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ASOB: Aerodynamic and Structural Optimization of modular Bicycles using HPC. Sub- Project number: 1304

Sub-projects’ review – 11 February 2026 (online)

Alexandros Kitselis, Advanced Engineering

4 February 2026

Consortium & Roles

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- **Advanced Engineering (AE)**: Project coordinator. Lead SME, designing and manufacturing bicycles for competitive and recreational cycling. Expertise in manufacturing with Carbon Fiber Reinforced Polymers (CFRP) and structural analysis. Role: Coordinate the project, receive training on HPC and use the provided tools by the other partners to aerodynamically and structurally optimize its bicycles.

- **National Technical University of Athens (NTUA)**: Expertise in CFD, aerodynamic optimization and HPC. Role: provide the tools and guidance/training for the aerodynamic shape optimization of the bicycles to be designed.

- **Politecnico di Milano (PoliMi)**: HPC/CFD expert. Role: Setup an automated CFD workflow for aerodynamic analysis and provide HPC-related guidance.

- **FOSS:** SME, HPC/Optimization expert. Role: Provide the black-box, AI-assisted tools and guidance/training for the structural optimization of the bicycle to be designed.

Business Problem

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- Before this project, AE was performing the aerodynamic and structural design of its bicycles through trial-and-error, using the limited computational resources at its disposal.

- This process could take up to a year for designing a new bicycle.

- With even small performance improvements proving critical in competitive cycling and the design rules changing frequently, this long, trial-and-error process was outdated and could not provide a competitive advantage to AE.

- **Target:** Set up an automated Computational Fluid Dynamics (CFD) and Computational Structural Mechanics (CSM) workflow that will assist with the aerodynamic and structural optimization of AE's bicycles, using HPC. This will allow shorter design cycles and better performing products, strengthening AE's position in the market.

Solution Approach

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- The approach followed consists of HPC-based, CFD and CSM optimization of modular bicycles (road bicycles which are very aerodynamic and with the change of a few components can be converted to triathlon bicycles). HPC is pivotal in the success of the project, since these optimizations are, practically, infeasible with the in-house hardware at AE.

- Initially, a CFD-based optimization workflow is setup to aerodynamically optimize the bicycle shape, targeting the reduction of a weighted sum of the drag and side forces exerted on the bicycle, under multiple bicycle and air flow velocities and angles (multi-point optimization). The optimization includes several geometric constraints (rule box, wheel-frame clearances, minimum thickness, housing of internal components, etc) to make sure the designed shape is practical and can be manufactured.

- This aerodynamically optimized bicycle is, then, structurally optimized. The goals are to reduce its weight, increase the lateral stiffness (increased performance) and improve vertical compliance (ride comfort), while complying with the necessary ISO certifications. To achieve this, multiple traits of the CFRP layout will be optimized (number of layers, angles between them, materials used, etc).

Main Achievements

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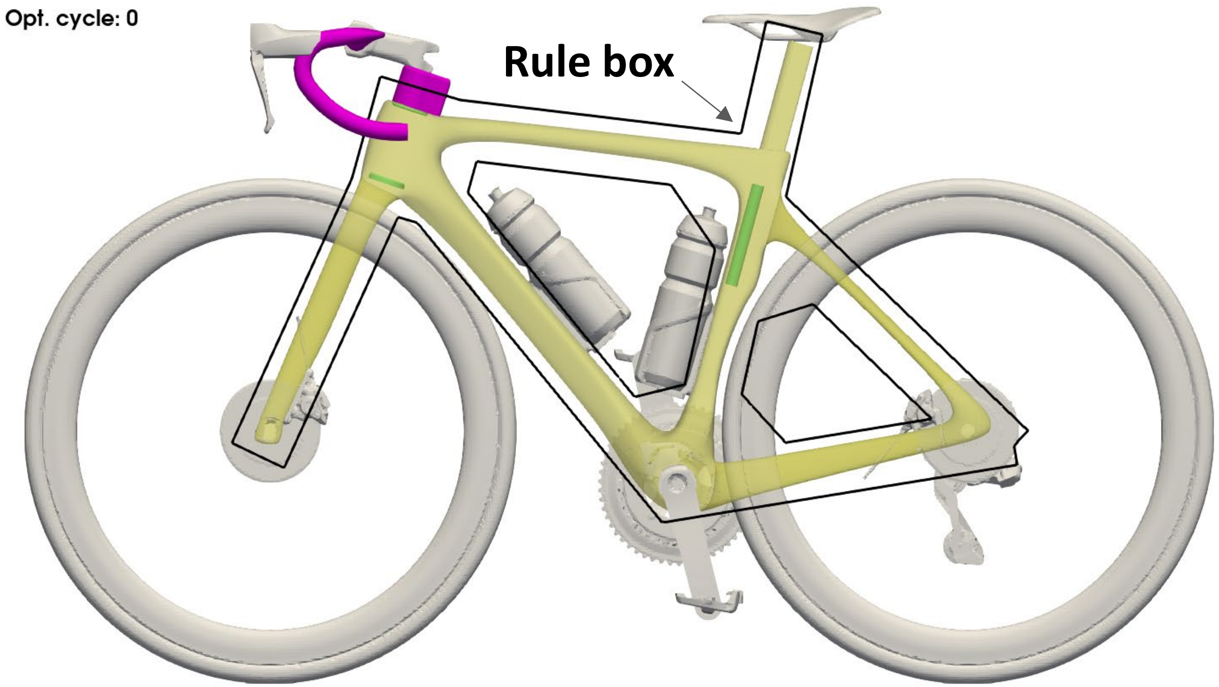
Op. point	U bike(m/s)	U wind(m/s)	Angle (°)
P1	11.66	0	0
P2	8.33	3.4	4
P3	8.33	3.4	12
P4	8.33	3.4	21

- Aerodynamic optimization has, practically, been completed. Two different bicycle sizes have been optimized and another one is almost ready. There is considerable improvement in the aerodynamic performance.



$$J=0.1F_1+0.45F_2+0.279F_3+0.171F_4$$

$$F_i=0.85F_{x,i}+0.15F_{y,i}, i\in[1,4]$$

- Optimized parts, to remain within the rule box
- Optimized parts, not constrained by the rule box
- Internal structure, not to be crossed by the optimized shape

Additional constraints:

- Geometry cannot move more than 2.5mm inwards (structural integrity)
- Front and rear wheels cannot get closer that 9mm and 6mm to the frame, respectively (safety)
- Frame cannot get closer than 3.5mm to the water bottles (usability)

Main Achievements – Aerodynamic optimization

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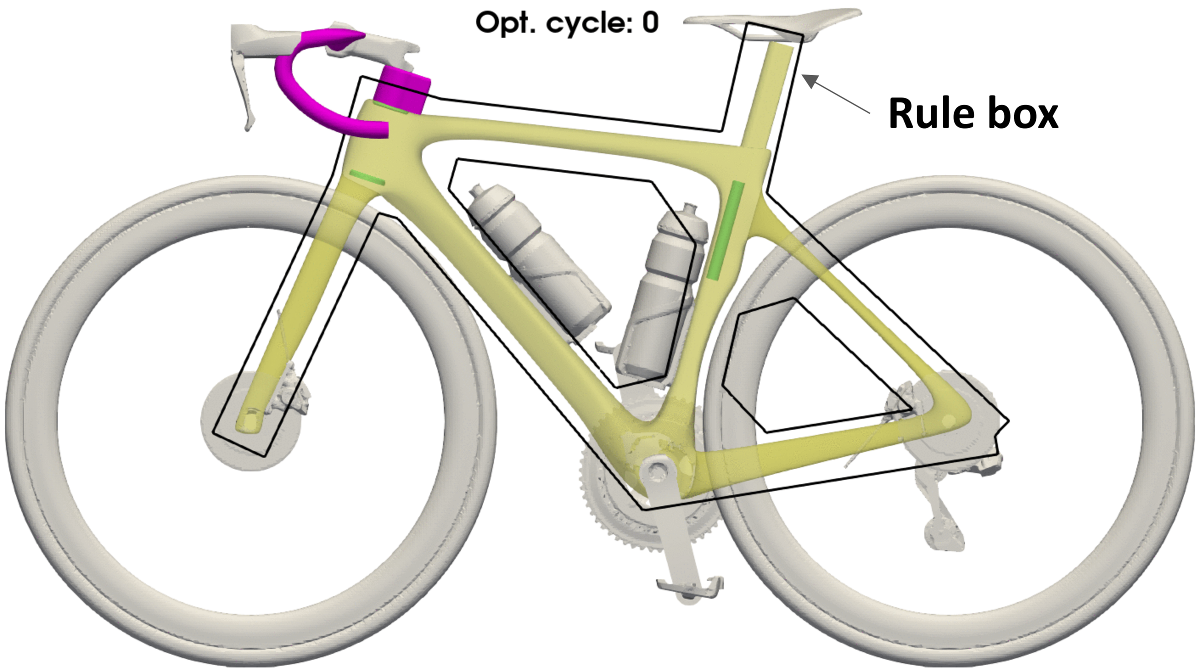
Small Frame



Point	Drag (N) Baseline	Drag (N) Opt.	Δ(Drag) (N)	Side (N) Baseline	Side (N) Opt.	Δ(Side) (N)
P1	6.07	5.59	-0.48	0.03	0.13	0.10
P2	6.60	6.06	-0.54	1.24	1.26	0.03
P3	6.58	6.10	-0.48	3.46	3.29	-0.16
P4	6.66	6.11	-0.55	5.88	6.20	0.32

- A considerable drag reduction of ~ 0.5N (7-8%) is observed in all operating points. At the same time, the side force remains almost constant in the first two operating points, with a reduction in the third one and an increase in the last one.

Main Achievements – Aerodynamic optimization

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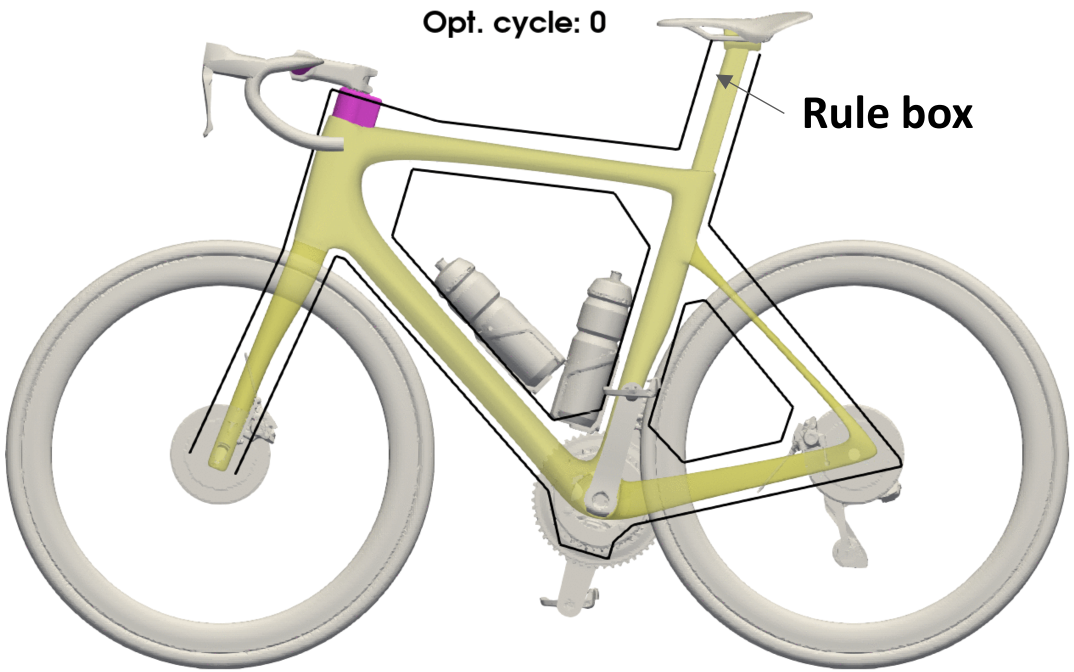
Large Frame



Point	Drag (N) Baseline	Drag (N) Opt.	Δ(Drag) (N)	Side (N) Baseline	Side (N) Opt.	Δ(Side) (N)
P1	6.70	6.10	-0.60	-0.01	0.00	0.01
P2	7.18	6.64	-0.54	0.81	1.00	0.20
P3	7.24	6.63	-0.61	2.98	3.17	0.19
P4	7.33	6.57	-0.77	5.70	6.62	0.92

- A considerable drag reduction of ~ 0.54N-0.77N (7-8%) is observed in all operating points. At the same time, the side force increases in all operating points, but less than the drag reduction.

Business Impact

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- Business impact:
  - The aerodynamic design of the bicycle that would take months using trial-and-error on limited hardware now takes roughly a day (once the framework has been established and an initial geometry has been designed), using automated aerodynamic optimization s/w and HPC resources.
  - This can substantially reduce the design cost and duration, allowing AE to follow a rapidly changing market and gradually get a larger share due to the high performance and unique modular frame offer. We have estimated to sell 50 more bicycles per year resulting in an additional revenue of €350.000,00/year* and create two full time job positions.
  - Additionally, the designed bicycles have aerodynamic coefficients that are similar to the top performing frames in the market which is great for the company's brand reputation and eventually sales.
- Commercial Exploitation:
  - AE will use its current client base (Owners of company's products already in the market, high-performance amateur and professional athletes, well known coaches) and social media to advertise the achievement of the project and gauge their reactions.
  - AE will consider manufacturing the designed frames and bring them to market, once the structural optimization has also been completed.
  - AE will use the acquired knowledge to develop more types of cycling equipment in the future and have a complete range of products such as wheels, handlebars, seatposts, stems, aerobars, cranksets and other components.
  - AE will also use this knowledge to enter new markets such as:

-High performance luxury boats (design of hydronamic or aerodynamic parts with optimized structural behavior), expected revenue €300.000,00/year* and two job positions.

-Sport cars (airfoils, lightweight racing parts, air ducts) €100.000,00/year* and one job position.

-Other fields we could not enter without HPC access (Multidisciplinary optimization, Design exploration, Material engineering etc).

*The estimated revenues came from quotations we had sent to customers but did not end up in an order because of the excessive time we needed to get to an analysis result without HPC and then manufacture it. By the time we were able to finish the design, it is was already created or surpassed by another competitor.

Challenges of HPC use

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- Within AE, structural analysis is conducted using proprietary s/w running on Windows. There is no easy way to run this s/w on a Linux-based HPC cluster, necessitating the use of in-house resources for the structural optimization.
- Additionally, in LUMI, the restriction on the max. number of files per account was slightly limiting, since the utilized aerodynamic optimization s/w tends to produce many files, especially for multi-point optimizations run on many cores. This was however managed, with proper planning.
- Adapting to an HPC environment and the utilized CFD analysis and optimization s/w was challenging for a team with background mainly in structural mechanics. This is still a work in progress.
- Data transfer, though not very frequent due to LUMI's virtual desktop environment, was a bottleneck at times.
- LUMI's significant down time for maintenance and the subsequent technical problems after the restart of the cluster have created the need to use in-house hardware in the last stages of Task 2.

Outlook & Next Steps

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- Technical next steps:
  - structural optimization of the aerodynamically optimized bicycle (Task 3).

- Exploitation:
  - Probing the market reaction on the performance of the modular aerodynamically and structurally optimized bicycle (road bicycles which are very aerodynamic and with the change of a few components can be converted to triathlon bicycles).
  - Construction of molds necessary for manufacturing the CFRP bicycle components.
  - Manufacture, advertise and sell the optimized bicycle.
  - Advertise the newly acquired knowledge to enter new markets such as luxury boats, sport cars etc.

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Any questions?

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