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EXPERTS IN
COMPUTATIONAL FLUID DYNAMICS

HH01: Road Bike Helmet Study and Competitor Analysis

To:	James Cook
Company:	HEXR
PO Number:	PO1723
Author:	John Chalke
Reviewer:	GM
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Summary:

This document presents aerodynamic results for a study of the HEXR helmet (in original and final designs), and four competitor designs. Helmets are analysed in two head positions and three yaw angles (0.5º, 10º and 20º), at a forward speed of 35kph.

- The cyclist has been 3D scanned, along with a generic bike frame, to provide a representative flow field in the vicinity of the helmet.
- Results show that the final HEXR helmet has the lowest drag in Position 2 and ranks 3rd in Position 1.

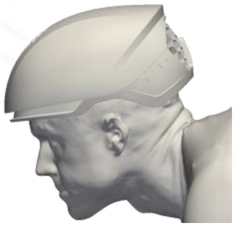
Introduction

The aim of this study is to compare aerodynamic performance of six road bike helmets using CFD, including the HEXR road bike helmet design.

- A cyclist has been scanned in a road-riding position (on drops), with two head positions. Four competitor helmets have also been scanned. The helmets are positioned on the rider in both head positions for CFD analysis.
- The neck/head of the two riding positions have been merged with the same body, meaning that the only geometric differences are from the neck upwards.
- A simplified bike scan (excluding brakes, spokes and chain) has been used in all cases. The bike includes representative wheel geometries, obtained by revolving a simplified extraction of the profile from the scan.

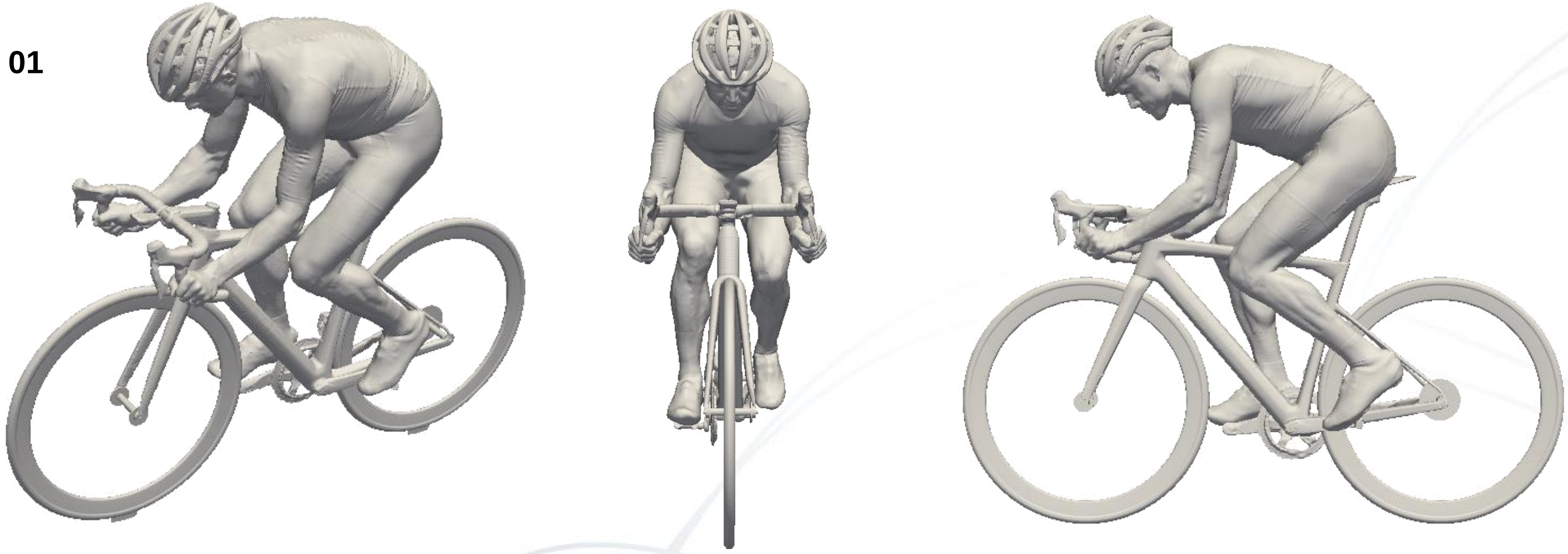
The following pages will give an overview of the geometries used and the simulation configurations.

Results are presented as overall drag (total rider and bike drag). Flow visualisation is included to show the changes between helmet designs, with comments included on the design guidelines to change from the initial to the final HEXR designs.

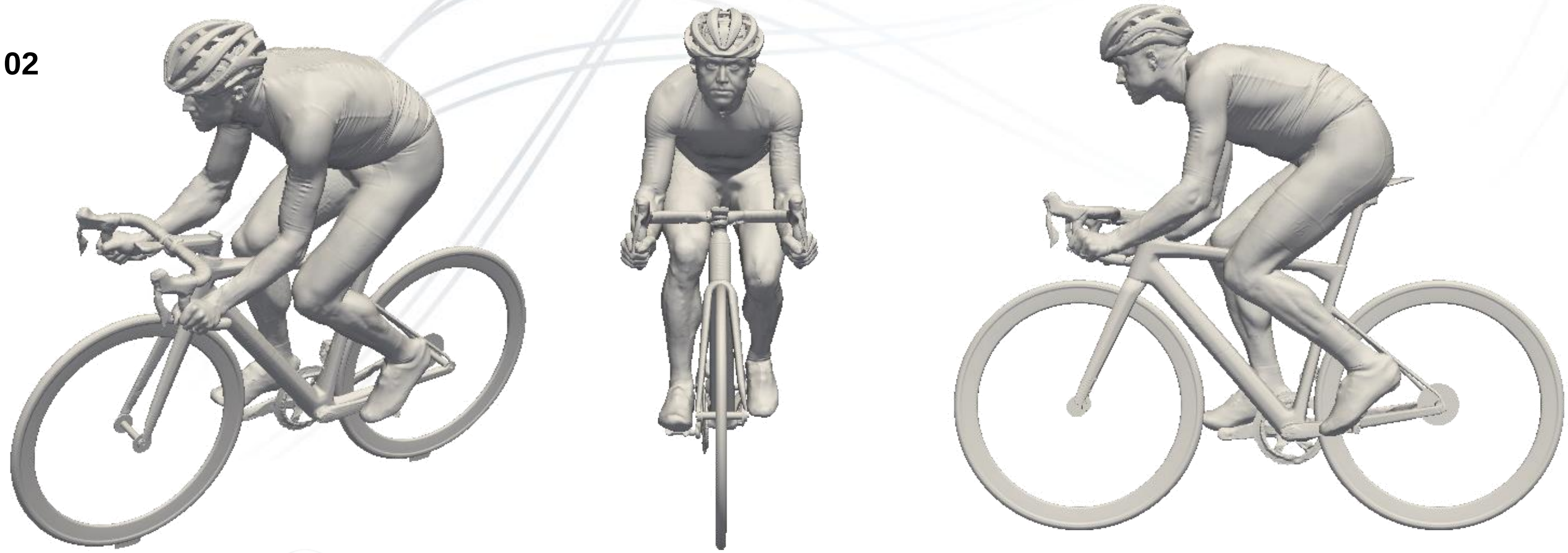
Rider Position 01		**Rider Position 02**	
			
Run	**Helmet**	**Run**	**Helmet**
R001	Giro-Aether	R002	Giro-Aether
R003	Kask Protone	R004	Kask
R007	HEXR (original design)	R008	HEXR (original design)
R009	POC Ventral	R010	POC Ventral
R011	Giro-Vanquish	R012	Giro-Vanquish
R014	HEXR (final design)	R015	HEXR (final design)

Riding Positions

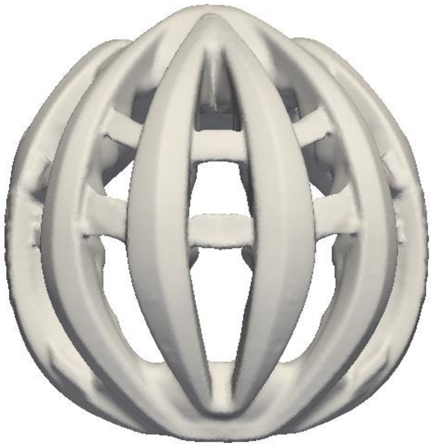
Position 01



Position 02

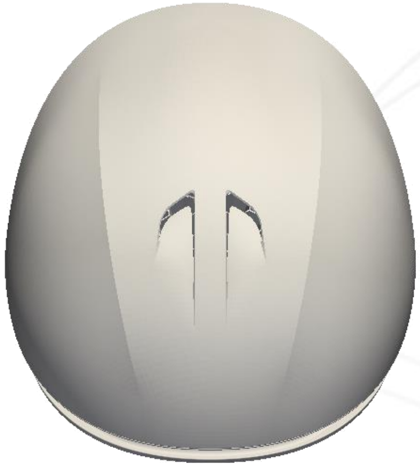


Helmet Geometries: Front View



Giro-Aether

Kask Protone



HEXR (original)

POC Ventral

Giro-Vanquish

HEXR (final)

Helmet Geometries: Side View

Giro-Aether

Kask Protone

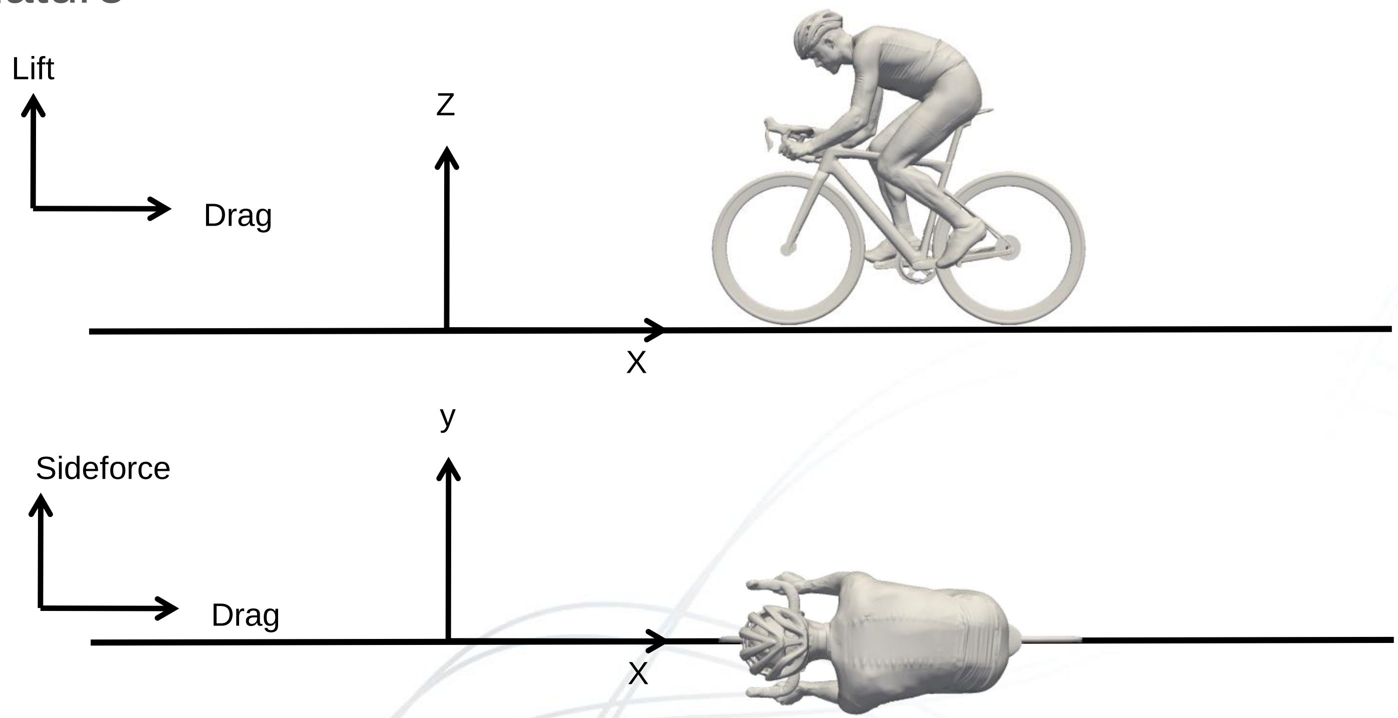
HEXR (original)

POC Ventral

Giro-Vanquish

HEXR (final)

Nomenclature



Drag and sideforce are always quoted in a bike-aligned system:

Drag: Force resolved parallel to ground in positive x-direction.

Cd.A: Drag coefficient multiplied by frontal area.

Side Force: Force resolved parallel to ground in positive y-direction.

Cp: Pressure coefficient – Non-dimensionalised static pressure.

CpX: Pressure coefficient resolved in the x-direction.

CpY: Pressure coefficient resolved in the y-direction.

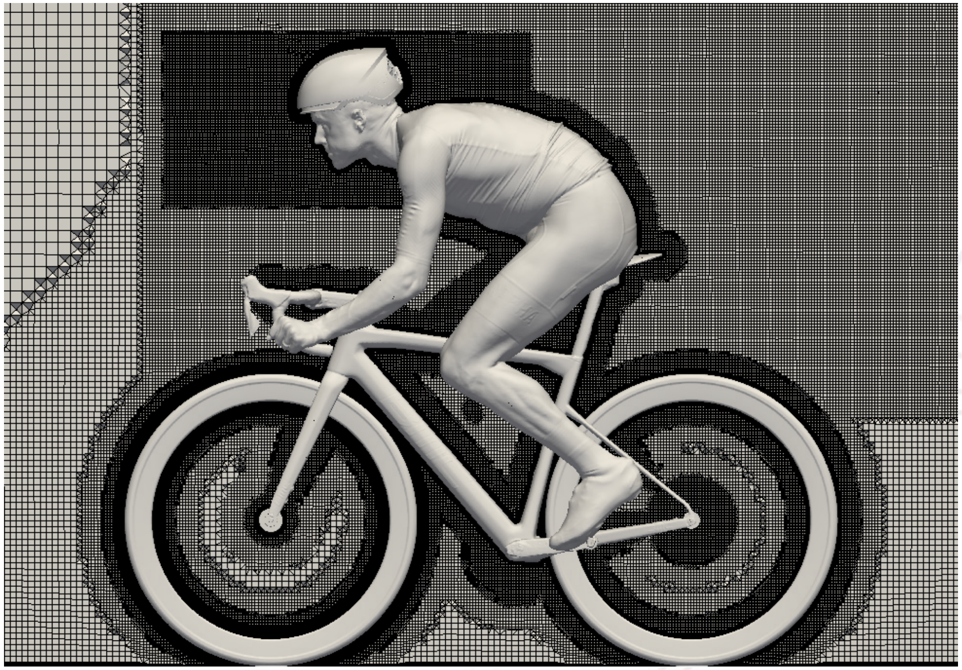
CpT: Total pressure coefficient – A measure of the energy in the flow.

Uw: Near wall velocity- Velocity of the flow near the geometry, which can be used to identify regions of slow or separated flow.

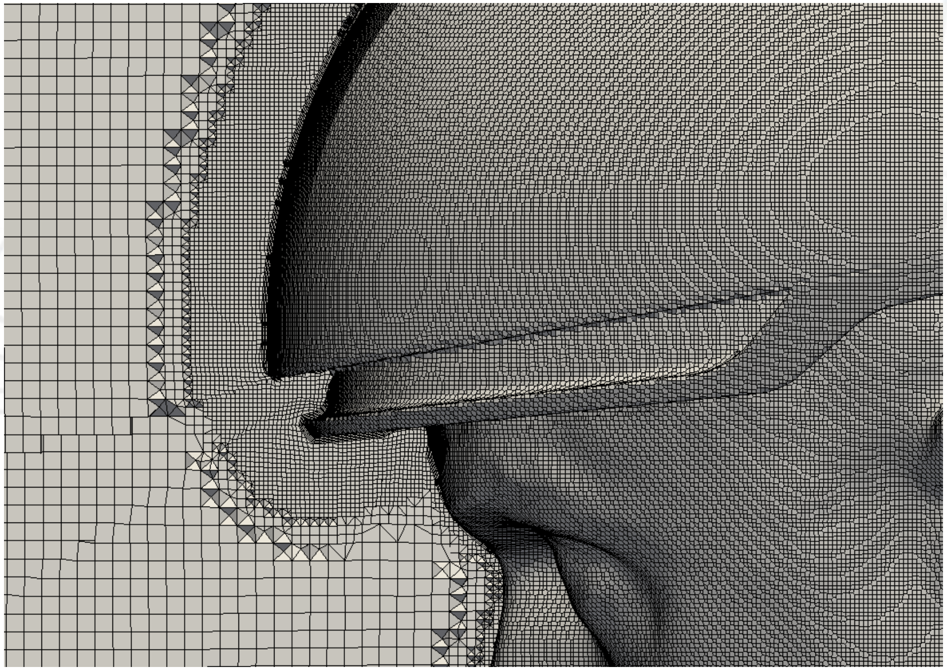
$$C_d \cdot A = \frac{D}{\frac{1}{2}\rho_\infty u_\infty^2} \qquad C_p = \frac{p - p_\infty}{\frac{1}{2}\rho_\infty u_\infty^2} \qquad C_p T = \frac{p_s + \frac{1}{2}\rho_\infty u^2}{p_\infty + \frac{1}{2}\rho_\infty u_\infty^2}$$

Mesh Details

The geometry of the bike, cyclist and helmet have been meshed using snappyHexMesh according to TotalSim's best practice. The mesh uses predominantly hexahedral cells and has been refined in the important regions close to the geometry. The mesh for each CFD simulation consists of approximately 50 million cells.



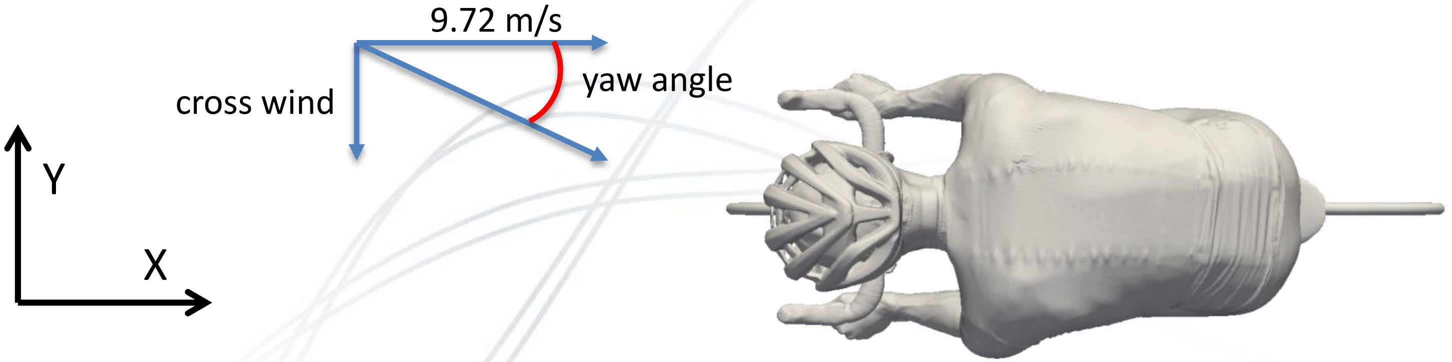
Mesh slice through rider at a constant central Y-position showing the mesh refinement close to the geometry.



Surface mesh detail on helmet and rider's head

Simulation Setup

- Each helmet has been tested with the rider in both head positions and different cross wind velocities corresponding to yaw angles of 0.5, 10 and 20 degrees. The purpose of this approach is to make sure the results are robust across a range of wind conditions experienced during a ride. There are a total of six simulations for each helmet, with the exception of the S-Works helmet which has only been tested in riding position 01.
- The data is processed using a yaw weighting where the data at 0.5, 10 and 20deg yaw is weighted by 90%, 9%,1% respectively. These weighting factors are specified by HEXR and can be changed in the supplied spreadsheet.
- The forward speed of the cyclist and bicycle has been kept constant at 35kph for all the simulations and the cross wind has been varied between the different simulations to achieve the three different yaw angles. The cyclist has been tested in a single leg position with stationary legs.



- The flow is assumed to be fully turbulent, unsteady and incompressible. The model is solved using a DES turbulence approach. The simulations use a timestep of 0.0005s and are run for 2.0 seconds of physical time (4,000 time steps).
- The forces and flow field are averaged during the last second (1.0s – 2.0s) of the unsteady CFD simulation to determine the average drag and the mean flowfield. Images shown throughout the report show the time-averaged mean flow field; drag and sideforce are quoted in bike-aligned coordinates.

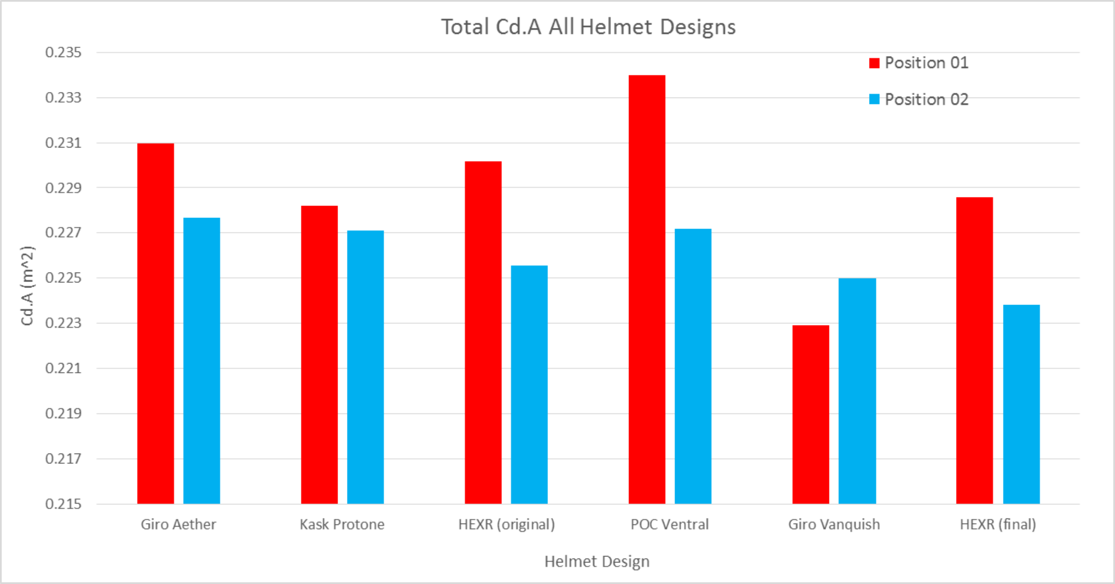
Results: Comparison of Drag

- Drag coefficient from the entire rider + bike (Cd.A) from different yaw angles have been combined for each helmet and riding position based on a weighting supplied by HEXR that assumes 90% of cycling at 0.5º yaw, 9% at 10º yaw and 1% at 20º yaw.
- A spreadsheet with a detailed breakdown of forces is also provided. This allows the user to specify a different yaw weighting if desired. The spreadsheet also converts the drag data into a time for 40km at a specified power input and allows time savings to be compared between designs.

Results: Total Cd.A and Heat Transfer from all Simulations

The graphs show yaw averaged data using the weightings mentioned previously.

The data shows that the drag of the final HEXR helmet ranks as the lowest of all designs in position2, and 3rd lowest drag in Position 1.



Results: Total Cd.A and Heat Transfer from all Simulations

The table below shows the Cd.A values for each helmet and riding position. Data is yaw weighted using the weightings mentioned previously. The supplied spreadsheet contains more detailed breakdown of forces for each run.

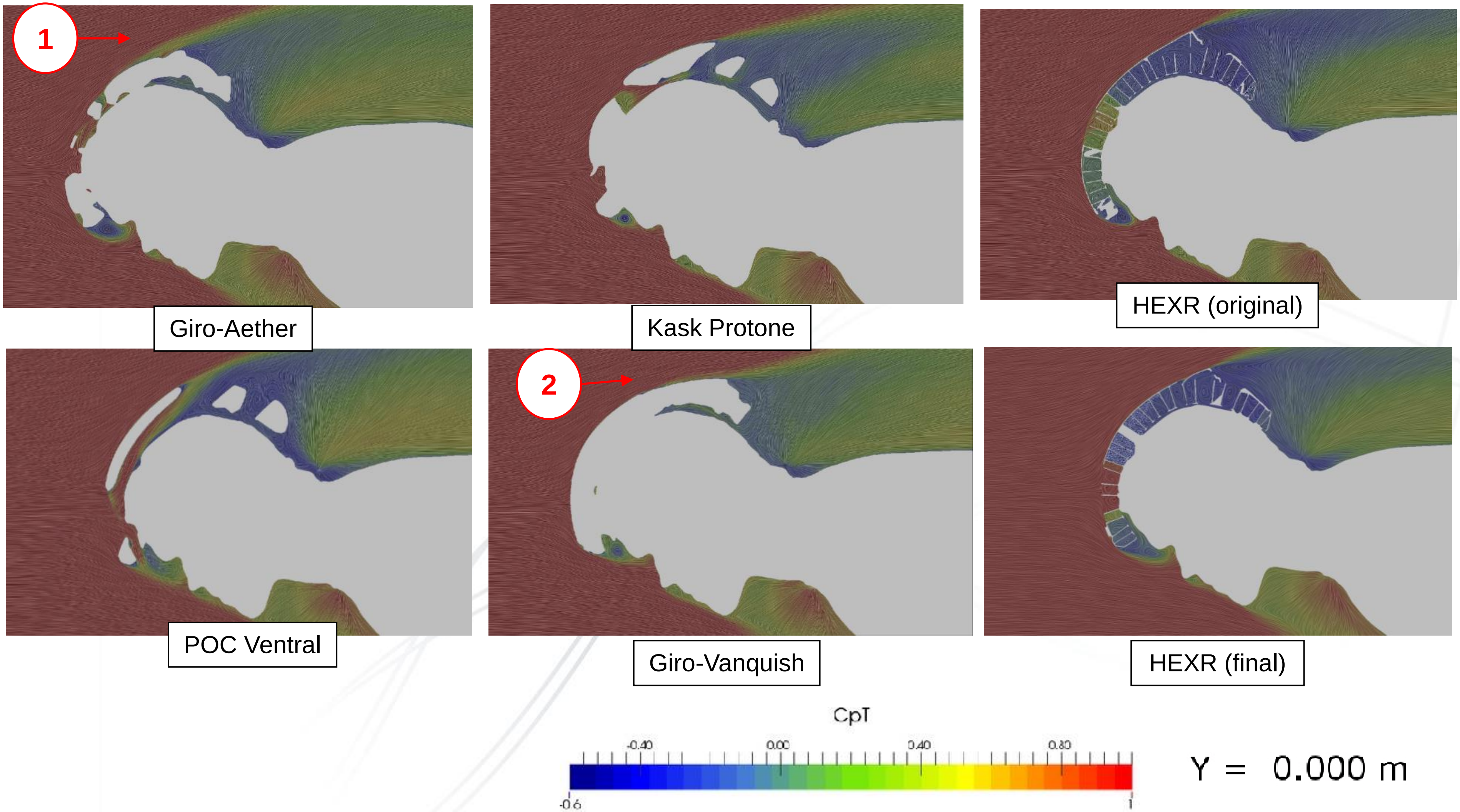
- Note that the simplified bike model and stationary legs/pedals result in a reduction in Cd.A; however, the results remain valid for direct comparison between runs.
- Results from individual yaw angles are provided in a separate spreadsheet.

	Position 1		Position 2	
Helmet	**Run**	**Cd.A**	**Run**	**Cd.A**
Giro Aether	R001	0.231	R002	0.228
Kask Protone	R003	0.228	R004	0.227
HEXR (original)	R007	0.230	R008	0.226
POC Ventral	R009	0.234	R010	0.227
Giro Vanquish	R011	0.223	R012	0.225
HEXR (final)	R014	0.229	R015	0.224

Results: Comparison of CpT on a Central Y Plane

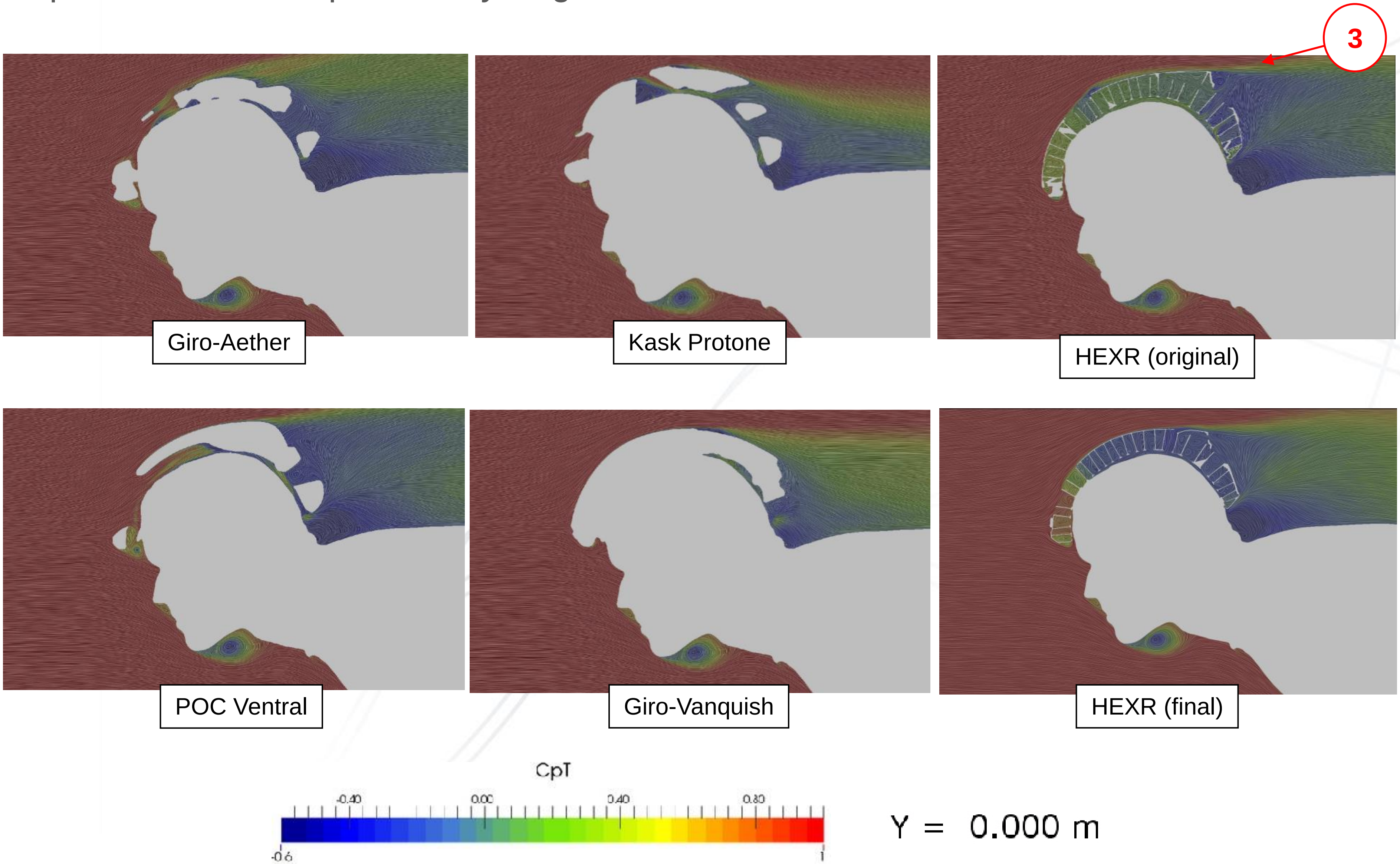
- CpT is the Total Pressure Coefficient. It is a measure of the energy within the flow and low values show the wake structures.
- The plots include streamlines to show mean flow paths passing the rider.
- All plots are at an a yaw angle of 0.5 degrees.

CpT on a central Y plane – Cycling Position 01



Highlighted points 1-2 are discussed in the following slides.

CpT on a central Y plane – Cycling Position 02



Highlighted point 3 is discussed in the following slide.

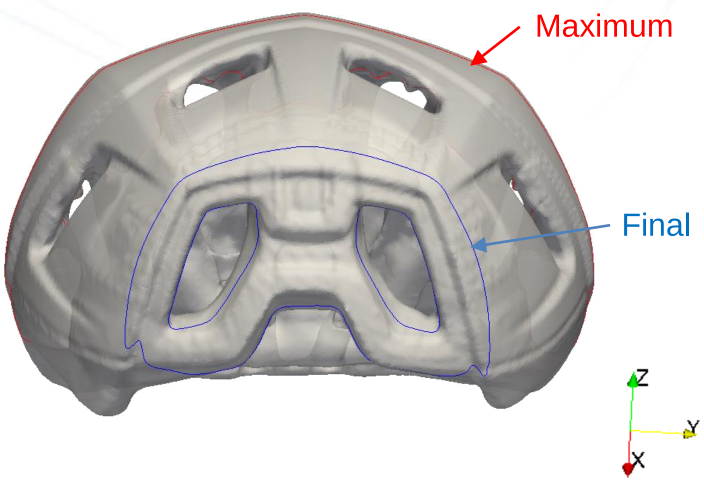
Results: Comparison of CpT on a Central Y Plane

The points below correspond to highlighted points 1-3 on the contour plots:

1. All of the helmets in rider position 01 deflect air upwards, increasing the size of the wake and contributing to drag. The angle that the air is travelling at the point of separation plays a significant role in the pressure downstream of the helmet, and therefore the 'suction' acting on the rear-facing surfaces of the helmet (pressure drag).

2. The Giro Vanquish provides smooth curved surfaces that turn the flow while reducing the cross section and pulling the wake down towards the rider's back. The image below shows the maximum and final cross-section of the helmet. Although the HEXR (original) provides smooth curved surfaces for the airflow, in comparison to the Giro-Vanquish, the HEXR (original) does not provide a smooth reduction in cross-section. The sharp turn at the top rear end of the HEXR (original) causes airflow to separate with no change in trajectory. To reduce drag, it is advisable to incorporate a gradual reduction in cross-section towards the rear of the helmet that would release the air at an angle closer to the rider's back and reduce the size of the wake. This feature was addressed in the development from the original to the final HEXR designs.

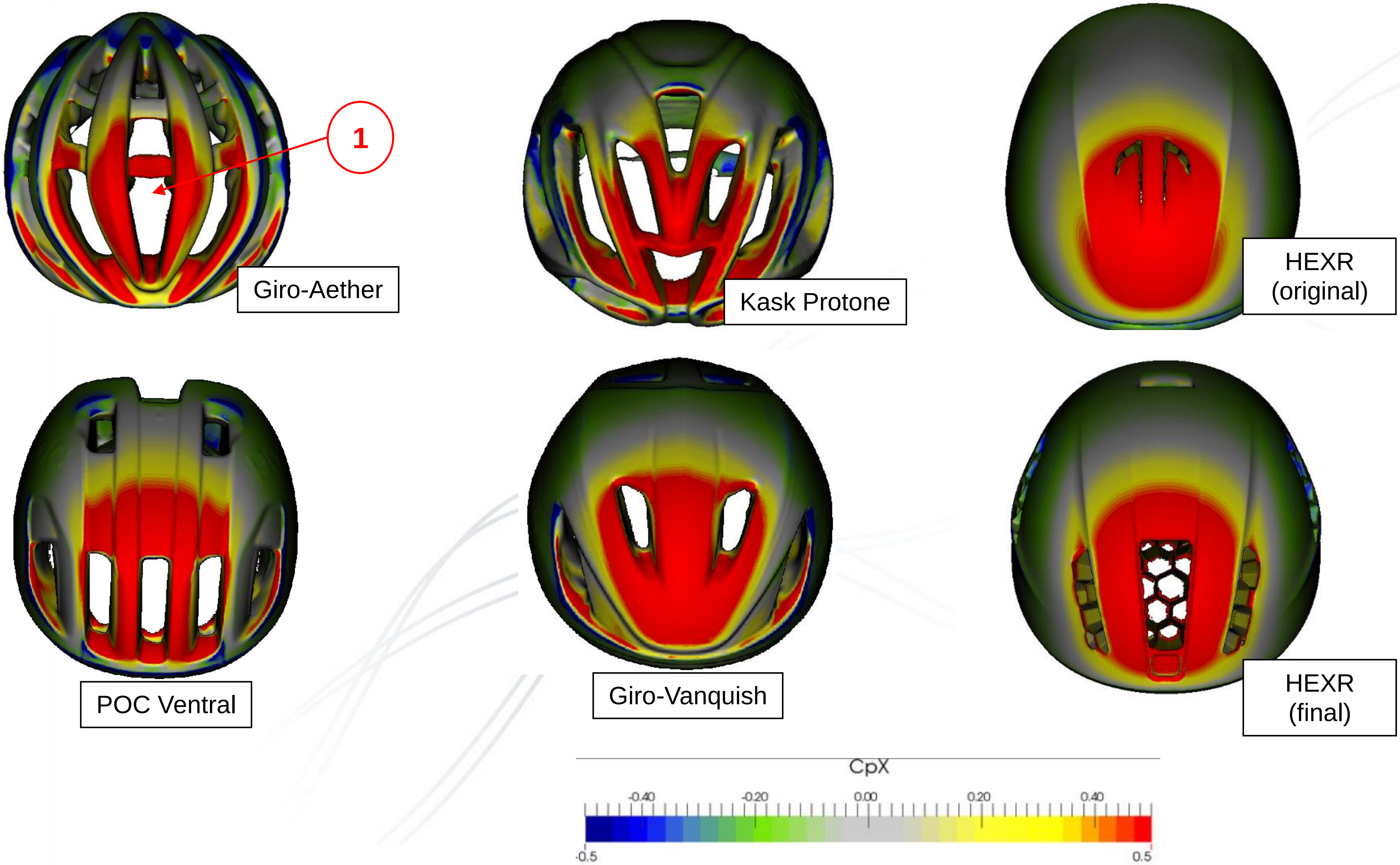
3. In rider position 02, the flow leaves the helmet at an angle closer to the rider's back, reducing drag in most cases.



Results: Comparison of CpX on Helmet Surfaces

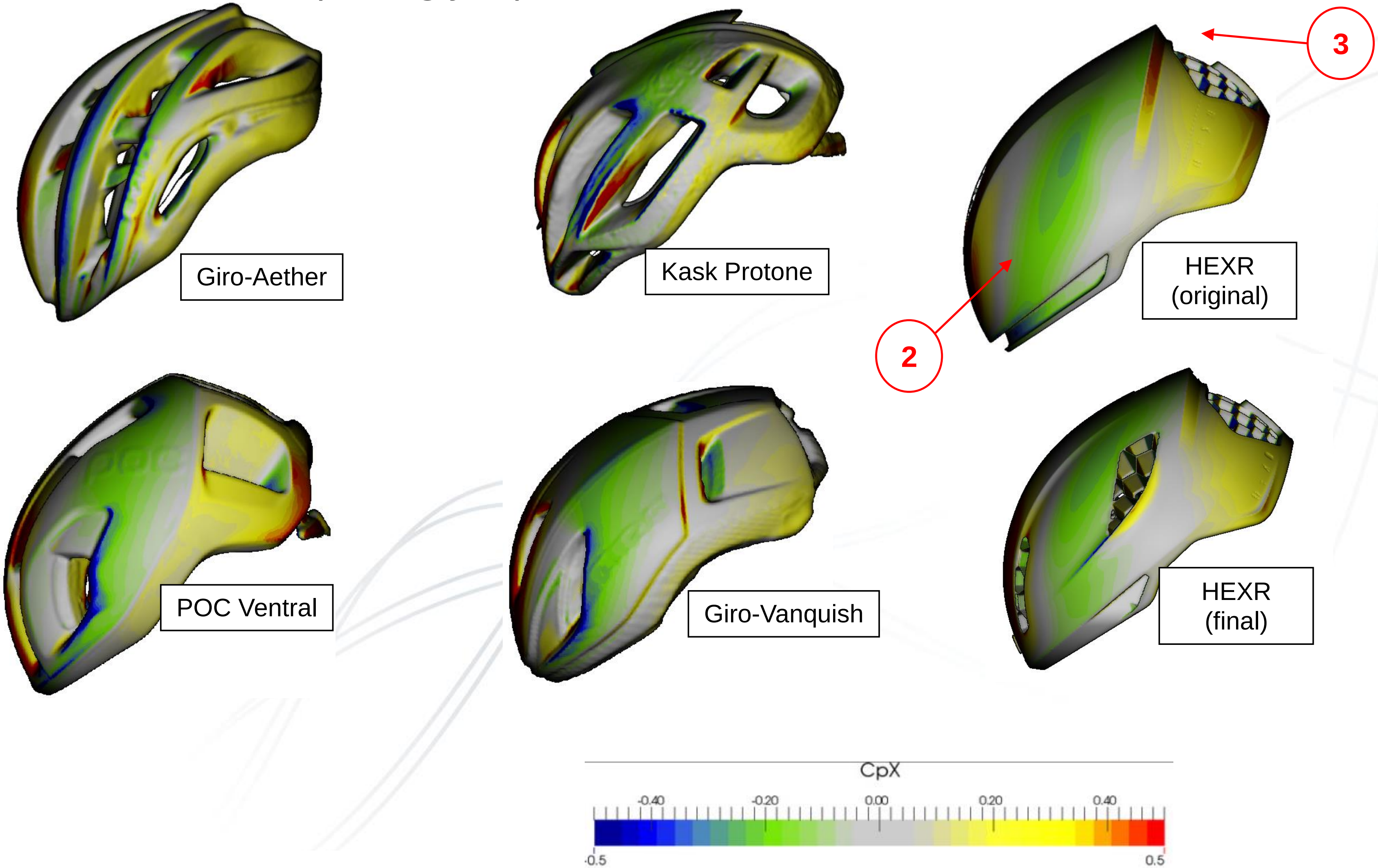
- CpX is the Pressure Coefficient acting in the X (drag) direction.
- Red regions contribute to drag, while blue regions contribute a thrust (counteracting drag).
- All plots are at an a yaw angle of 0.5 degrees.

CpX on Helmet Surfaces (0.5deg yaw) – Front View – Position 01



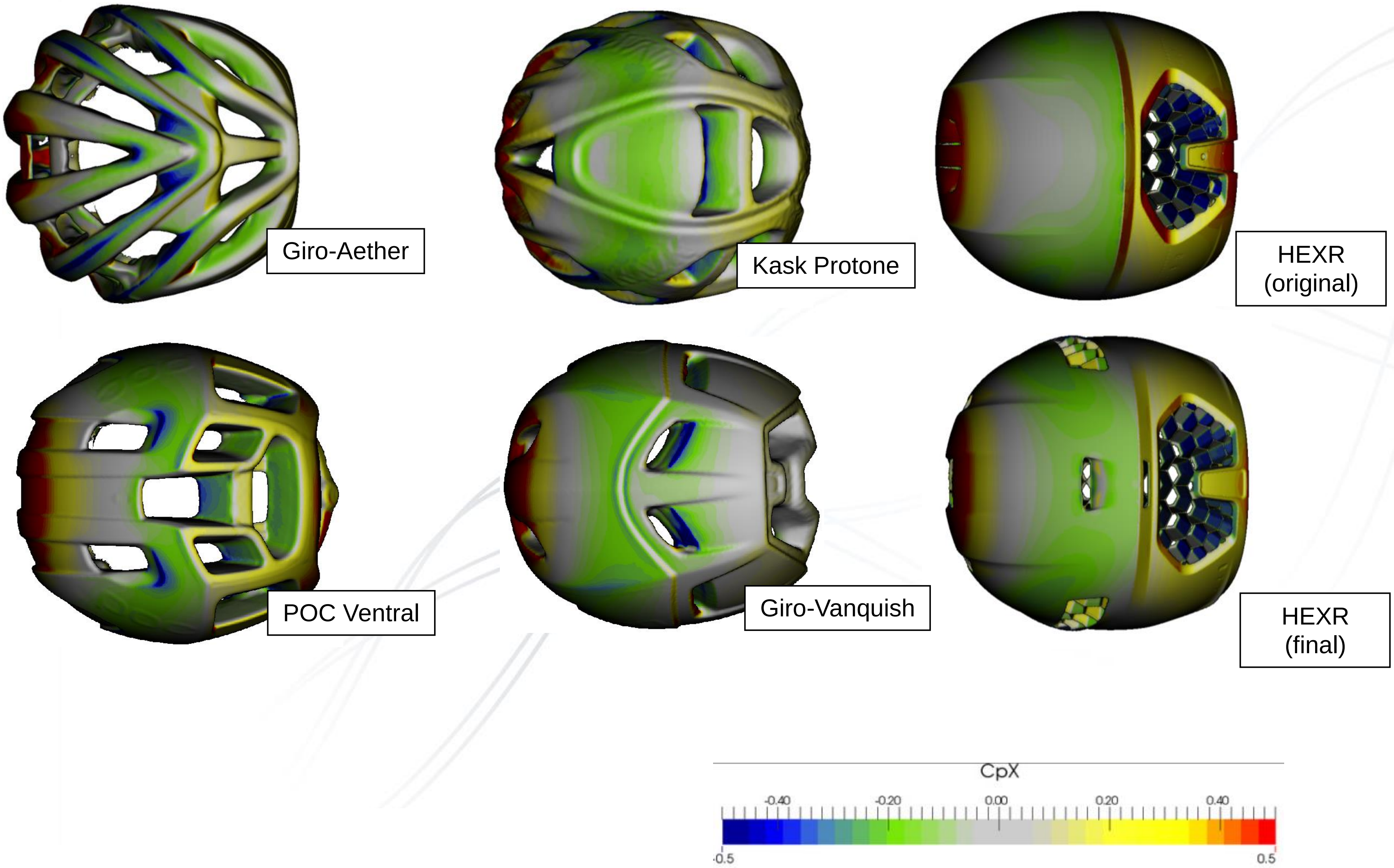
Highlighted point 1 is discussed in the following slide.

CpX on Helmet Surfaces (0.5deg yaw) – Side View – Position 01

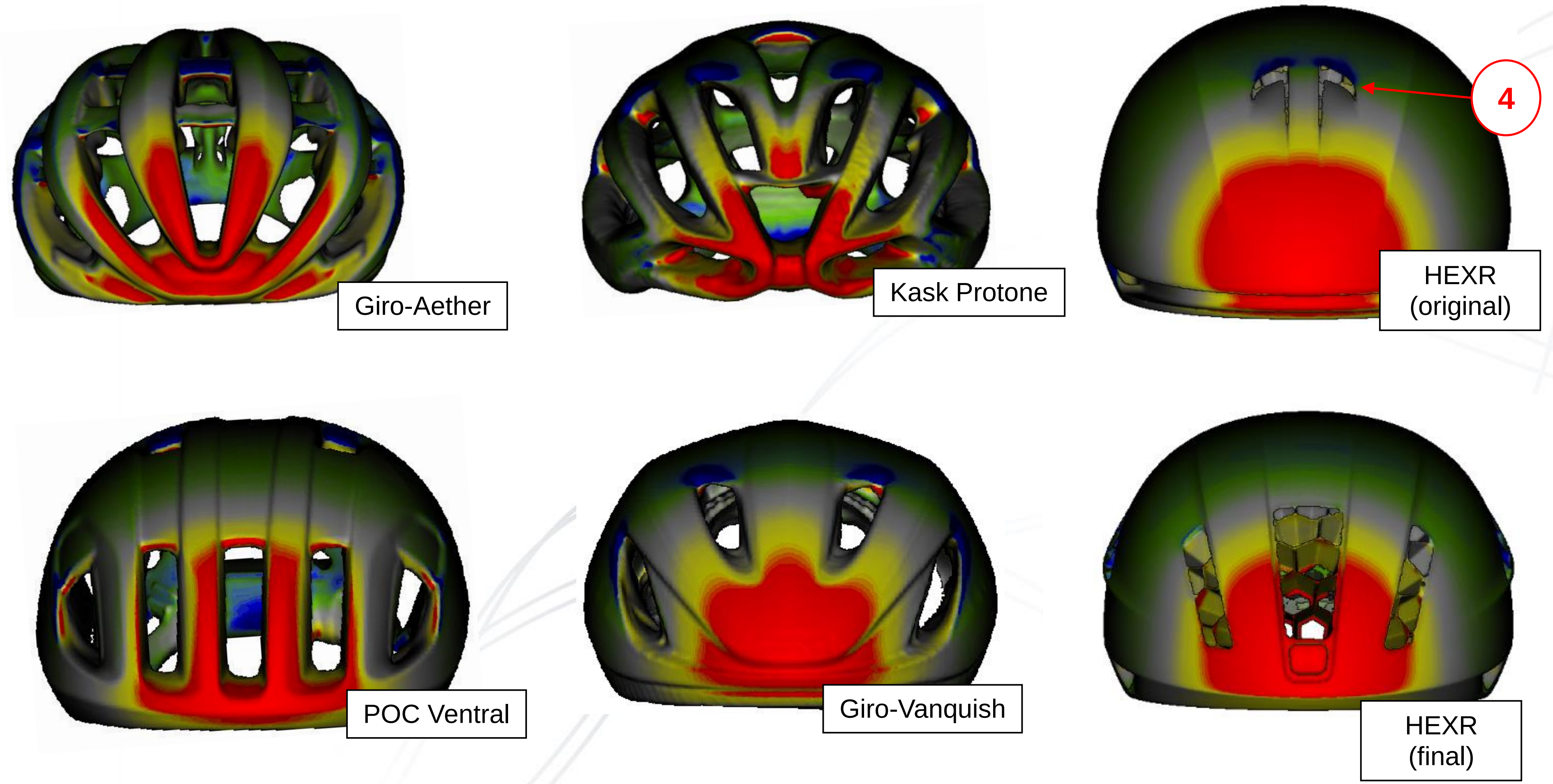


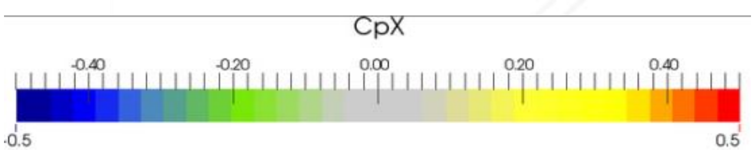
Highlighted points 2&3 are discussed in the following slides.

CpX on Helmet Surfaces (0.5deg yaw) – Top View – Position 01



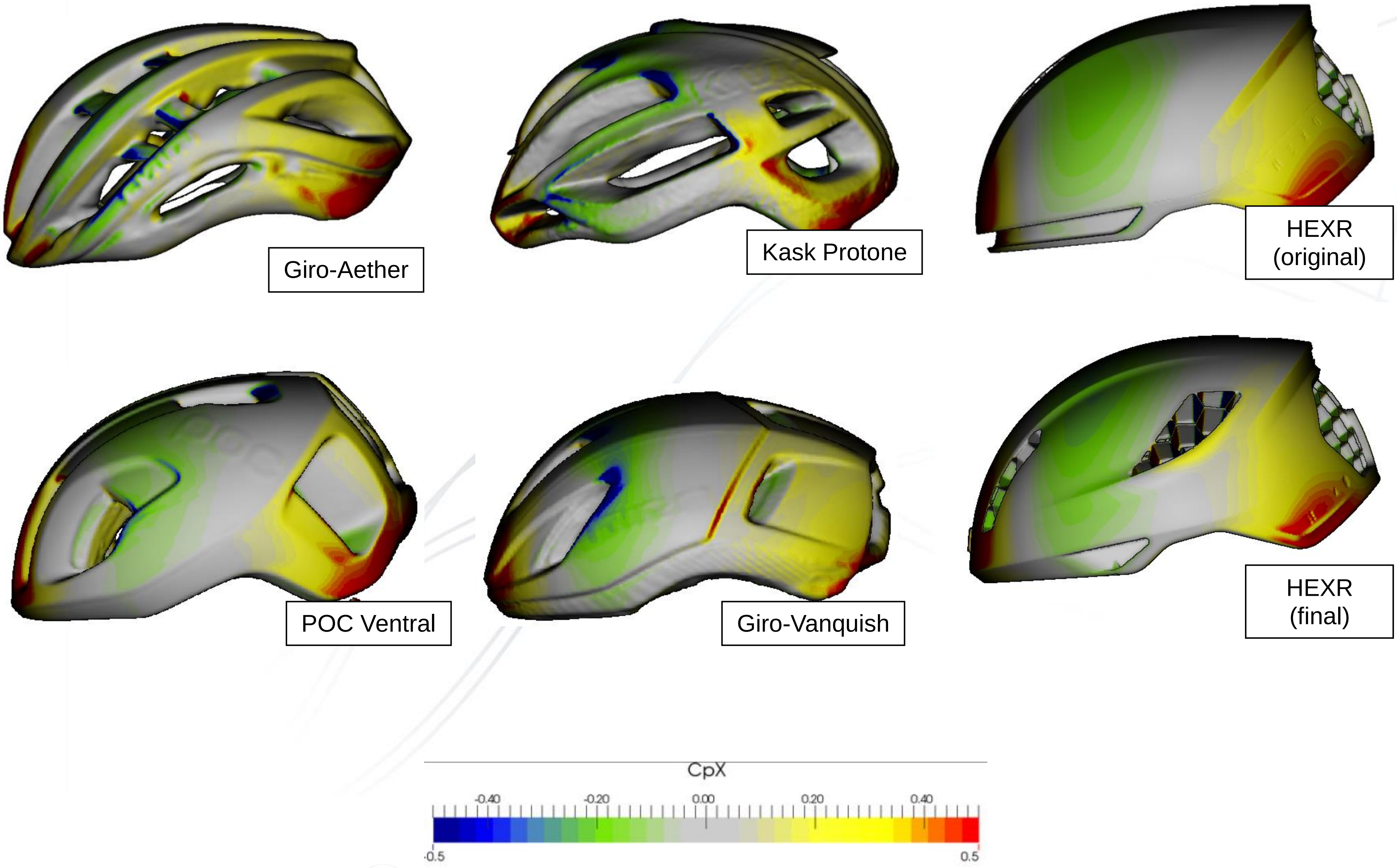
CpX on Helmet Surfaces (0.5deg yaw) – Front View – Position 02



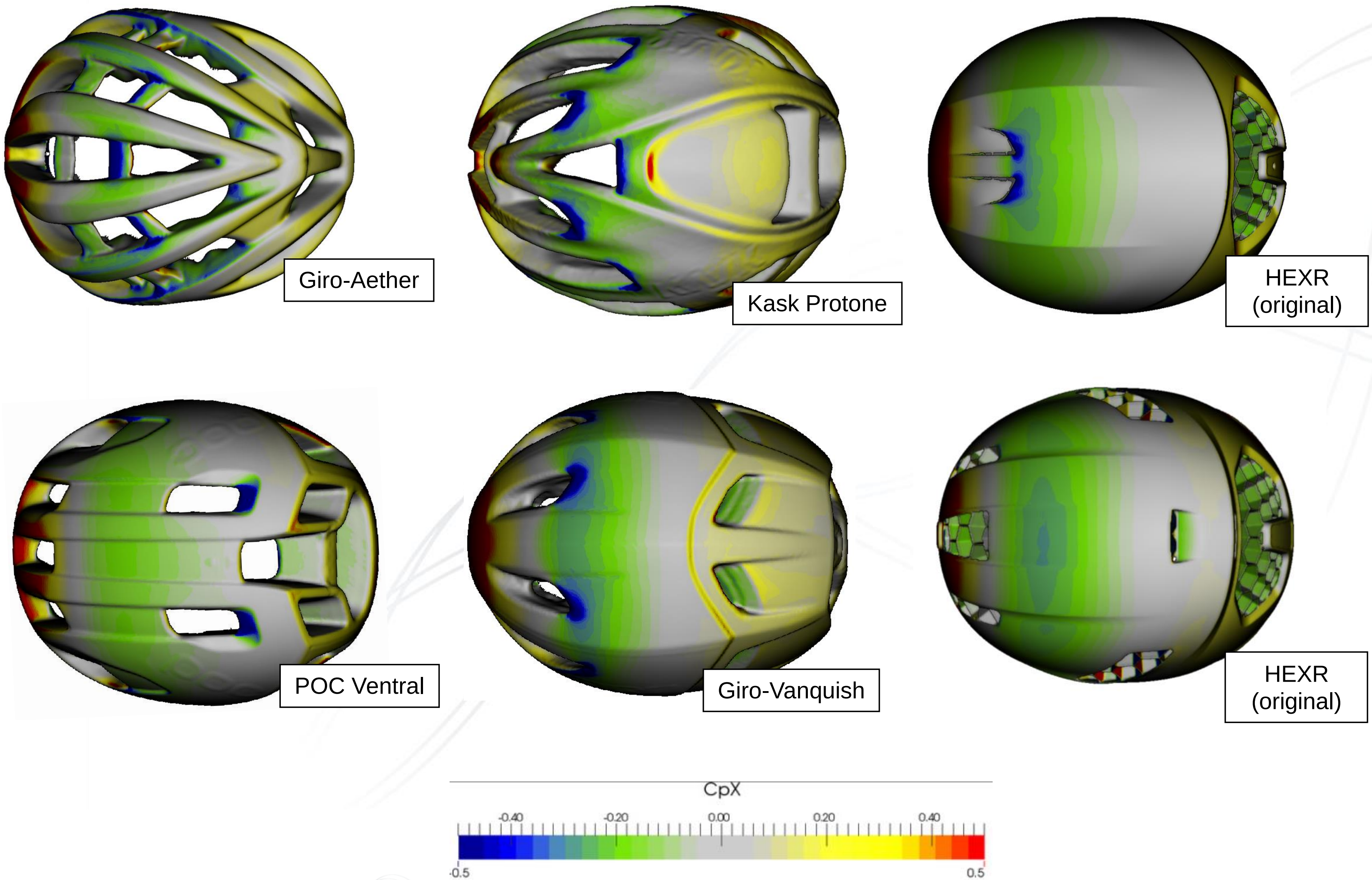


Highlighted point 4 is discussed in the following slides.

CpX on Helmet Surfaces (0.5deg yaw) – Side View – Position 02



CpX on Helmet Surfaces (0.5deg yaw) – Top View – Position 02



Results: Comparison of CpX on Helmet Surfaces

The points below correspond to highlighted points 1-4 on the contour plots:

1. In all cases a large stagnation (red) region is observed on the front facing surfaces, due to the airflow deceleration in this region; this positive CpX acts to push the rider's head backwards (drag). The helmets with large gaps appear to have less stagnation pressure, however much of this high pressure will still exist, acting directly on the rider's head.

2. The smooth curvature of the helmets accelerates the airflow over the front-facing surfaces, producing a thrust (green/blue) to counteract drag. It is desirable to maximise the magnitude and size of these thrust regions.

3. The sharp edge of the HEXR (original) rear end can be seen to produce a strong positive CpX along a (red) rear-facing strip of the helmet, providing a smooth gradual reduction in cross-section should help to prevent this and therefore reduce drag. This is addressed in the final HEXR design.

4. In position 02, the vents of the HEXR (original) are located downstream of the stagnation region on the front of the helmet. This means that:

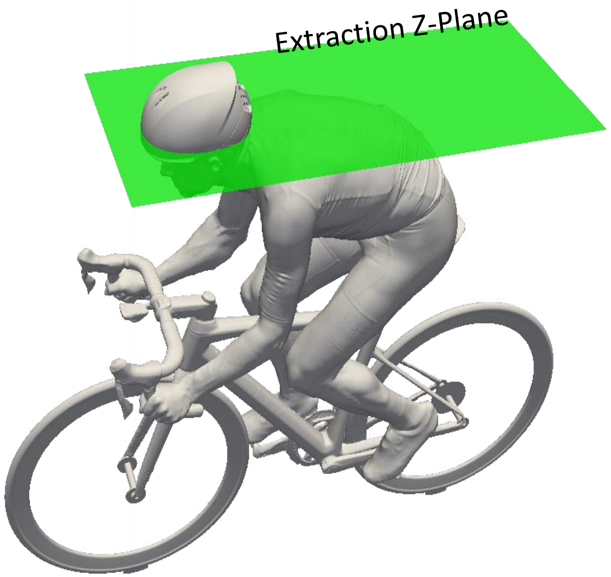
    - The vents cut into the thrust producing region of the front facing surfaces; due to the geometry of the hexagonal chambers beneath, this thrust is likely not recovered inside the helmet.

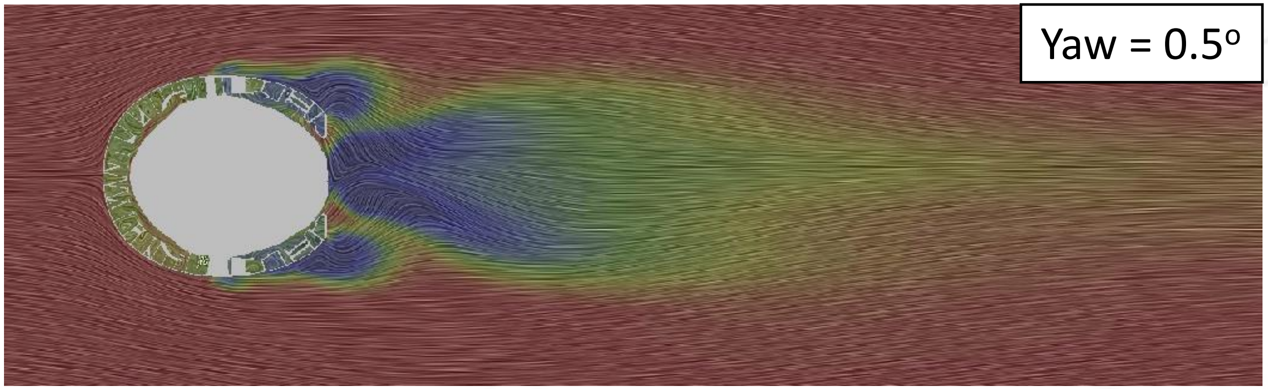
   The size of the vents in the HEXR (original) helmet are considerably smaller than the other road helmets, however, and if they were larger, the effect on drag would be expected to be larger.

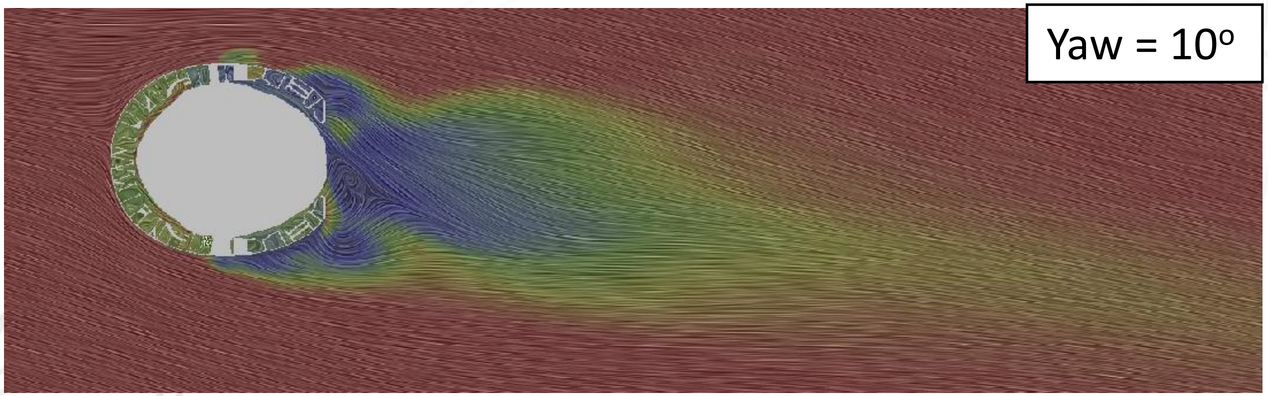
Results: Comparison of CpT over Yaw Sweep

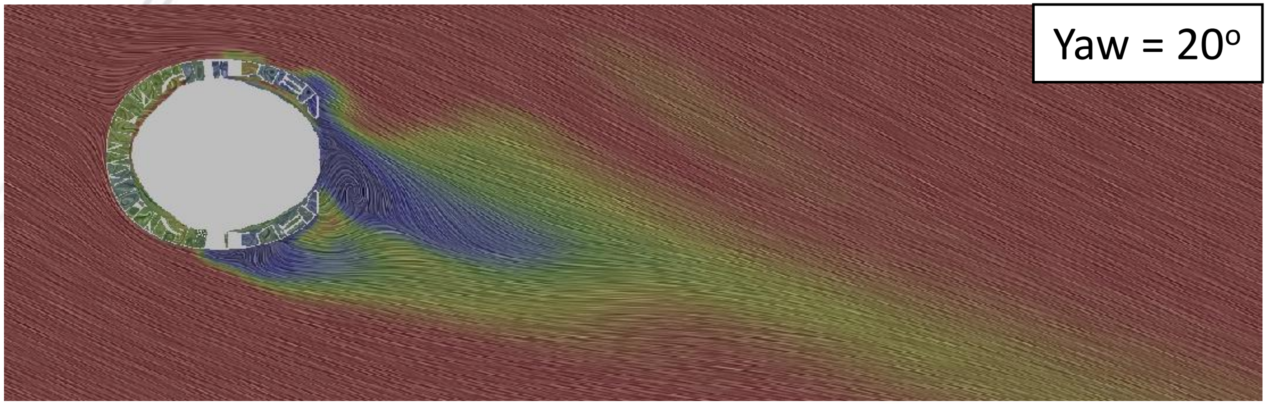
- CpT is the Total Pressure Coefficient. It is a measure of the energy within the flow and low values show the wake structures.
- The plots include streamlines to show mean flow paths passing the rider.
- All plots are on a Z-Plane 1.05m from the ground.
- Although the majority of plots included in this report show the flow at 0.5deg yaw, this section is included to indicate the variation of flow over the sweep of yaw angles.

CpT on Z-Plane at Three 0.5º, 10º and 20º Yaw for the HEXR (original) in Rider Position 02







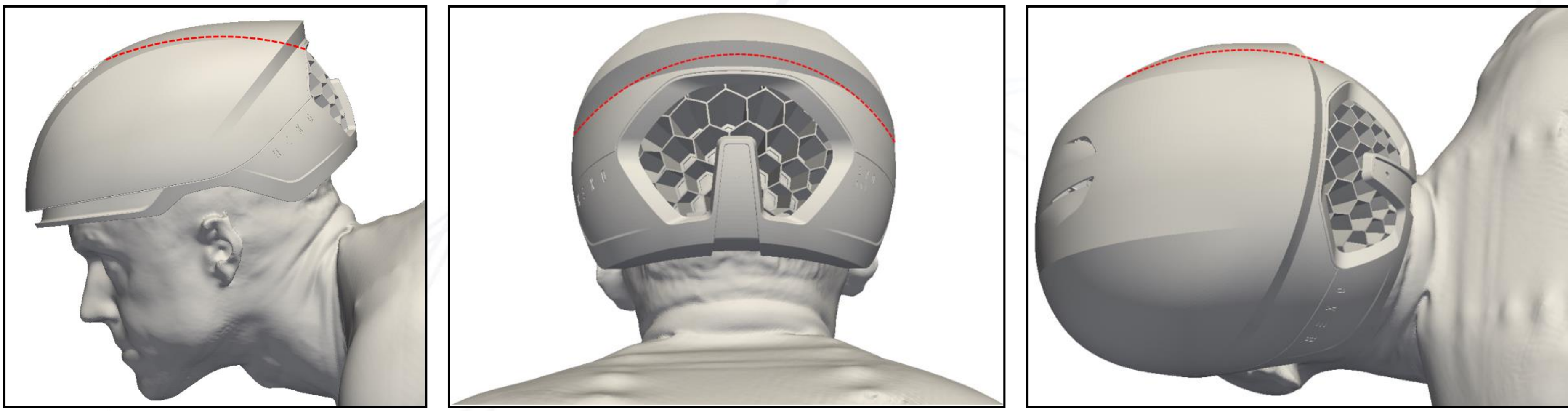


The plots show there is a significant change in wake structure due to the yaw angle, as the flow separates from different points on the helmet.

Conclusion

This report has detailed the flow behaviour and drag characteristics of a cyclist using different helmets in two riding positions and three yaw angles. Key points raised from the analysis are:

- The data shows that the drag of the final HEXR helmet ranks as the lowest of all designs in position2, and 3rd lowest drag in Position 1.
- The final design of the HEXR helmet shows a drag reduction in both head positions compared to the original HEXR helmet. This is achieved despite an increase in the area of vents.
- The images below show the design guidelines provided during the study for the development of the helmet.



The red line gives guidance for design changes (provided during this study) between the HEXR original and HEXR final helmets.

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COMPUTATIONAL FLUID DYNAMICS

T: +44 (0) 1280 840 316 E: info@totalsim.co.uk

@totalsimltd

WWW.TOTALSIMULATION.CO.UK

TotalSim Ltd Top Station Road, Brackley, Northamptonshire, NN13 7UG