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

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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

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

$$D = 173.35 \text{ N}$$

$$c_d = 0.794$$

- 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

Drag-force histogram
### CFD Results

**Downforce and $c_l$ numerical results**

\[
L = \frac{1}{2} \rho Sv^2 c_l
\]

\[-L = 58.51 \text{ N}\]

\[c_l = -0.268\]

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

TRADITIONAL APPROACH

AUTOMATIC PARAMETRIC OPTIMIZATION

MESH MORPHING
RBF Mesh Morphing

Mesh morpher used:

(\textit{rbf-morph})

**Radial Basis Functions:**

- **INPUT**
  - Radial Functions set
  - Source points
  - Assigned displacements

- **OUTPUT**
  - Motion solution

**Set-up shape changes**

**Design shape changes**

\textbf{OPTIMIZATION}

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RBF-Morph Grafic-User-Interface inside ANSYS Fluent
Shape changes

Front panel vertical translation

Motion set-up

- **Chassis surface** selection
- Definition 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 caps**
- **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

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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

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Design shape changes

Rear profile rotation

- Baseline
- Intermediate amplitude
- Maximum amplitude
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

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Driver size changes

Selection encap, translation

Selection encap, null displacement

Morphing domain
Driver size changes

Comparison between driver sizes before and after morphing action
Parametric optimization inside ANSYS Workbench (DesignXplorer)

- Shape changes made **parametric** by means of RBF-Morph directly in the Fluent case
- Definition of **15 input parameters** (shape changes) and **2 output parameters** (drag-force, downforce)
- Definition of upper and lower bound for each parameter

Optimization accomplished with DesignXplorer linked to CFD by the defined parameter set
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
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
Goal Driven Optimization

Choice of the optimal configuration through *Goal Driven Optimization*

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

Both drag-force and downforce value improvement

\[ D_{opt} = 169.36 \text{ N} \quad \text{and} \quad L_{opt} = 71.85 \text{ N} \]

- 2.3% gain over the baseline drag-force value
- 22% improvement in terms of downforce
Comparison between baseline and drag-force optimized configurations (right side)
Comparison between baseline and drag-force optimized configurations (left side)
Comparison between baseline and downforce optimized configurations (right side)
Comparison between baseline and downforce optimized configurations (left side)
Results

Medium-size driver optimization

- 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

Small-size driver optimization
Comparison between optimized configurations in both medium- and small-size driver options
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.
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Software used: