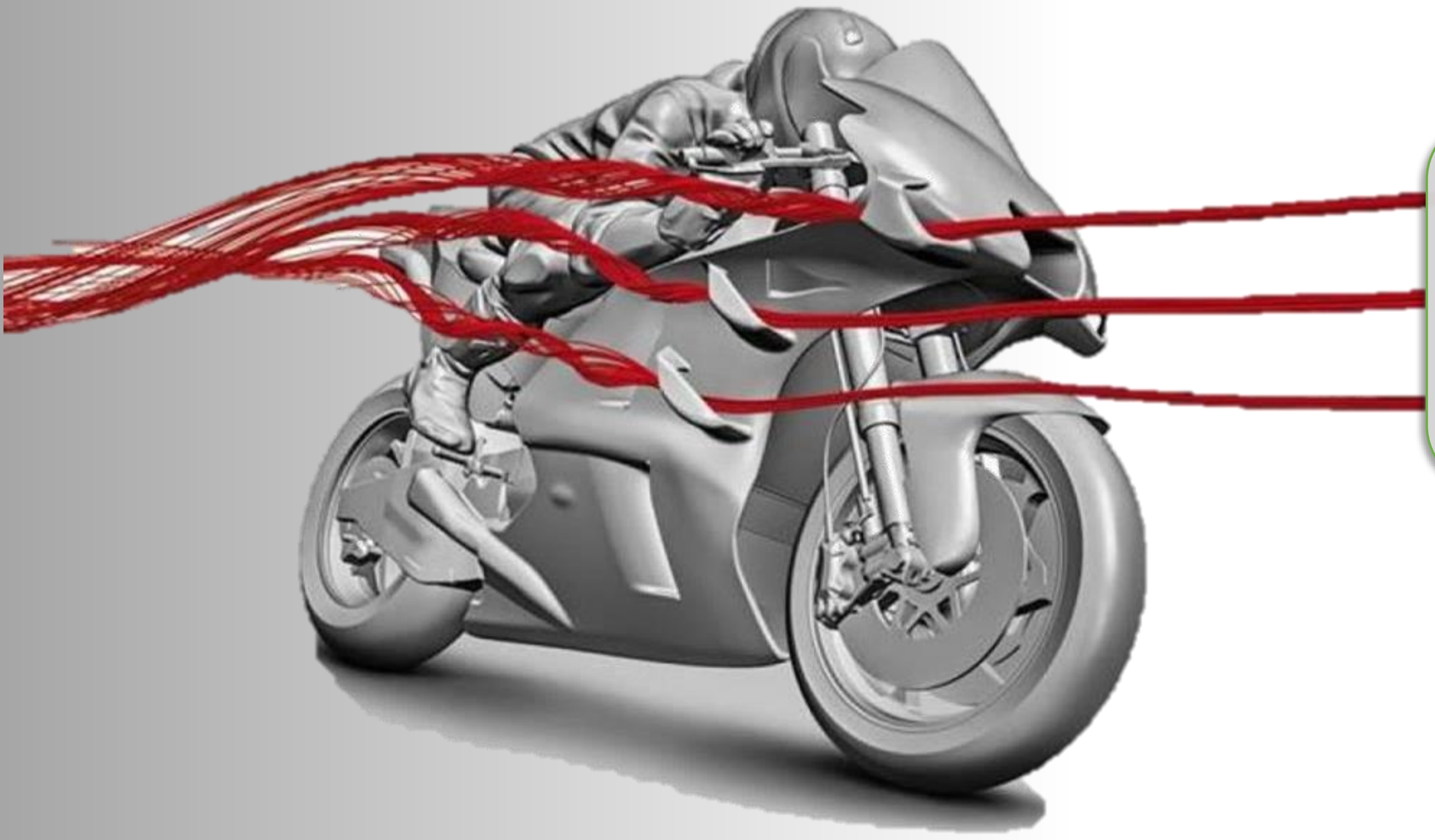
Aerodynamic Optimization of a MotoGP Motorcycle using CFD and Mesh Morphing



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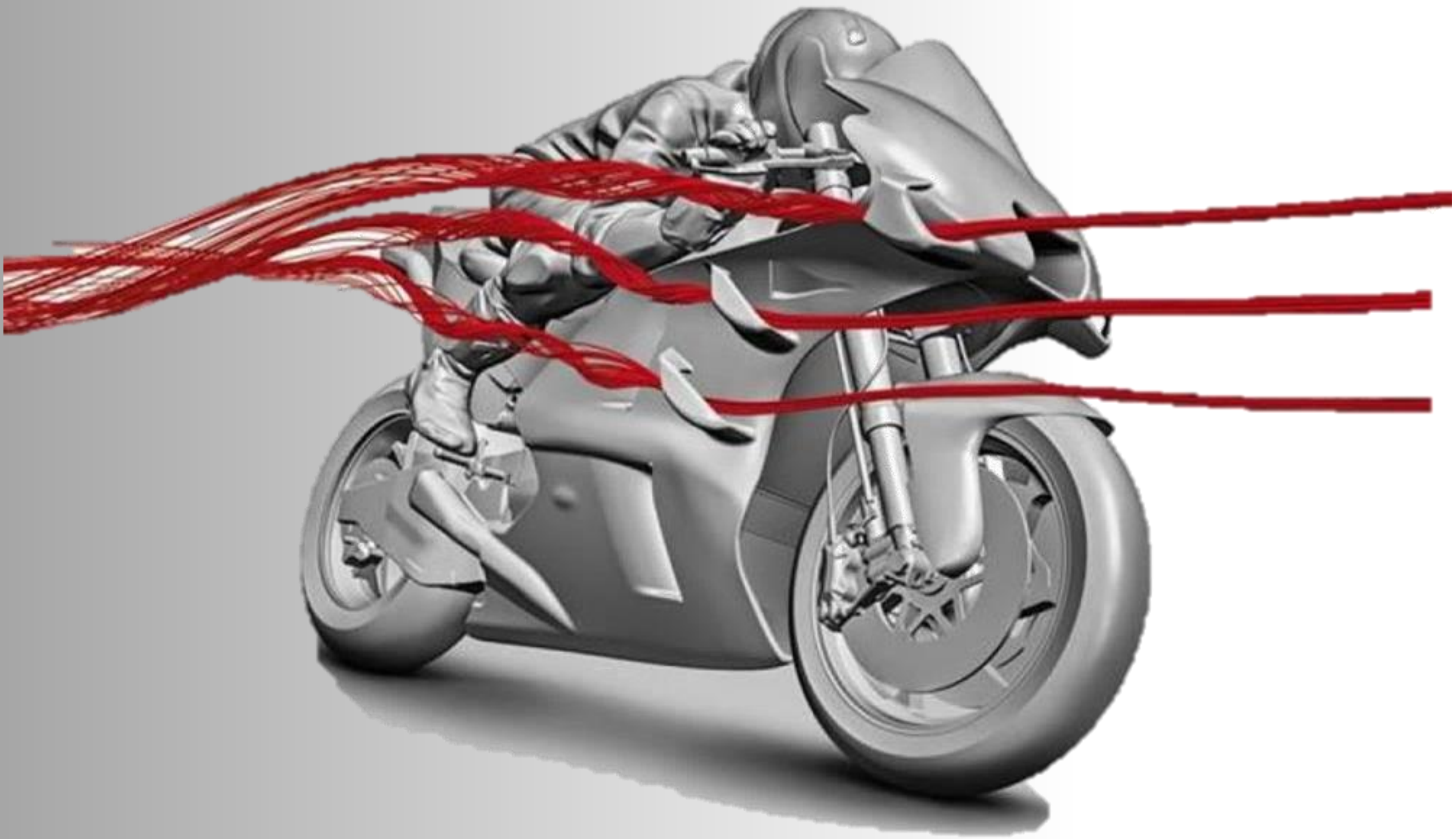


Fluid Dynamic Analysis

⇩

Optimization using RBF Morph

⇩

Results analysis

Fluid dynamics

Methodology

- Identification of the relevant equations
- Creation and validation of the model
- Optimization targets

Fluid dynamics

CFD approach

Relevant equations

Istantaneous Navier-Stokes equations:

- *Conservation of mass:*

$$\frac{\partial u_i}{\partial x_i} = 0$$

- *Conservation of momentum:*

$$\frac{\partial u_i}{\partial t} + u_j \frac{\partial u_i}{\partial x_j} = -\frac{1}{\rho}\frac{\partial p}{\partial x_i} + \nu \frac{\partial^2 u_i}{\partial x_j \partial x_j}$$

Reynolds decomposition: $\boldsymbol{u} = \boldsymbol{U} + \boldsymbol{u}'$

Averaged Navier-Stokes equations (RANS):

- *Conservation of mass:*

$$\frac{\partial U_i}{\partial x_i} = 0$$

- *Conservation of momentum:*

$$\frac{\partial U_i}{\partial t} + U_j \frac{\partial U_i}{\partial x_j} = -\frac{1}{\rho}\frac{\partial P}{\partial x_i} + \frac{\partial}{\partial x_j}\left(\nu \frac{\partial U_i}{\partial x_j} - \overline{u_i' u_j'}\right)$$

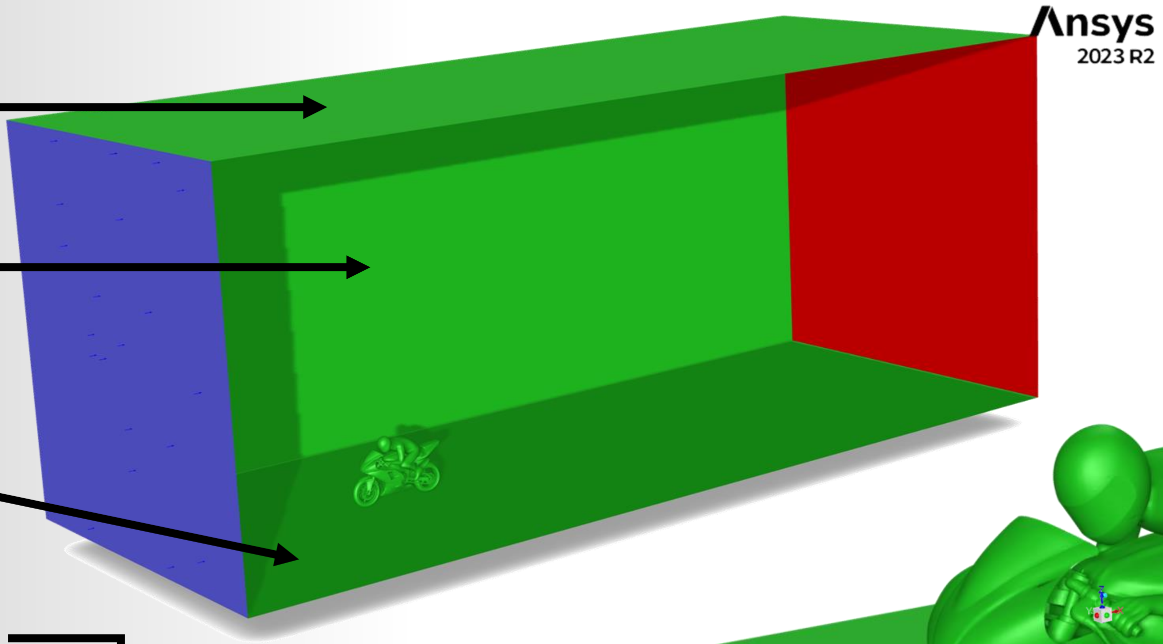
Turbulence

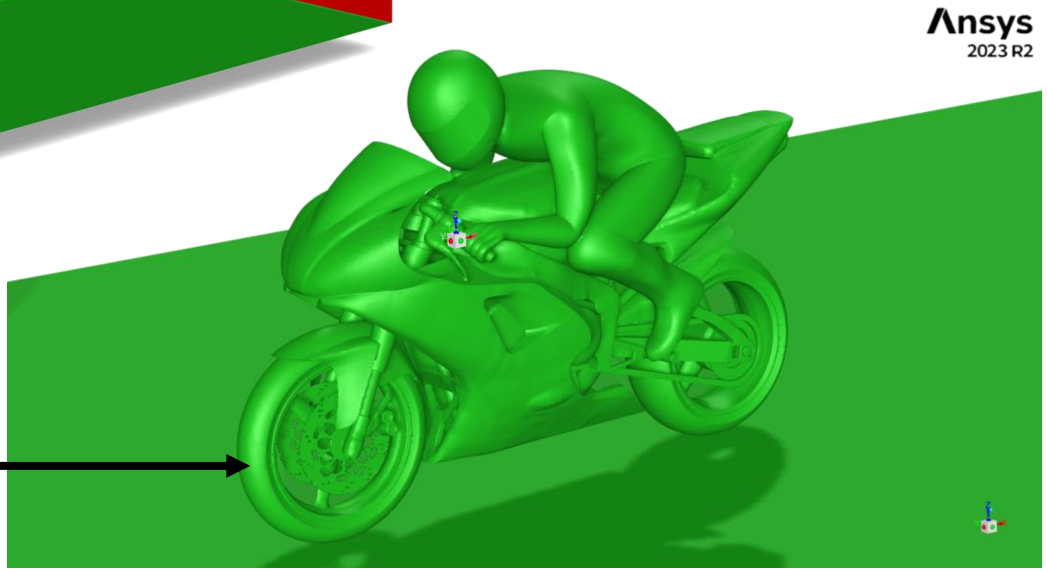
Fluid dynamics

CFD approach

Model creation

- **Inlet**: 200 km/h
- **Wall**:
  - Stationary
  - Moving translational
  - Moving rotational
- **Outlet**: 0 Pa





Fluidodynamic

CFD approach

Goals

Optimization parameters:

- Turbulence intensity
- Drag coefficient: $C_d = \frac{F_d}{\frac{1}{2}\rho v^2 A}$
- Lift coefficient: $C_l = \frac{F_l}{\frac{1}{2}\rho v^2 A}$

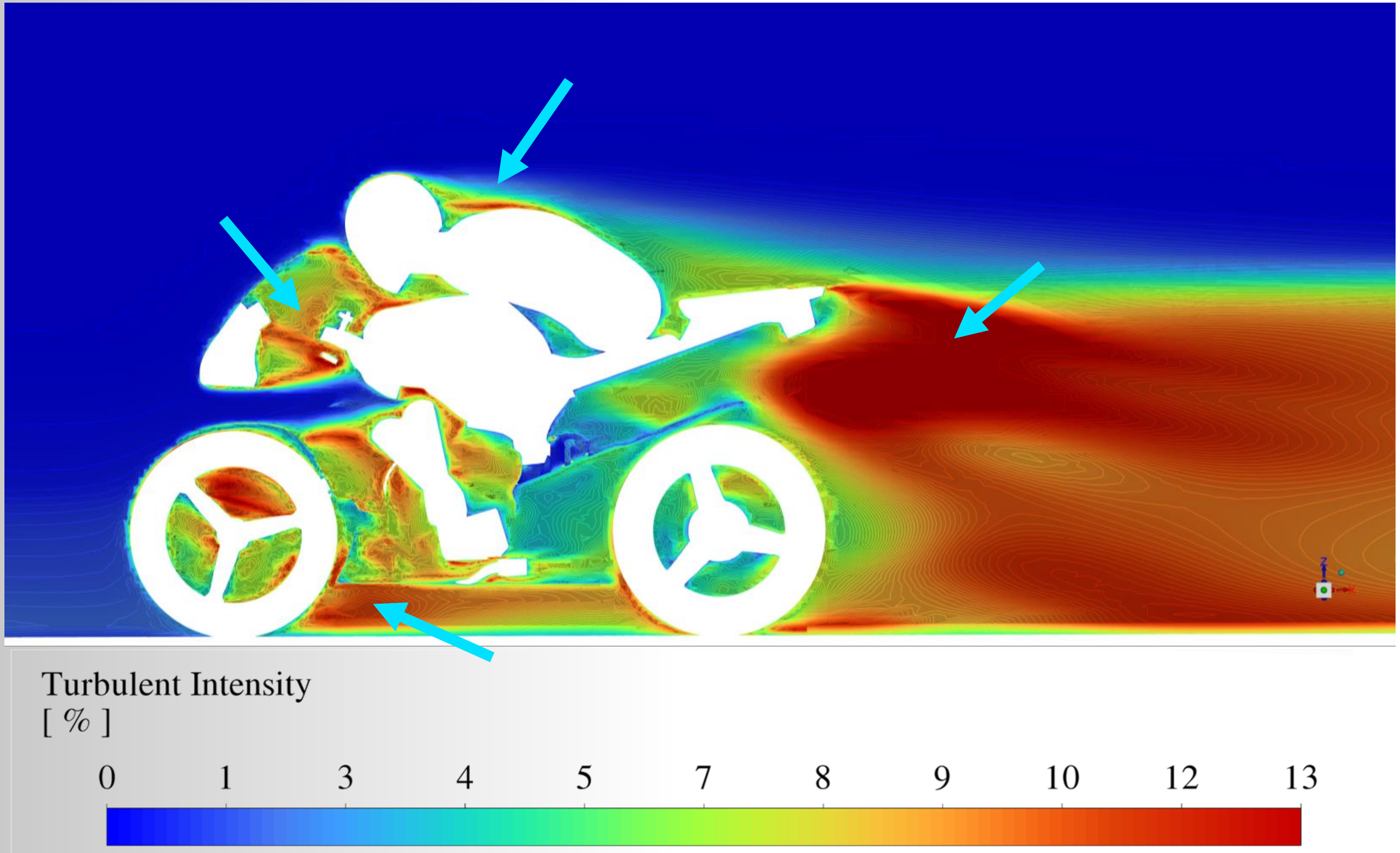
Optimization goals:

- Vibrations, noise, wake effect
- Drag force: $F_d = \frac{1}{2}\, C_d\, \rho v^2 A$
- Lift force: $F_l = \frac{1}{2}\, C_l\, \rho v^2 A$

Fluidodynamic

CFD approach

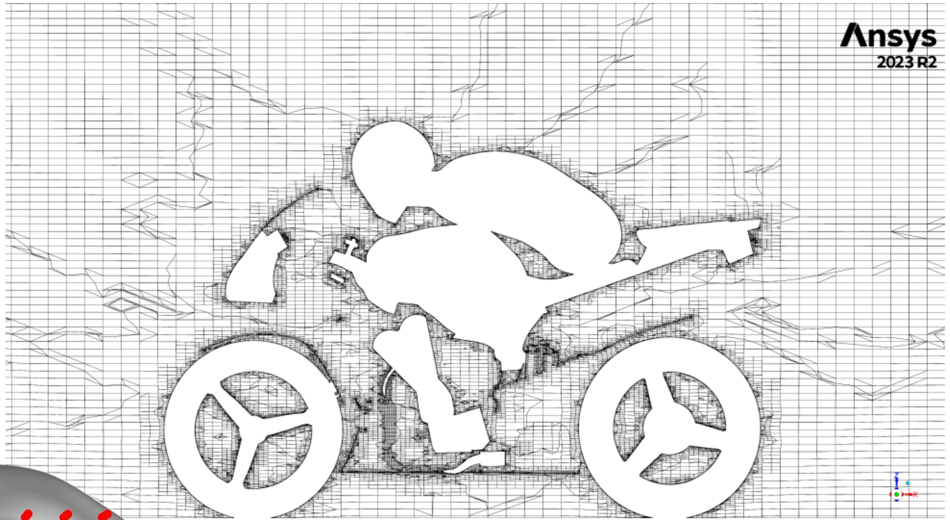
Goals



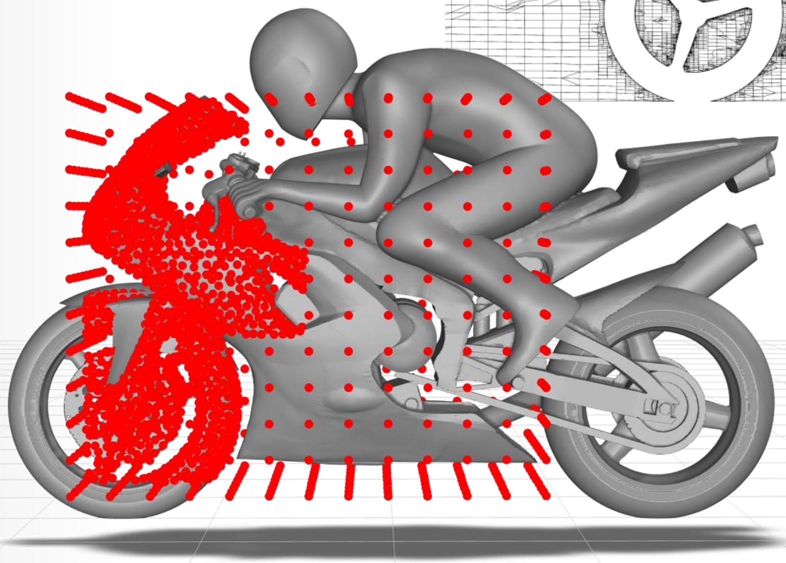
Mesh Morphing

RBF Morph

Goals



- Use of the mesh
- How it is modified
- Advantages
- Application to the study case



v1 model

Optimizations

Helmet

<u>Reason</u>:

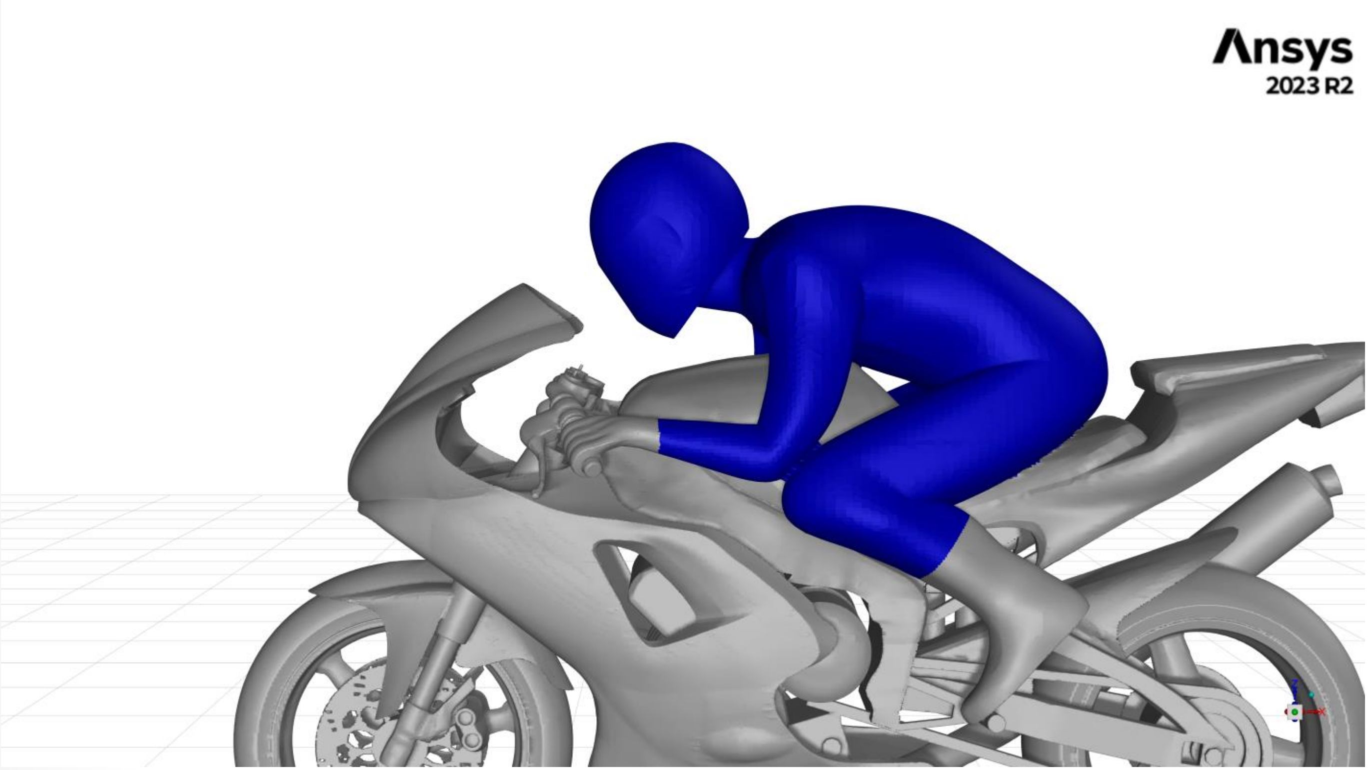
Turbulence between the helmet and the rider's back

<u>Modification</u>:

Downward translation of the helmet

<u>Involved surfaces</u>:

- Moving: Helmet
- Free to move: Neck
- Blocked: Tank, handlebar, windshield

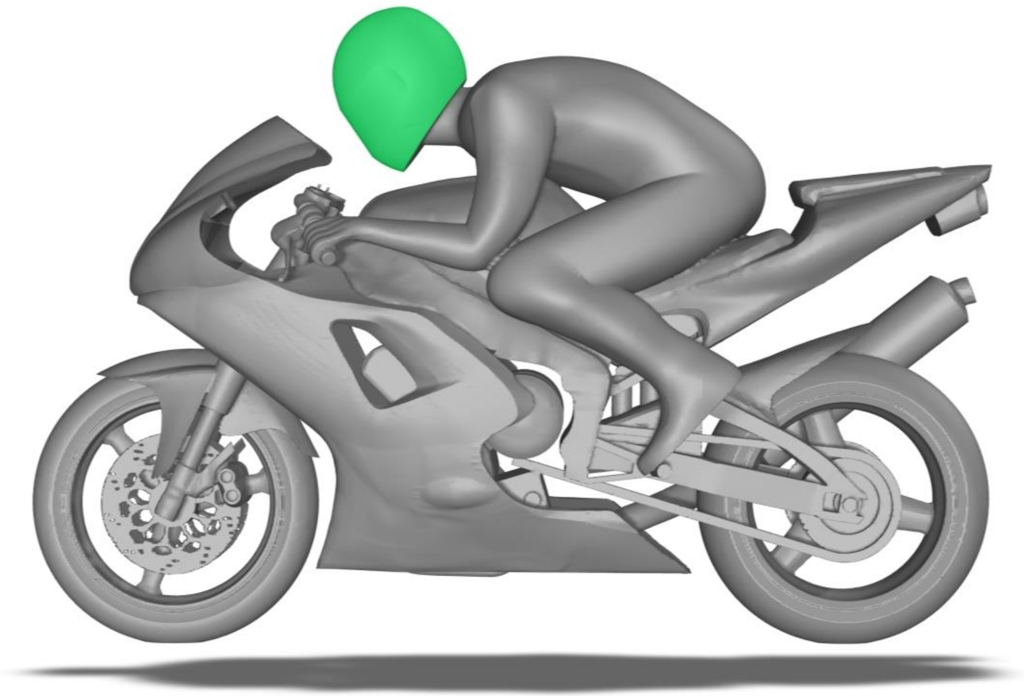


v1 model

Optimizations

Helmet

	Initial	v1	Gap
C_d	0.4900	0.4973	+1.4897 %
C_l	0.0860	0.0807	-6.1627 %
F_d [N]	487.2254	489.7514	+2.5259
F_l [N]	85.5130	79.4750	-6.0379

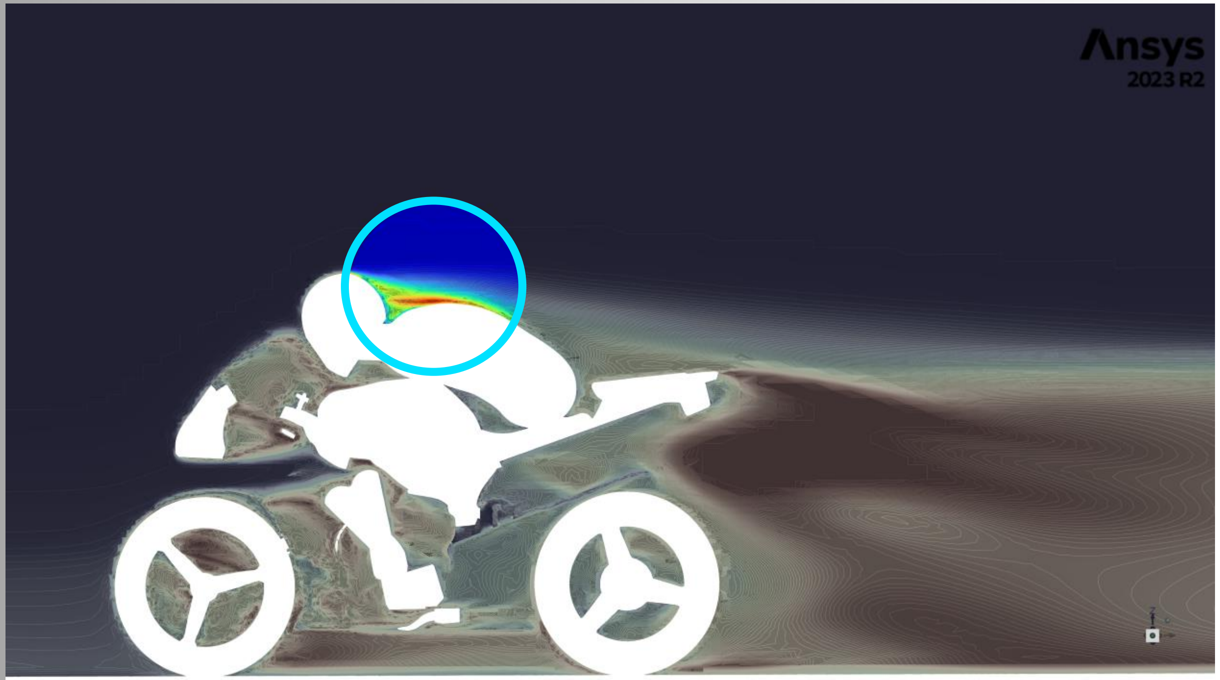


v1 model

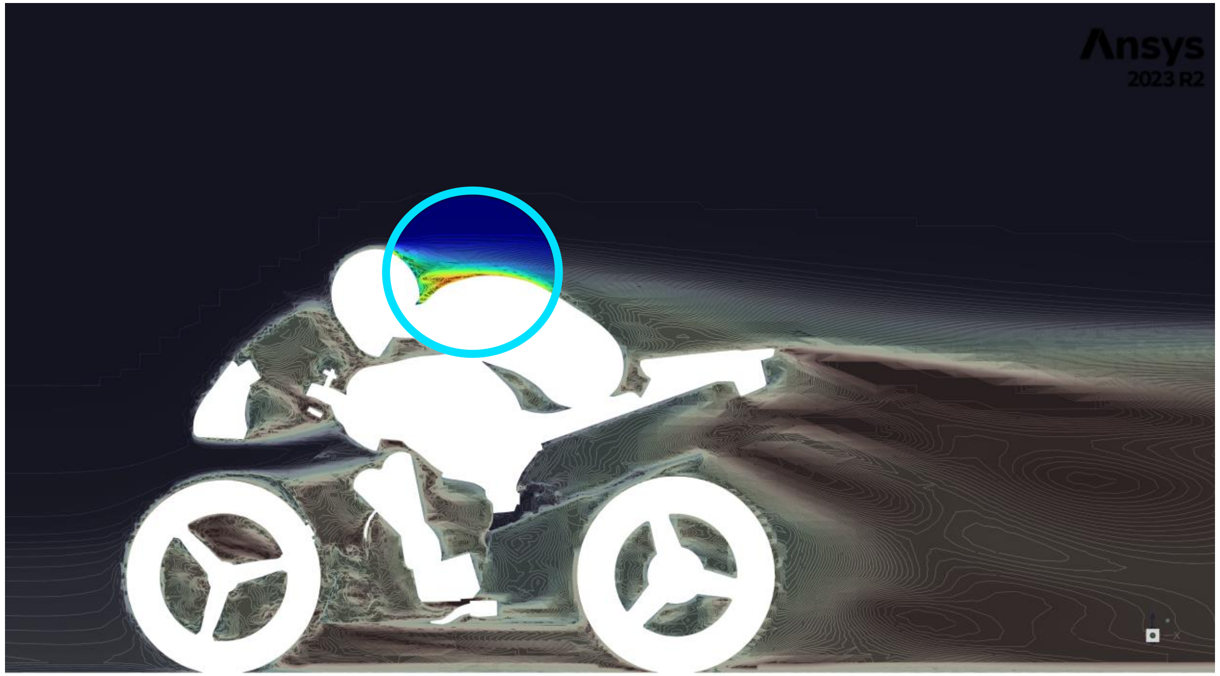
Optimizations

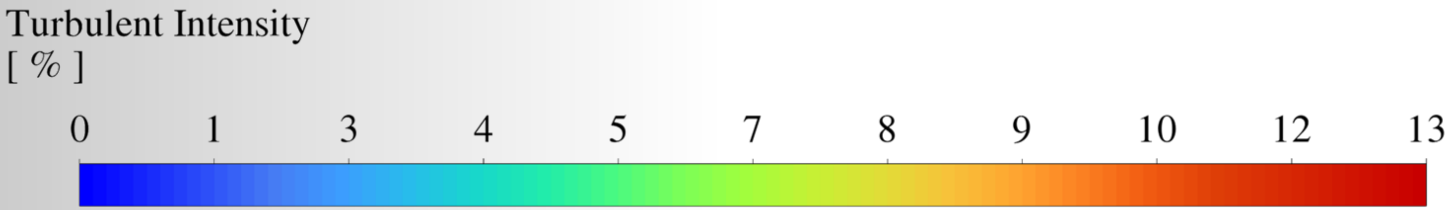
Helmet

Initial



Helmet downward translation





v2 model

Optimizations

Front fairing

Reason:

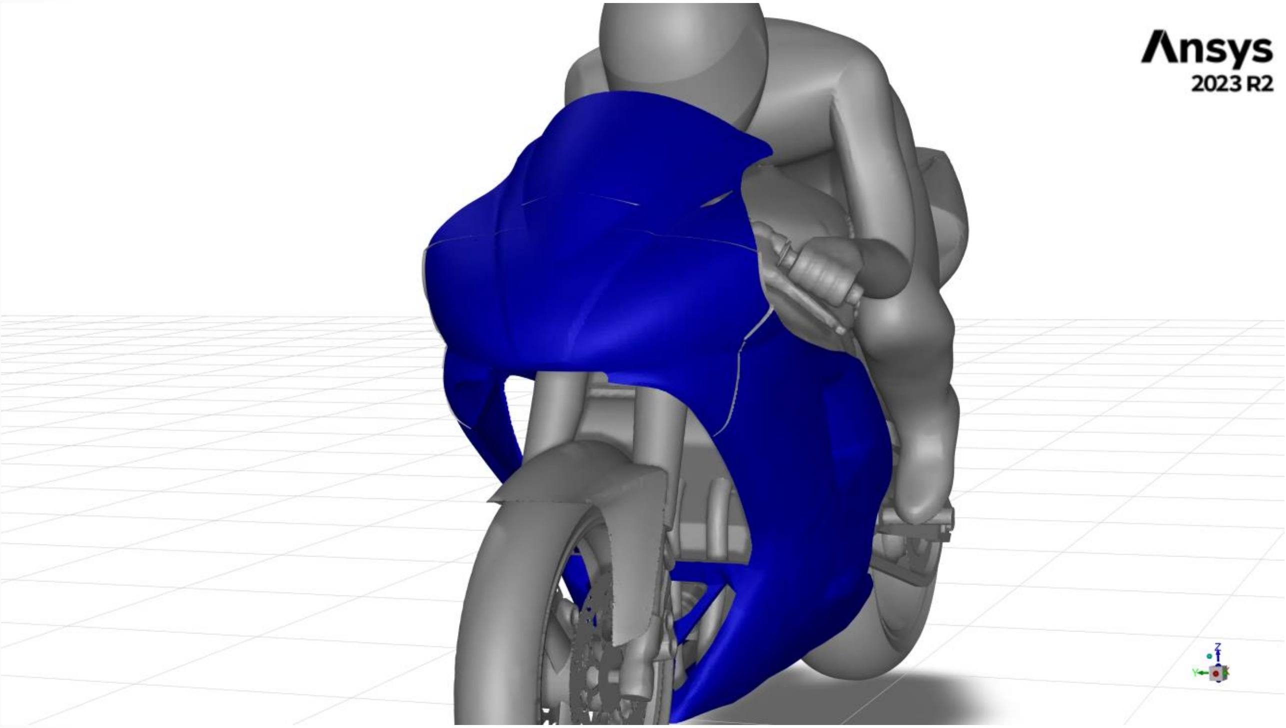
Turbulence on the handlebar and on rider's shoulders

Modifications:

Increase and decrease width of front fairing

Involved surfaces:

- Moving: Front fairing
- Free to move: Dash-board
- Blocked: Frame, radiator, handlebar



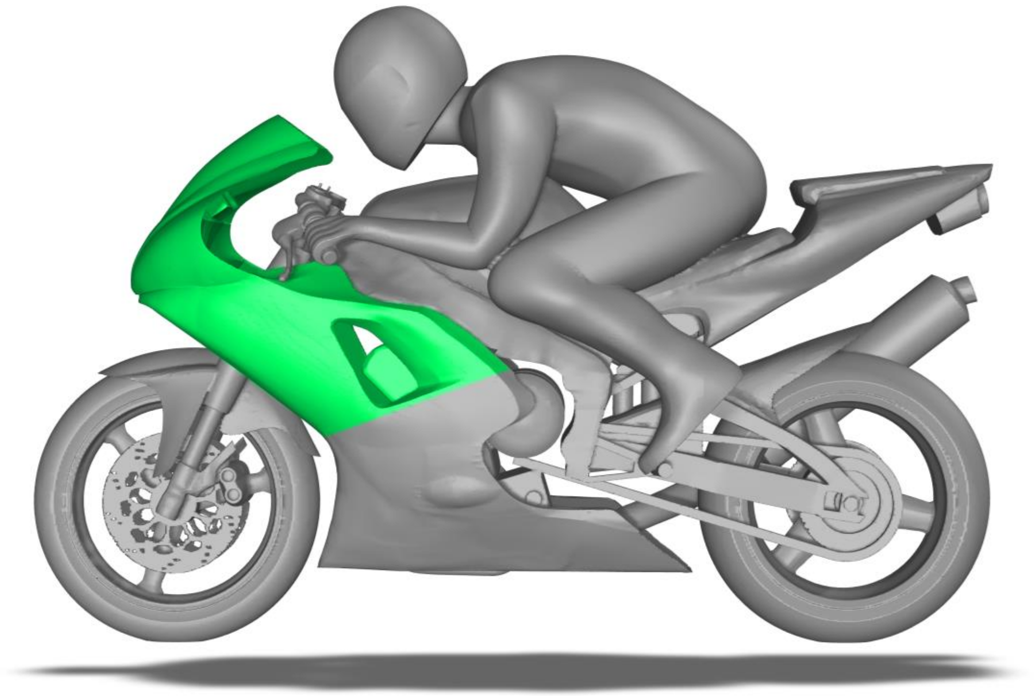
v2 model

Optimizations

Front fairing

	Initial	Increase width	Gap
C_d	0.4900	0.5026	+2.5714 %
C_l	0.0860	0.0922	+7.2093 %
F_d [N]	487.2254	499.7731	+12.5476
F_l [N]	85.5130	91.6814	+6.1683

	Initial	Decrease width	Gap
C_d	0.4900	0.4717	-3.7346 %
C_l	0.0860	0.1053	+22.4418 %
F_d [N]	487.2254	467.2327	-19.9927
F_l [N]	85.5130	104.3027	+18.7896

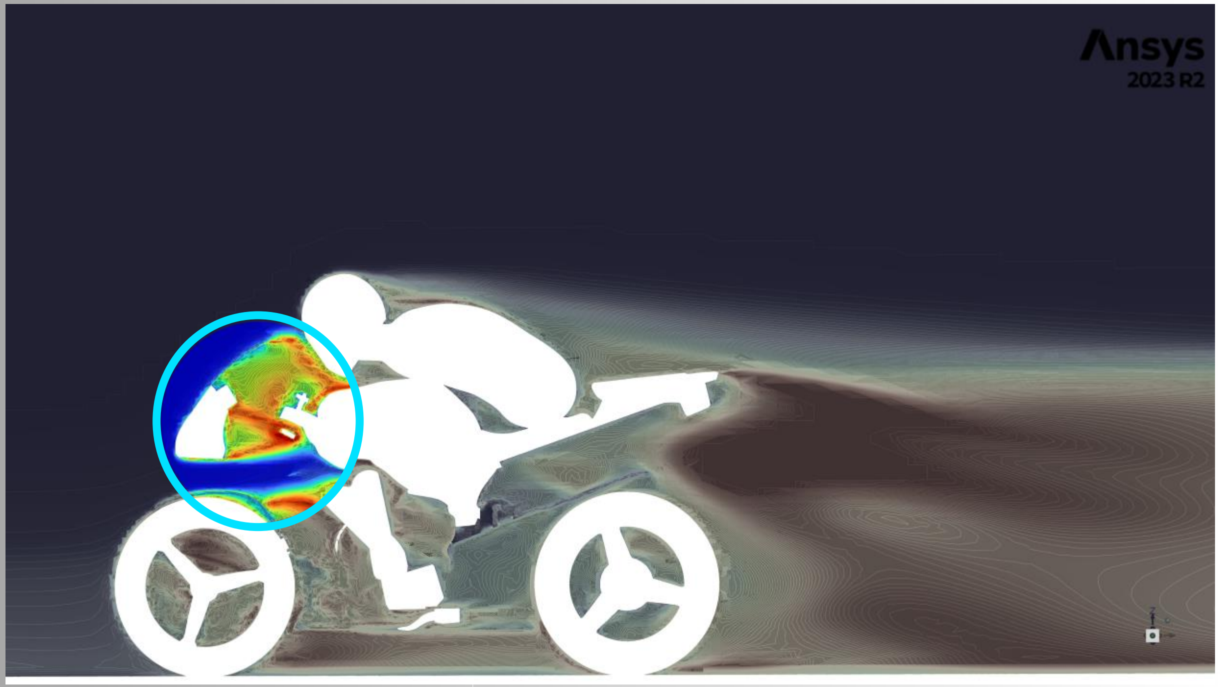


v2 model

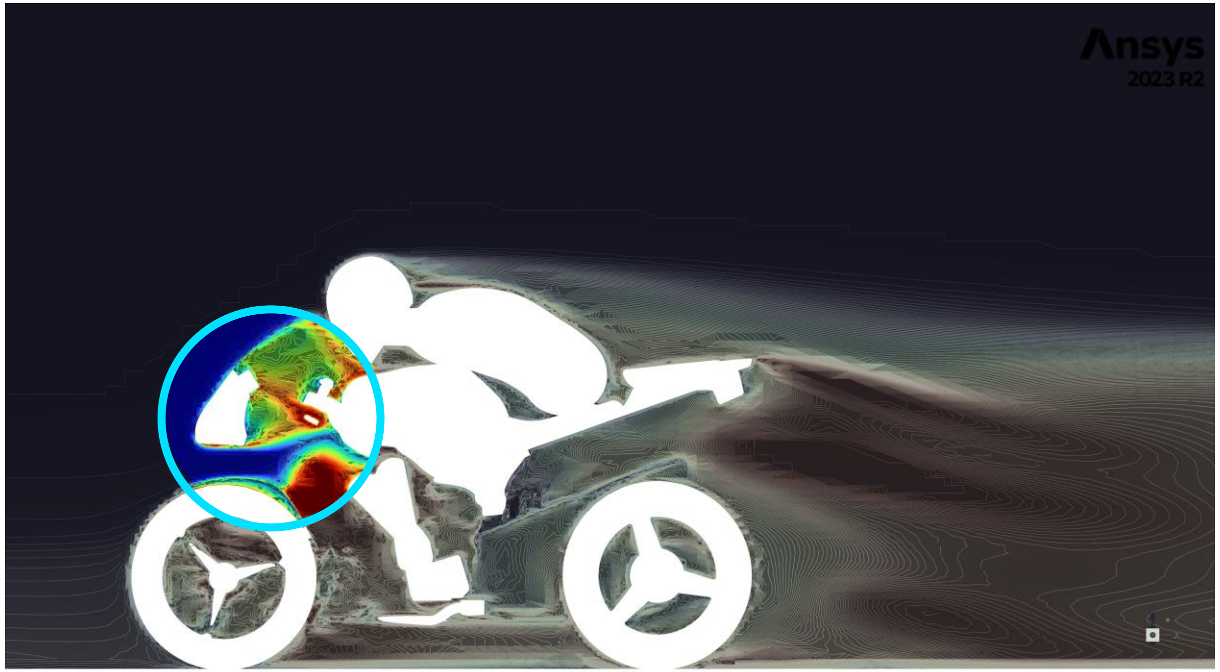
Optimizations

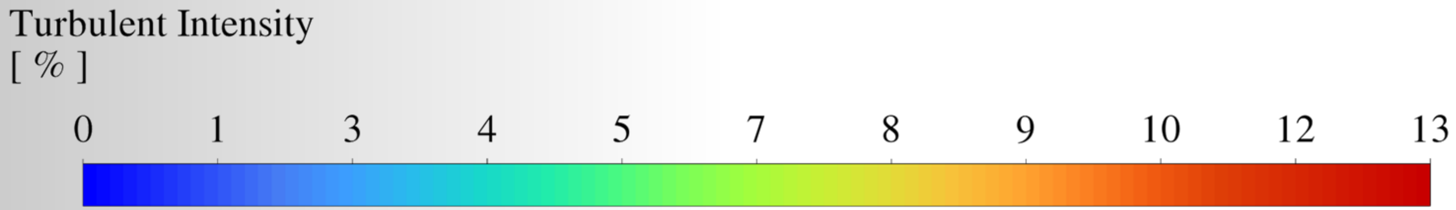
Front fairing

Initial



Front fairing width increase





v3 model

Optimizations

Lower fairing

Reason:

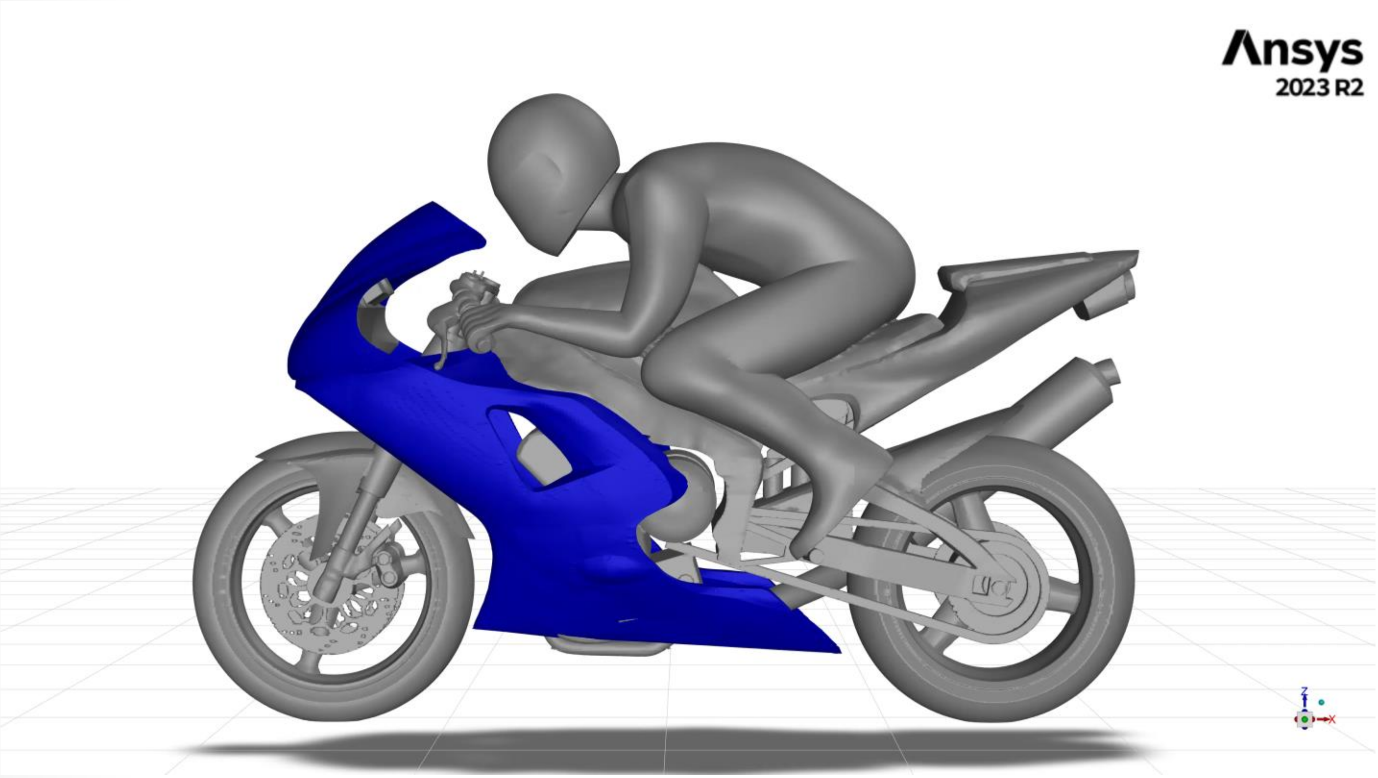
Turbulence behind front wheel

Modification:

Increase and decrease inclination of the lower fairing

Involved surfaces:

- Moving: Lower fairing
- Free to move: Central fairing
- Blocked: Front wheel, frame, exhaust



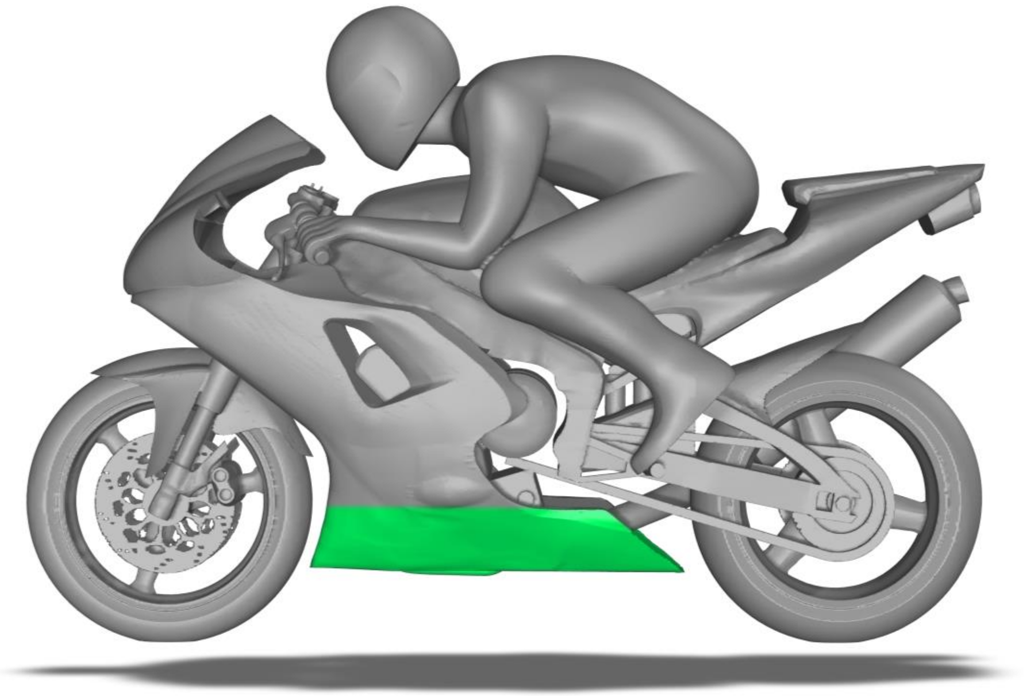
v3 model

Optimizations

Lower fairing

	Initial	Counterclockwise	Gap
C_d	0.4900	0.4909	+0.1836 %
C_l	0.0860	0.0687	-20.1162 %
F_d [N]	487.2254	489.8727	+2.6472
F_l [N]	85.5130	68.5562	-16.9567

	Initial	Clockwise	Gap
C_d	0.4900	0.4849	-1.040 %
C_l	0.0860	0.0914	+6.2790 %
F_d [N]	487.2254	482.0266	-5.1987
F_l [N]	85.5130	90.8584	+5.3453

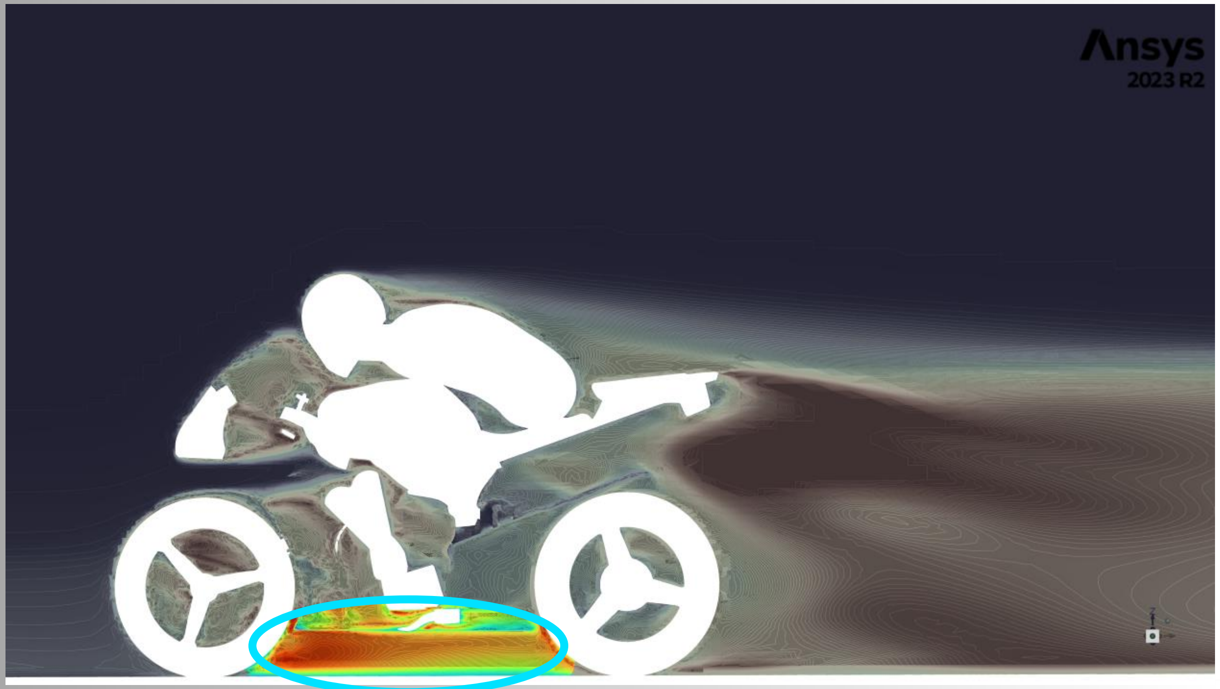


v3 model

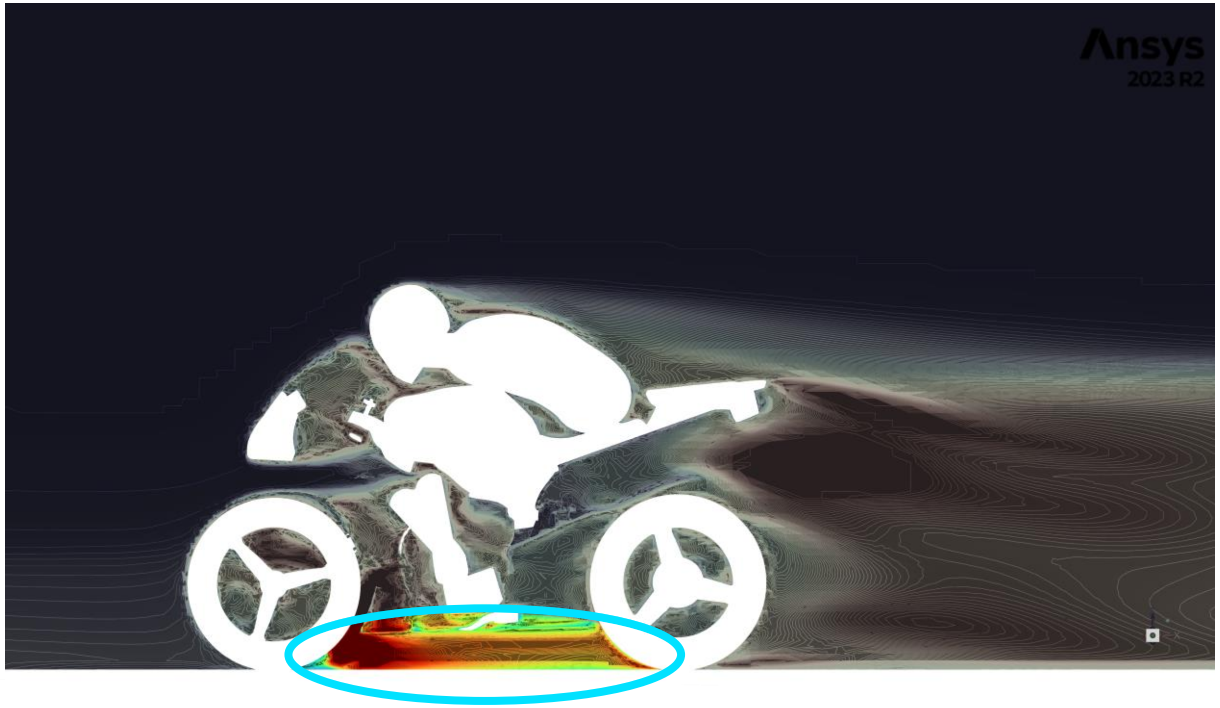
Optimizations

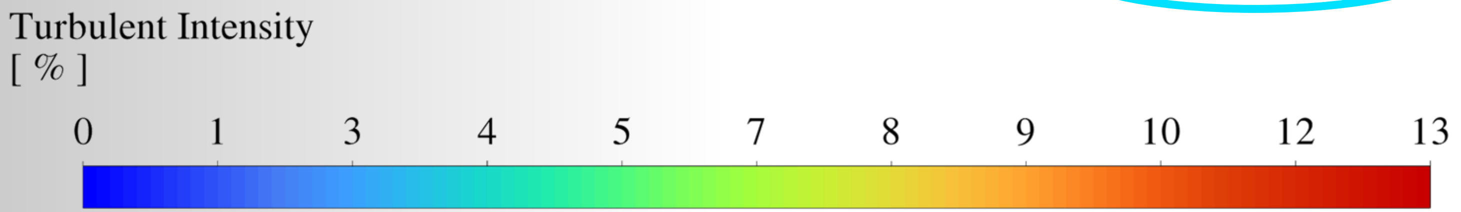
Lower fairing

Initial



Counterclockwise rotation of lower fairing





v4 model

Optimizations

Rear seat width

<u>Reason</u>:

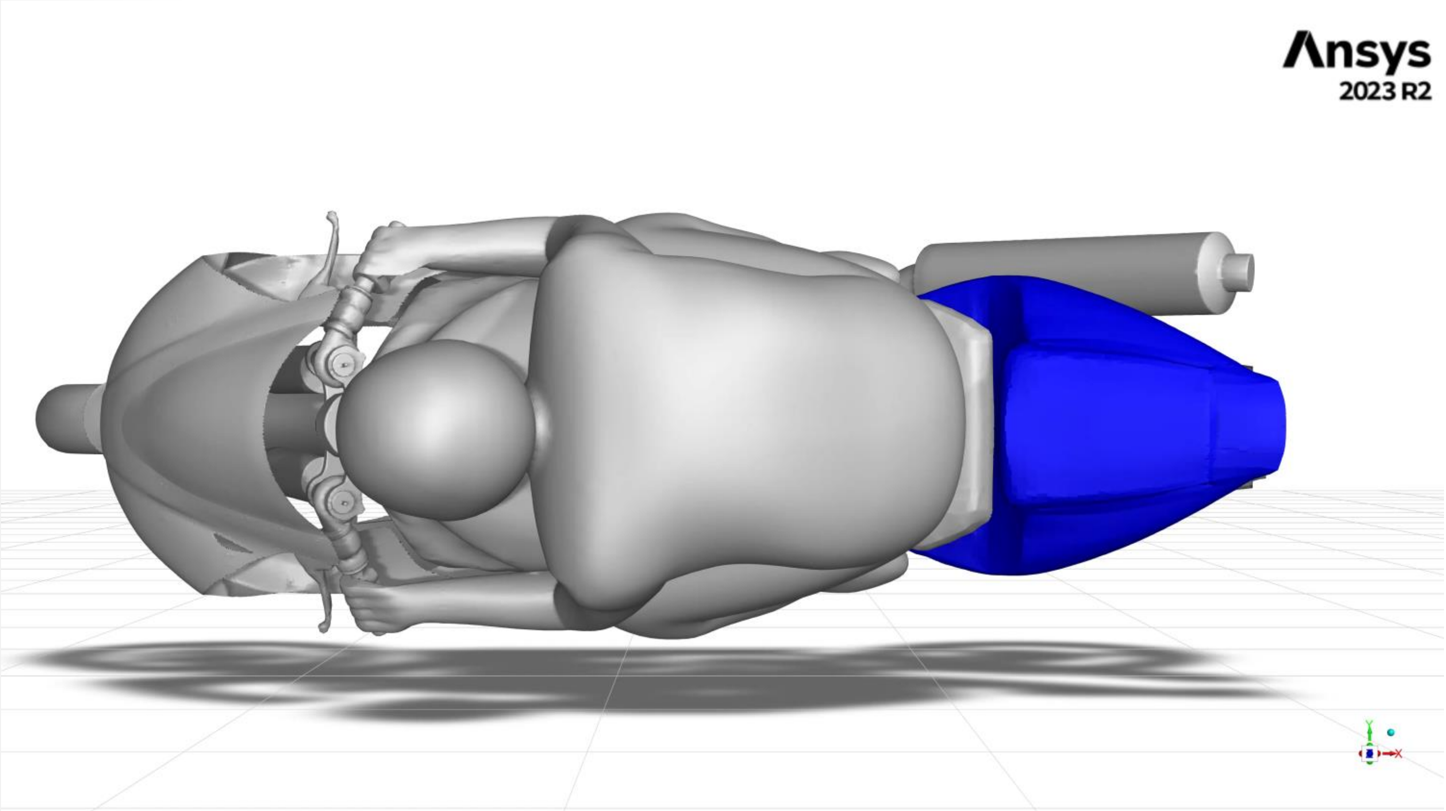
Turbulence behind the bike

<u>Modification</u>:

Increase and decrease width of the rear seat

<u>Involved surfaces</u>:

- Moving: Rear seat
- Free to move: Rear seat support
- Blocked: Seat, rider's body, exhaust



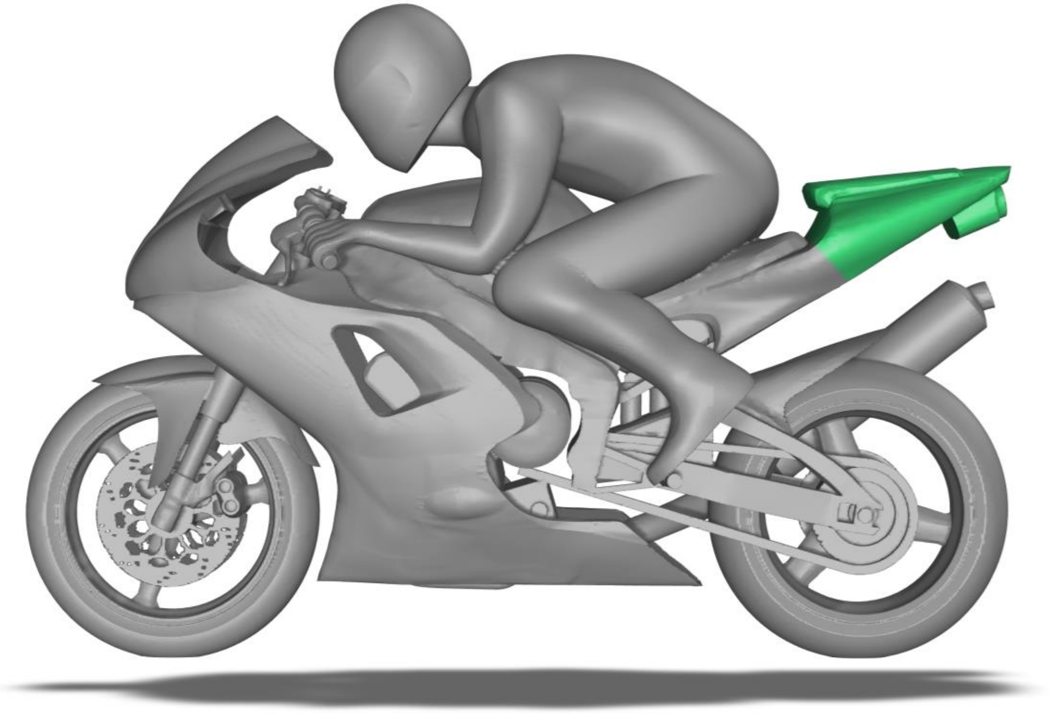
v4 model

Optimizations

Rear seat width

	Initial	Increased	Gap
C_d	0.4900	0.4912	+0.2448 %
C_l	0.0860	0.0897	+4.3023 %
F_d [N]	487.2254	488.4186	+1.1932
F_l [N]	85.5130	89.1920	+3.6790

	Initial	Decreased	Gap
C_d	0.4900	0.4880	-0.4081 %
C_l	0.0860	0.0840	-2.3255 %
F_d [N]	487.2254	485.2367	-1.9886
F_l [N]	85.5130	83.5243	-1.9886

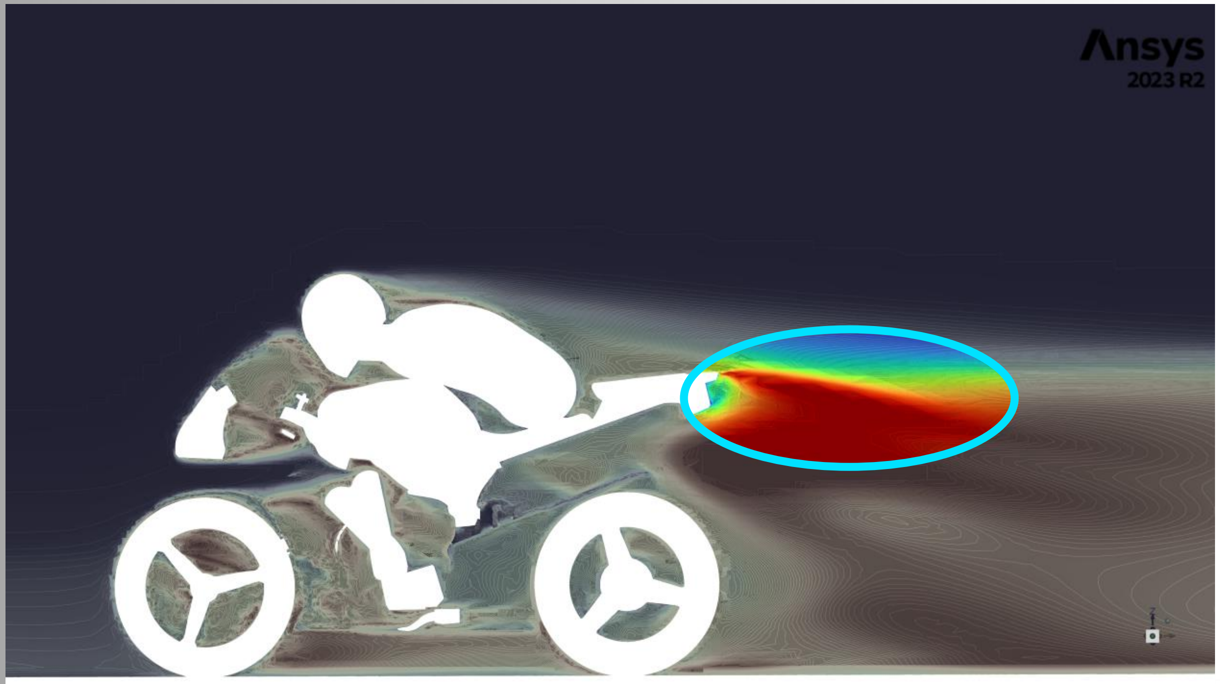


v4 model

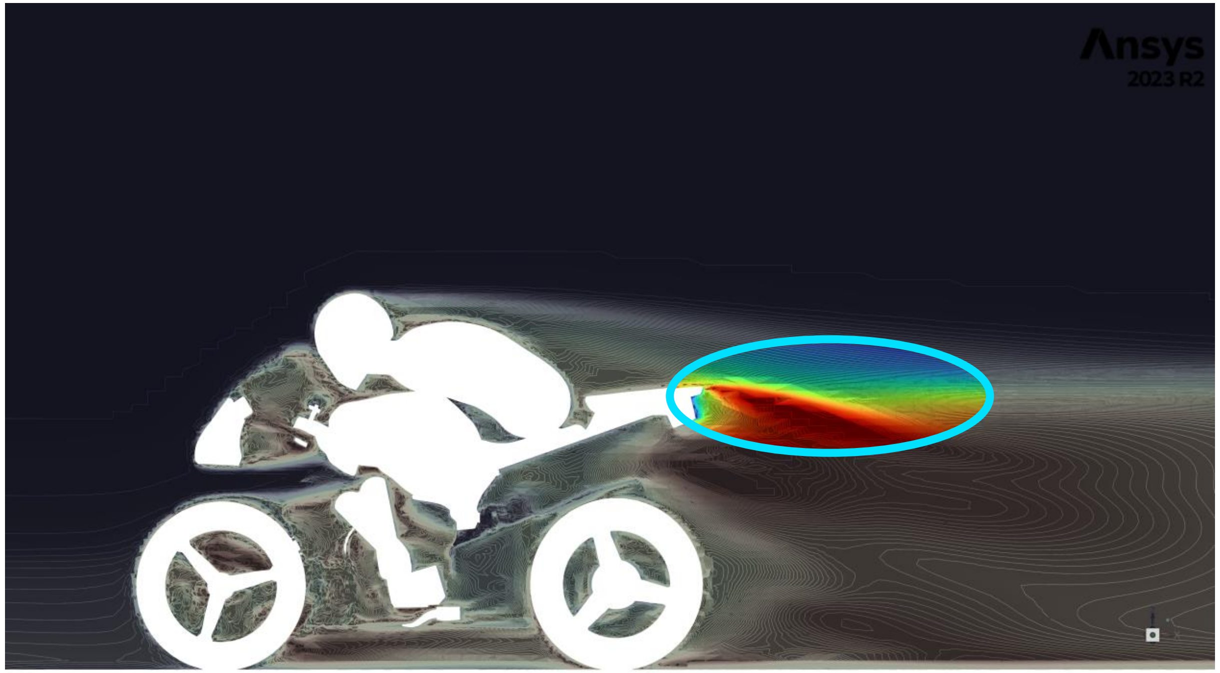
Optimizations

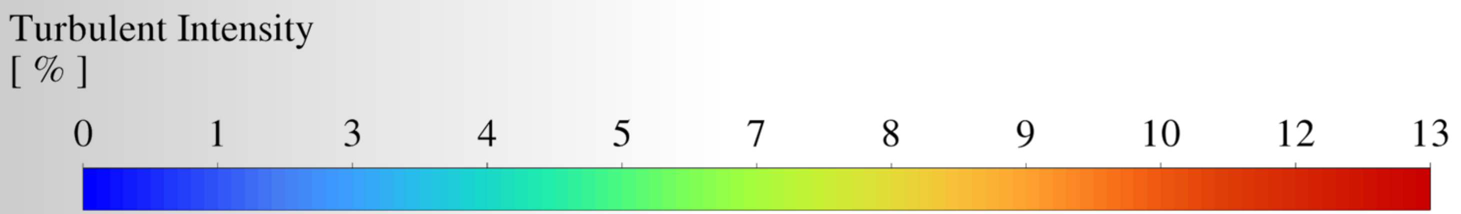
Rear seat width

Initial



Rear seat width decrease





v5 model

Optimizations

Rear seat height

Reason:

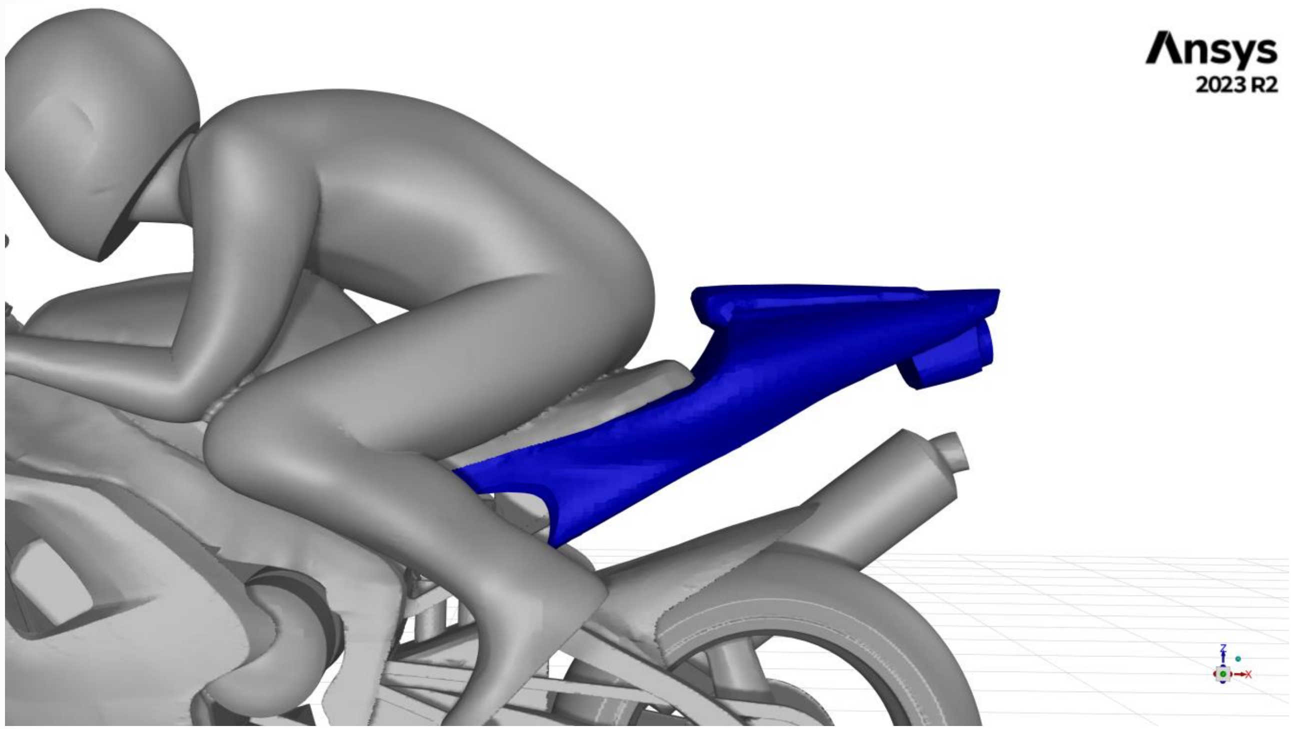
Turbulence behind the bike

Modification:

Increase and decrease height of the rear seat

Involved surfaces:

- Moving: Rear seat
- Free to move: Rear seat support
- Blocked: Seat, rider’s body, exhaust



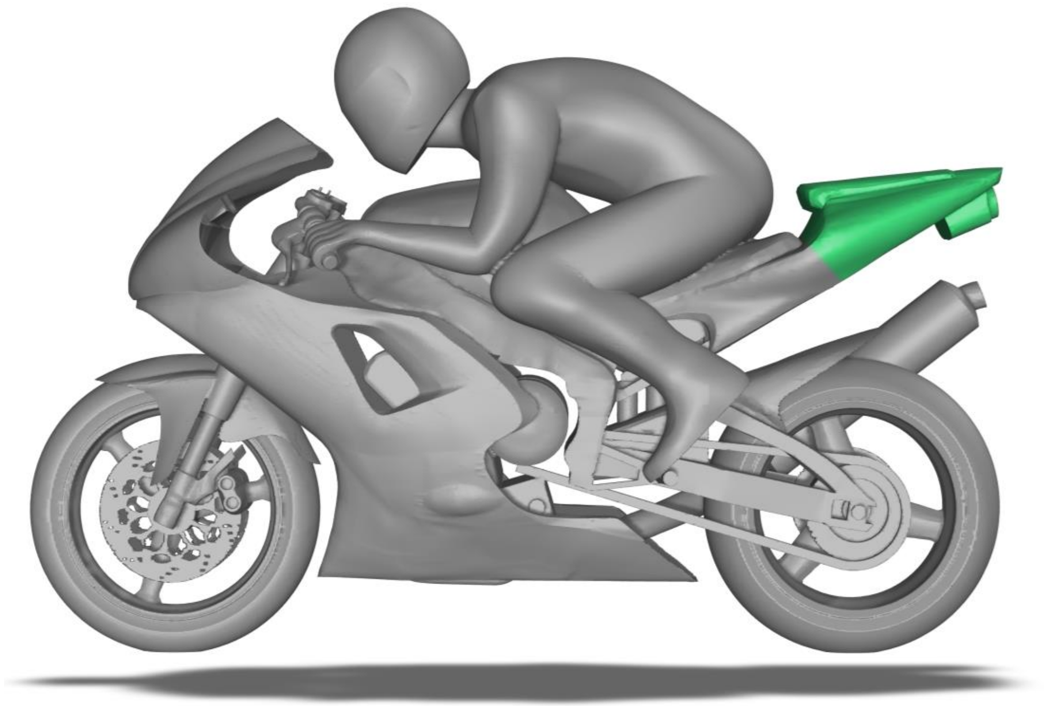
v5 model

Optimizations

Rear seat height

	Initial	Increased	Gap
C_d	0.4900	0.4890	-0.2040 %
C_l	0.0860	0.0938	+9.0697 %
F_d [N]	487.2254	486.2311	-0.9943
F_l [N]	85.5130	93.2688	+7.7558

	Initial	Decreased	Gap
C_d	0.4900	0.4851	-1.023 %
C_l	0.0860	0.0870	+1.1627 %
F_d [N]	487.2254	482.3532	-4.8722
F_l [N]	85.5130	86.5073	+0.9943

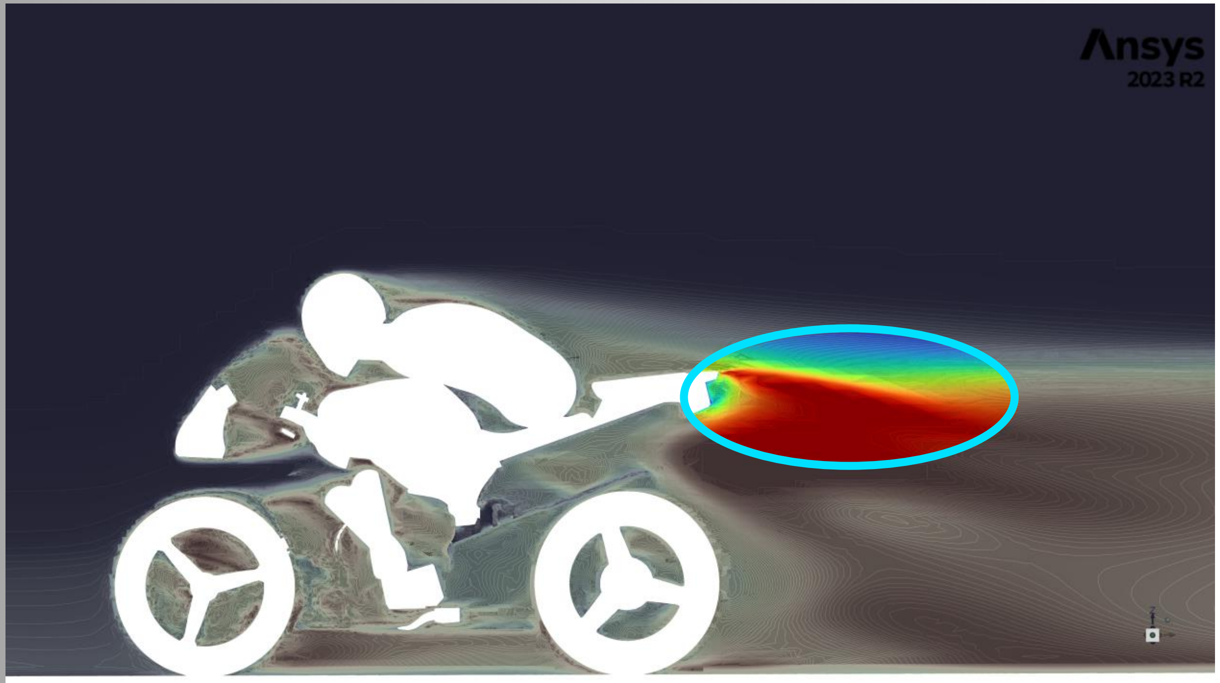


v5 model

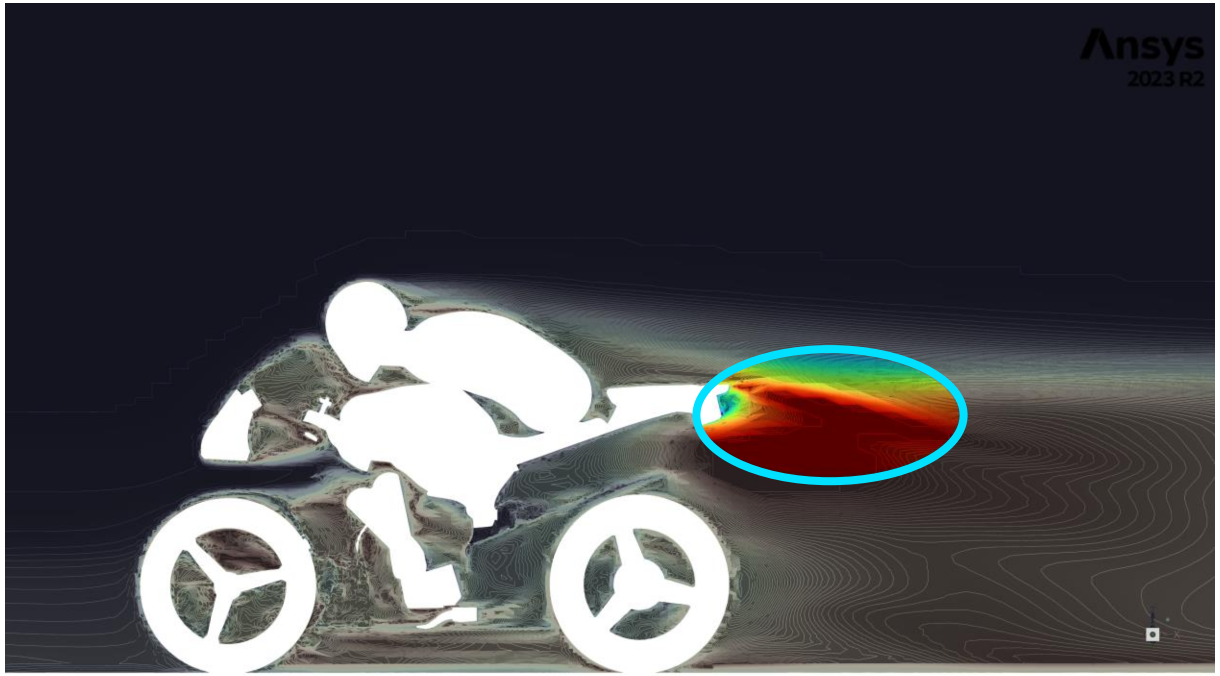
Optimizations

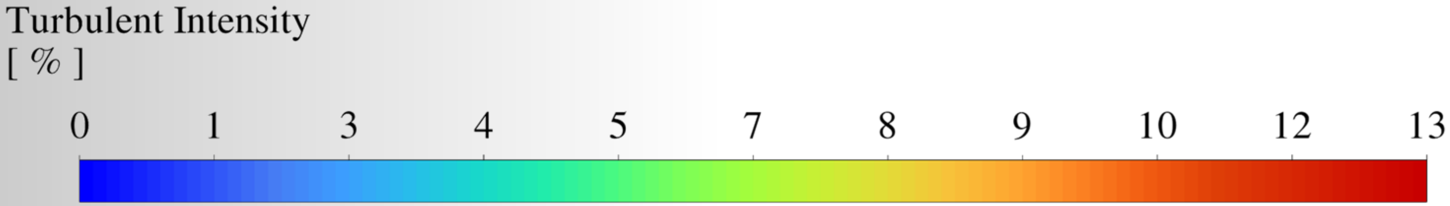
Rear seat height

Initial



Rear seat height increase





Multi-Sol model

Optimizations

Combination

<u>Selection criterion</u>:

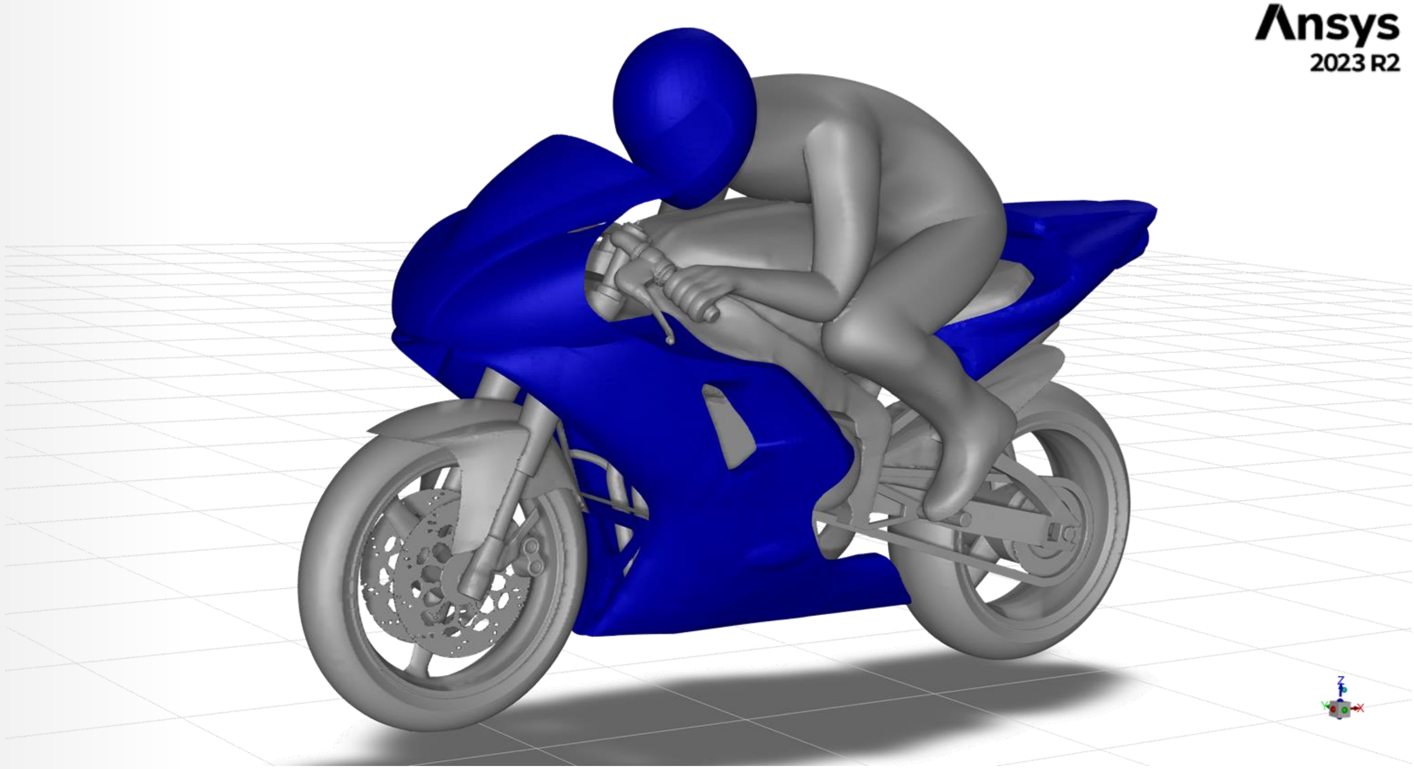
Superposition of the best optimizations for each turbulence zone

<u>Method</u>:

Use of Multi-Sol with predetermined amplification coefficient

<u>Involved surfaces</u>:

- Superposition of individual surfaces

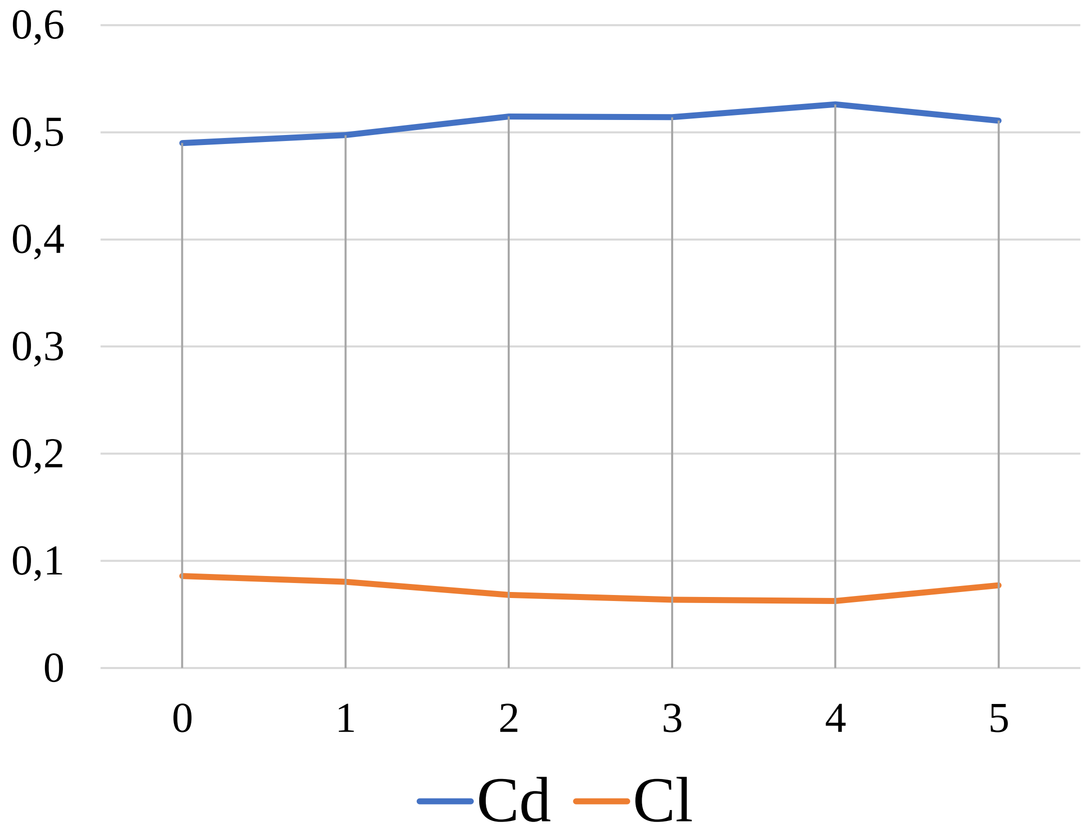


Multi-Sol model

Optimizations

Combination

	C_d	C_l	F_d [N]	F_l [N]
Initial	0.4900	0.0860	487.2255	85.5130
Helmet translation	+1.4897 %	-6.1627 %	+2.5259	-6.038
Front fairing decrease	+5.0408 %	-20.4651 %	+22.1995	-17.8140
Lower fairing rotation (CCW)	+4.8979 %	-25.8140 %	+21.8468	-22.3247
Rear seat width decrease	+7.3265 %	-27.2093 %	+35.0749	-23.3415
Rear seat height decrease	+4.2653 %	-10.0090 %	+ 18.7765	-8.8550



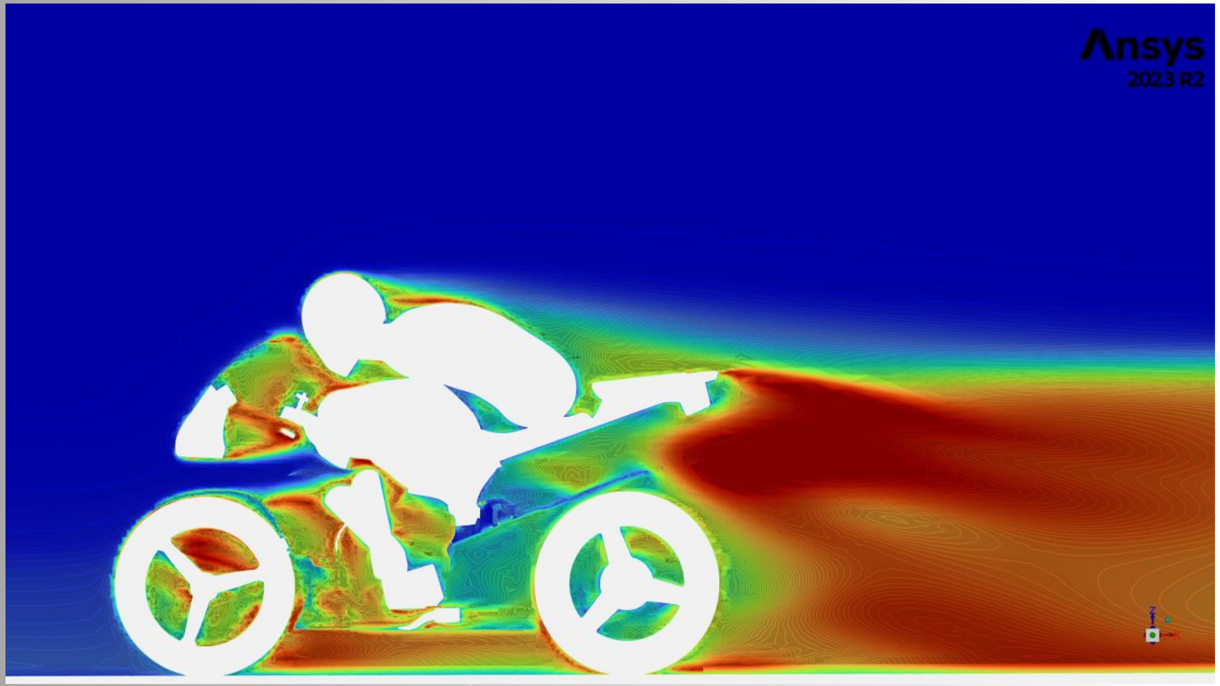
The values of the gaps represented in this table are referred to the optimization above, allowing to sequentially check which is more significant for the final value.
The last values represent the combination of all the five optimizations.

Multi-Sol model

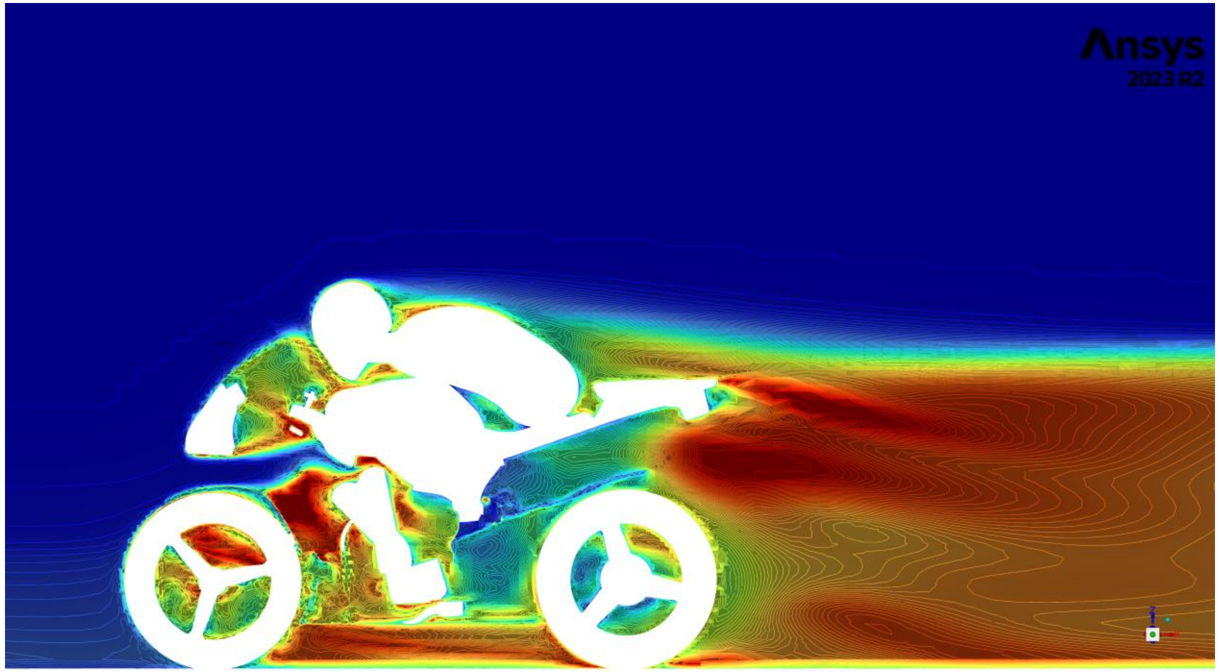
Optimizations

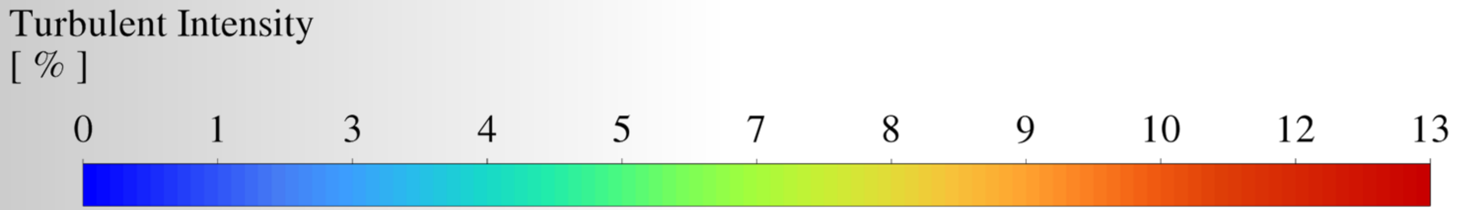
Combination

Initial



Combination of improvements





Conclusions

Results analysis

Best and worst coefficients

Individual improvement

	C_d %	C_l %
Helmet translation	+1.4897	-6.1627
Front fairing increase	+2.5714	+7.2093
Front fairing decrease	-3.7346	+22.4418
Lower fairing rotation (CCW)	+0.1836	-20.1162
Lower fairing rotation (CW)	-1.0408	+6.2790
Increase rear seat width	+0.2448	+4.3023
Decrease rear seat width	-0.4081	-2.3255
Increase rear seat height	-0.2040	+9.0697
Decrease rear seat height	-1.0013	+1.1627

Combination

	C_d %	C_l %
Initial	-	-
Helmet translation	+1.4897	-6.1627
Front fairing decrease	+5.0408	-20.4651
Lower fairing rotation (CCW)	+4.8979	-25.8139
Decrease rear seat width	+7.3265	-27.2093
Decrease rear seat height	+4.2653	-10.0411

The values of the gaps represented in this table are referred to the optimization above, allowing to sequentially check which is more significant for the final value.
The last values represent the combination of all the five optimizations.

Future developments

- More combinations of the improvements
- Add new aerodinamic elements to the model:
  - Wheel covers
  - Front wings
  - Rear wings
  - Air conveyor

Thanks for the attention