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Go-kart aerodynamic optimization by means of CFD and RBF Mesh Morphing

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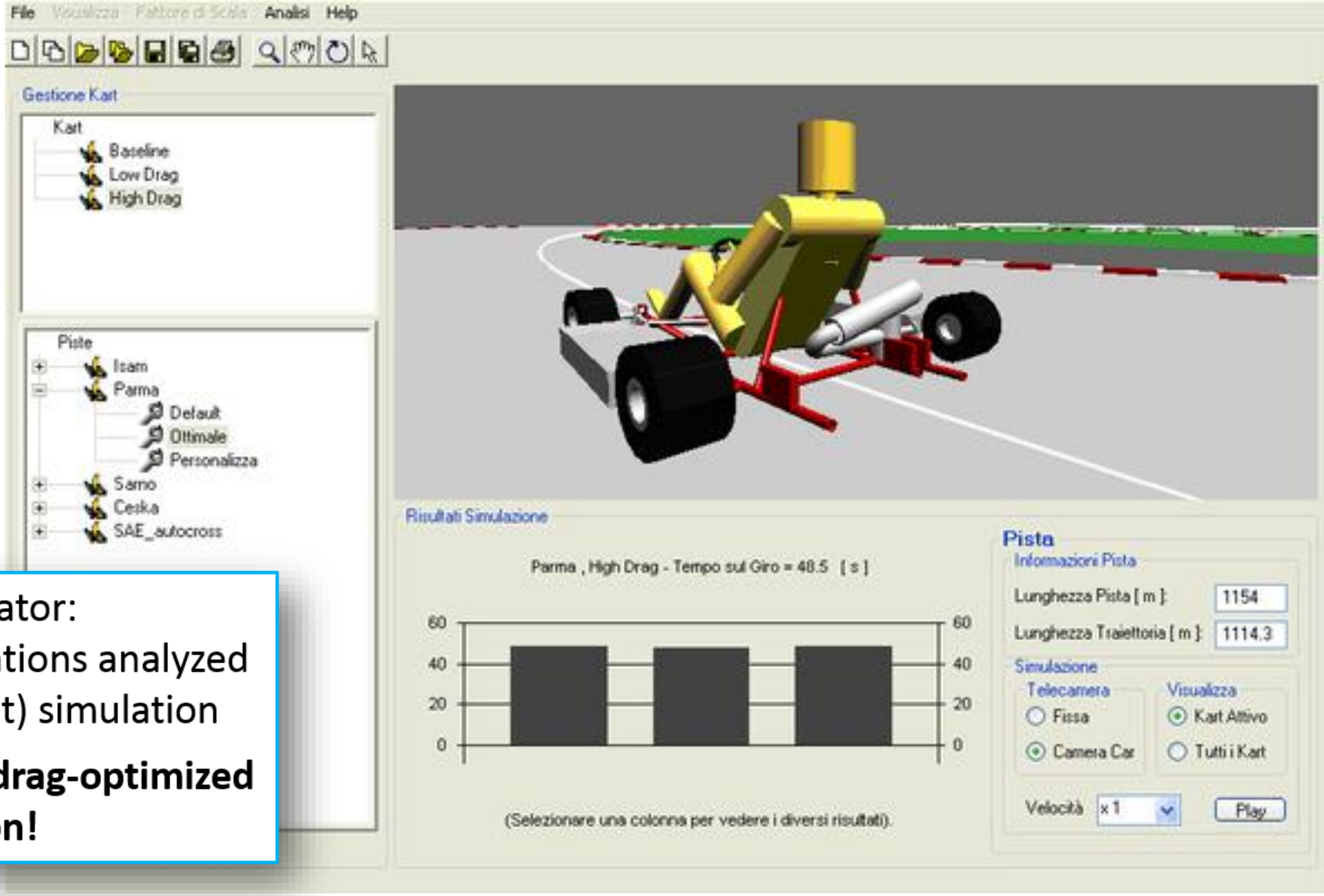
Goals

The aim of this study is the optimization of a go-kart bodywork shape, in terms of drag-force reduction, by means of CFD and RBF Mesh Morphing, evaluating the best configuration also in terms of downforce value and driver body size

Topic choice

Why go-kart aerodynamics?

- **High C_d**, between 0,75 and 0,9
- Considerable lap-time improvement thanks to aerodynamic optimization



KP Studio lap-time simulator:

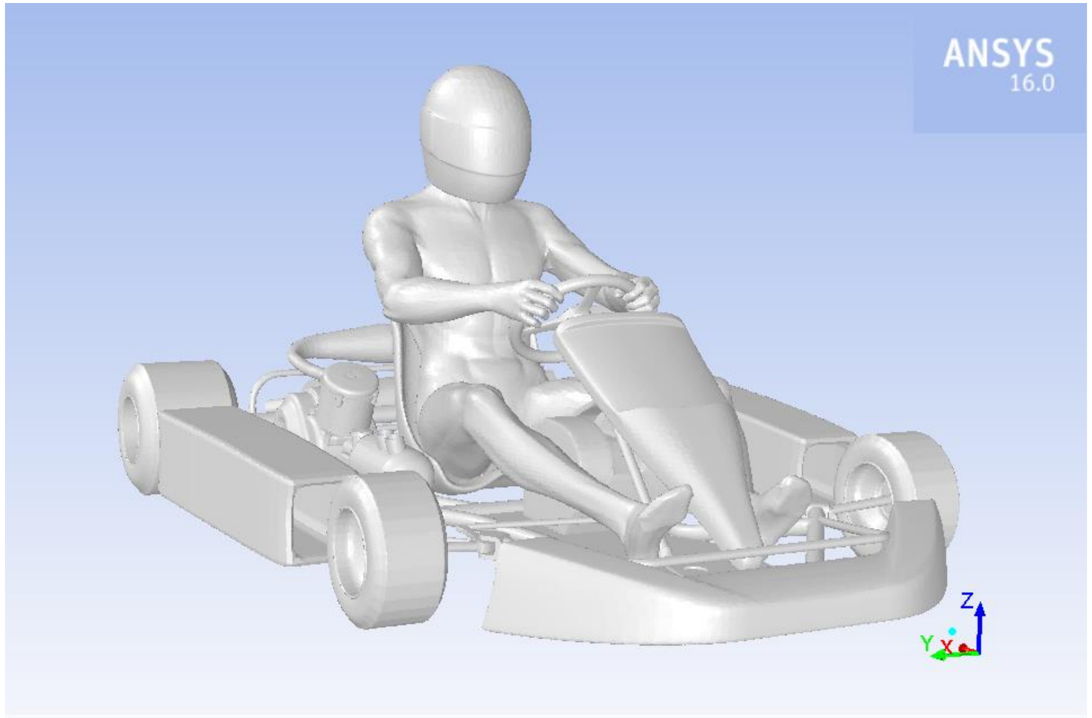
- 3 drag-force configurations analyzed
- Parma circuit (1154 mt) simulation

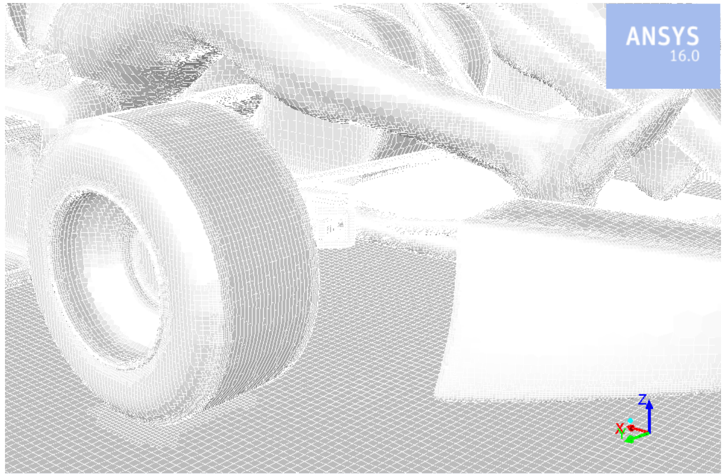
0,2 sec gained with the drag-optimized configuration!

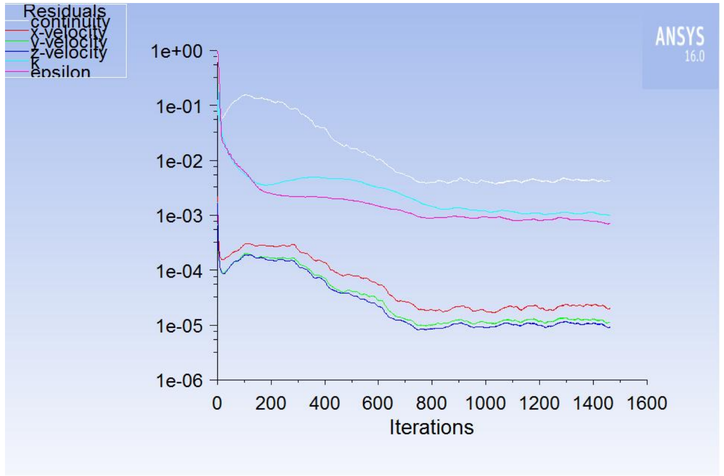
CFD Model

CFD Model set-up inside ANSYS Fluent 16.0 at 90 km/h and *standard* atmospheric conditions

- **6,5 Million** fluid cells
- ***Realizable k-ε*** turbulence model
- ***Moving wall*** boundary conditions
- **1461 iterations** at convergence
- Calculation activities run at UTV **HPC facilities**



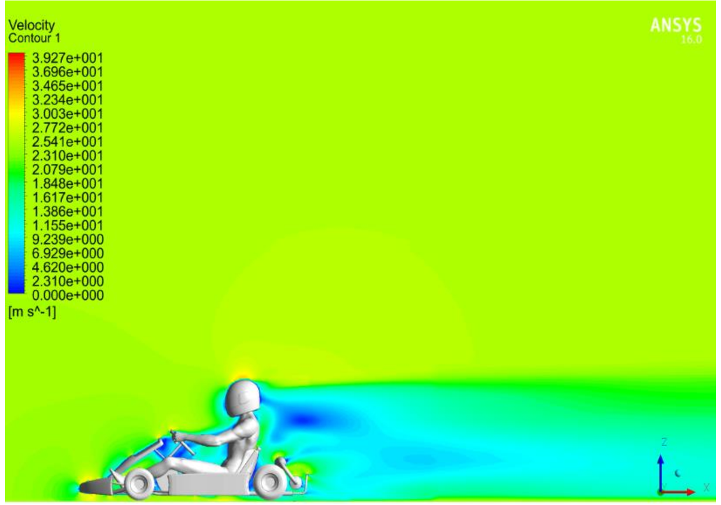


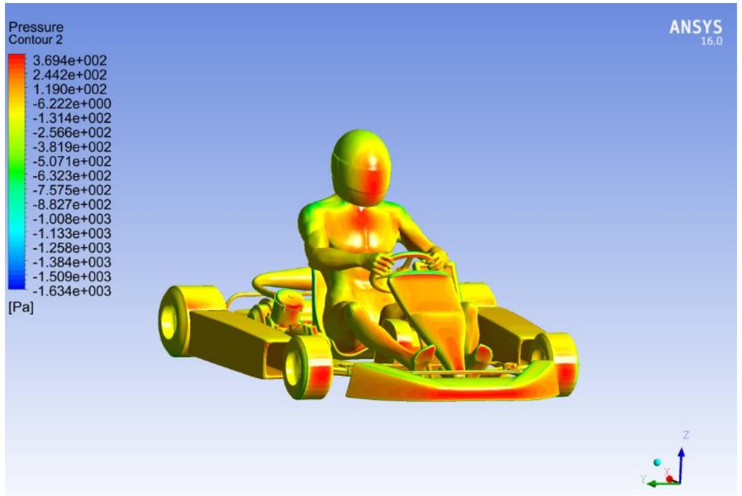


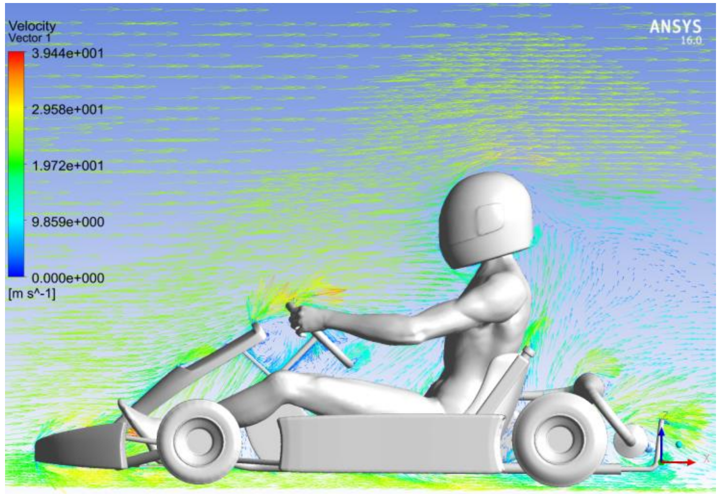
CFD Results

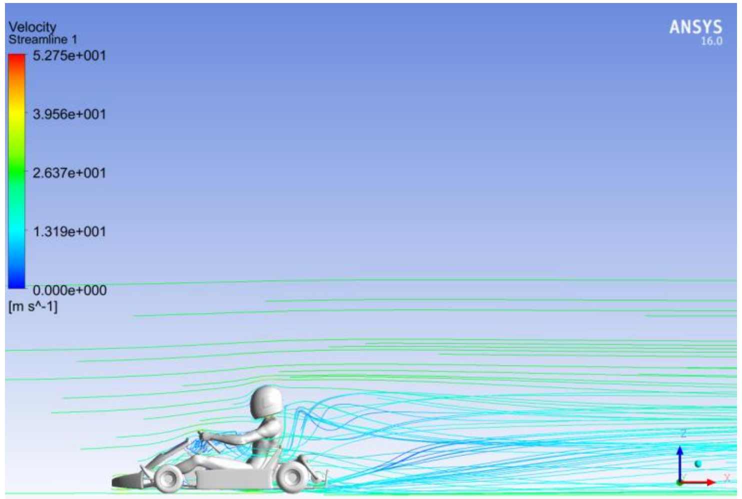
Postprocessing using ANSYS CFD Post

- Fluid dynamic variables plots
- Streamlines
- Vectorial fields
- Custom plot surfaces definition









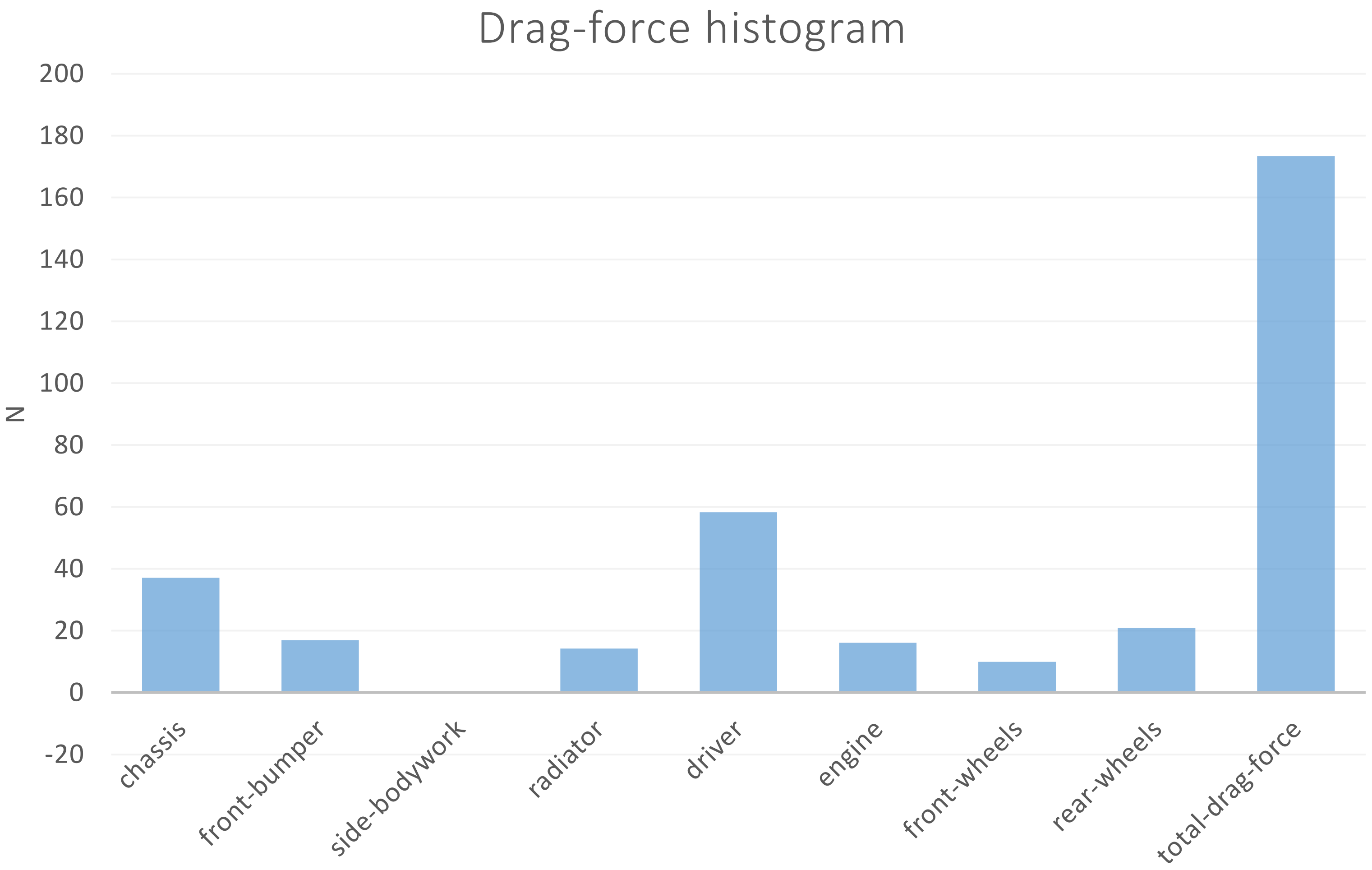
CFD Results

Optimization areas chosen in terms of numerical drag-force and c_d values

$$D = \frac{1}{2}\rho S v^2 c_d$$

$$D = 173,35\ N$$

$$c_d = 0,794$$



- 33% of total drag caused by the driver
- Relevant front bodywork contribution
- Lateral bodywork contribution apparently negligible but fundamental in driving flow over go-kart rear wheels

CFD Results

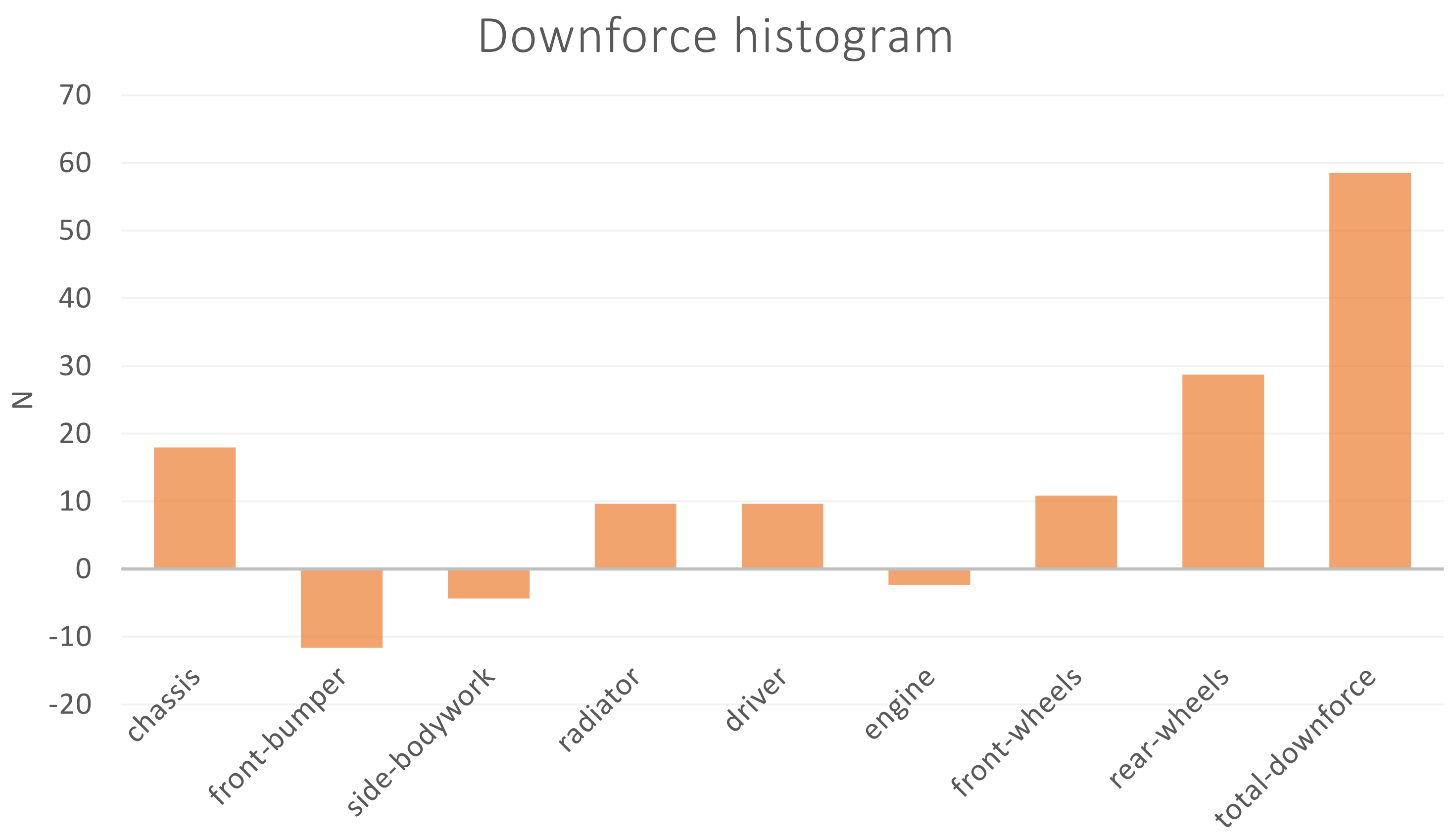
Downforce and c_l numerical results

$$L = \frac{1}{2}\rho S v^2 c_l$$

$$-L = 58{,}51\,N$$

$$c_l = -0{,}268$$

- Positive total downforce value
- 49% of total value caused by rear wheels
- Lifting contribution from front bumper

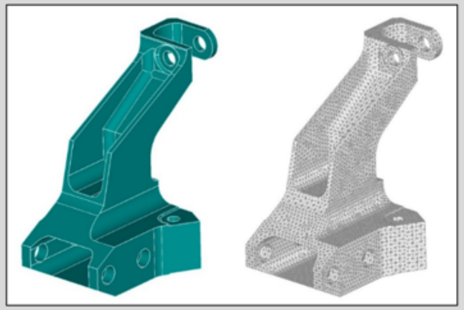


CFD and Mesh Morphing

TRADITIONAL APPROACH

3D MODEL

MESHING

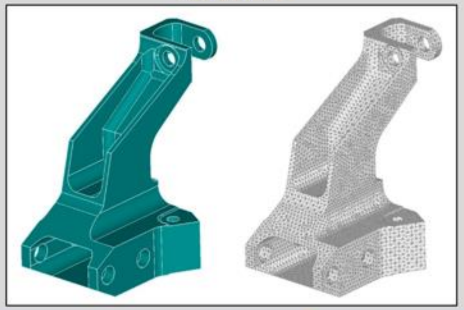


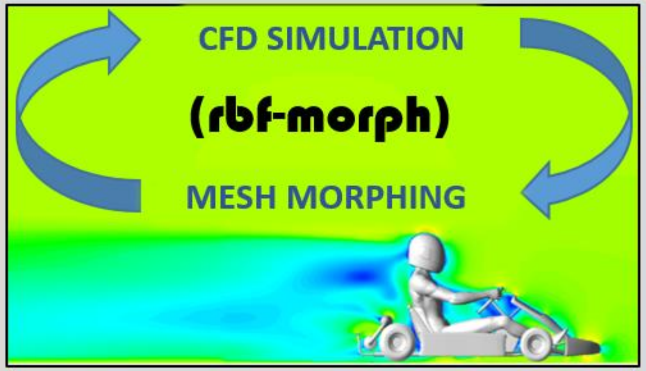
OPTIMIZED SOLUTION AFTER n-CYCLES

MESH MORPHING

3D MODEL

MESHING





AUTOMATIC PARAMETRIC OPTIMIZATION

RBF Mesh Morphing

Mesh morpher used:

(rbf-morph)

Radial Basis Functions:

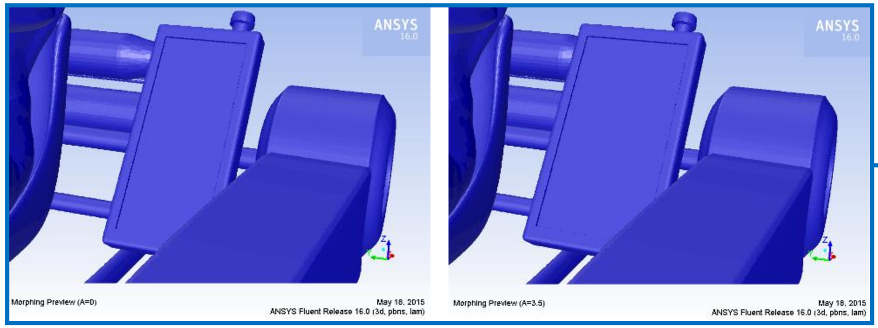
INPUT

- Radial Functions set
- Source points
- Assigned displacements

OUTPUT

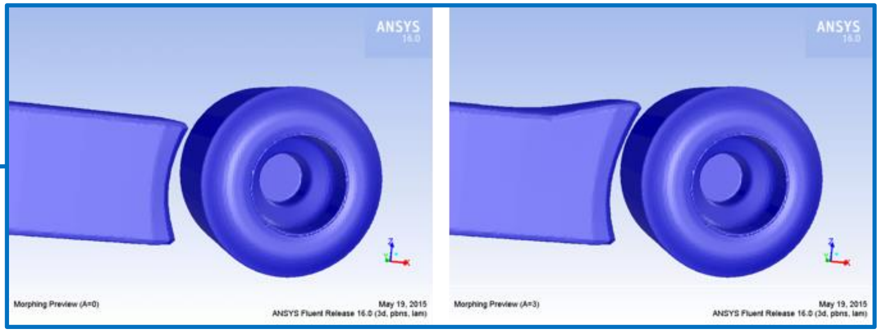
- Motion solution

Set-up shape changes



OPTIMIZATION

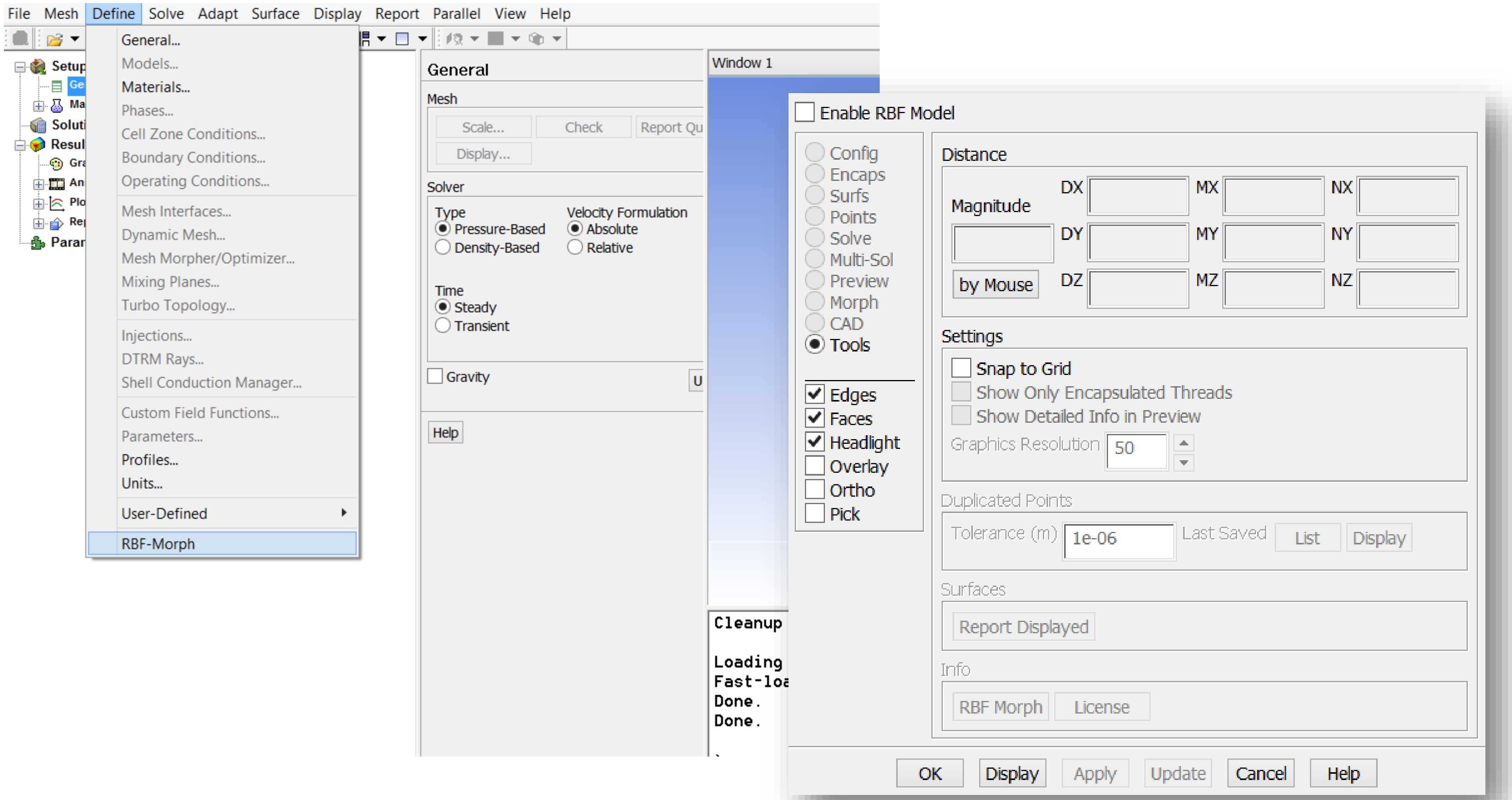
Design shape changes



(rbf-morph)™ ANSYS®

RBF-Morph

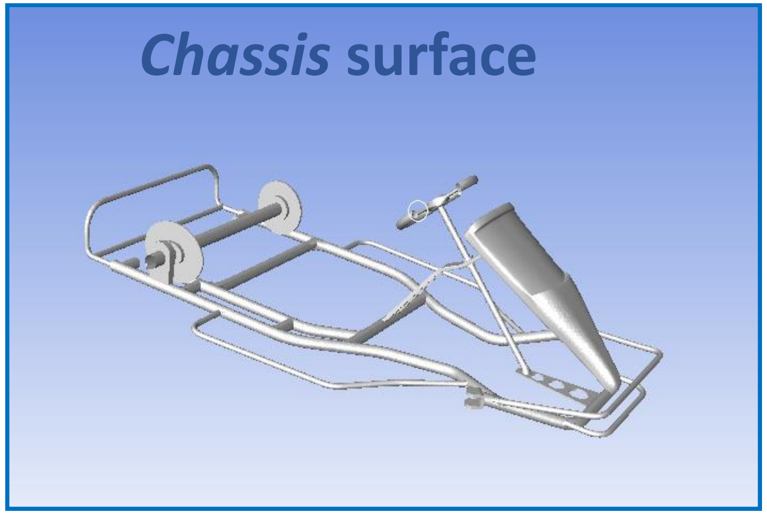
RBF-Morph Grafic-User-Interface inside ANSYS Fluent

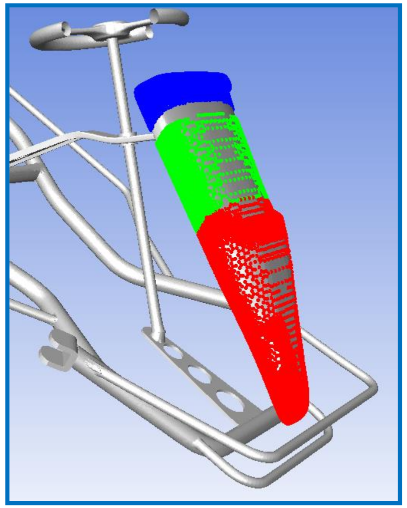


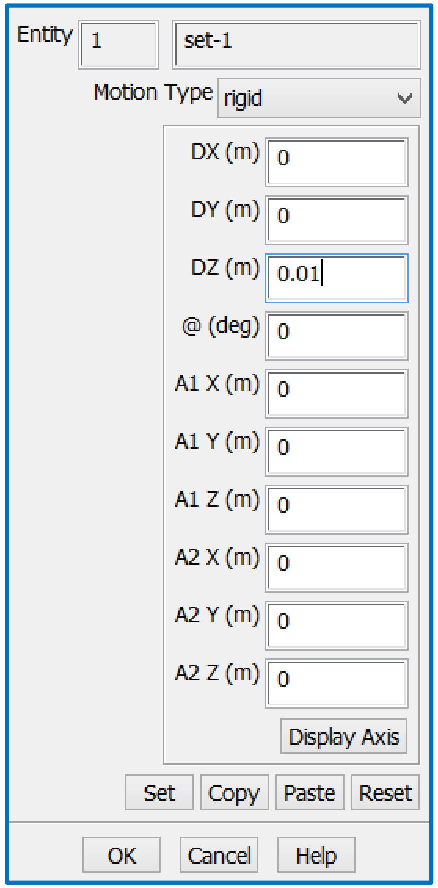
Front panel vertical translation

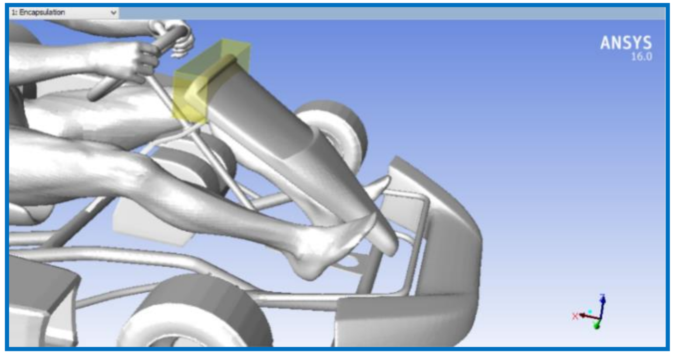
Motion set-up

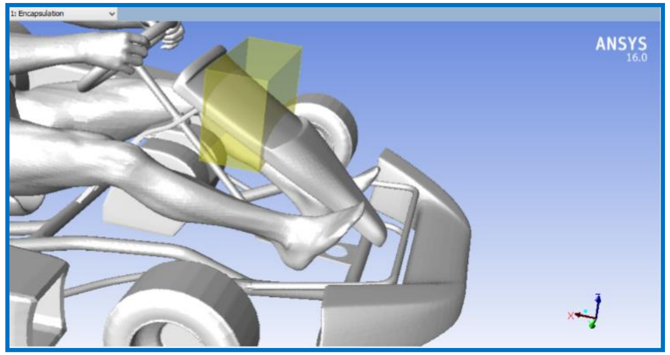
- ***Chassis* surface** selection
- Defintion of **3 *selection encaps***
- **Unitary vertical translation** of selected points inside selection encaps

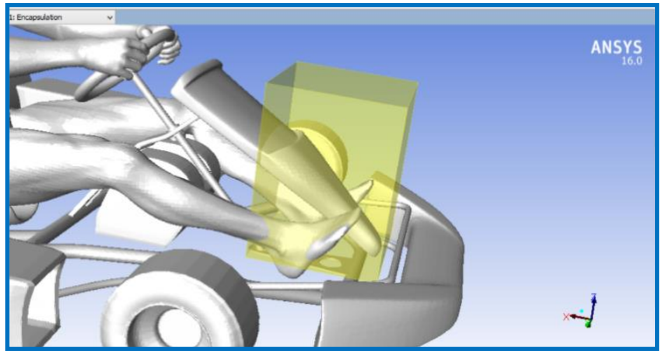








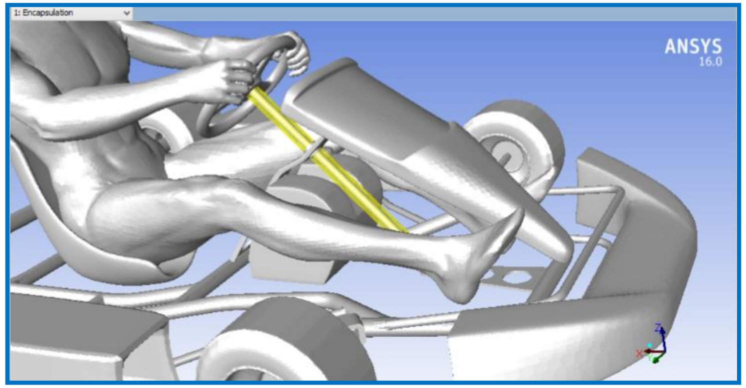


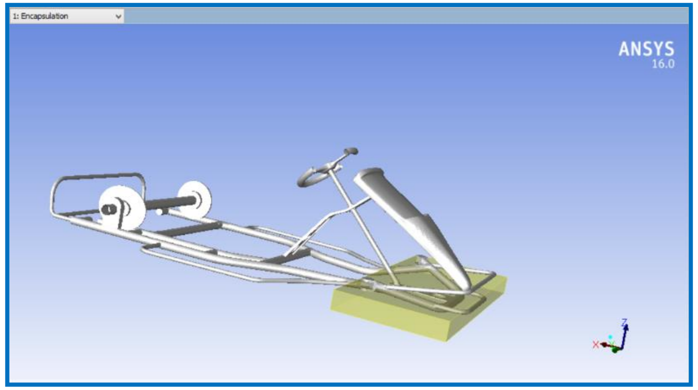


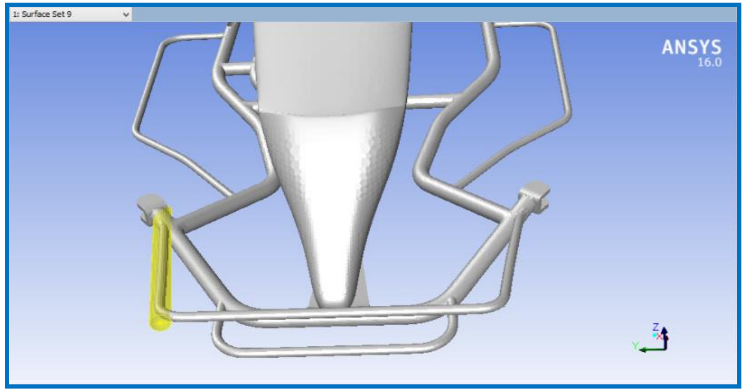
Shape changes

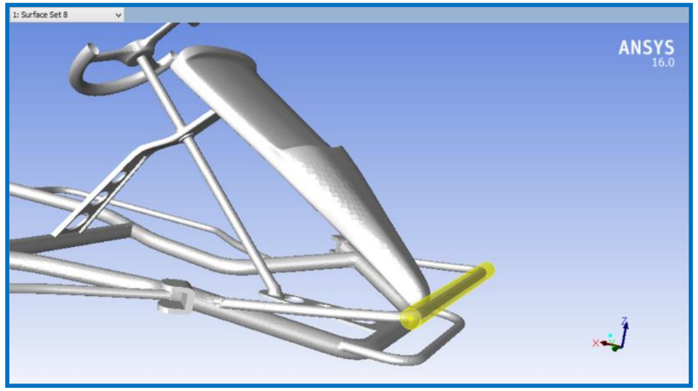
Locking **surface sets**

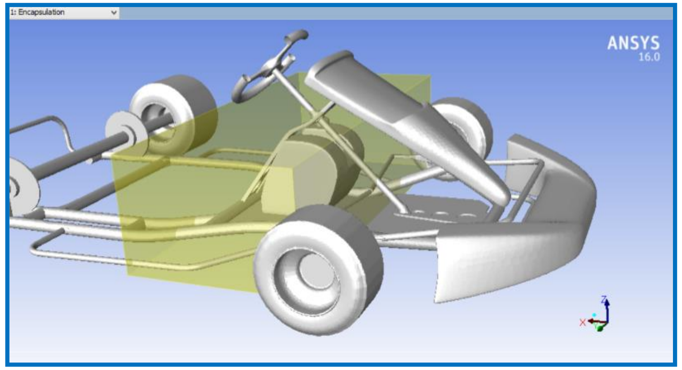
- ***Chassis*** **surface** selection
- Definition of **7 selection encaps**
- **Null motion** prescribed to selected surfaces

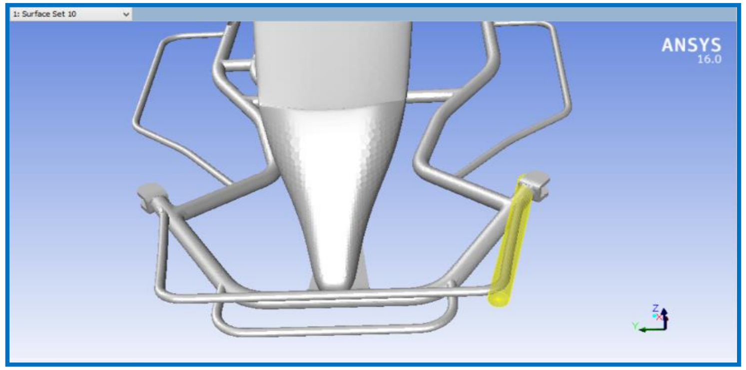


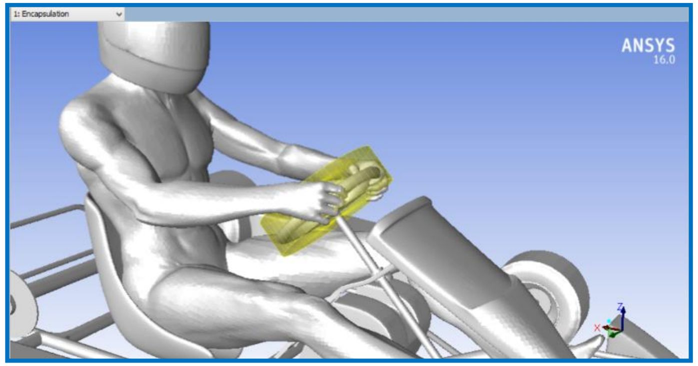








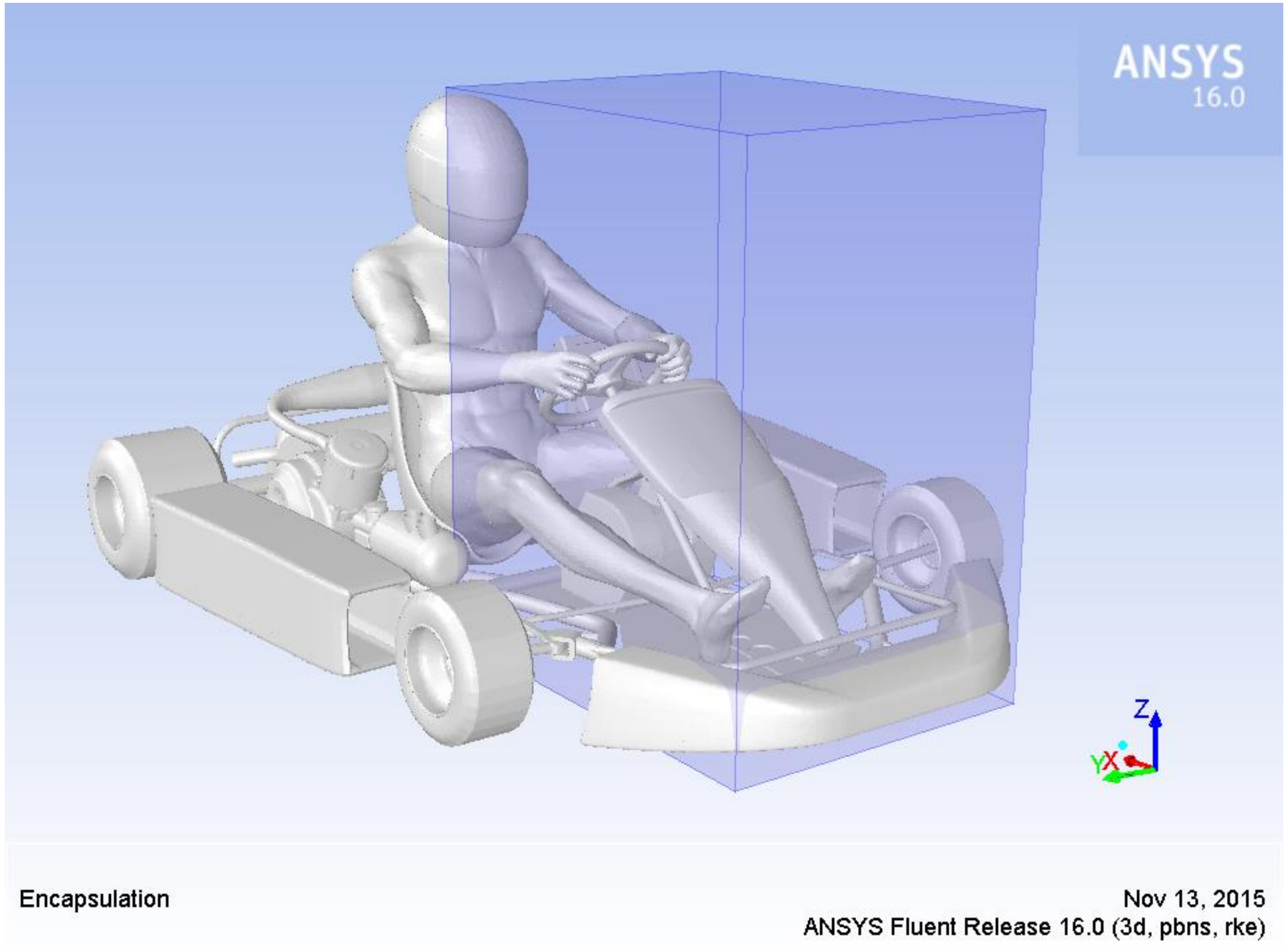




Shape changes

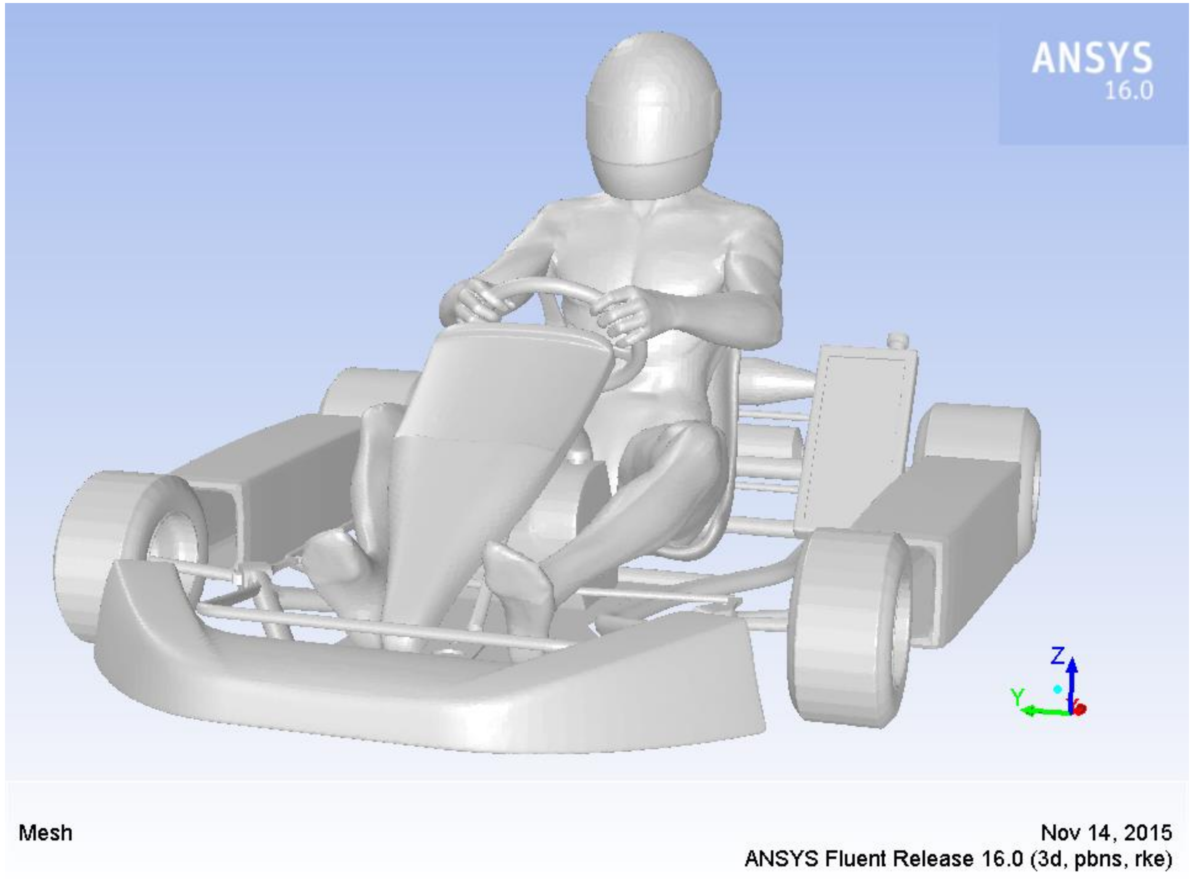
Morphing domain

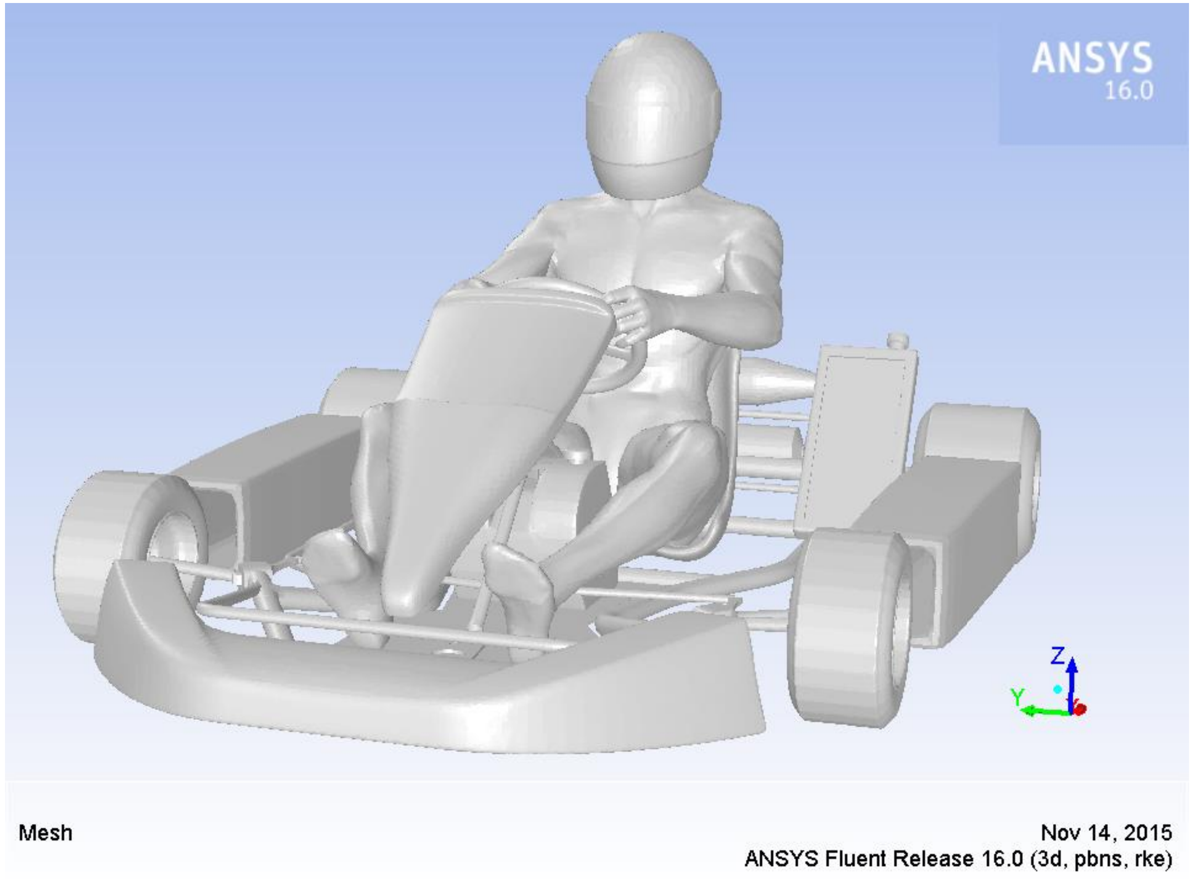
- Reduces the morphing action extent within the selected domain



Shape changes

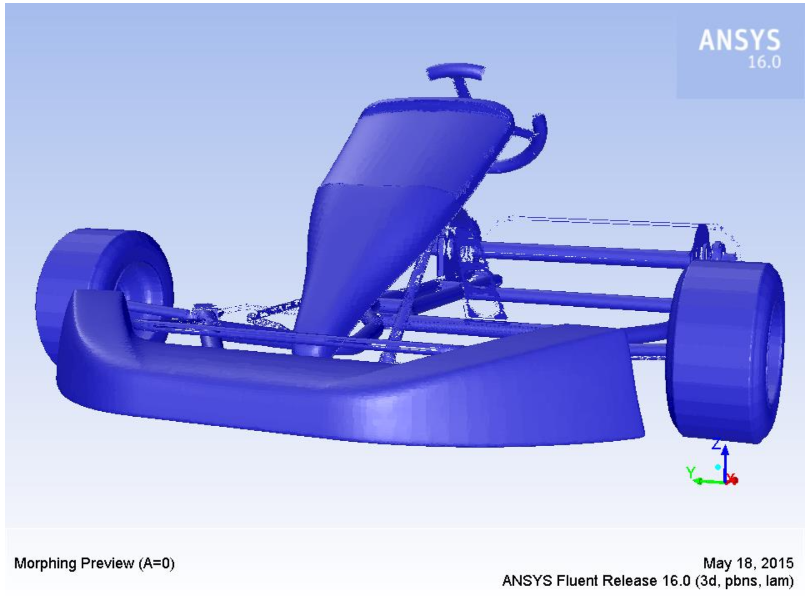
Morphing action results

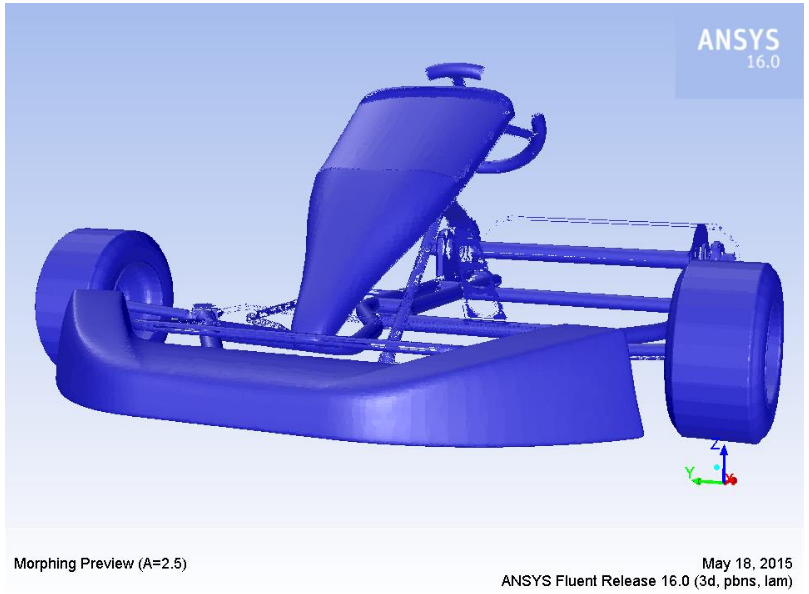


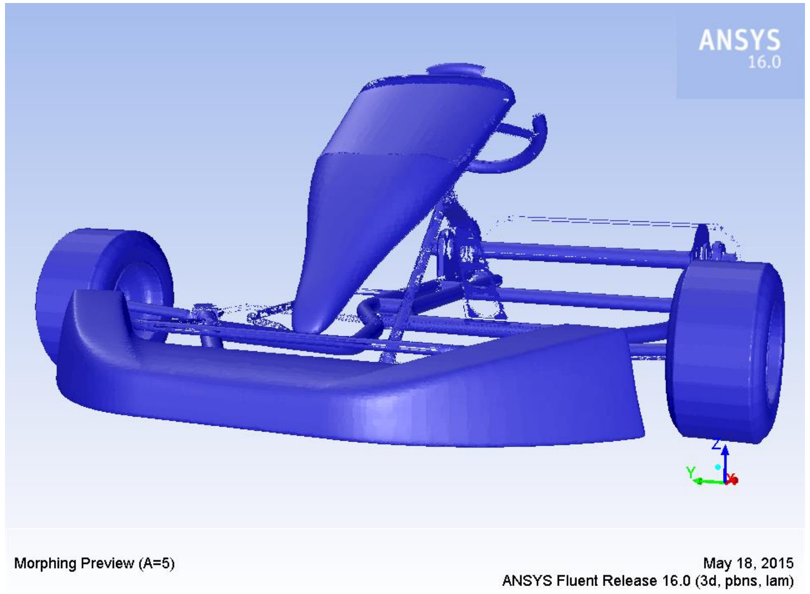


Design shape changes

Front panel vertical translation



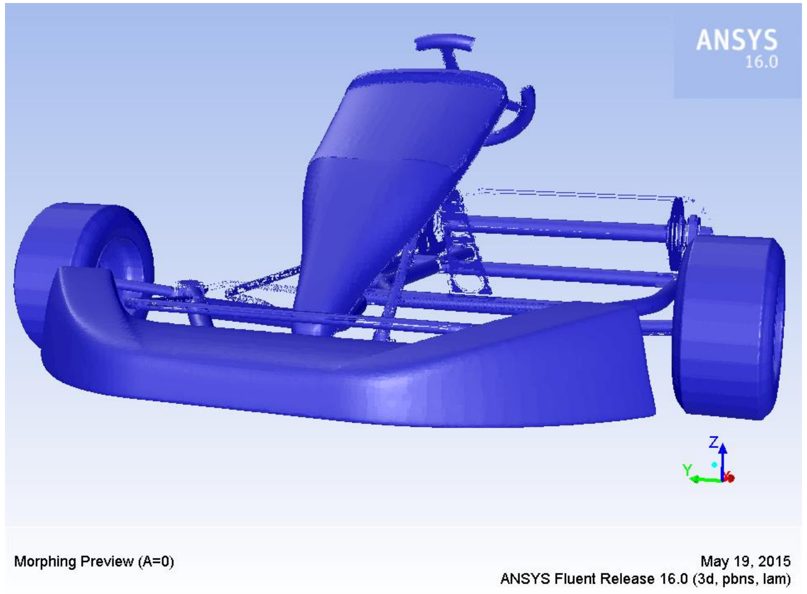


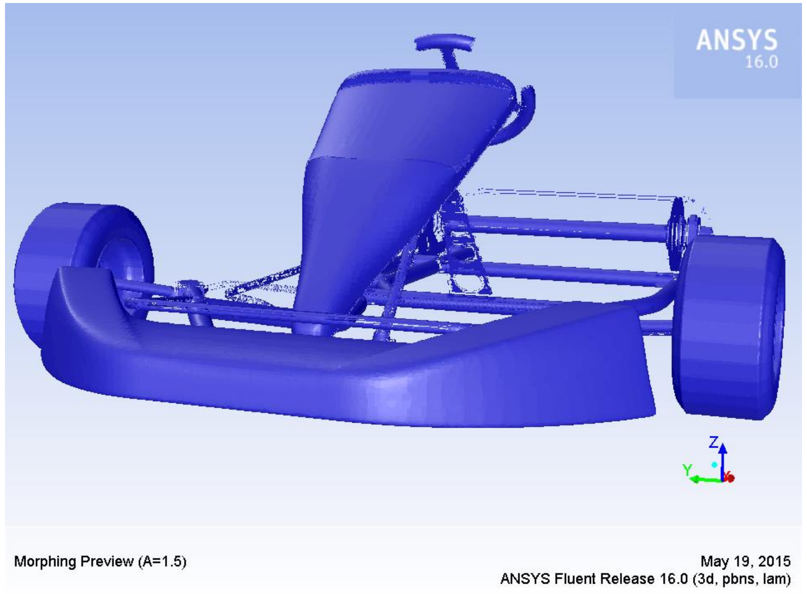


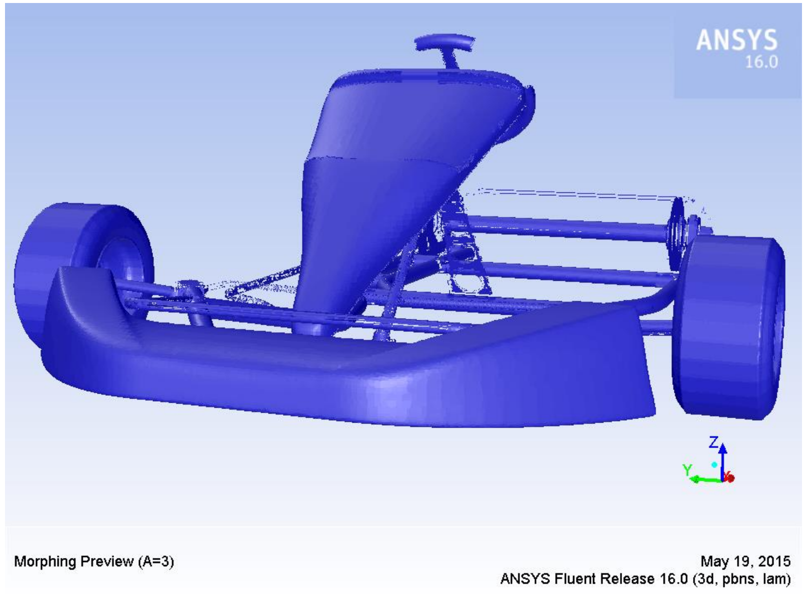
- Baseline
- Intermediate amplitude
- Maximum amplitude

Design shape changes

Front panel widening



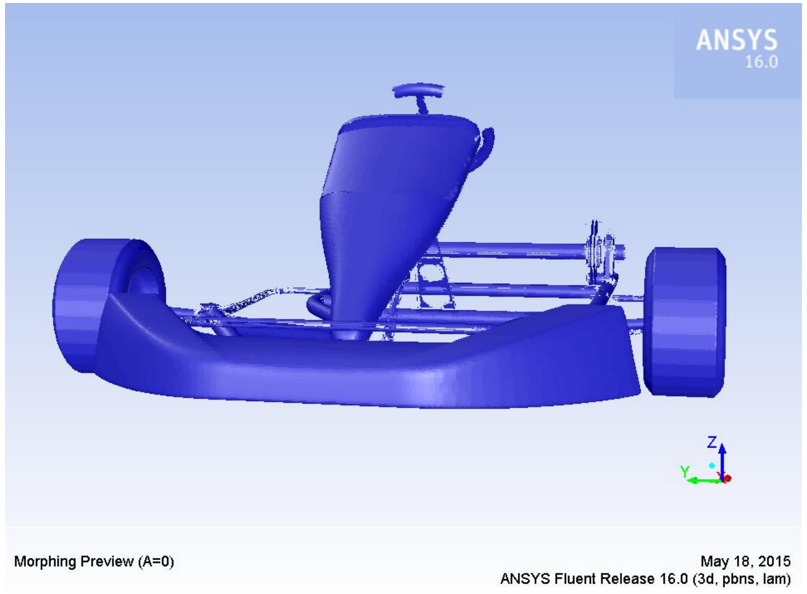


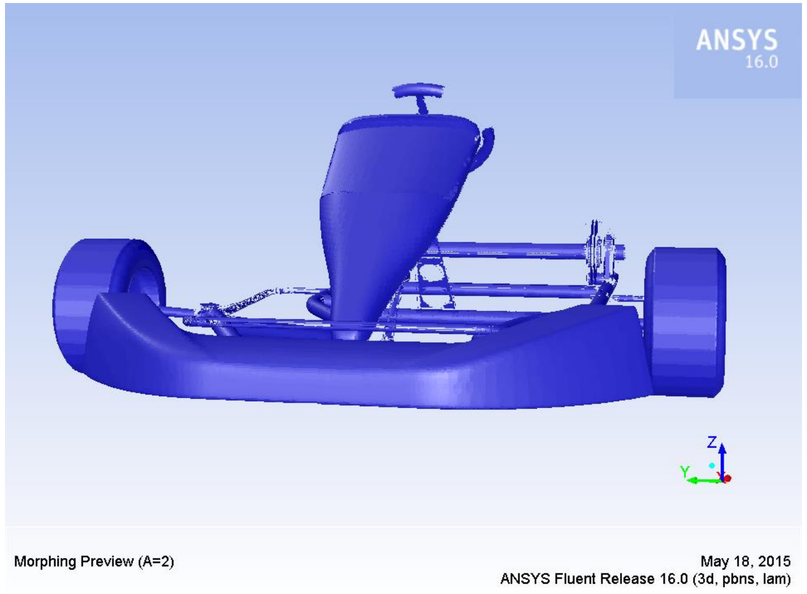


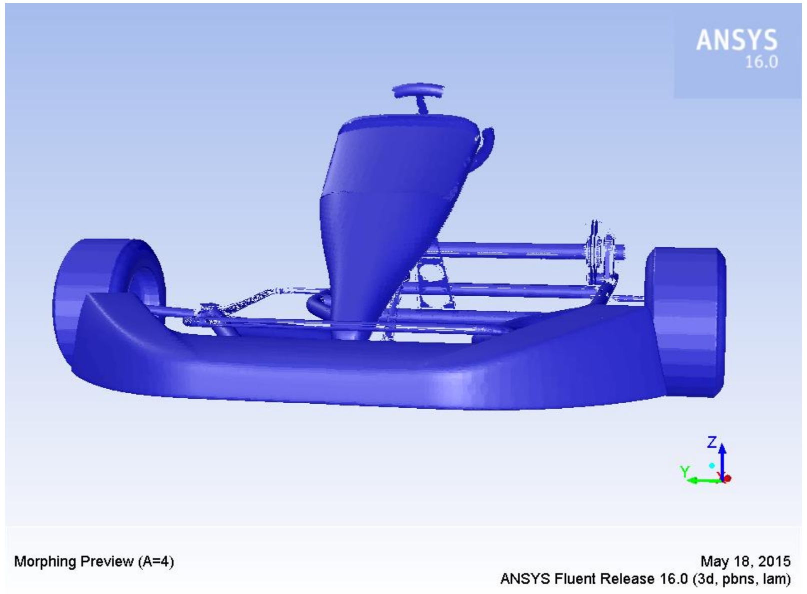
- Baseline
- Intermediate amplitude
- Maximum amplitude

Design shape changes

Front bumper widening (centre)



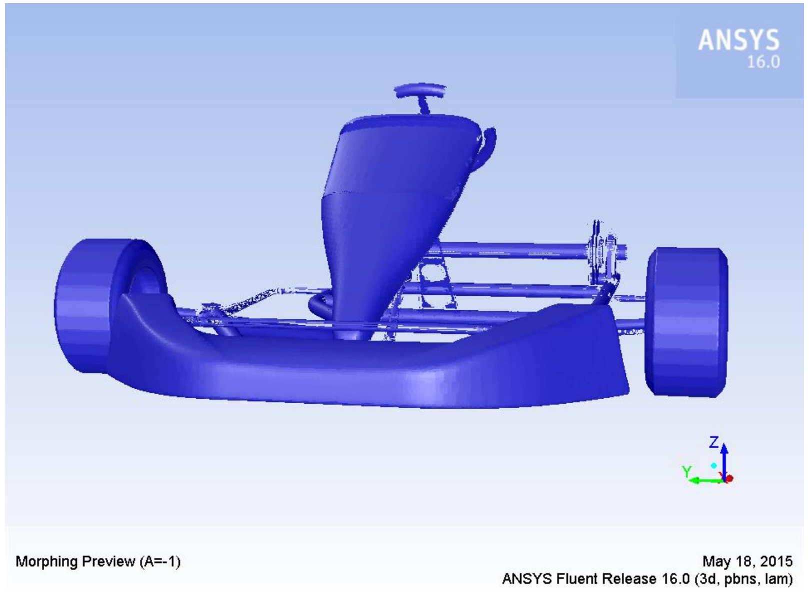


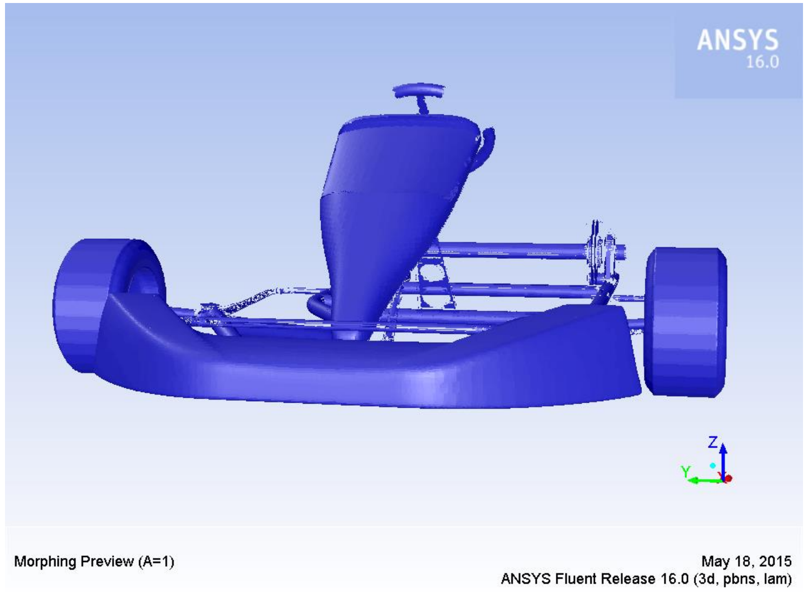


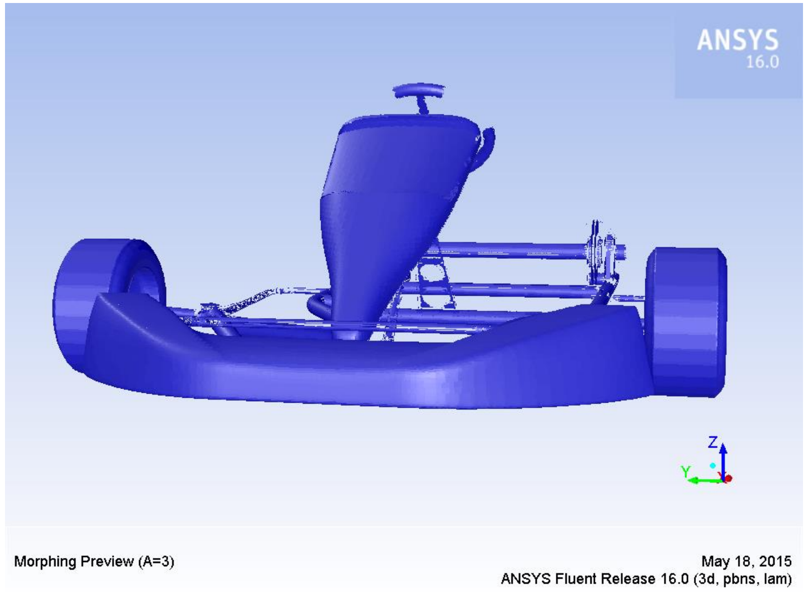
- Baseline
- Intermediate amplitude
- Maximum amplitude

Design shape changes

Front bumper widening (side)



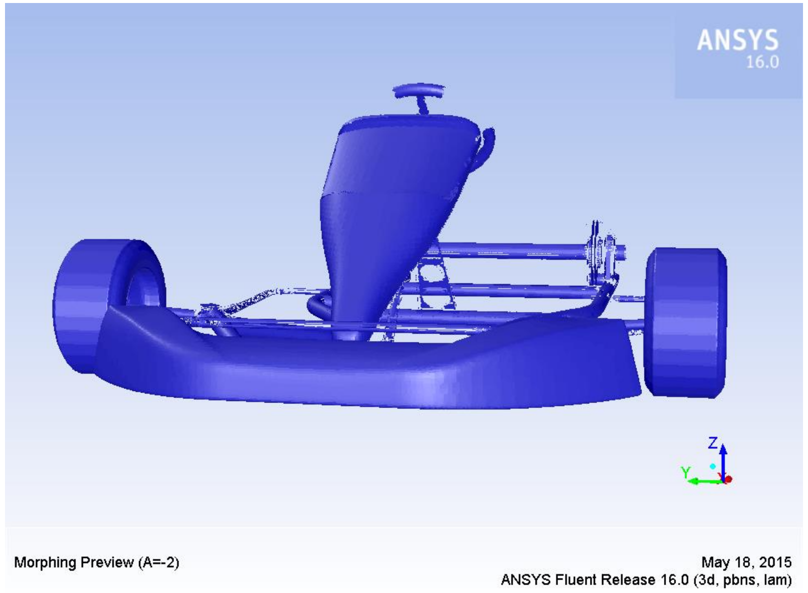


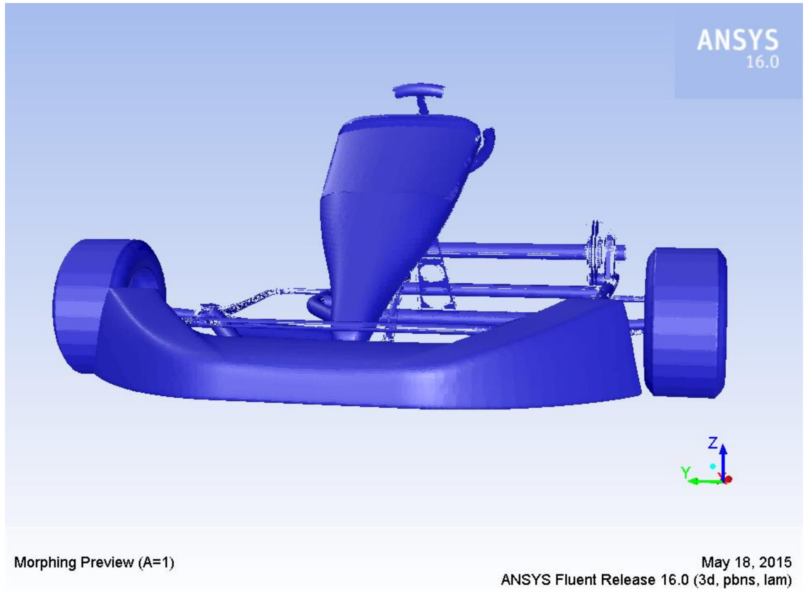


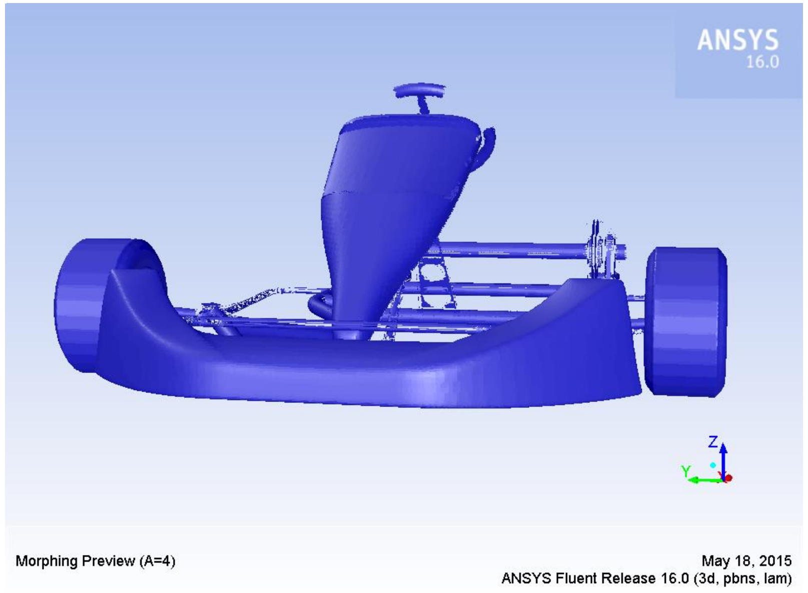
- Minimum amplitude
- Intermediate amplitude
- Maximum amplitude

Design shape changes

Upper front bumper rotation (side)





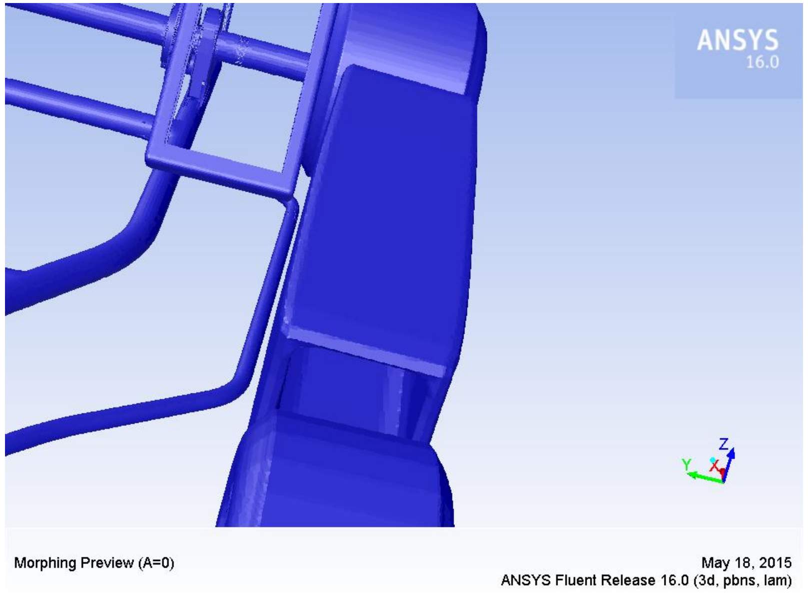


- Minimum amplitude
- Intermediate amplitude
- Maximum amplitude

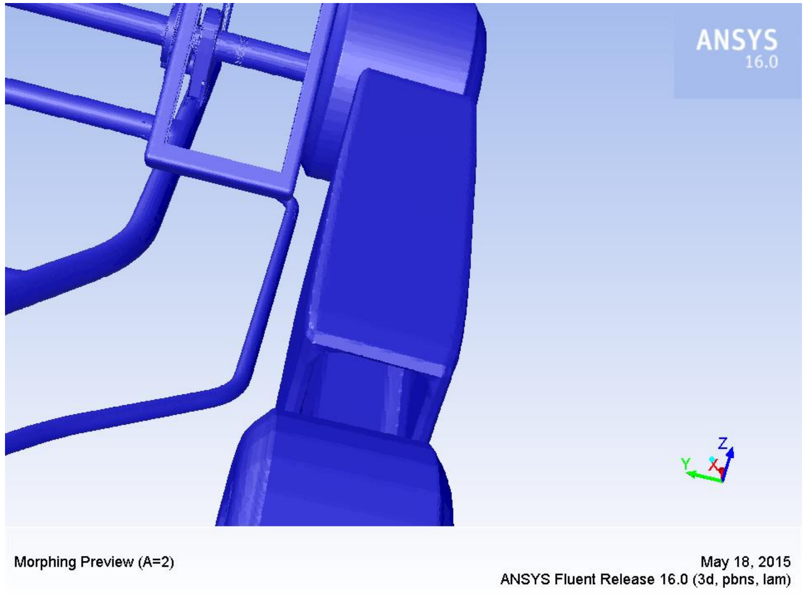
Design shape changes

Independent side bodywork shape changes due to go-kart asymmetry

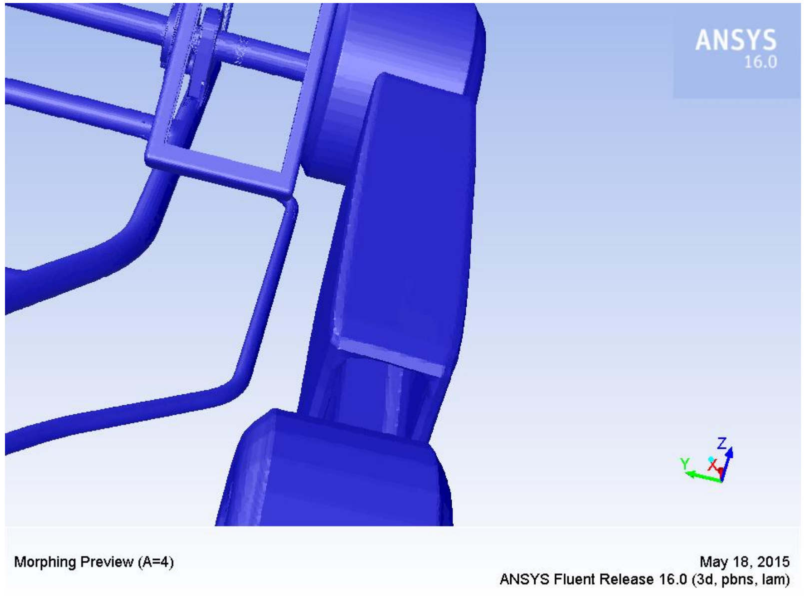
Width reduction



❖ Baseline



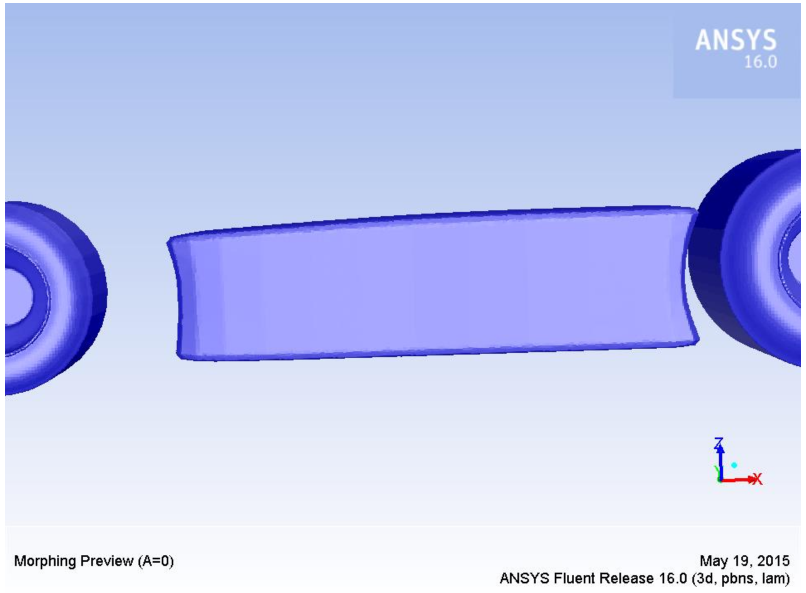
❖ Intermediate amplitude

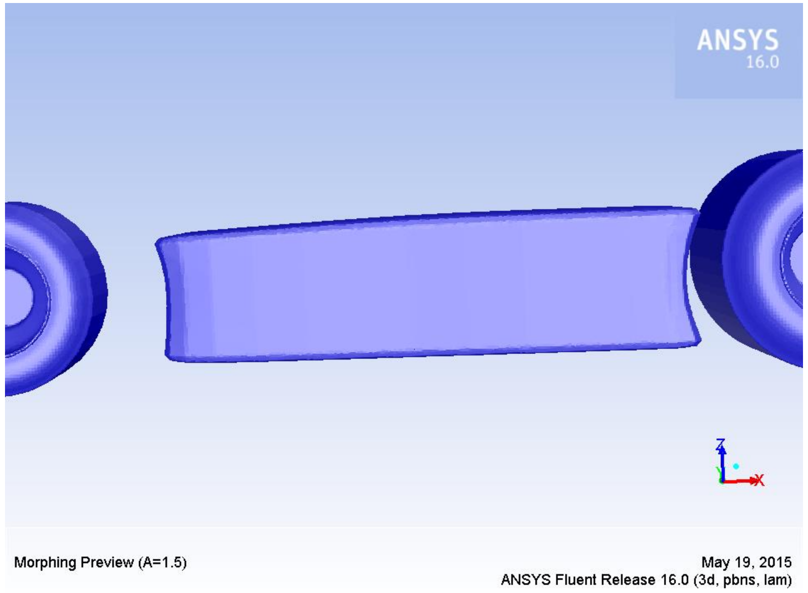


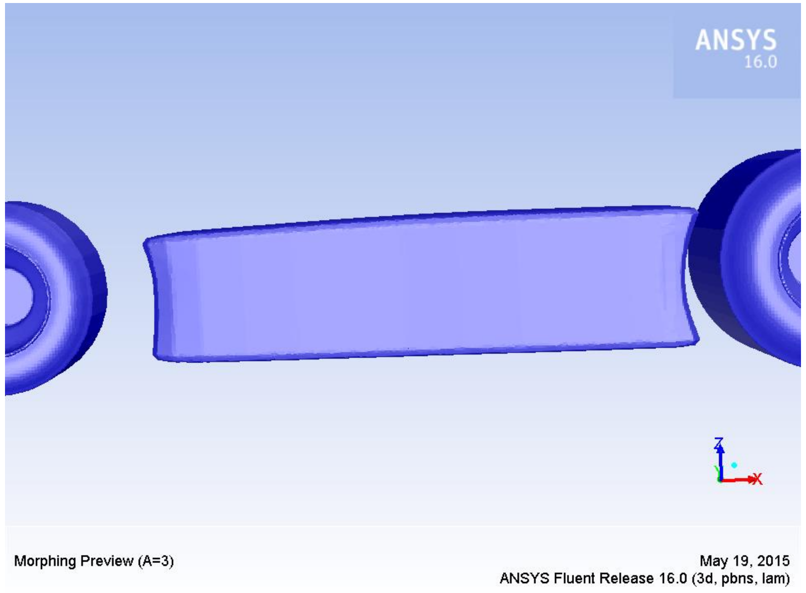
❖ Maximum amplitude

Design shape changes

Stretching



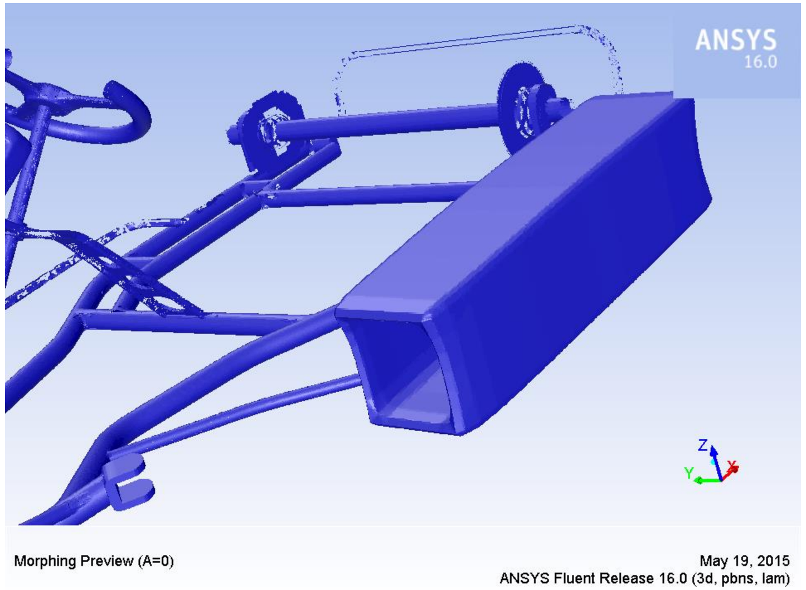


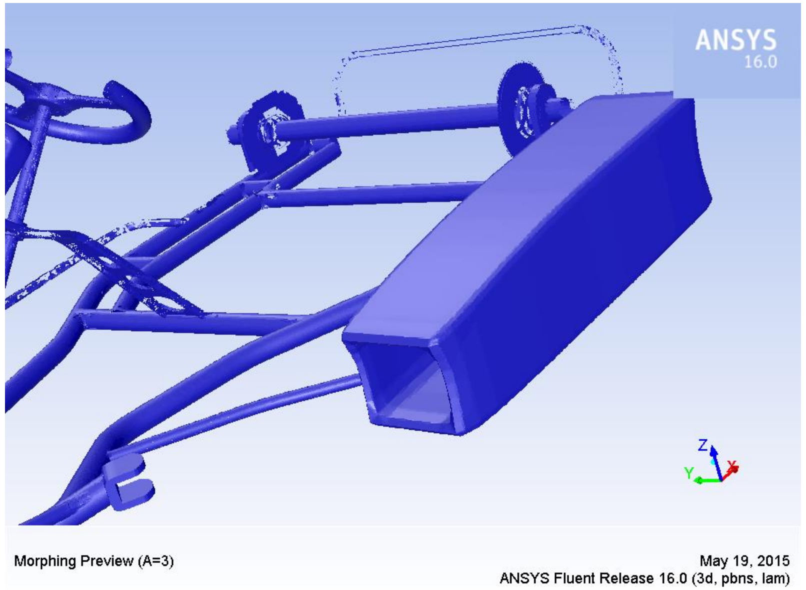


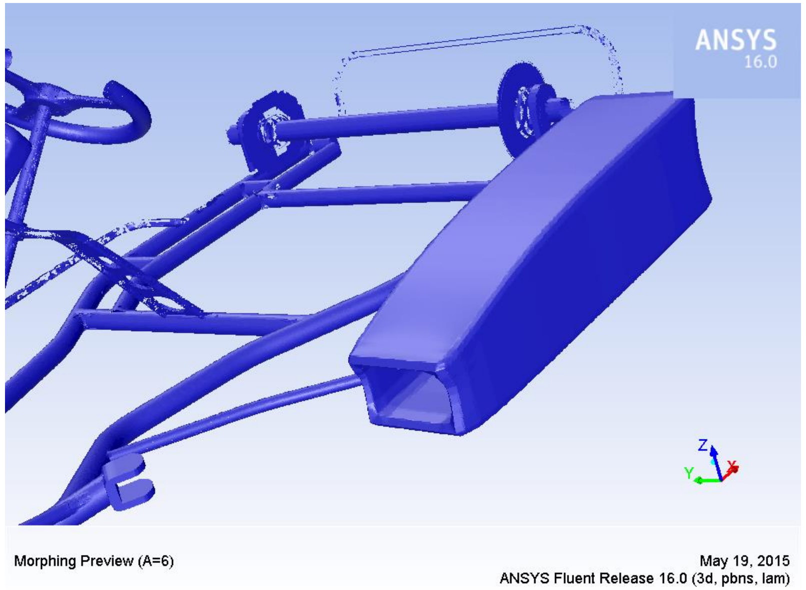
- Baseline
- Intermediate amplitude
- Maximum amplitude

Design shape changes

Frontal zone lowering



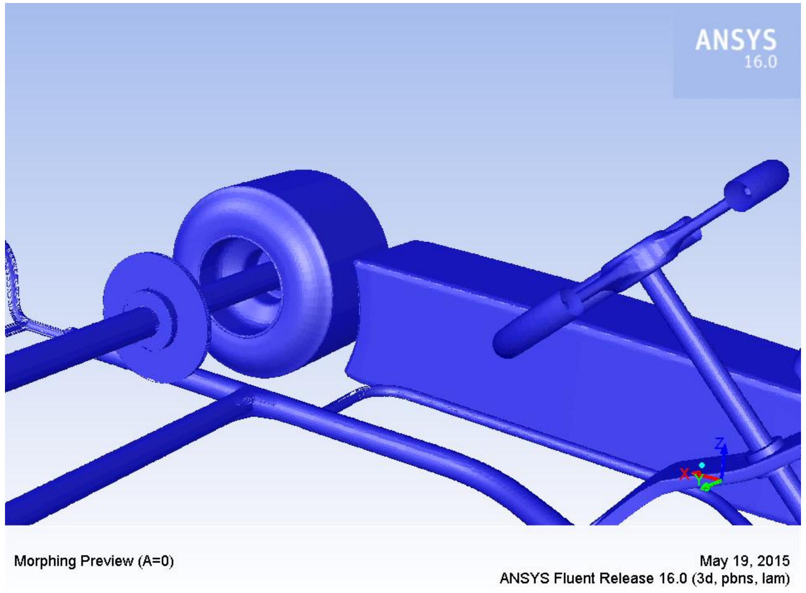


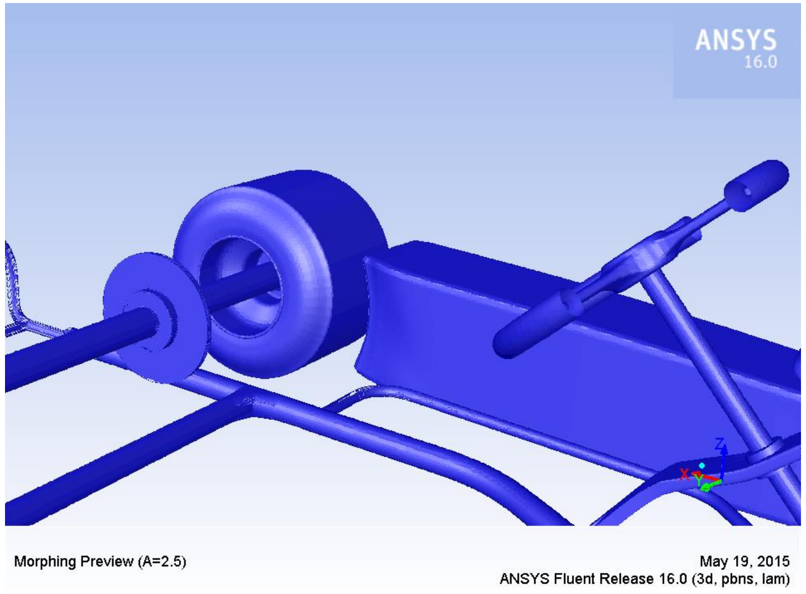


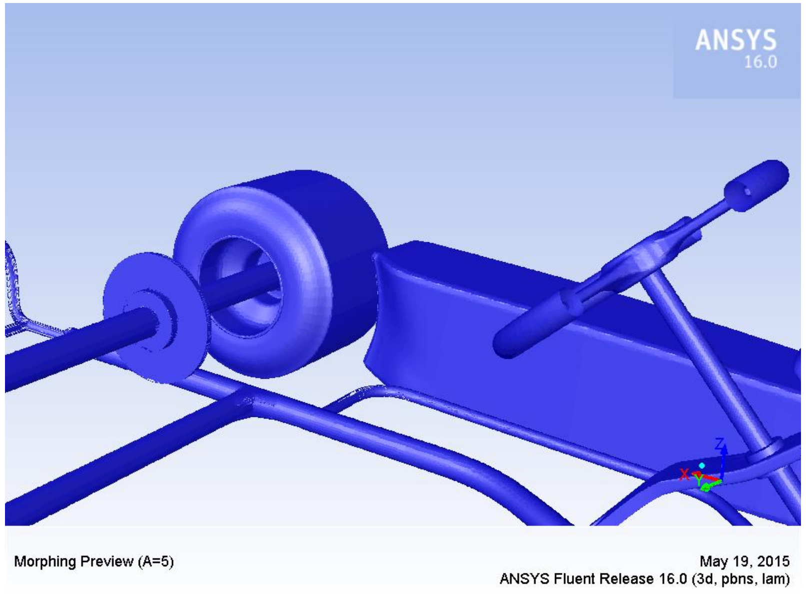
- Baseline
- Intermediate amplitude
- Maximum amplitude

Design shape changes

Rear inner corner rounding



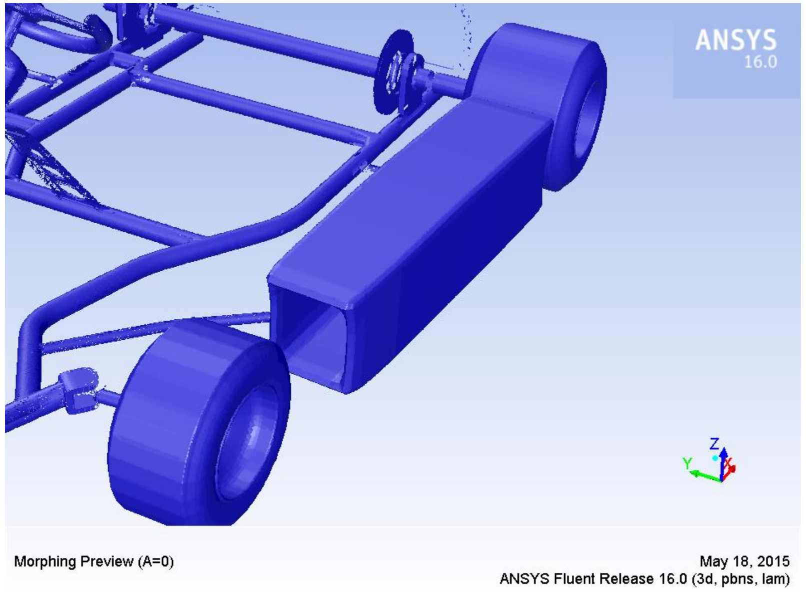


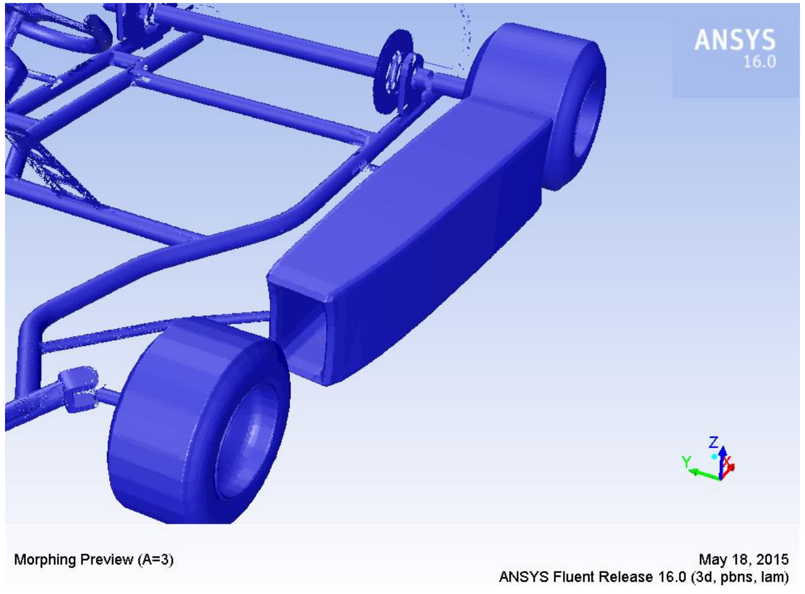


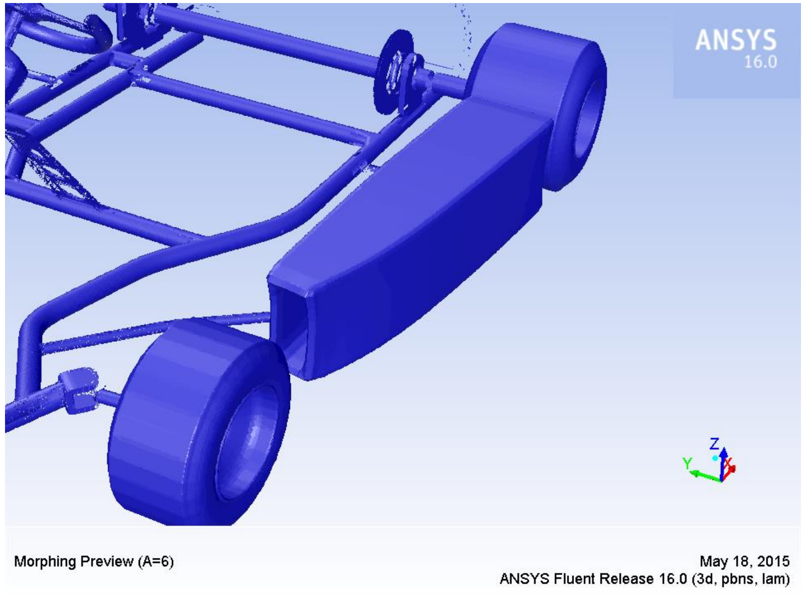
- Baseline
- Intermediate amplitude
- Maximum amplitude

Design shape changes

Frontal zone reduction



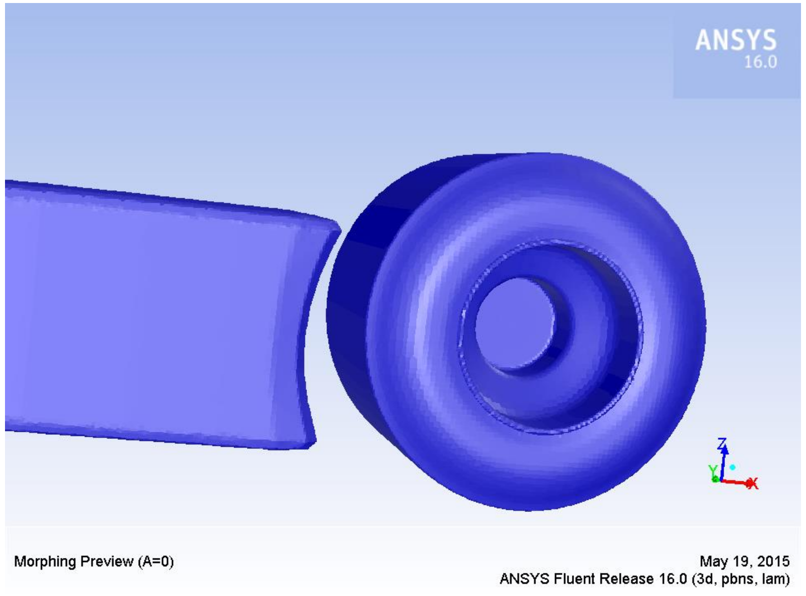


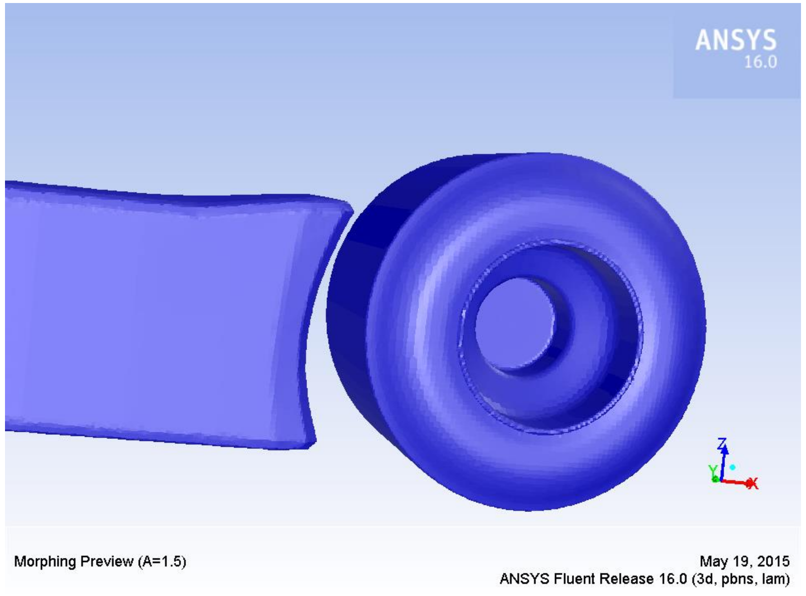


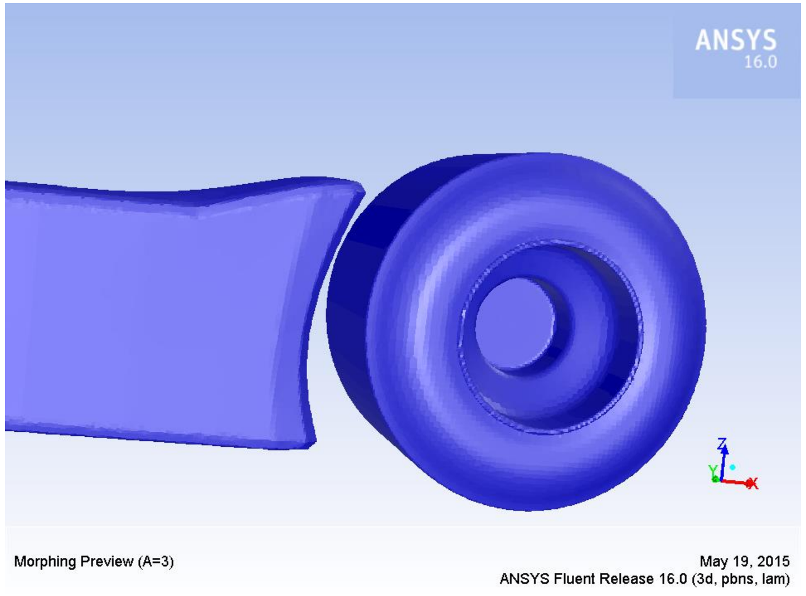
- Baseline
- Intermediate amplitude
- Maximum amplitude

Design shape changes

Rear profile rotation







- Baseline
- Intermediate amplitude
- Maximum amplitude

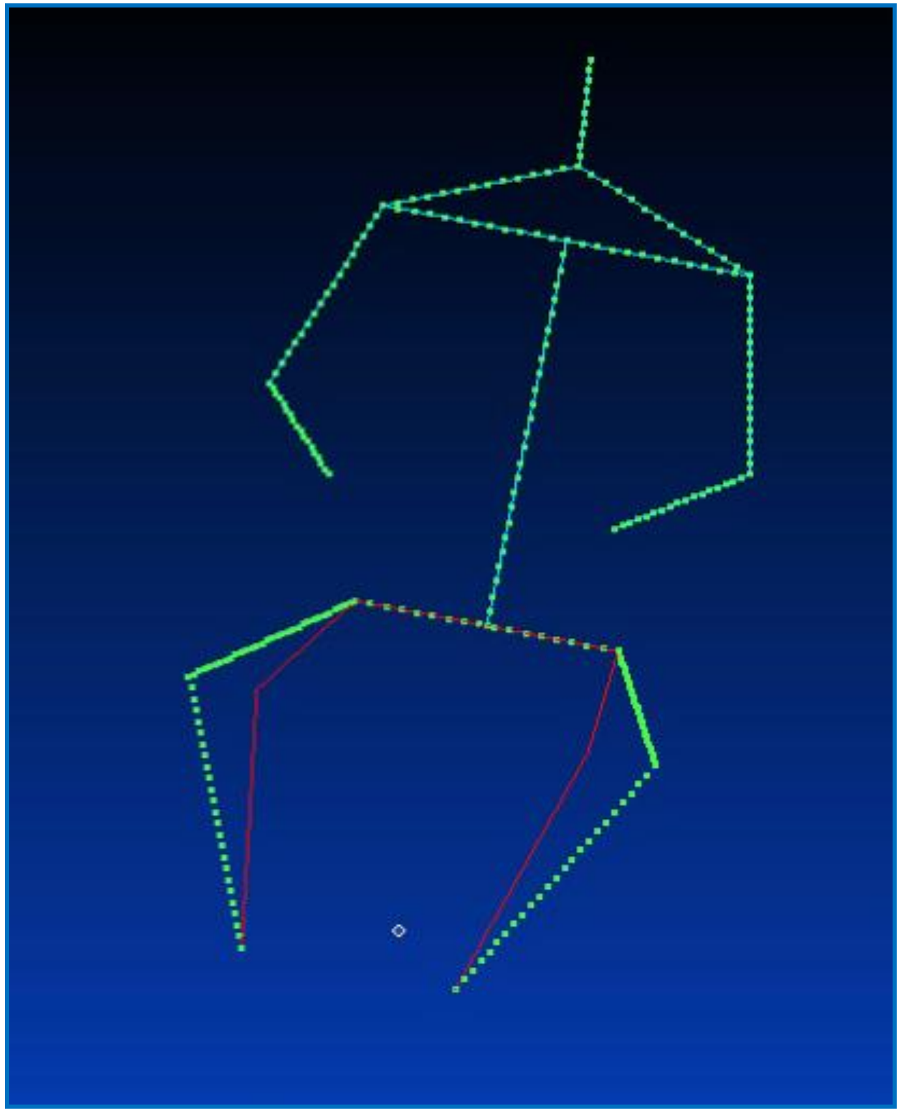
Driver size changes

The driver is exposed to the airflow and represents a major portion of the go-kart frontal area:

- Evaluation of the **driver body size effect** on aerodynamic penetration
- Evaluation of the **optimal configuration related to different driver sizes**

Driver size changes

Stick-model inside Siemens Femap to move driver's arms and legs with few control points



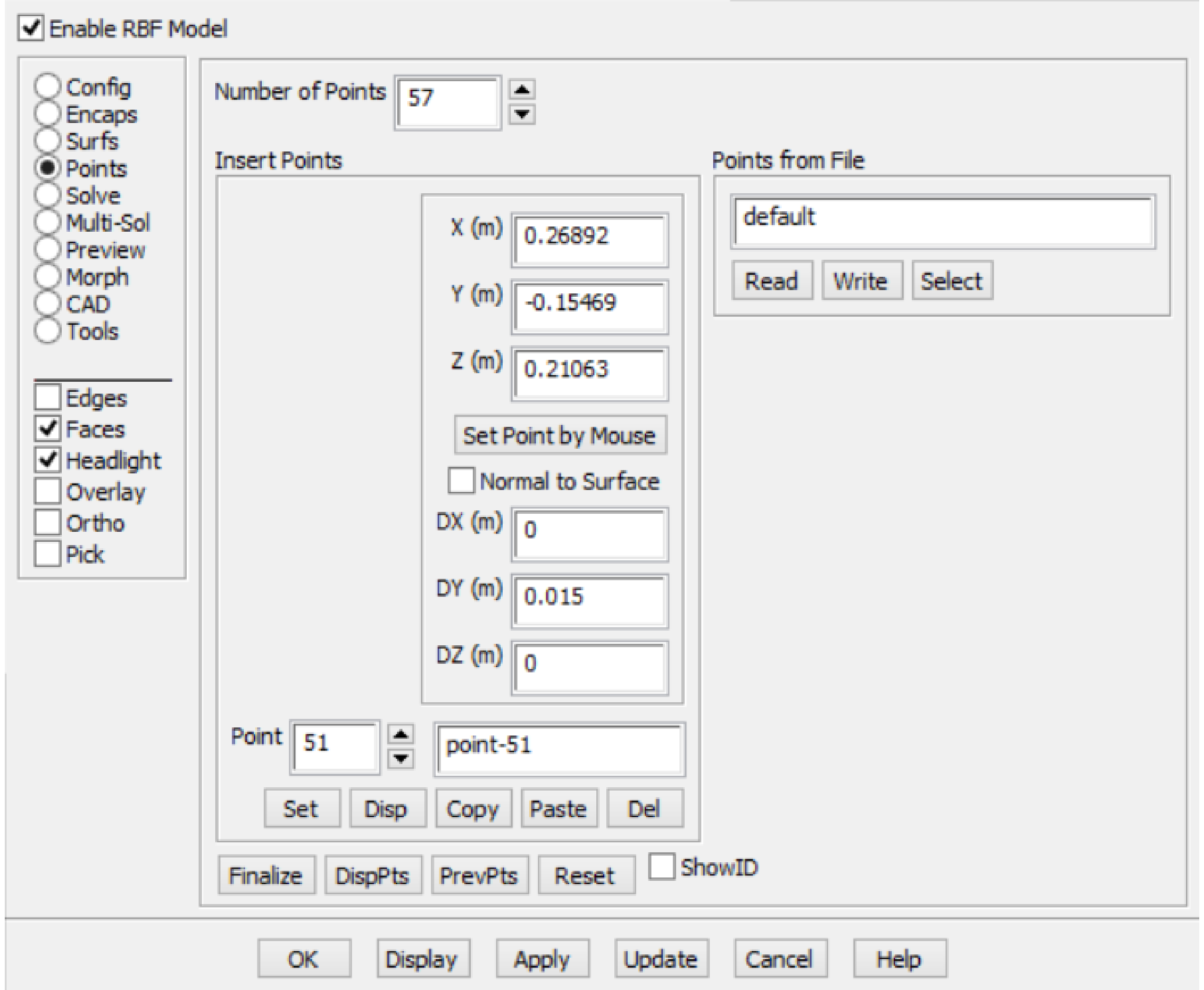
Driver size changes

Points coordinates and related displacements exported in PTS format compatible with RBF-Morph

File Modifica Formato Visualizza ?

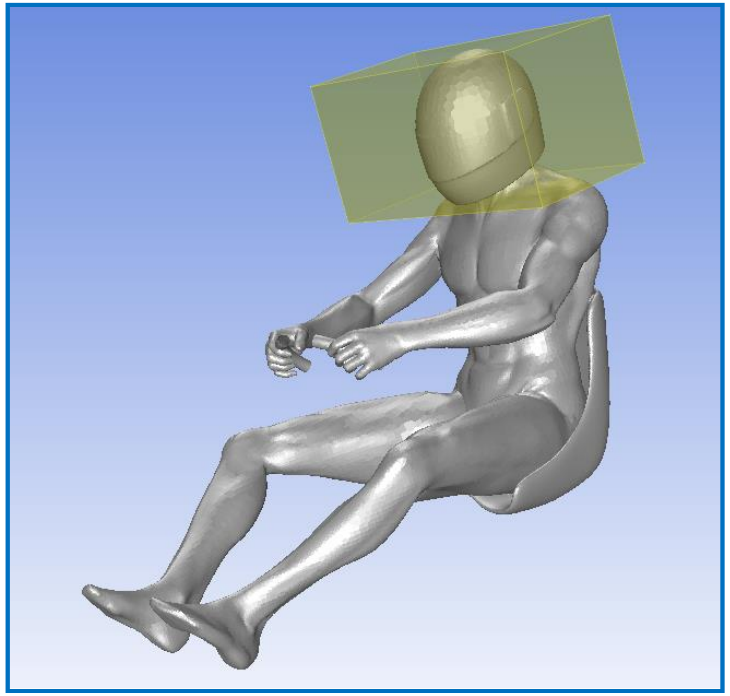
```
57
-0.44263 0.11000 0.16140 0.00000 0.00000 0.00000 0 0 brake point-1
-0.42907 0.11542 0.16717 0.00000 -0.00334 0.00125 0 0 brake point-2
-0.41551 0.12083 0.17295 0.00000 -0.00666 0.00250 0 0 brake point-3
-0.40195 0.12625 0.17872 0.00000 -0.01000 0.00376 0 0 brake point-4
-0.38839 0.13167 0.18450 0.00000 -0.01334 0.00500 0 0 brake point-5
-0.37483 0.13708 0.19028 0.00000 -0.01666 0.00625 0 0 brake point-6
-0.36127 0.14250 0.19605 0.00000 -0.02000 0.00750 0 0 brake point-7
-0.34771 0.14792 0.20182 0.00000 -0.02334 0.00876 0 0 brake point-8
-0.33415 0.15333 0.20760 0.00000 -0.02666 0.01000 0 0 brake point-9
-0.32059 0.15875 0.21337 0.00000 -0.03000 0.01125 0 0 brake point-10
-0.30703 0.16417 0.21915 0.00000 -0.03334 0.01250 0 0 brake point-11
-0.29347 0.16958 0.22492 0.00000 -0.03666 0.01376 0 0 brake point-12
-0.27992 0.17500 0.23070 0.00000 -0.04000 0.01500 0 0 brake point-13
-0.26636 0.18042 0.23647 0.00000 -0.04334 0.01625 0 0 brake point-14
-0.25280 0.18583 0.24225 0.00000 -0.04666 0.01750 0 0 brake point-15
-0.23924 0.19125 0.24803 0.00000 -0.05000 0.01874 0 0 brake point-16
-0.22568 0.19667 0.25380 0.00000 -0.05334 0.02000 0 0 brake point-17
-0.21212 0.20208 0.25958 0.00000 -0.05666 0.02124 0 0 brake point-18
-0.19856 0.20750 0.26535 0.00000 -0.06000 0.02250 0 0 brake point-19
-0.18500 0.21292 0.27112 0.00000 -0.06334 0.02376 0 0 brake point-20
-0.17144 0.21833 0.27690 0.00000 -0.06666 0.02500 0 0 brake point-21
-0.15788 0.22375 0.28268 0.00000 -0.07000 0.02625 0 0 brake point-22
.....................................................................

.....................................................................
```

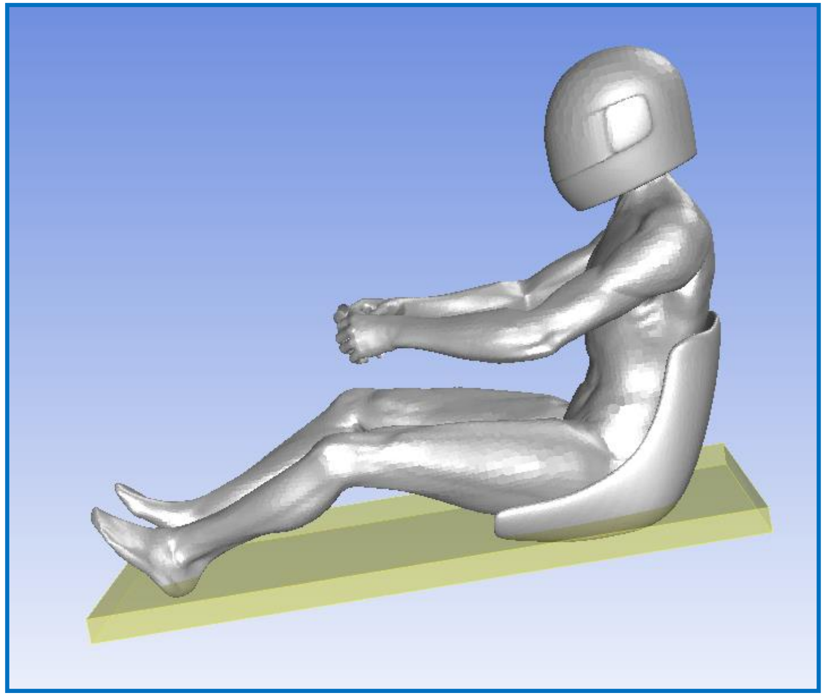


Driver size changes

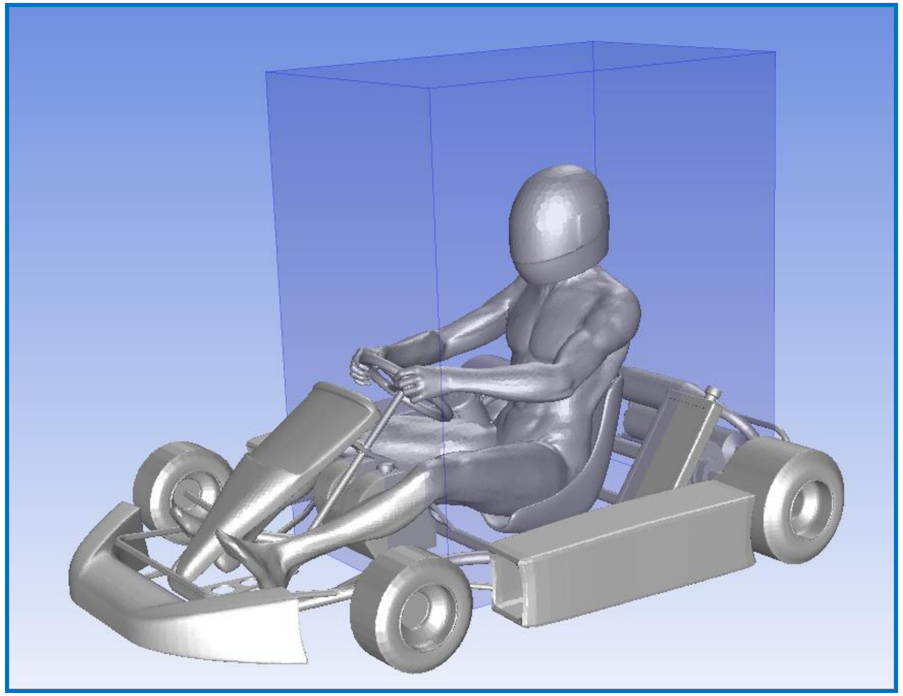
Selection encap, translation



Selection encap, null displacement

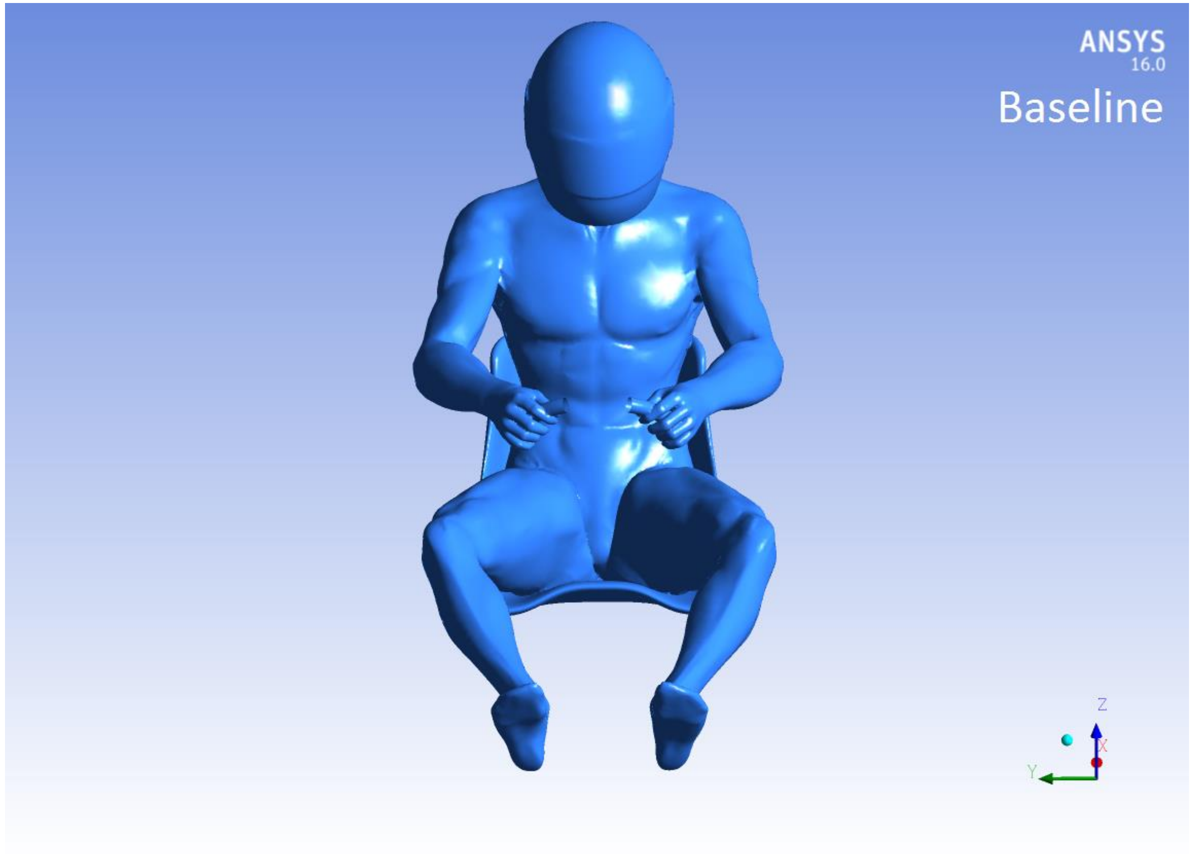


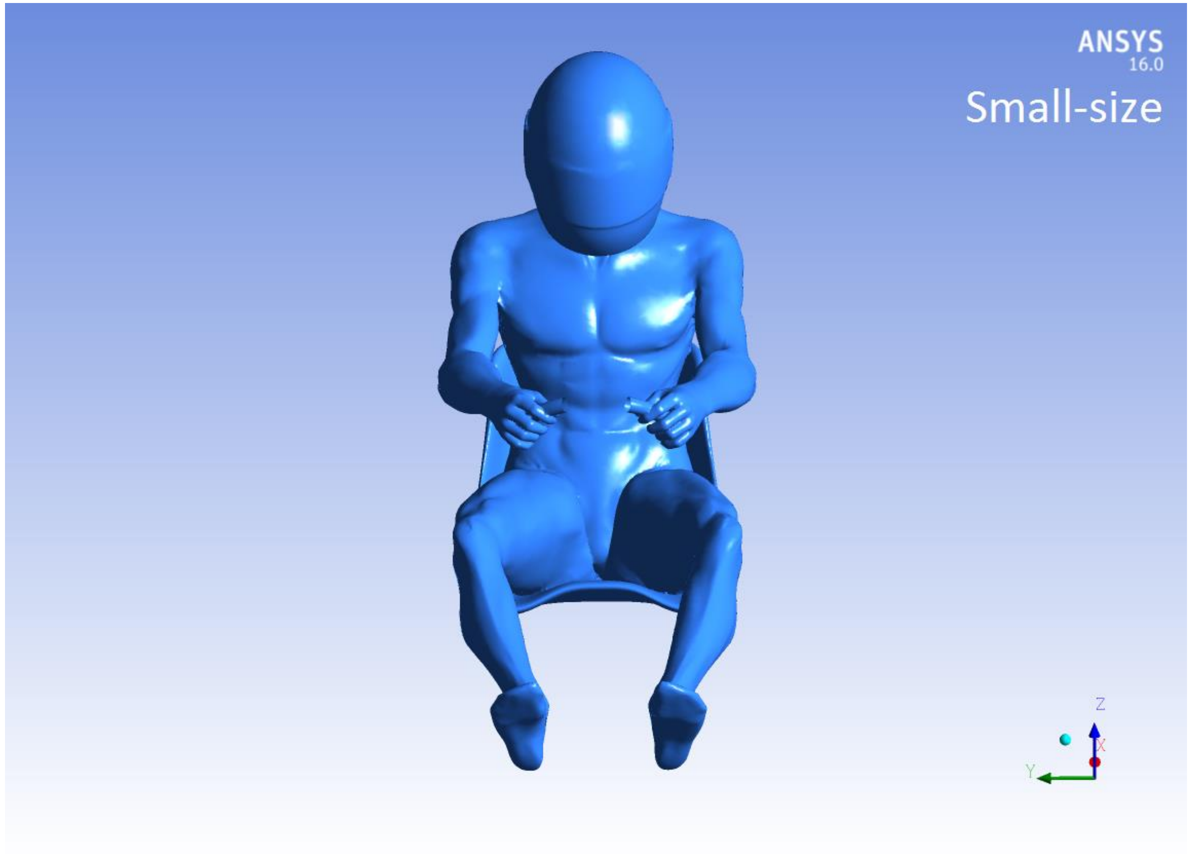
Morphing domain



Driver size changes

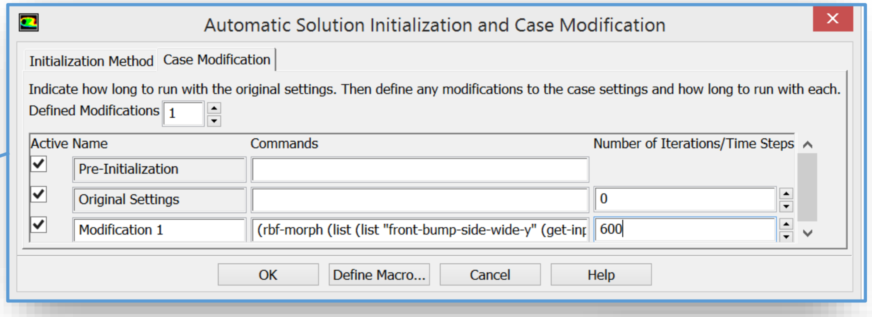
Comparison between driver sizes before and after morphing action



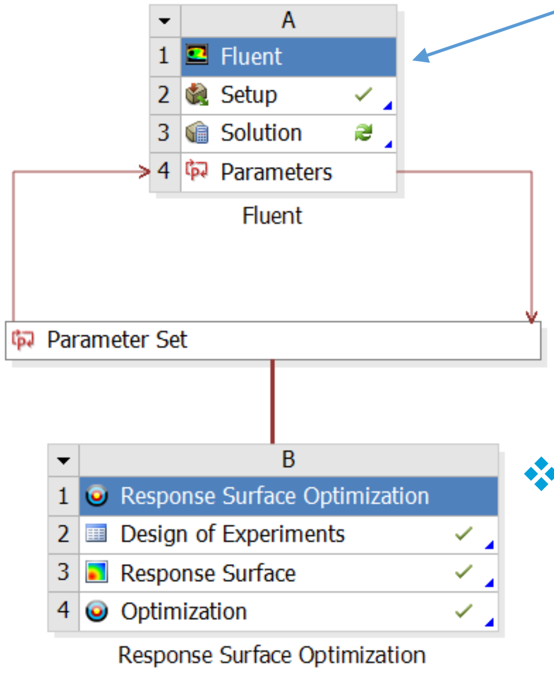


Optimization

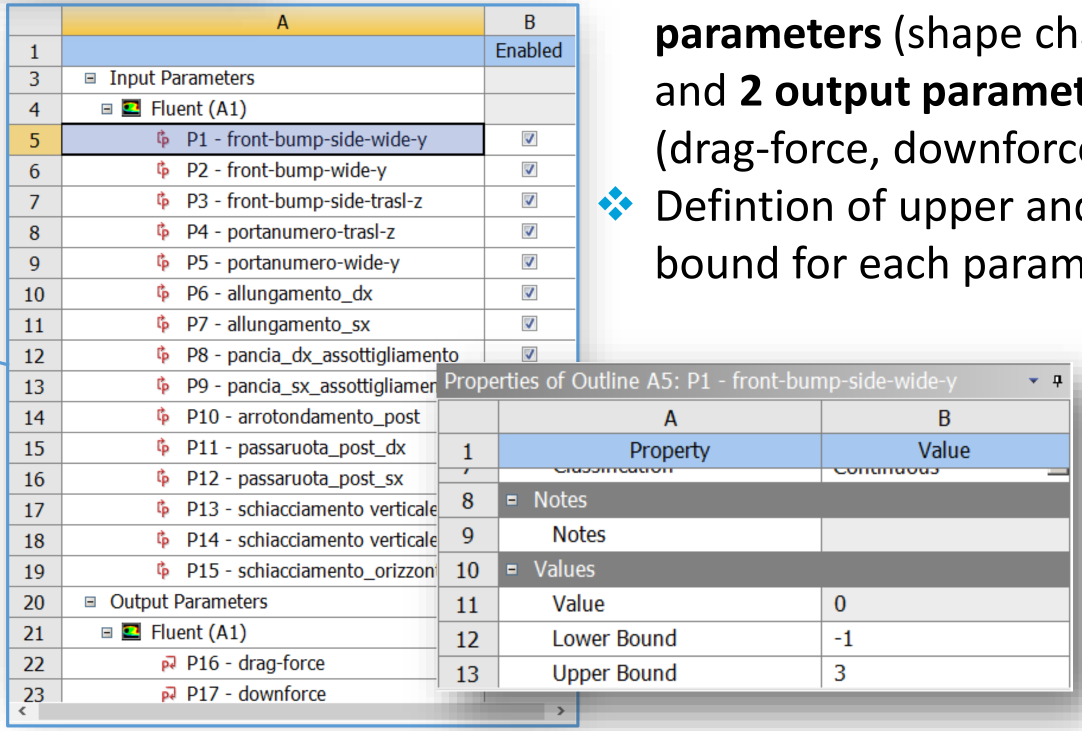
Parametric optimization inside ANSYS Workbench (DesignXplorer)



- Shape changes made **parametric** by means of RBF-Morph directly in the Fluent case



- Optimization accomplished with **DesignXplorer** linked to CFD by the defined parameter set



- Definition of **15 input parameters** (shape changes) and **2 output parameters** (drag-force, downforce)
- Defintion of upper and lower bound for each parameter

Design of Experiment

Optimization based on custom *Design of Experiment*

- **Design of Experiment** built on the 17 parameters defined with RBF-Morph
- DOE size equal to **97 Design points**, to ensure accuracy and to meet time constraints
- **600 iterations** per DP (60000 total iterations) and **80 hours** of overall calculation time

Outline of Schematic B2: Design of Experiments

	A	B
1		Enabled
2	Design of Experiments	
3	Input Parameters	
4	Fluent (A1)	
5	P1 - front-bump-side-wide-y	☑
6	P2 - front-bump-wide-y	☑
7	P3 - front-bump-side-trasl-z	☑
8	P4 - portanumero-trasl-z	☑
9	P5 - portanumero-wide-y	☑
10	P6 - allungamento_dx	☑
11	P7 - allungamento_sx	☑
12	P8 - pancia_dx_assottigliamento	☑
13	P9 - pancia_sx_assottigliamento	☑
14	P10 - arrotondamento_post	☑
15	P11 - passaruota_post_dx	☑
16	P12 - passaruota_post_sx	☑
17	P13 - schiacciamento verticale_dx	☑
18	P14 - schiacciamento verticale_sx	☑
19	P15 - schiacciamento_orizzontale	☑
20	Output Parameters	
21	Fluent (A1)	
22	P16 - drag-force	
23	P17 - downforce	

Properties of Outline : Design of Experiment

	A	B
1	Property	Value
6	Design of Experiments	
7	Design of Experiments Type	Custom + Sampling
8	Total Number of Samples	97

Table of Schematic B2: Design of Experiments (Custom)

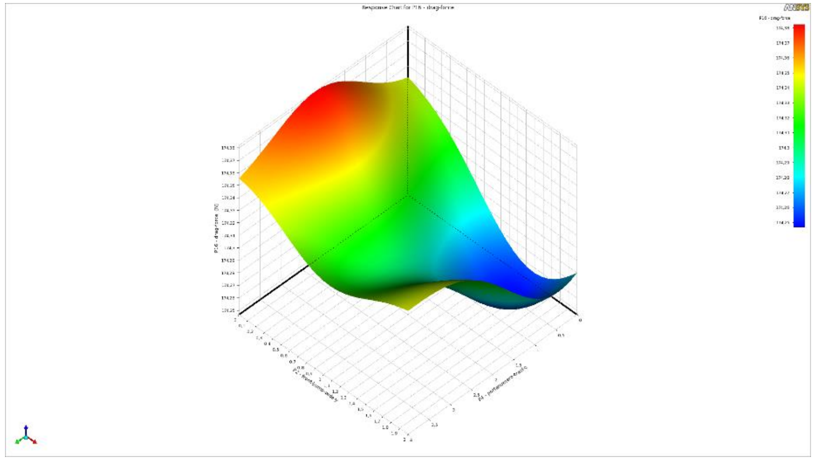
	A	B	C	D	E	F
1	Name	P1 - front-bump-side-wide-y	P2 - front-bump-wide-y	P3 - front-bump-side-trasl-z	P4 - portanumero-trasl-z	P5 - portanum
2	1 DP 0	0	0	0	0	0
3	2	-0,875	0,5625	0,71875	0,125	1,1875
4	3	-0,625	1,0625	-0,53125	3,375	0,8125
5	4	-0,375	0,4375	3,8438	3,625	1,3125
6	5	-0,125	0,9375	1,0313	2,375	0,1875
7	6	0,125	0,8125	3,5313	2,875	0,6875
8	7	0,375	1,3125	-0,21875	3,125	1,4375
9	8	0,625	1,9375	2,9063	0,875	0,3125
10	9	0,875	1,1875	3,2188	1,375	1,6875
11	10	1,125	0,6875	1,6563	0,375	1,9375
12	11	1,375	1,8125	1,3438	1,625	0,9375
13	12	1,625	1,6875	0,09375	0,625	0,4375
14	13	1,875	0,0625	-0,84375	1,875	1,5625
15	14	2,125	0,3125	1,9688	1,125	0,0625
16	15	2,375	1,5625	0,40625	3,875	1,0625
17	16	2,625	1,4375	2,5938	2,625	1,8125
18	17	2,875	0,1875	2,2813	2,125	0,5625
19	18	-0,975	0,5375	2,0313	1,325	0,7875
20	19	-0,925	1,1875	-0,03125	3,475	1,8625
21	20	-0,875	1,9875	3,4687	2,375	1,0375
22	21	-0,825	0,7625	1,8438	1,275	0,4125
23	22	-0,775	1,4125	2,5938	1,225	1,4375
24	23	-0,725	1,5875	-0,71875	3,225	0,4375
25	24	-0,675	0,6125	1,0938	0,675	1,8375
26	25	-0,625	0,0375	1,4063	2,225	1,2125
27	26	-0,575	0,3375	1,2188	2,175	0,1125
28	27	-0,525	0,2875	0,34375	1,175	0,5375
29	28	-0,475	1,6375	3,6562	1,475	0,2375

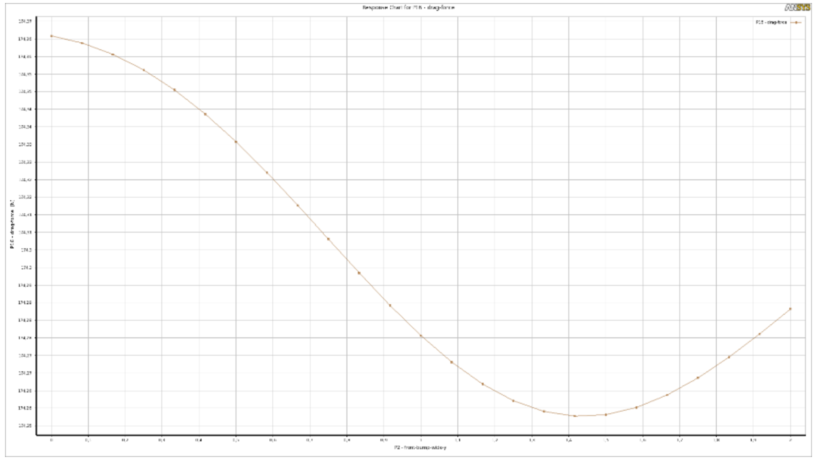
Chart: No data

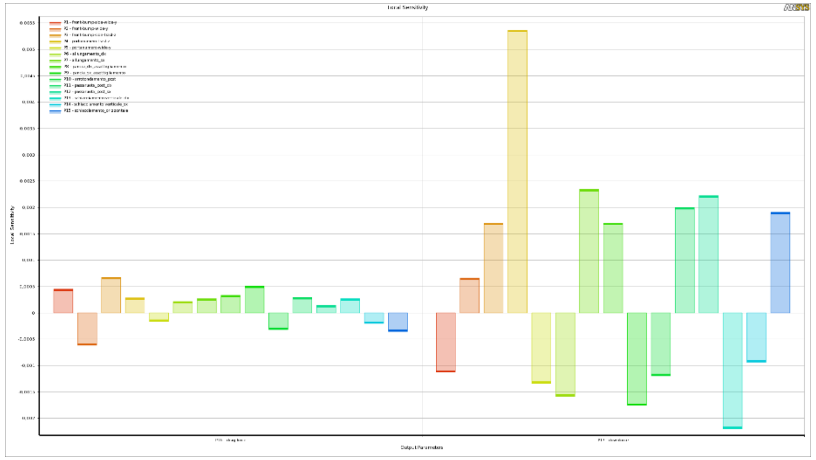
Response Surface

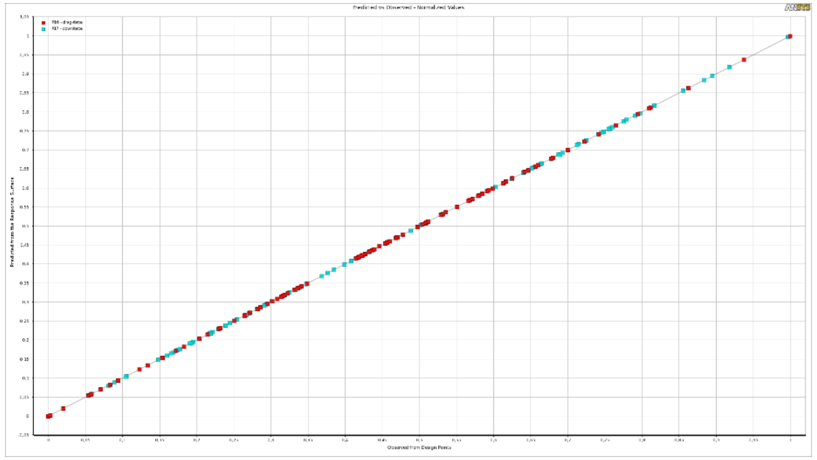
Evaluation of parameters influence on the results by means of *Response Surface*

- 2D/3D response
- Histogram/sensitivity curves
- Max/Min search
- Interpolated data quality









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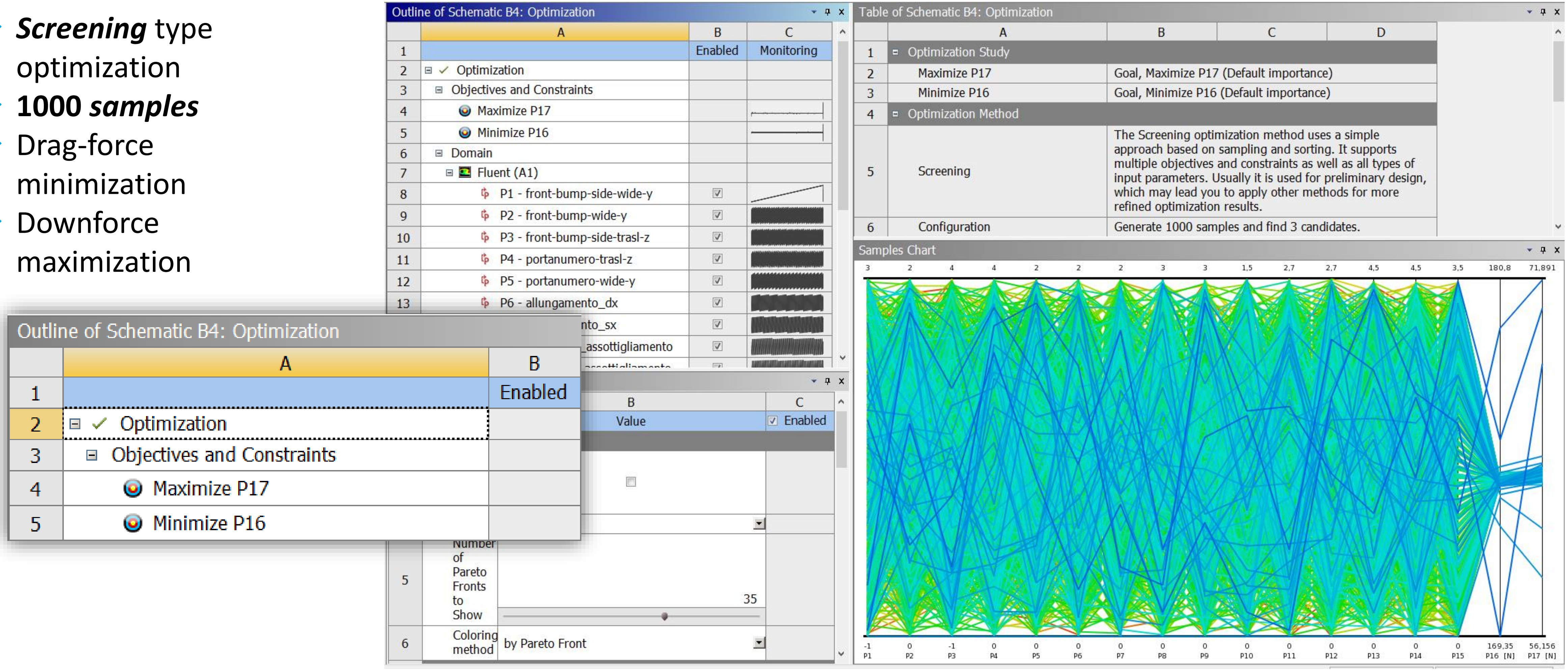
Goal Driven Optimization

Choice of the optimal configuration through *Goal Driven Optimization*

- ***Screening*** type optimization
- **1000 *samples***
- Drag-force minimization
- Downforce maximization



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Results

Both drag-force and downforce value improvement

$$D_{opt} = 169,36\ N \qquad -L_{opt} = 71,85\ N$$

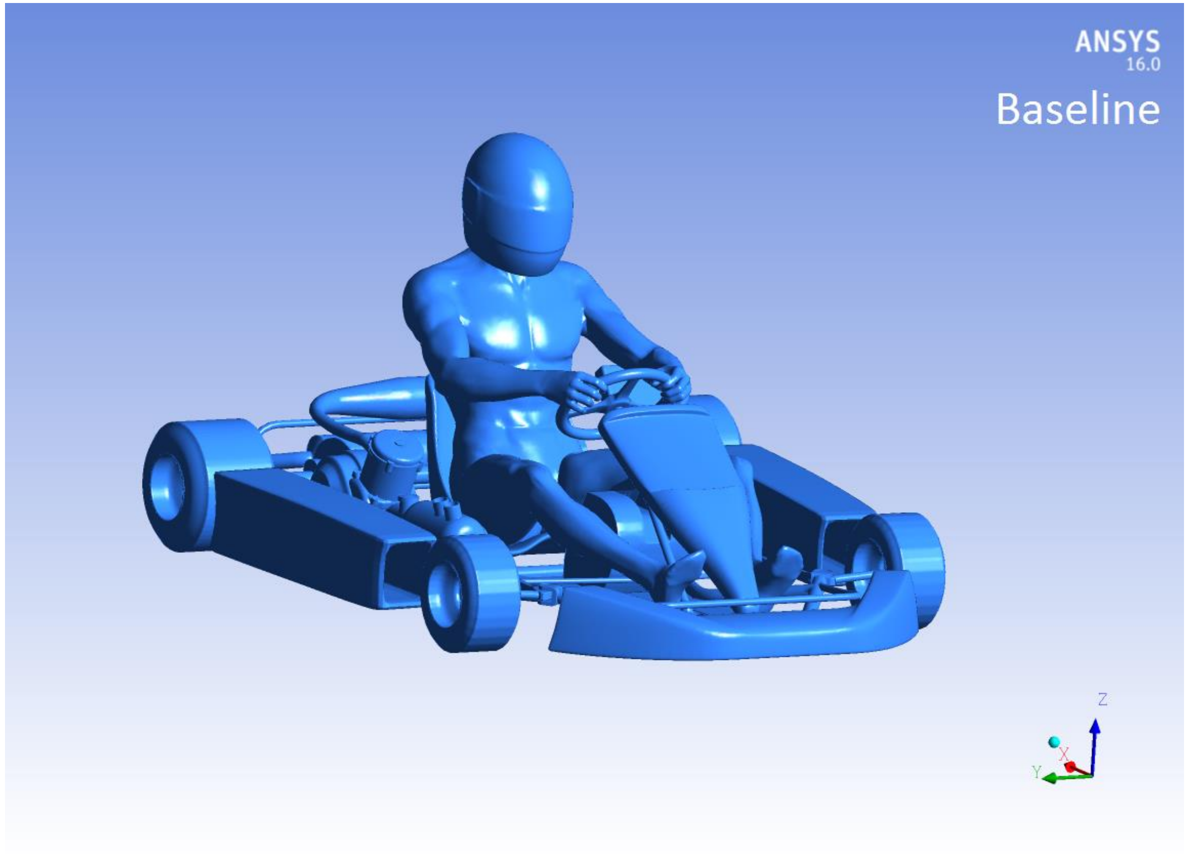
Table of Schematic B4: Optimization , Candidate Points

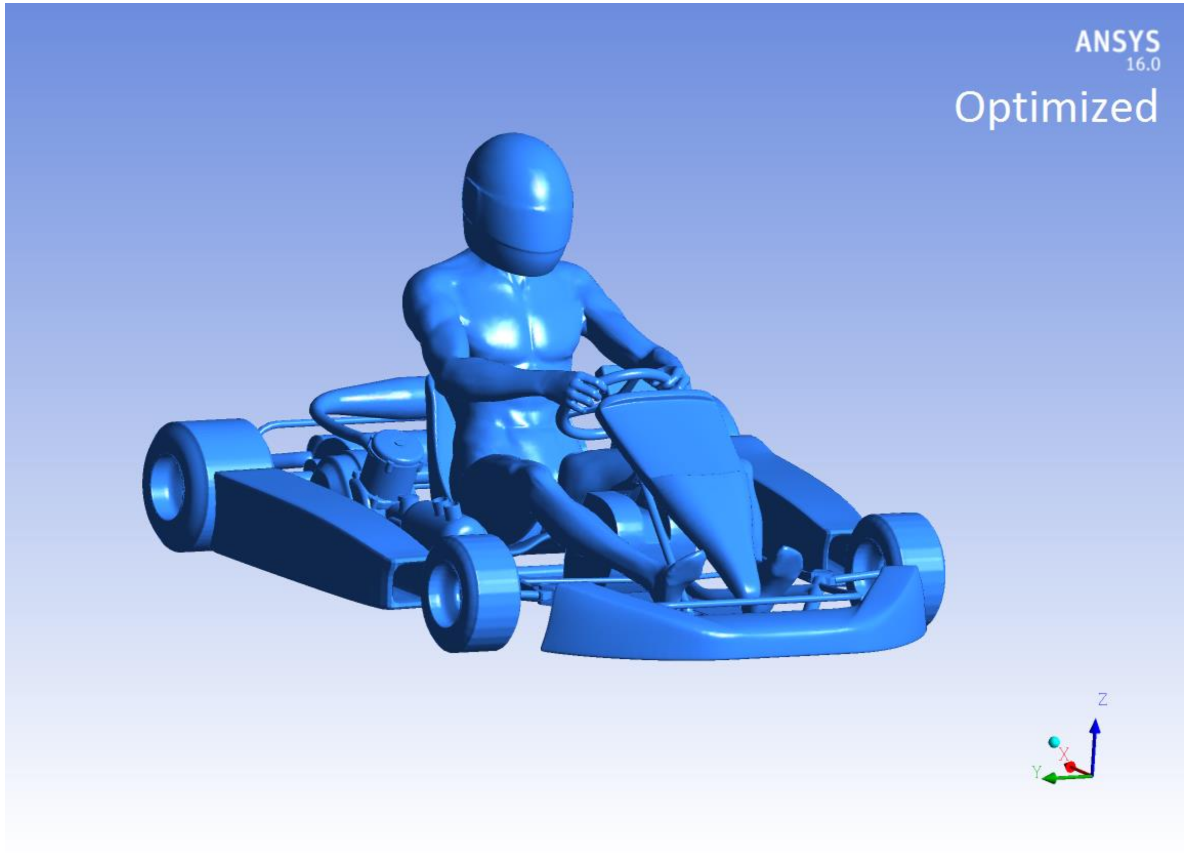
	A	B	Q	R	S	T	U
1	Reference	Name	P15 - schiacciamento_orizzontale	P16 - drag-force (N)		P17 - downforce (N)	
2				Parameter Value	Variation from Reference	Parameter Value	Variation from Reference
3	○	Candidate Point 1	2,0781	★★★ 169,36	-2,30%	★★ 68,126	15,65%
4	○	Candidate Point 2	3,4773	– 175,66	1,33%	★★★ 70,594	19,84%
5	○	Candidate Point 3	1,2031	×× 179,22	3,39%	★★★ 71,847	21,97%
6	◉	Baseline	0	★ 173,35		×× 58,908	

- **2,3%** gain over the baseline **drag-force** value
- **22%** improvement in terms of **downforce**

Results

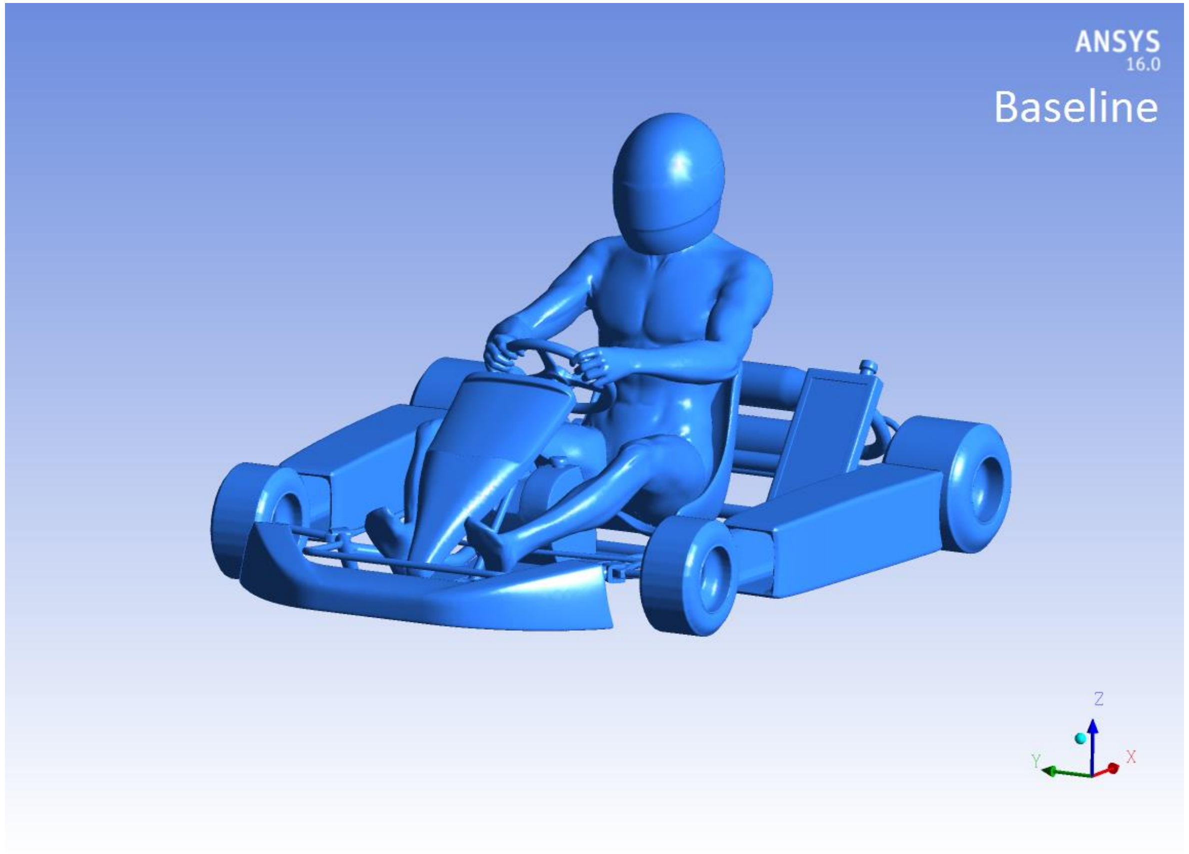
Comparison between baseline and drag-force optimized configurations (right side)

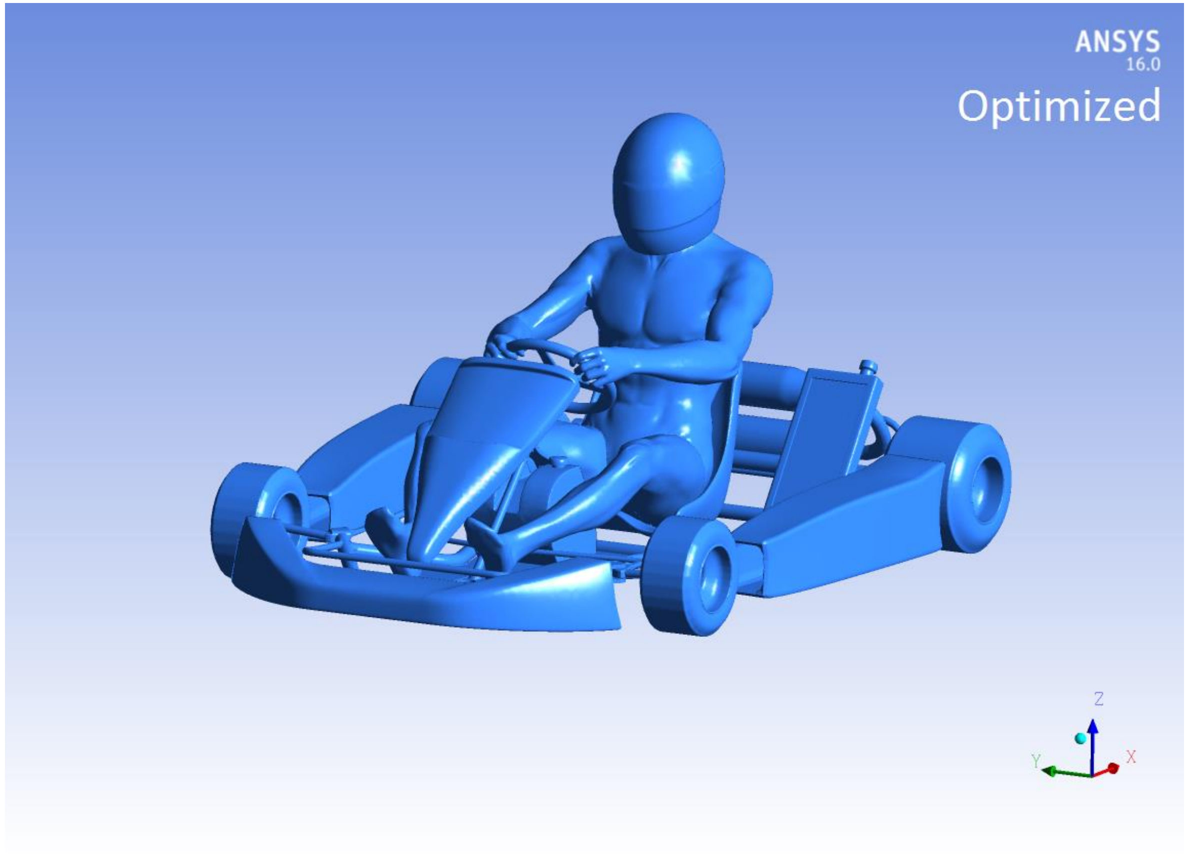




Results

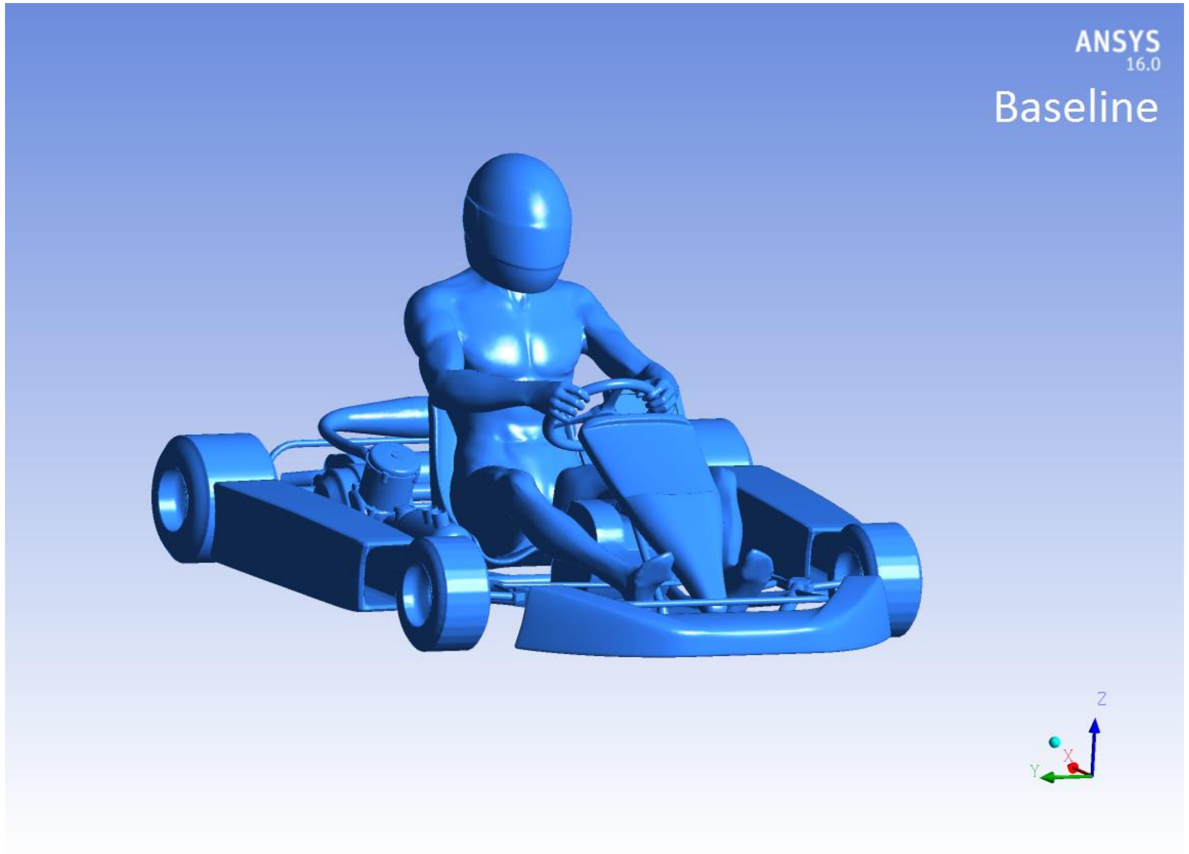
Comparison between baseline and drag-force optimized configurations (left side)

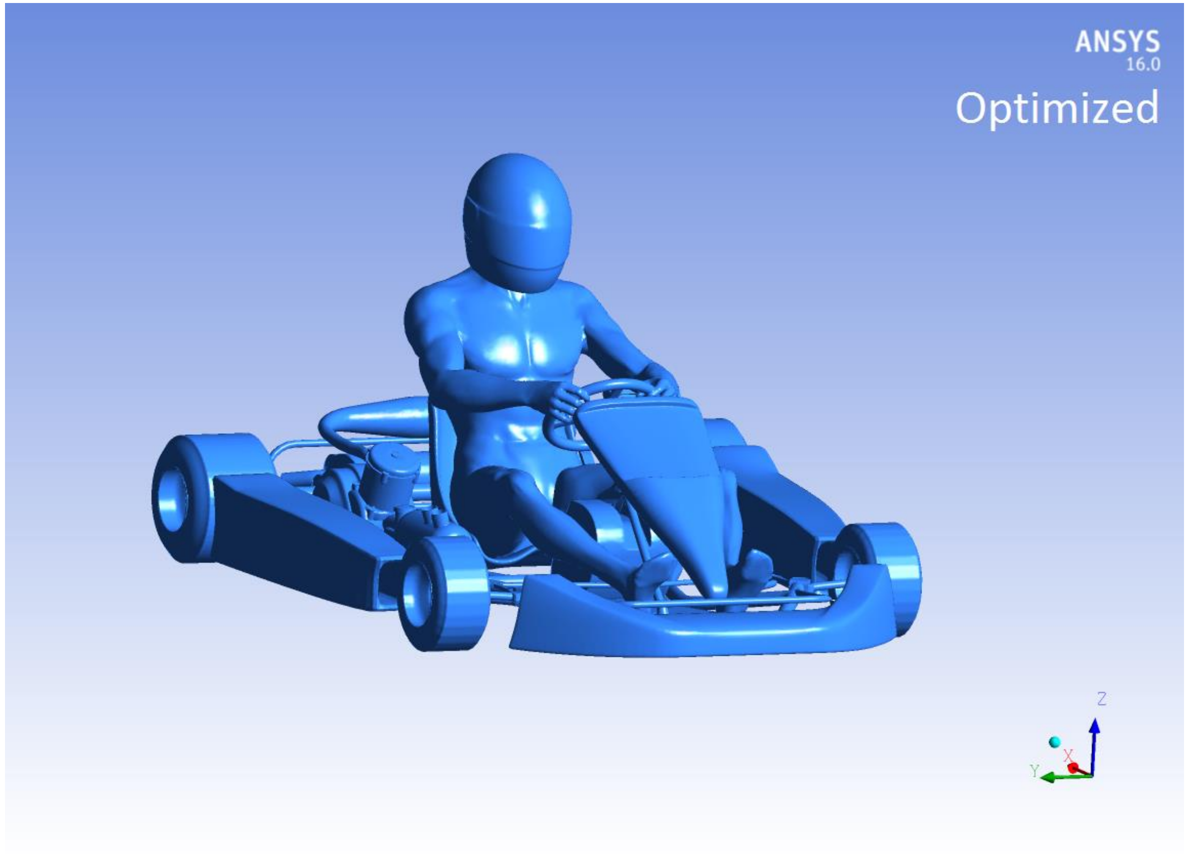




Results

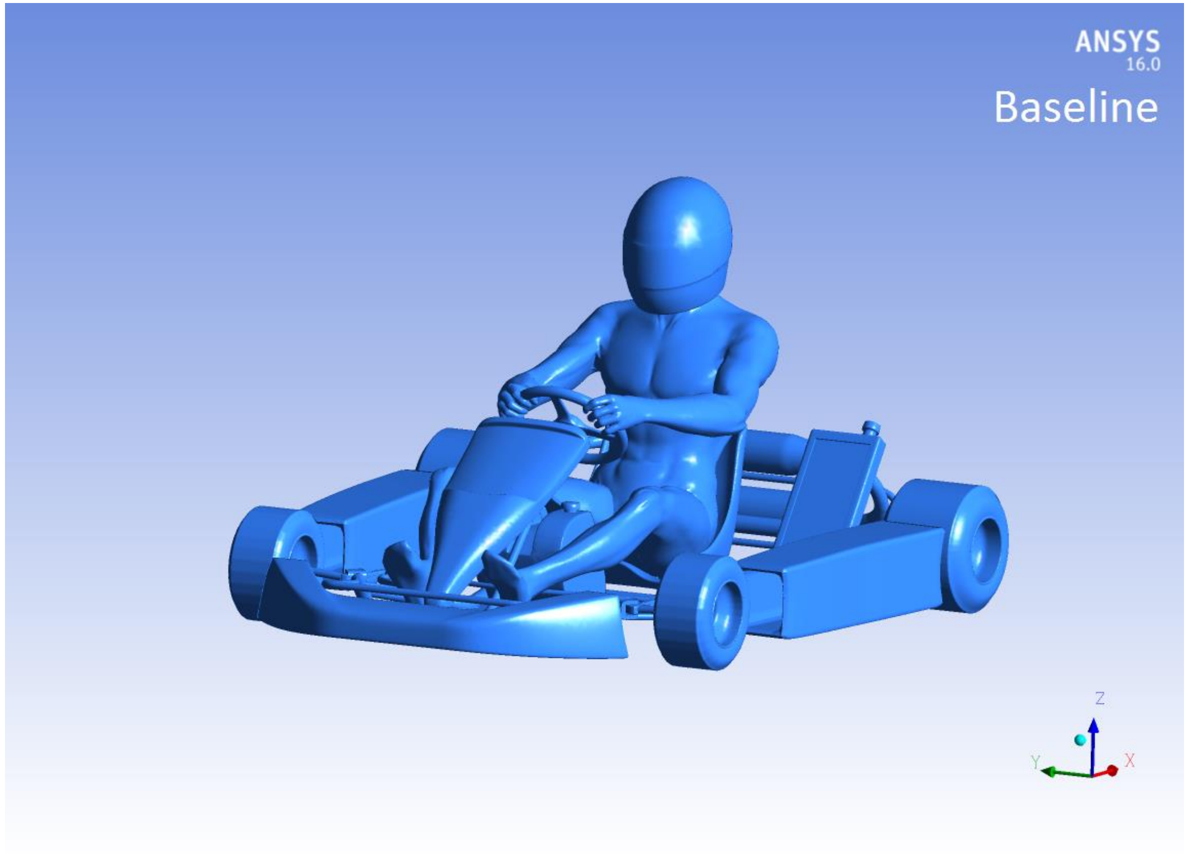
Comparison between baseline and downforce optimized configurations (right side)

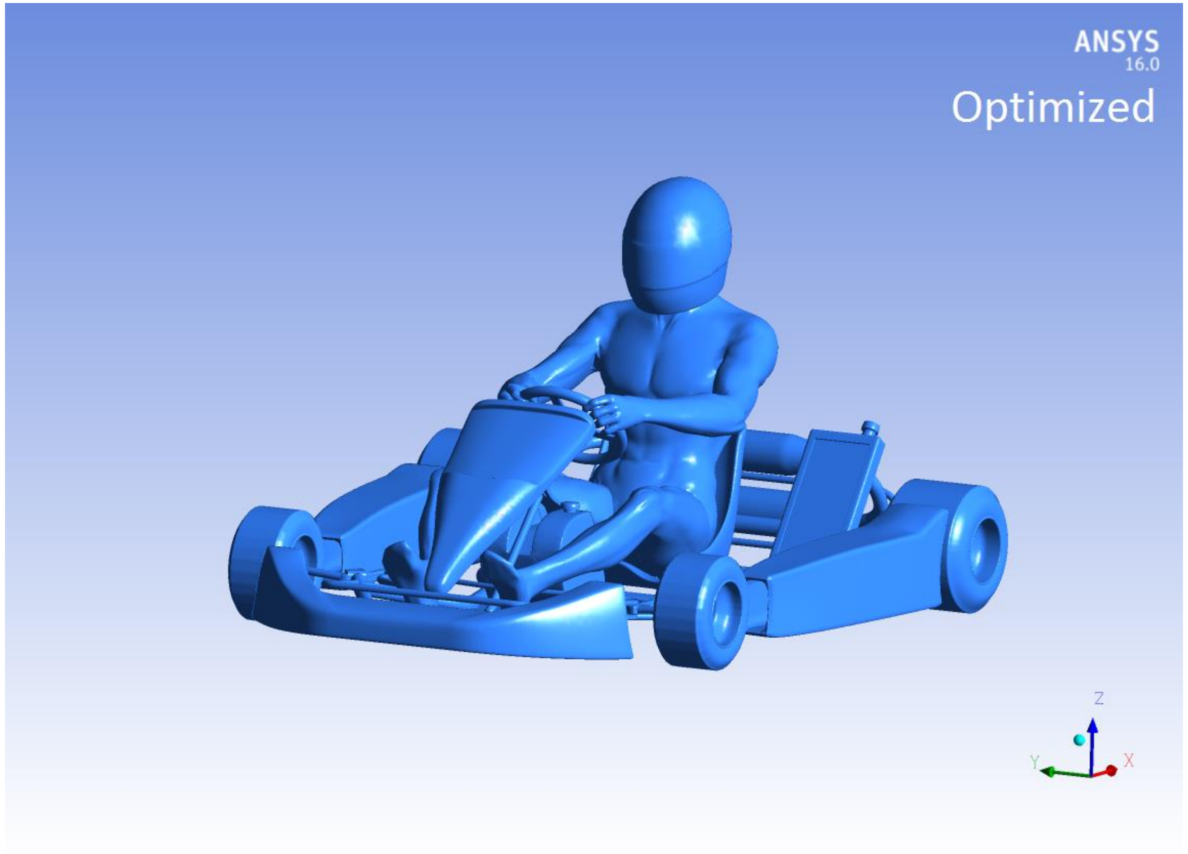




Results

Comparison between baseline and downforce optimized configurations (left side)





Results

- Shape changes **contribution is higher** with the small-size driver
- **3,1% improvement** (6 N) with the small-size driver option
- **10% total improvement** of the optimized small driver-size configuration over the standard bodywork configuration with medium-size driver

Medium-size driver optimization

Table of Schematic B4: Optimization , Candidate Points

	A	B		R	S	T	U
1	Reference	Name		P16 - drag-force (N)		P17 - downforce (N)	
2				Parameter Value	Variation from Reference	Parameter Value	Variation from Reference
3	○	Candidate Point 1		★★★ 169,36	-2,30%	★★ 68,126	15,65%
4	○	Candidate Point 2		– 175,66	1,33%	★★★ 70,594	19,84%
5	○	Candidate Point 3		×× 179,22	3,39%	★★★ 71,847	21,97%
6	◉	base		★ 173,35	0,00%	×× 58,908	0,00%

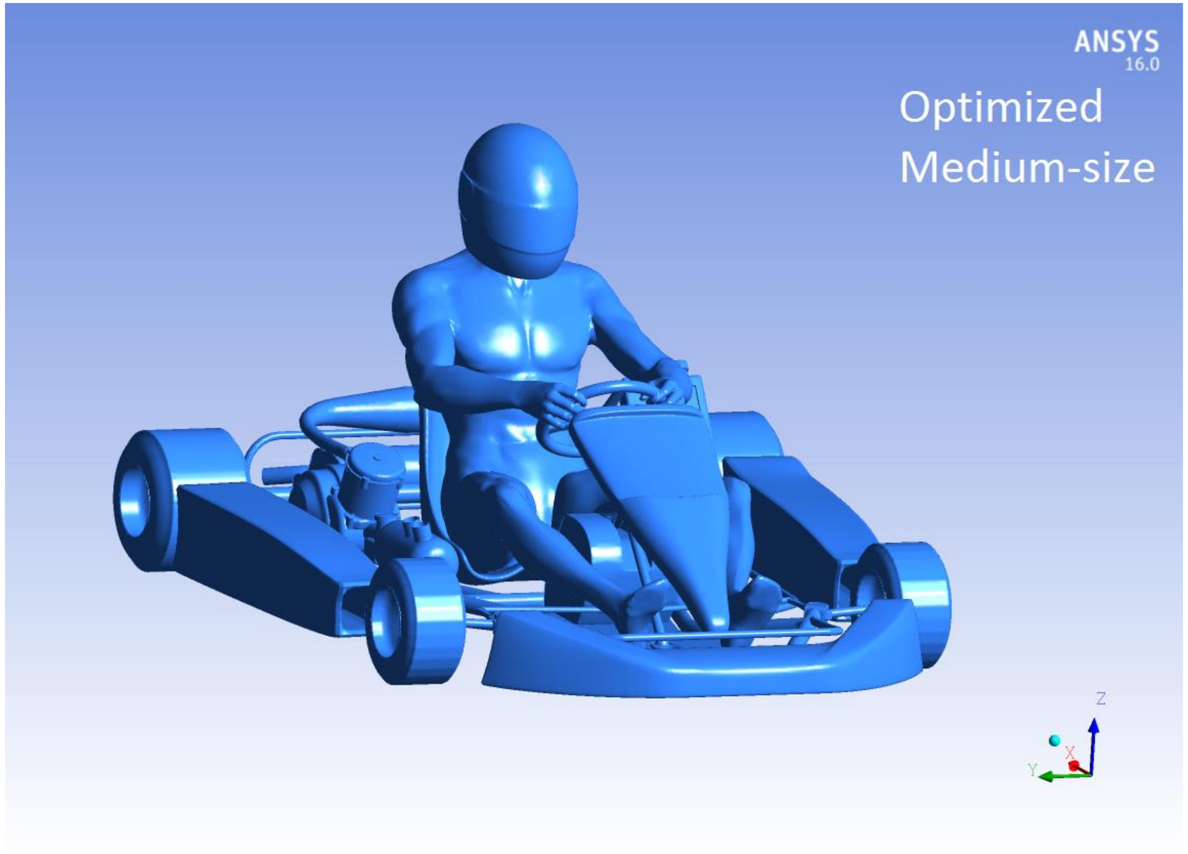
Small-size driver optimization

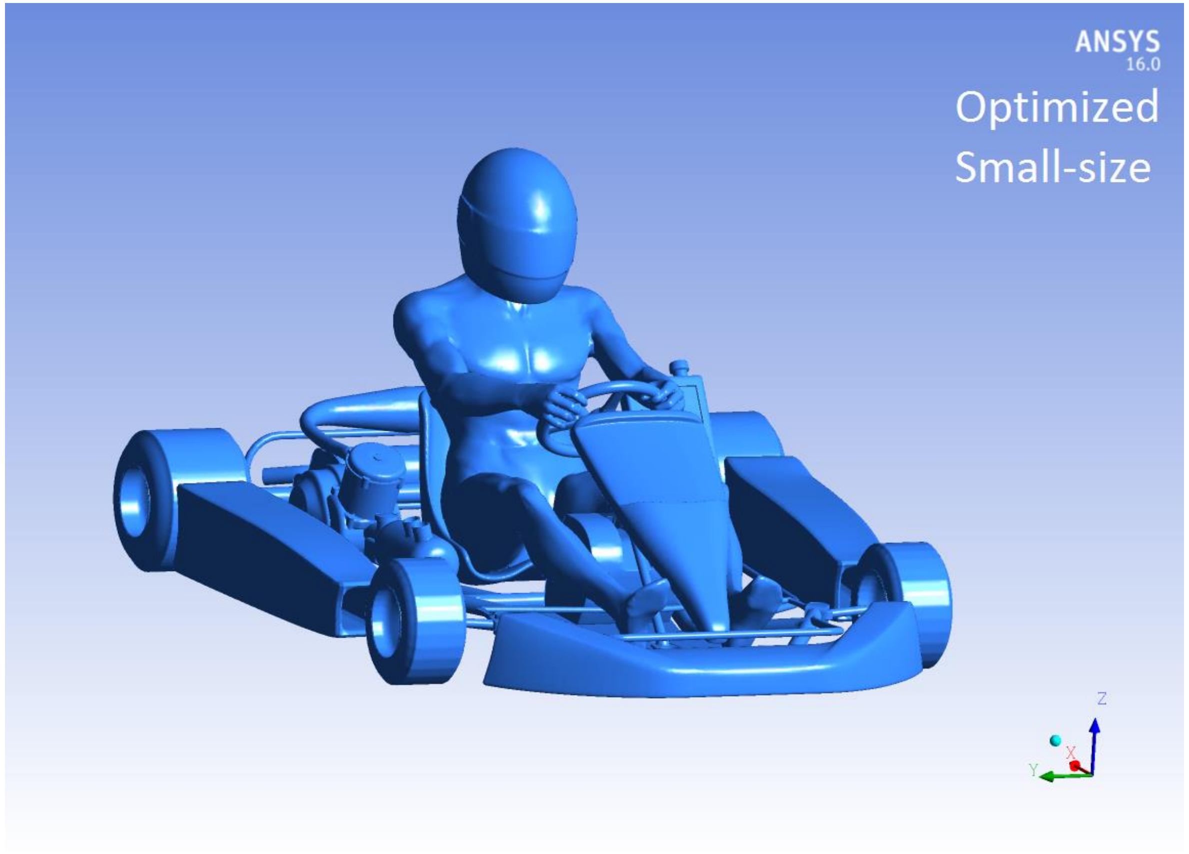
Table of Schematic B4: Optimization , Candidate Points

	A	B		R	S	T	U
1	Reference	Name		P16 - drag-force (N)		P17 - downforce (N)	
2				Parameter Value	Variation from Reference	Parameter Value	Variation from Reference
3	○	Candidate Point 1		★★★ 161,79	-3,12%	★★ 62,02	16,32%
4	○	Candidate Point 2		– 169,91	1,74%	★★★ 64,07	20,18%
5	○	Candidate Point 3		×× 173,73	4,03%	★★★ 65,06	22,04%
6	◉	base		★ 167,00	0,00%	×× 53,31	0,00%

Results

Comparison between optimized configurations in both medium- and small-size driver options





Conclusions

The results of the parametric optimization show:

- **2,3% drag-force reduction.** Predictable result since the performed study has been developed on an already designed bodywork hence presumably optimized
- **22% downforce increase.** Consistent positive result which indeed highlights the poor optimization, in terms of downforce, of the baseline bodywork configuration
- **Variability of the optimal drag-force wise configuration with the driver body size.** Predictable variability due to the high contribution of the driver to the total drag-force value
- **Invariability of the optimal downforce wise configuration with the driver body size.** Contrary to what is observed in terms of drag-force, the contribution of the driver to the total downforce value is not significantly high. Therefore the optimal configuration is not affected by the driver size variation

Links

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Supervisor:

- Prof. Marco Evangelos Biancolini, biancolini@ing.uniroma2.it

Software used:

- RBF-Morph, http://www.rbf-morph.com/
- ANSYS Fluent, DesignXplorer, http://www.ansys.com/
- Siemens PLM Femap, http://www.plm.automation.siemens.com/en_us/products/femap/index.shtml