# Industrial Application of the Meshless Morpher *RBF Morph* to a Motorbike Windshield Optimisation

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# Outline

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# Morphing & Smoothing

- A mesh morpher is a tool capable to perform **mesh modifications**, in order to achieve arbitrary shape changes and related volume smoothing, without changing the mesh topology.
- In general a morphing operation can introduce a reduction of the **mesh quality**
- A **good** morpher has to minimize this effect, and maximize the possible shape modifications.
- If mesh quality is well preserved, then using the **same mesh structure** it's a clear benefit.

# The Aim of *RBF Morph*

- The aim of *RBF Morph* is to perform **fast** mesh morphing using a mesh-independent approach based on state-of-the-art RBF (Radial Basis Functions) techniques.
- The use of *RBF Morph* allows the CFD user to perform **shape modifications**, compatible with the mesh topology, directly in the **solving stage**, just adding a single command line in the input file.

# Specifications

- Mesh-independent solution
- Parallel morphing of the grid
- Large size models (many millions of cells) must be morphed in a reasonable short time
- Management of every kind of mesh element type (tetrahedral, hexahedral, polyhedral, prismatic, hexcore, non-conformal interfaces, etc.)
- Support of the CAD re-design of the morphed surfaces

# Goals

The final goal is to perform **parametric studies** of component shapes and positions typical of the fluid-dynamic design like:

•Design Developments

•Multi-configuration studies

•Sensitivity Studies

•DOE (Design Of Experiment)

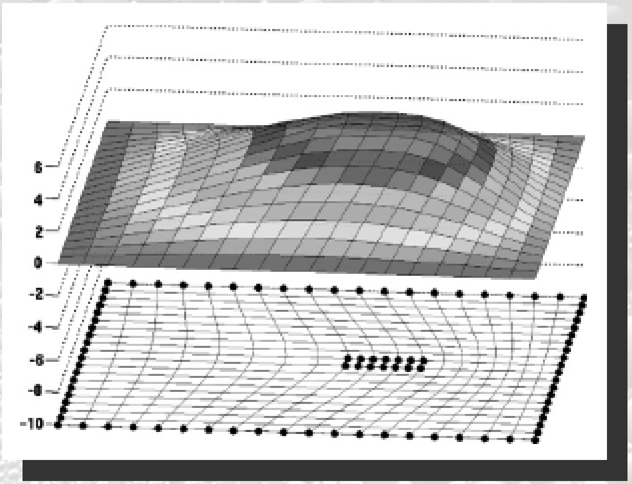
•Optimization

# RBF Morph Features

- **Product Integration**: full integration with FLUENT.
- **User Interface**: dedicated GUI and TUI (scriptable).
- **Process Integration**: morphing directly inside the solver.
- **Mesh Topology**: morphing by nodal smoothing preserving topology.
- **Surface Morphing**: free surface deformation, rigid movement or scaling.
- **Volume Smoothing**: high quality smoothing of the volume mesh.
- **Mesh Independency**: mesh-less approach.
- **Versatility**: handling every possible type of mesh element.
- **Reusability**: a solution can be applied to any different mesh.
- **Consistency**: mesh characteristics are preserved.
- **Parallelism**: parallel calculation for large models (many millions of cells).
- **Efficiency**: flow solutions are fully readable on the morphed mesh.
- **Precision**: exact nodal movement and exact feature preservation.
- **Parameterization**: multi-parameter and multi-step problems.
- **CAD**: dedicated feature to support the re-design of the morphed surfaces.

# Background (1)

- A system of radial functions is used to produce a solution for the mesh movement/morphing, from a list of source points and their displacements. This approach is valid for both surface shape changes and volume mesh smoothing.
- The RBF problem definition does not depend on the mesh
- Radial Basis Function interpolation is used to derive the displacement in any location in the space, so it is also available in every grid node.
- An interpolation function composed by a radial basis and a polynomial is defined.



$$s(\mathbf{x}) = \sum_{i=1}^{N} \gamma_i \phi\left(\left\|\mathbf{x} - \mathbf{x}_i\right\|\right) + h(\mathbf{x})$$

# Background (2)

- A radial basis fit exists if desired values are matched at source points with a null poly contribution
- The fit problem is associated with the solution of a linear system
- **M** is the interpolation matrix
- **P** is the constraint matrix
- **g** are the scalar values prescribed at source points
- γ and β are the fitting coefficients

$$s(\mathbf{x}_{k_i}) = g(\mathbf{x}_{k_i}) \quad 1 \le i \le N$$

$$0 = \sum_{i=1}^{N} \gamma_i q(\mathbf{x}_{k_i})$$

$$\begin{pmatrix} \mathbf{M} & \mathbf{P} \\ \mathbf{P}^{\mathrm{T}} & \mathbf{0} \end{pmatrix} \begin{pmatrix} \boldsymbol{\gamma} \\ \boldsymbol{\beta} \end{pmatrix} = \begin{pmatrix} \mathbf{g} \\ \mathbf{0} \end{pmatrix}$$

$$M_{ij} = \phi\left(\left\| \mathbf{x}_{k_i} - \mathbf{x}_{k_j} \right\|\right) \quad 1 \le i \quad j \le N$$

$$\mathbf{P} = \begin{pmatrix} 1 & x^0_{k_1} & y^0_{k_1} & z^0_{k_1} \\ 1 & x^0_{k_2} & y^0_{k_2} & z^0_{k_2} \\ \vdots & \vdots & \vdots & \vdots \\ 1 & x^0_{k_N} & y^0_{k_N} & z^0_{k_N} \end{pmatrix}$$

# Background (3)

- The radial function can be fully or compactly supported. The bi-harmonic kernel fully supported gives the best results for smoothing.
- For the smoothing problem each component of the displacement prescribed at the source points is interpolated as a single scalar field.

| Radial Basis Function | $\phi(r)$ |
|---|---|
| Spline type ($R_n$) | $\lvert r\rvert^n$, n odd |
| Thin plate spline ($TPS_n$) | $\lvert r\rvert^n \log\lvert r\rvert$, n even |
| Multiquadric(MQ) | $\sqrt{1+r^2}$ |
| Inverse multiquadric (IMQ) | $\frac{1}{\sqrt{1+r^2}}$ |
| Inverse quadratic (IQ) | $\frac{1}{1+r^2}$ |
| Gaussian (GS) | $e^{-r^2}$ |

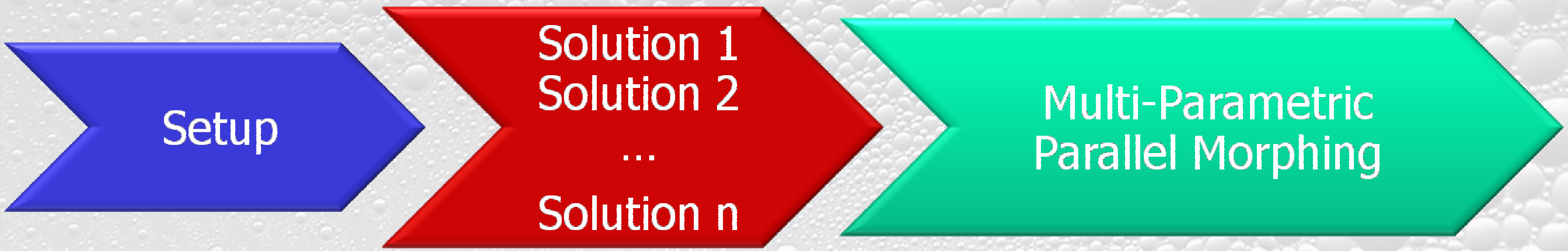
$$\begin{cases} v_x = s_x(\mathbf{x}) = \sum_{i=1}^{N} \gamma_i^x \phi\left(\left\|\mathbf{x}-\mathbf{x}_{k_i}\right\|\right) + \beta_1^x + \beta_2^x x + \beta_3^x y + \beta_4^x z \\ v_y = s_y(\mathbf{x}) = \sum_{i=1}^{N} \gamma_i^y \phi\left(\left\|\mathbf{x}-\mathbf{x}_{k_i}\right\|\right) + \beta_1^y + \beta_2^y x + \beta_3^y y + \beta_4^y z \\ v_z = s_z(\mathbf{x}) = \sum_{i=1}^{N} \gamma_i^z \phi\left(\left\|\mathbf{x}-\mathbf{x}_{k_i}\right\|\right) + \beta_1^z + \beta_2^z x + \beta_3^z y + \beta_4^z z \end{cases}$$

# Background (4)

- The evaluation of RBF at a point has a cost of order N
- The fit has a cost of order $N^3$ for a direct fit (full populated matrix); this limit to ~10.000 the number of source points that can be used in a practical problem
- Using an iterative solver (with a good pre-conditioner) the fit has a cost of order $N^2$; the number of points can be increased up to ~70.000
- Using also space partitioning to accelerate fit and evaluation the number of points can be increased up to ~300.000 (current implementation of *RBF Morph*)
- The method can be further accelerated using fast pre-conditioner building and FMM RBF evaluation (available for future versions of *RBF Morph*)

# How it Works: the work-flow

- *RBF Morph* basically requires three different steps:
- **Step 1 [SERIAL] setup** and definition of the problem (source points and displacements).
- **Step 2 [SERIAL] solution** of the RBF system.
- **Step 3 [SERIAL or PARALLEL] morphing** of the surface and volume mesh.

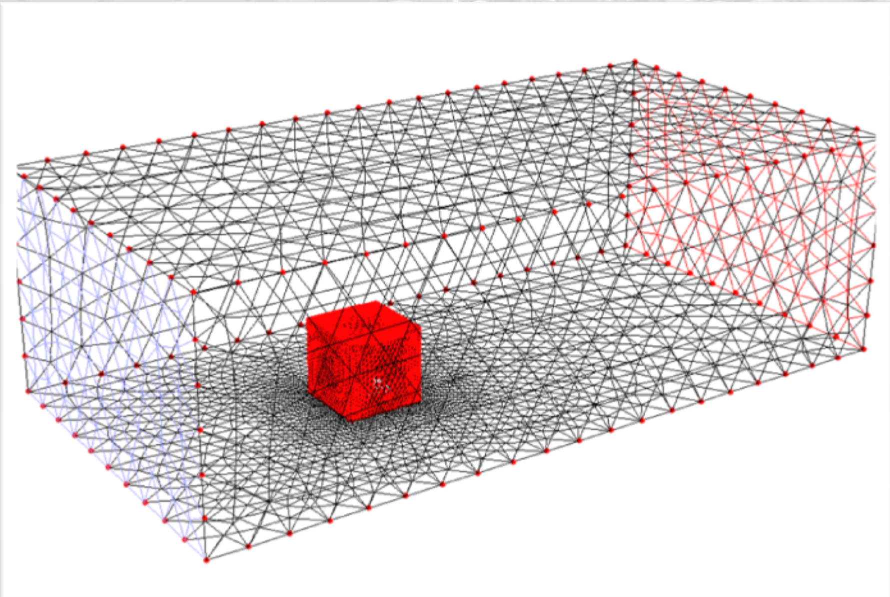


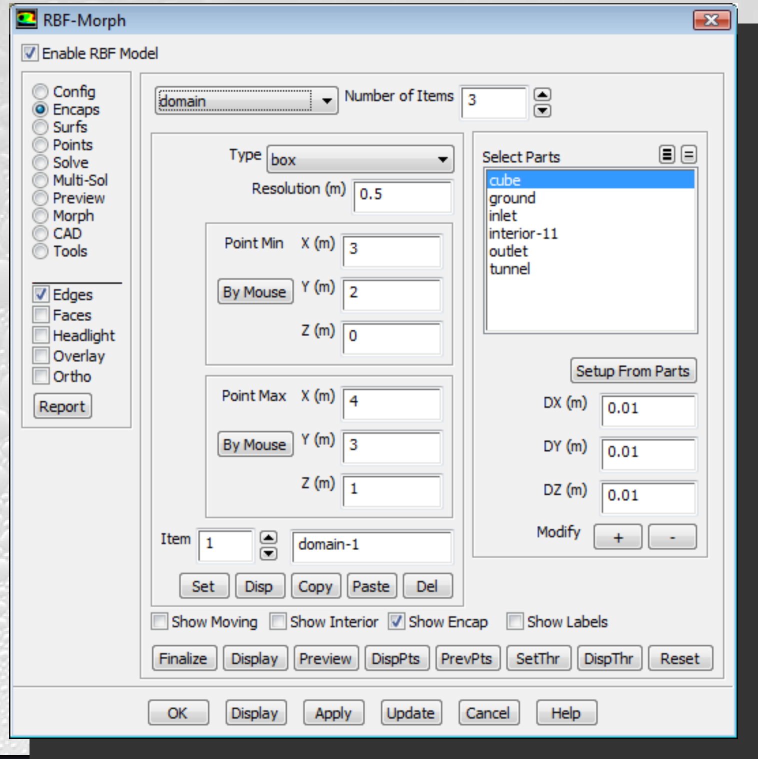
# How it Works: the problem setup

- The problem must describe correctly the **desired changes** and must **preserve exactly** the fixed part of the mesh.
- The prescription of the **source points** and their displacements fully defines the *RBF Morph* problem.
- The problem is **mesh-independent**, and could be defined using grid nodes as well as arbitrary point locations.
- Each problem and its solution define a mesh **modifier** of **parameter**.

# How it Works: the interface

- One of the key aspects of *RBF Morph*, in respect to FLUENT integration, is related to the ability of extracting information from the FLUENT mesh and to the user interface GUI



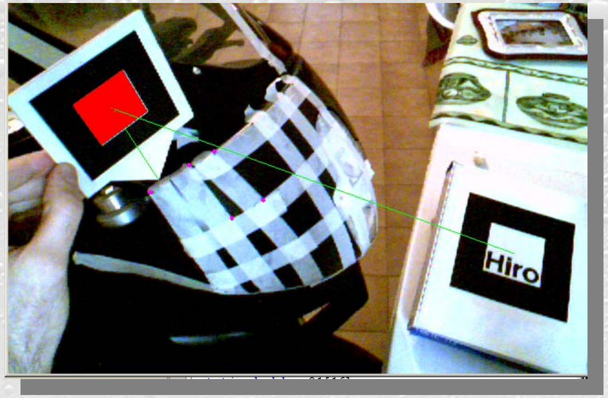


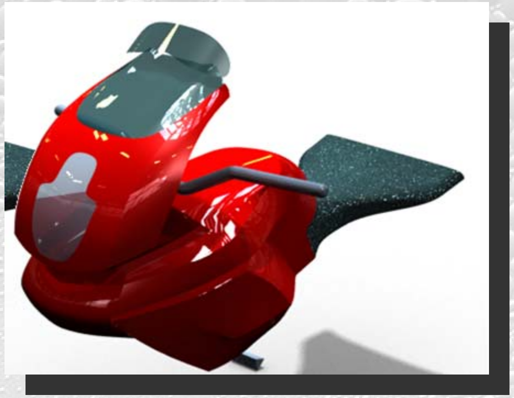
# Industrial Application:
# a motorbike windshield optimisation

- Variotouring windshield introduced in 2002 by the German company MRA to control the shape of the flux that acts on the driver.
- The aim of the variotouring is to control the fluxes path to limit the annoyance thanks to a special shape of the screen and an adjustable deflector.
- The system acts as a flux splitter and if properly tuned allows to obtain a substantial benefit in term of riding comfort.

# Design loop

- Acquisition of the actual geometry of part of the motorbike by means of a reverse engineering tool
- Definition of the new windshield geometry and introduction of the driver in the CAD model
- Calculation mesh and CFD model of the baseline geometry
- Shape optimisation of the new geometry.






# Explored 45 configurations

- changing of driver height

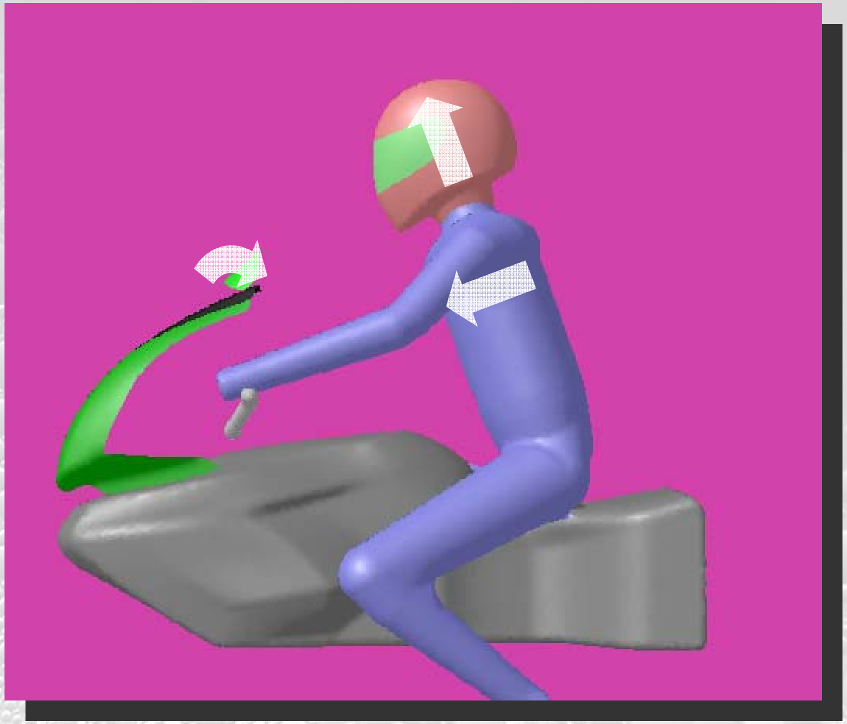
**[-5 cm, 0 cm, 5 cm]**;

- changing of driver position acting on the hunching angle

**[0°,7.5°,15°]**;

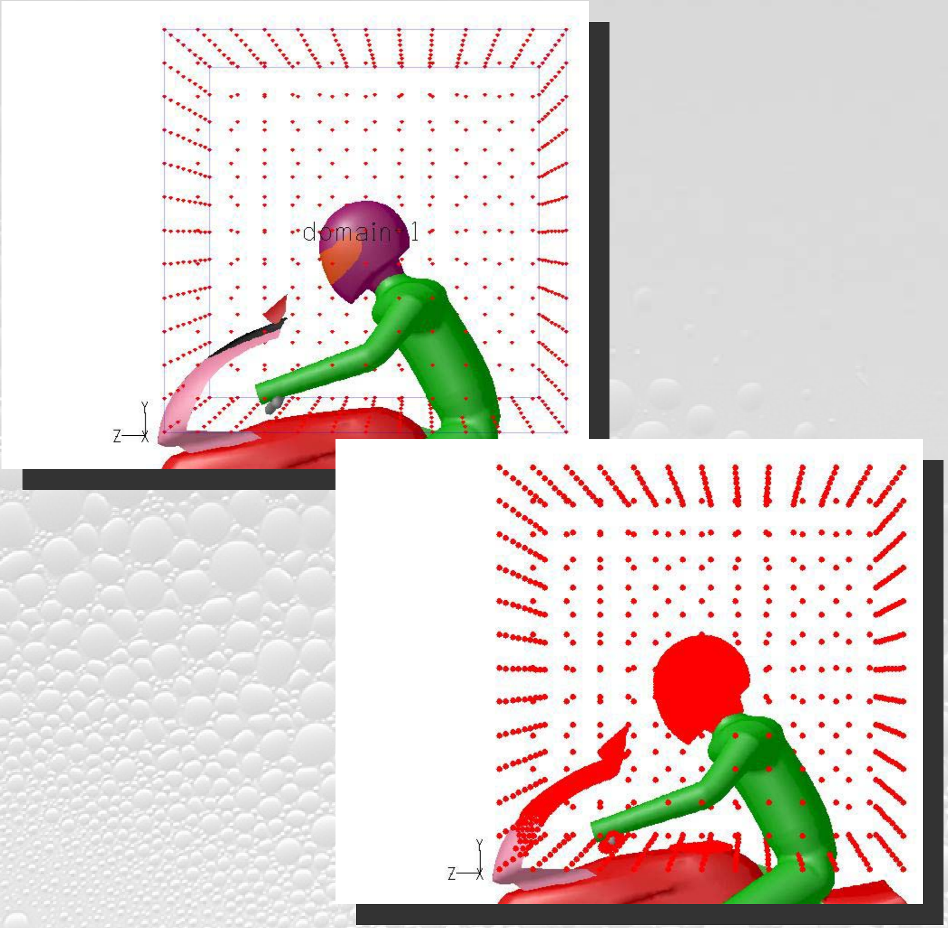
- adjustment of the vario-touring acting on the deflector angle

**[-10°, -5°, 0°, 5°,10°]**;



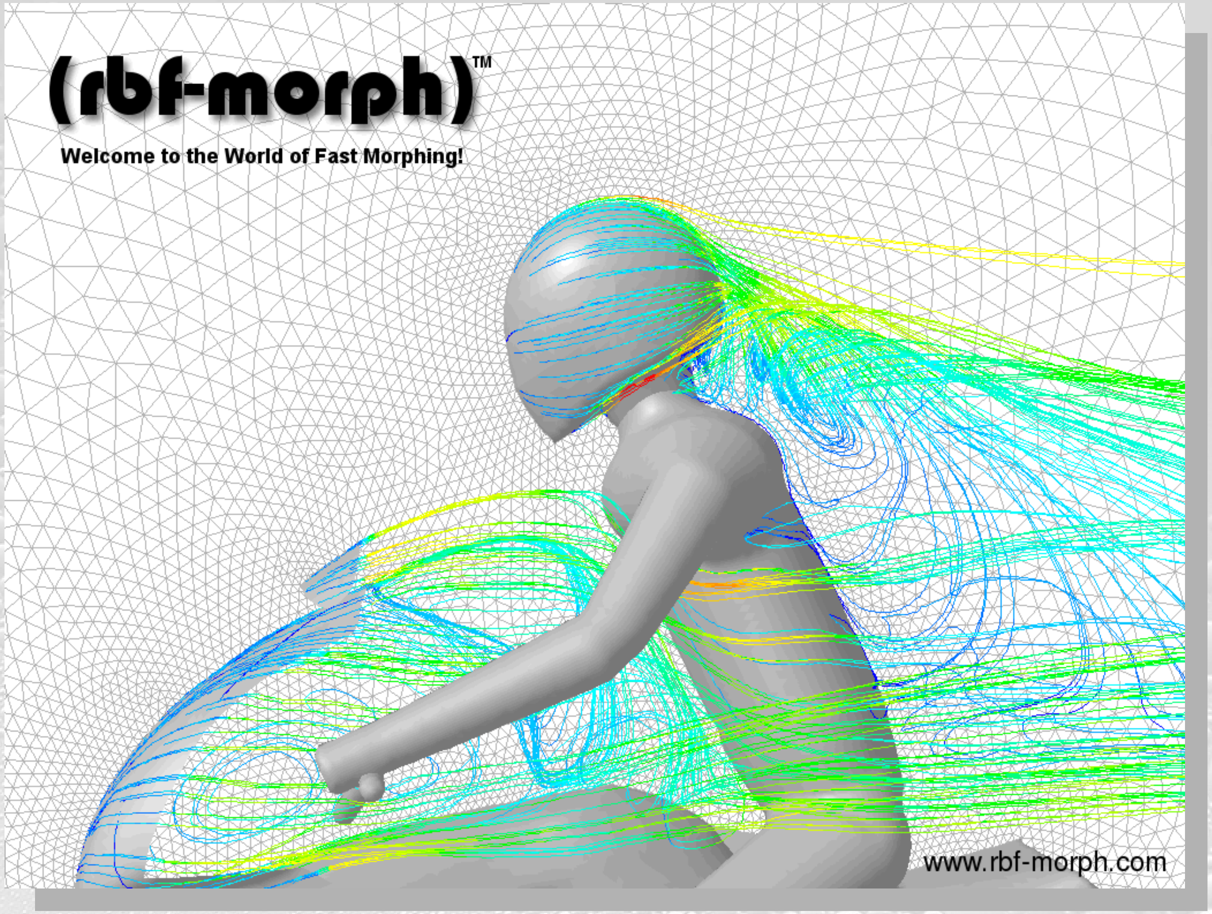
# Set up of RBF Morph

- The morphed action is limited in the box region “domain 1”.
- The motion of the surfaces inside the encapsulation domain is imposed to the points on the windshield (fixed), the fairing (fixed) and the helmet (moving).



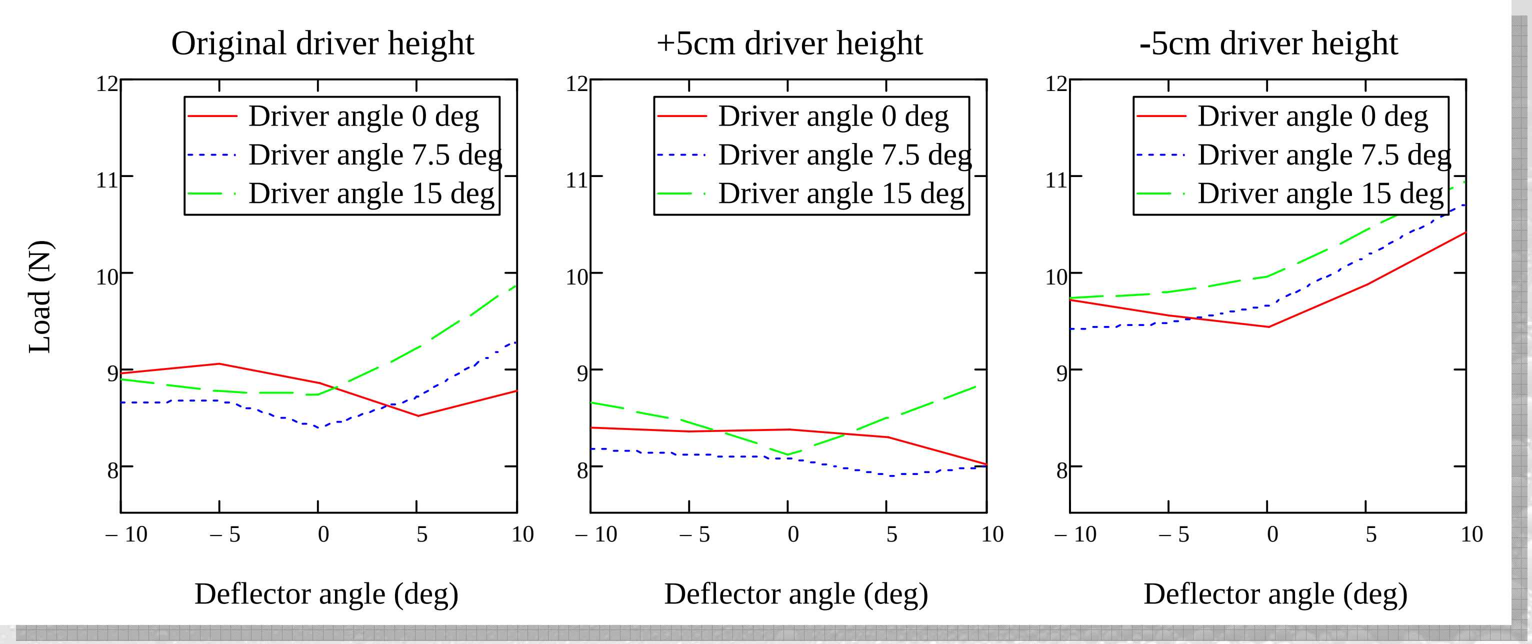
# Results(1)

- Driver height and position have a substantial effect on flow pattern
- Deflector angle plays an important role on the flow pattern encountered by the driver



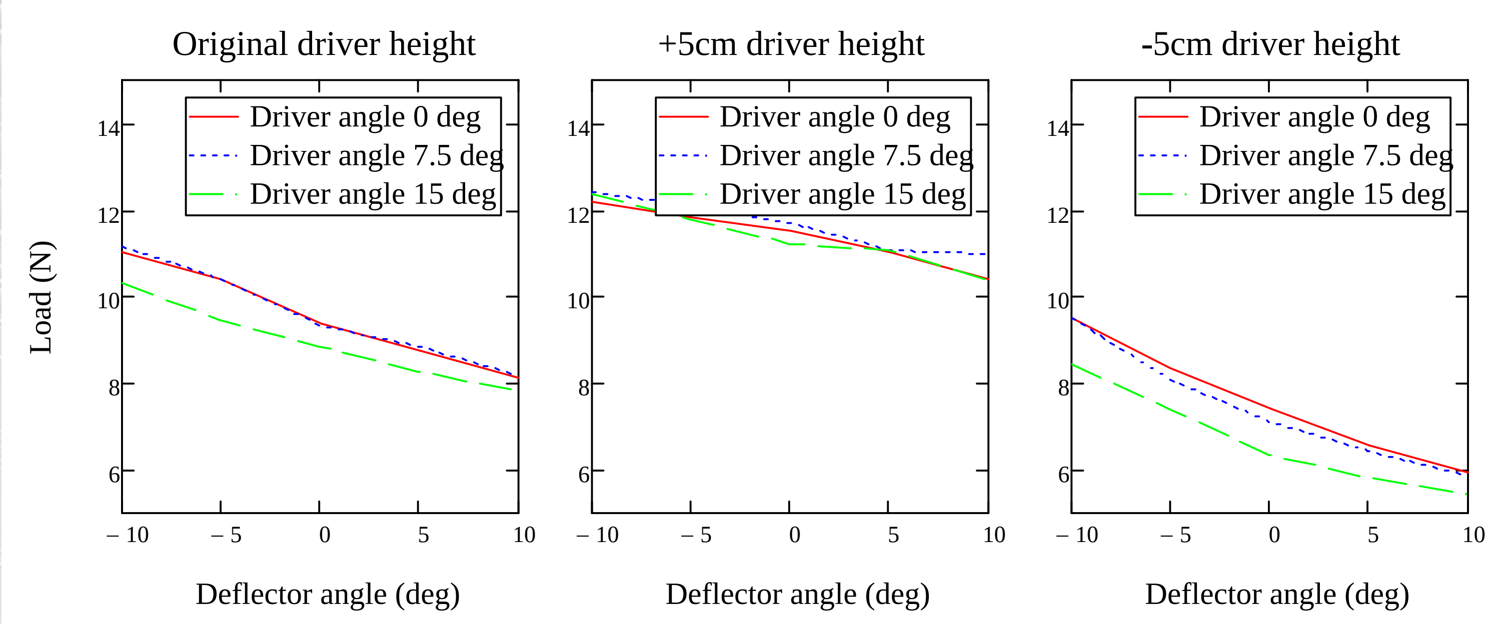
# Results(2)

- The vertical load on the helmet can be reduced acting on the deflector and the optimum angle depends on the driver height and angle the load is higher for driver of reduced heights.



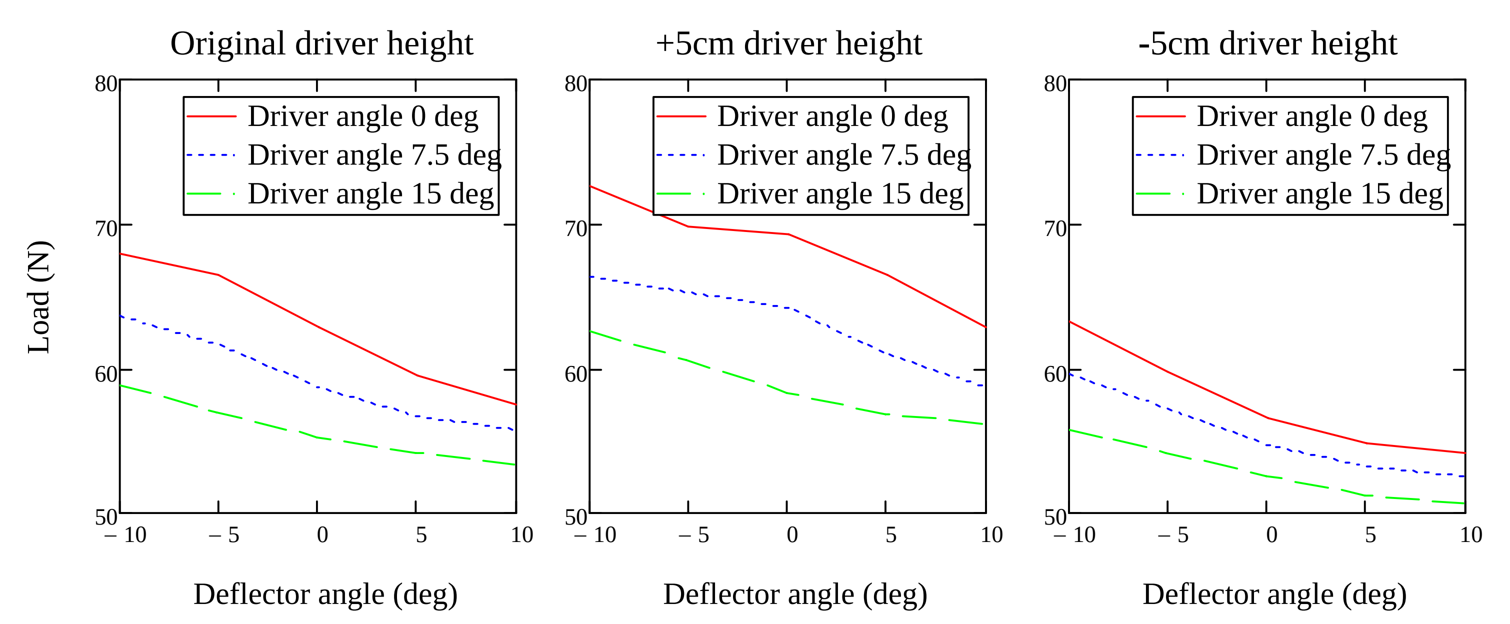
# Results(3)

- The horizontal load on the helmet is higher for driver of increased heights (higher exposition to the flux) and decreases monotonically with the deflector angle.



# Results(4)

- Also the horizontal load on the driver is higher for driver of increased heights (higher exposition to the flux) and decreases monotonically with the deflector angle.



# Concluding remarks

- *RBF Morph* has proven to be very useful for the presented industrial application and allowed to successfully managing all the desired configurations.
- The effect of adjustable deflector on the flow can be appreciated even with a simple steady analysis.
- An optimal deflector angle can be found for a prescribed driver height and position.
- The windshield optimisation project is still open and ongoing activities include the study of the effect of screen and deflector shape, the definition of further comfort parameters (turbulence intensity, transitory analysis).

# Thank you for your attention!

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