible to a risk of fluttering because of transient aerodynamic effects. On the other hand, they have to protrude out of the base body in order to reach relevant parts of the flow field and quite often they have tiny cross sections to avoid a negative influence on the overall flow pattern.



3 AERODYNAMIC LOADS CAUSING STRUCTURAL STRESSES

Using coupled CFD and FEA for rear spoiler optimization.



1 FORMULA1 2017

Ferrari SF70H.

2 FORMULA1 2017

Mercedes F1 W08 EQ
Power+.

Digging for Winning Smallest Advantages

As the regulations are quite clear-cut in terms of limitations leading to a close competition, engineers are digging for the smallest advantages. This leads to taking interactions of CFD with other physical effects into account to get a complete understanding of all effects involved. These interactions can occur in different areas: for example, during the detailed simulation of boundary conditions, in particular on street level, the turbulence of the whole wind tunnel jet or the effect of hot air in certain areas of the vehicle surface.

The Discovery of Secondary Effects

One very important effect is the influence of an altering geometry under real driving conditions. We have seen several phases the industry went through. The first discovery phase can be described as *“getting rid of all the structural weaknesses”*.

These can be distinguished into

- critical safety issues,
- issues that complicate finding a vehicle setup,
- weaknesses in terms of deviations from regulations, and
- weaknesses which can cause gradual or aggressive performance loss.

Let me give you an example of the type which complicates set up and which can be reason for a loss of performance.



There are very well-known effects such as camber loss while cornering which have been investigated by generations of engineers. Multilink axles with sophisticated wheel travel during bump/rebound and steering – i.e. very good kinematic performance – were developed. At the same time, the suspension structure must react to heavy road loads. Pulling forces on the upper links and pushing forces on the lower links together with the weakness in the ball joints lead to a camber reduction. As a further consequence, the position of the wheel on the road might suffer and the whole vehicle might lose grip.

The second phase can be characterized as "*Weakness2performance*". At a certain stage, purposely designed weaknesses, which promised increased performance, gained a lot of attention. But it did not take a long time until FIA's regulations were extended and banned these designs. The most familiar approach was to foresee a weakness in terms of stiffness of the rear wing strut, thereby reducing the angle of attack with increasing speed.

I call the third phase "*recognition of skin alterations*". These alterations are typically caused by aero-dynamical pressures or other influences such as centrifugal forces or thermal expansion.

Having understood this principle, one can try to take advantages out of these alterations. This fourth phase can be described as "*advantageous skin trimming*".

CFD

Aerodynamic fields incorporating current deflection

- OpenFOAM
- ANSYS Fluent
- Star-CCM+
- API to interface with inhouse code

1

RelWallForce/OverPressure

Reasoning

Probably the Formula 1 car with its open wheel configuration has the most altering surface when running on the street in the course of a race distance. The “monoposto” with its protruding wheels changes its basic geometry continuously because the relative position of wheel and body towards each other are changing constantly during bump, rebounds and steering.

But this is only one side of the coin: most likely, the dominant effect is the geometrical change of the tire itself which is a significant part of the overall geometry.

Why is this deformation so important? The tire is made to deflect. As the one and only interface between car and road it can only produce reaction forces via initial deflection. As good as the deflection is for the road holding requirement, as big is the uncertainty whether this deflection is advantageous or not for the overall aerodynamic performance.

Beyond the fundamental functional principle, there are at least two nonintentional deflections:

- widening circumference as a result of centrifugal forces when spinning fast and
- flattening the cross section as a consequence of vertical forces (weight and dynamic weight transfer).

The new race car regulations at the beginning of the 2017 season emphasize this situation: the tires, for example, are now more than 25 % wider than last

FEA

Deflection of thin structure
spoiler, wing

- Abaqus
- ANSYS Mechanical
- MSC.Nastran
- API to interface with inhouse code

NPosition

year. This likely means that the physical effect stemming from the tires might also increase by 25%! Probably, this is even a very cautious estimation. **Therefore – and because of a lot of other geometrical/aero-dynamical effects on the car – I personally feel that it was never more promising to try to use a multiphysics approach** as the current regulations in general and the bigger tires in particular will have an ever bigger influence on the aerodynamic body design.

Multiphysics Solution with MpCCI

MpCCI CouplingEnvironment is an ideal tool for coupled FSI simulations as it can integrate in- and output of different computational solvers seamlessly into each other with a very reasonable amount of extra engineering effort! The advantages of *MpCCI CouplingEnvironment* are well known and the tool has been successfully used in various industries.

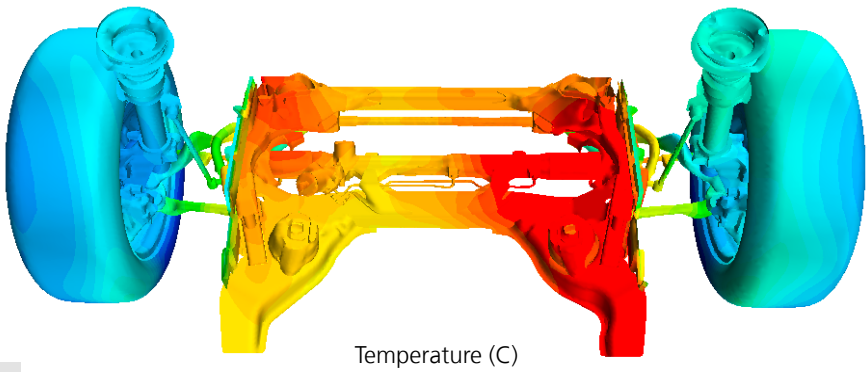
It might not be as well known that this engineering tool is also successfully in use in Formula 1. *MpCCI CouplingEnvironment* from Fraunhofer SCAI has been integrated into the design workflows of leading F1 teams and is successfully used to optimize the aerodynamic behavior of the car while taking the structural behavior into account. The related time and cost savings provide a considerable competitive advantage to these teams.

1 CO-SIMULATION

The MpCCI

CouplingEnvironment
has interfaces to the
commercial and inhouse
simulation codes.





1

1 THERMAL MANAGEMENT

Coupled STAR-CCM+ and RadTherm solution – temperature distribution on a BMW front axle.

2 DRIVING THROUGH POTHOLE

Co-Simulation of Abaqus and MSC.Adams – plastic deformation of single components.

3 FREQUENCY RESPONSE ANALYSIS

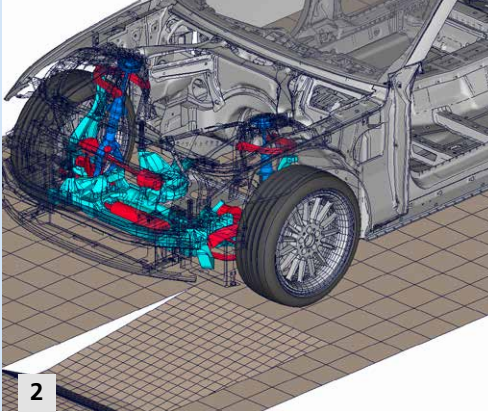
MpCCI FSIMapper builds the link between the simulation of the vehicle's aerodynamics and the NVH-simulation.

MpCCI Coupling Environment

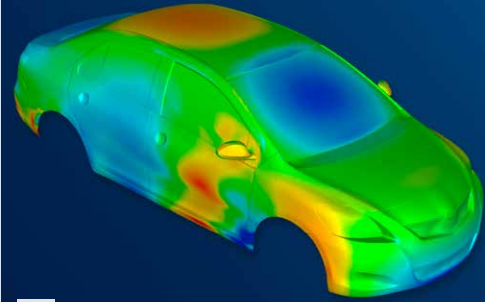
MpCCI is a vendor neutral interface for co-simulation:

- neighborhood calculation and mapping algorithms,
- various synchronization schemes, and
- predefined setups for typical applications.

Structural Analysis	Abaqus ANSYS Mechanical MSC.Nastran and MSC.Marc
Computational Fluid Dynamics (CFD)	ANSYS ICEPAK ANSYS Fluent FINE/Open and FINE/Turbo OpenFOAM STAR-CCM+ and STAR-CD
Electromagnetic Modelling	ANSYS Emag FLUX JMAG
Radiation	RadTherm/TAITherm
System Models	Flowmaster/FloMASTER FMI interface (prototype) MATLAB MSC.Adams SIMPACK



2



3

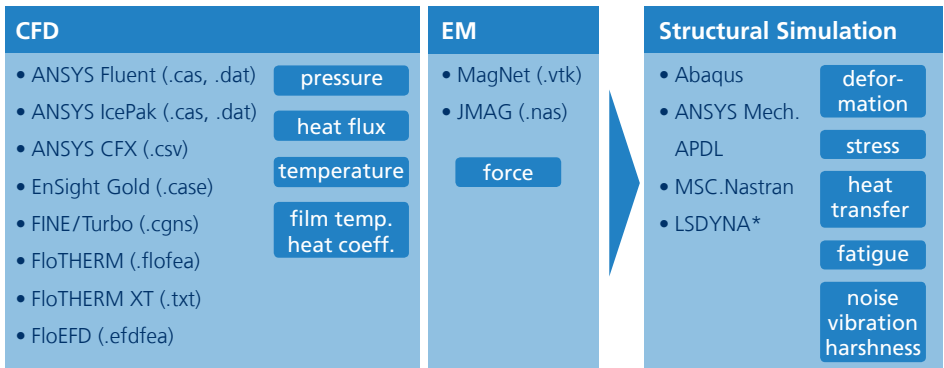
MpCCI FSIMapper

Many vibration and acoustic effects in full vehicles are caused by fluctuating aerodynamic loads. Related tasks in automotive development are

- analysis of underbody paneling and attachment to body,
- analysis of engine hood flutter, and
- interior acoustic analysis with external aero-acoustic loads.

In order to perform realistic noise vibration harshness (NVH) analysis, the exciting aerodynamic forces have to be taken into account.

The tool *MpCCI FSIMapper* transfers the pressure excitation from the CFD calculation to the (not necessarily matching) NVH-mesh. The transient pressure fluctuations on the vehicle's surface can be automatically transformed by a Fourier decomposition in order to create the frequency dependent loading for the vibration analysis.



* Only for Fourier transformed transient data

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