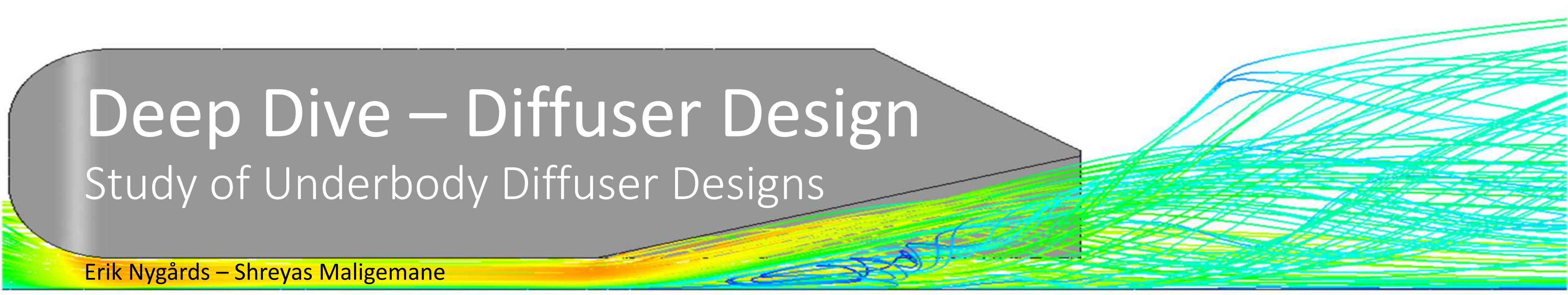

Deep Dive – Diffuser Design

Study of Underbody Diffuser Designs

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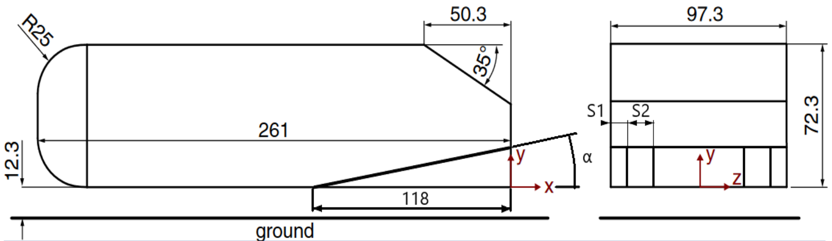
Aerodynamics is a key factor in increasing the performance of any transport by guiding the airflow in favorable ways to generate downforce or reduce drag. Formula 1 cars, as of 2018 regulations, generated around 65% of their total downforce with the floor and diffuser, while adding only 15% of the total drag [1]. Hence it is the logical first area of improvement.

The aim of this study was to investigate the impact on aero-performance by different diffuser designs on an Ahmed body[2]. The diffuser was studied with side skirts, 0-, 1-, and 2-strake configurations, and with sharp or rounded leading edge. The designs were optimized for maximum downforce using response surfaces generated with data from numerous CFD simulations. Simulations were made in ANSYS CFX.

METHODS

Geometry: Fig.[1] with reference to Venning [3], symmetry used for computational efficiency.



Fig[1]: modified Ahmed body with a diffuser. α – diffuser angle, S1 S2 strake position.

Mesh: A mesh of 512k nodes , 15 inflation layers, 3 bodies of influence and a first cell height of 0.06[*mm*] was used to capture the boundary layer, with $y^+ < 1$.

Boundary Conditions: Inlet velocity = 5.551[*m/s*] in accordance with $Re_{\sqrt{A}}$ =30000 (A=frontal shadow area), turbulence intensity of 1% , no-slip walls on the walls of the car and ground.

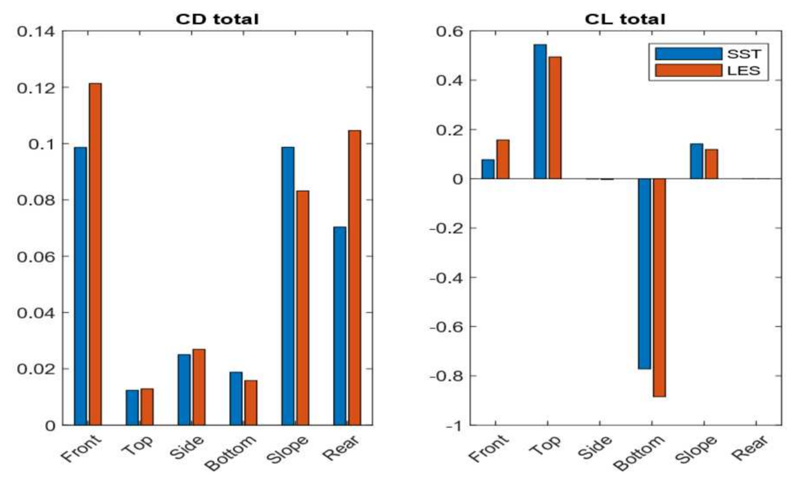
CFD Solver: Ansys CFX 2021 R1

Turbulence Modeling: RANS k-ω SST

Verification: The mesh was verified as per Celik [4] for total C_L and C_D. Attaining a GCI of 1.57% for drag and a e_a of 4.48% for lift. The mesh used thus consisted of 512 000 nodes. The residual was monitored to ensure a good convergence was attained.

Validation: The model was validated by comparing the total, pressure, friction drag, and lift components for each part of the car with accurate LES data, refer Fig.[2].

Optimization: The diffusers were optimized for maximum downforce. The parameters varied and their ranges were: diffuser angle 1≤ α ≤17 [degree], ride height between 5-15 [*mm*], LE radius 2≤ r ≤50 [*mm*], strake 1 position 5≤ S1 ≤20 [*mm*], strake 2 position 10≤ S2 ≤40 [*mm*]. The combinations optimized were: sharp LE with 0-, 1-, and 2-strakes; rounded LE with 1- and 0-strakes. All combinations with sideskirts.



Fig[2]: Validation plots comparing the forces at different locations on the car between LES and SST-model.

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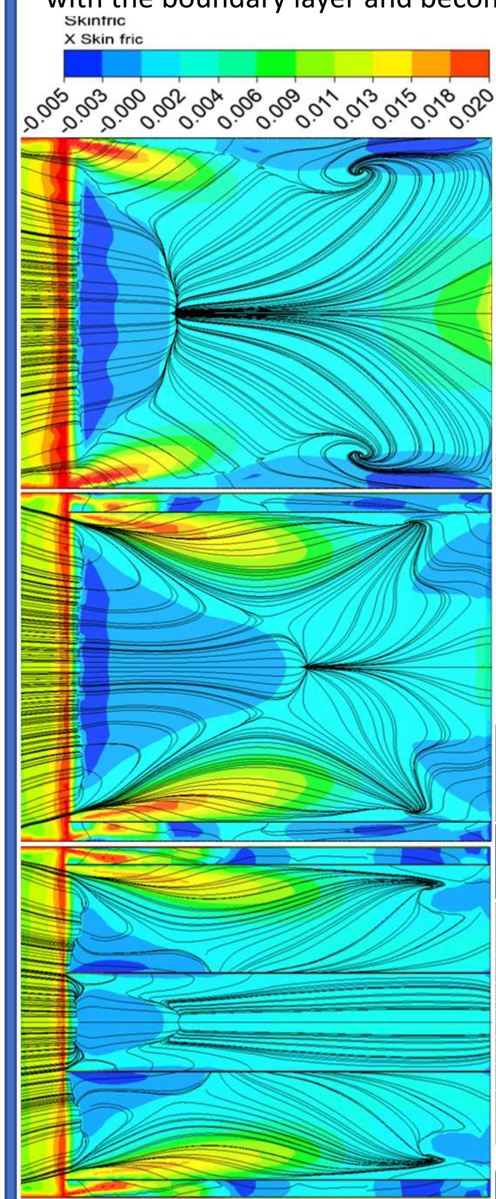
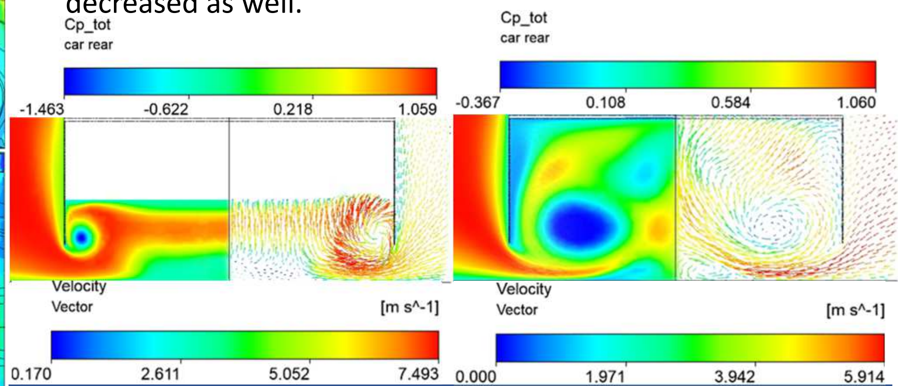
RESULTS

The results showed all diffusers giving more downforce than the baseline. The optimization showed that higher diffuser angles(α) led to the largest amounts of downforce, e.g., lower C_L, see Fig.[5]. However as ride height was lowered the downforce generated by high angle diffusers plummeted. This is likely due to the two counterrotating vortices generated at the skirts, see Fig.[4], interacting with the boundary layer and becoming inefficient, or collapsing [5] [6] [7].



Fig[3]: Skin friction in x-direction and surface streamlines on the diffuser surface for the optimized no-strake (top), 1-strake (middle), 2-strake (bottom). Flow from left to right.

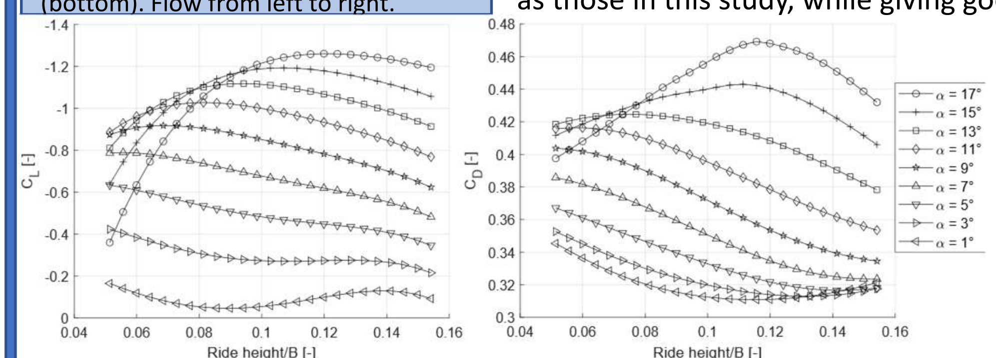
Fig.[3] shows the different surface flow patterns for optimized 0-, 1-, and 2-strake designs. Where the 0-strake diffuser shows good agreement with experimental data [5] [7]. According to Fig.[6] a 0-strake diffuser design produces more downforce than the other strake designs. The optimized points showed that the more strakes added, the lower the ride height had to be for maximum performance, see Tab.[1]. From that followed, according to Fig.[5] that the diffuser angle was decreased as well.



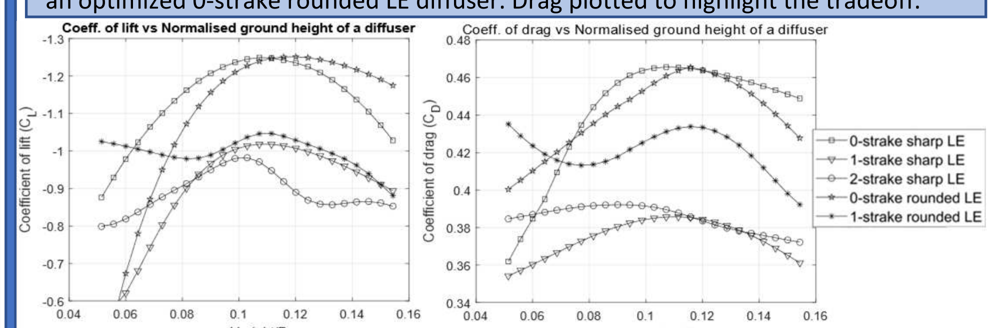
Fig[4]: $C_{p,tot}$ and velocity vectors at X=-75 mm (left), and X=0 mm (right), showing the skirt vortex forming and detaching from the skirt.

Tab.[1]: The parameters and performance of the optimized diffuser designs.

Sharp LE	Ride height/B [-] (Ride height [mm])	Angle α [°]	Strake 1 pos. [mm]	Strake 2 pos. [mm]	C_L	C_D
2-strake	0.102 (9.924)	12.609	5.062	35.070	-0.958	0.407
1-strake	0.108 (10.5)	15	5.525	-	-0.996	0.421
0-strake	0.116 (11.3)	17	-		-1.241	0.465
Rounded LE				Radius [mm]		
1-strake	0.108 (10.5)	15	5.525	2.248	-1.05	0.432
0-strake	0.111 (10.796)	16.647	-	2.263	-1.304	0.472
Base model	0.126 (12.3)	-			-0.009	0.324



Fig[5]: C_L and C_D variations with ride height changes, normalized by the breadth, for an optimized 0-strake rounded LE diffuser. Drag plotted to highlight the tradeoff.



Fig[6]: C_L and C_D variations with ride height, normalized by the breadth, for all optimized diffuser designs. Drag plotted to highlight the different tradeoffs.

CONCLUSION

A diffuser increases the amount of generated downforce, for a relatively small increase in drag. It can be a simple design, such as those in this study, while giving good performance when optimized.

The design generating the most downforce out of those studied here, without tires modeled, is a 0-strake rounded or sharp LE diffuser, with a high diffuser angle. Further investigation would be necessary before any implementations however, as the tires inject “bad” air into the diffuser and is the reason real cars have strakes.

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