
AUSTRIAN INSTITUTE OF TECHNOLOGY
TOMORROW TODAY

# Cooling Concept Design Aided by Numerical Simulations of Air Cooled Electric Drive

Alessandro Zanon

Alessandro.Zanon@ait.ac.at

# AIT Austrian Institute of Technology

## Mobility Department

# AIT Austrian Institute of Technology

- **Owners**
  - 50.46% Republic of Austria
    **BMVIT** Federal Ministry for Transport, Innovation and Technology
  - 49.54% **Federation of Austrian Industries**
- **Employees:** 900 plus 200-250 on contract basis, thereof 95 PhD students
- **Financial Goal:** 30% Cooperative Research, 30% Contract Research, 40% Basic Funding
- **Total Operating Income:** 118,8 Mio. Euro

# Outline

- Introduction
  - Why CFD is needed?
  - How?
- SyrNemo European Project
  - Numerical model description
  - Simulation Results
- EUNICE European Project
- Conclusion

# Introduction, why we use CFD?

- **High specific power densities** of the air-cooled **electric** drives

⇩

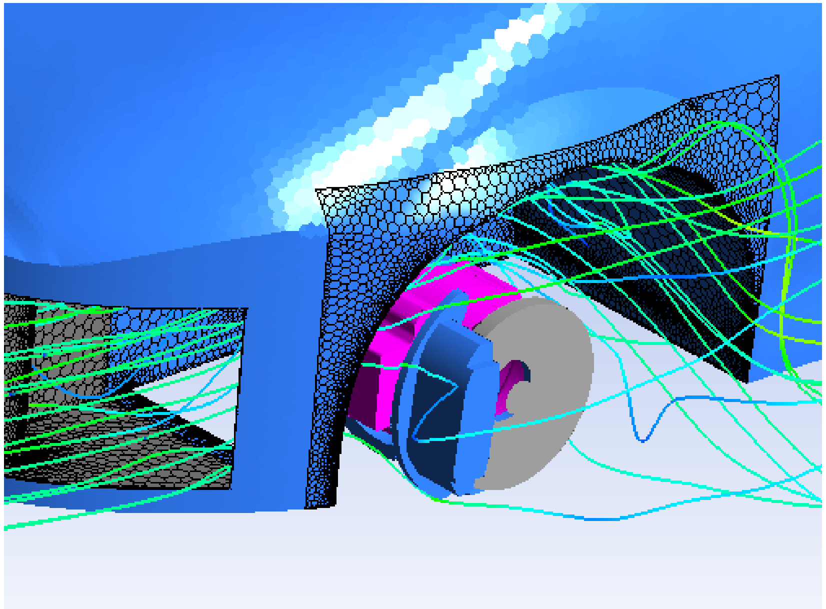
E.g., **In-wheel** solution where a **careful and accurate** design of the cooling fins and system layout **is essential**

# Introduction, why we use CFD?

- **High specific power densities** of the air-cooled **electric** drives
- Highly **complex 3D flow** due to installation effects

⇩

**Simplified** approach **cannot be** used due to inaccuracy

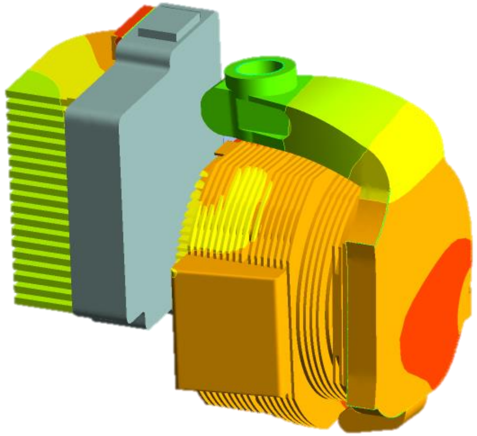


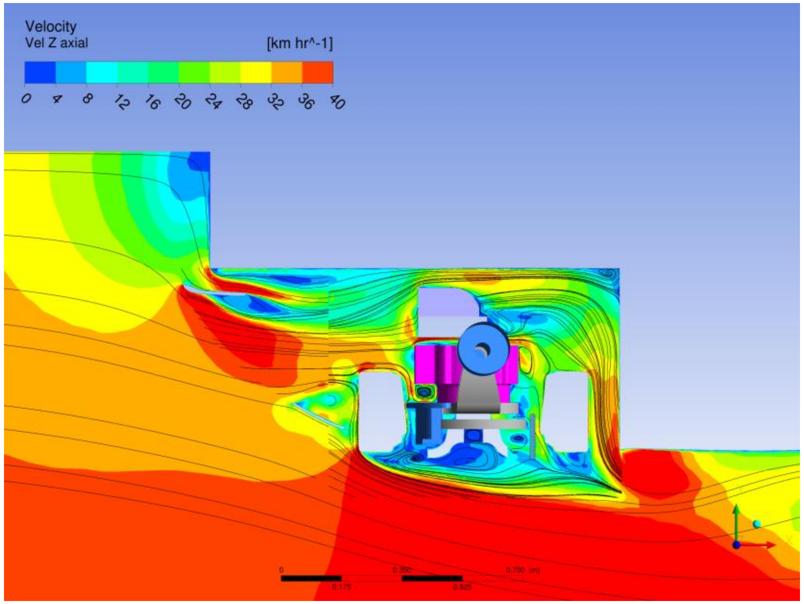
# Introduction, why we use CFD?

- **High specific power densities** of the air-cooled **electric** drives
- Highly **complex 3D flow** due to installation effects

⇩

**CFD** can offer a valuable **support to design and test** cooling concept in realistic working condition





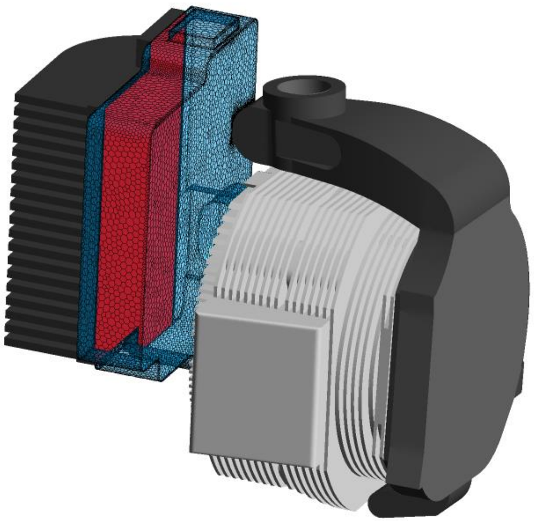
# Introduction, how?

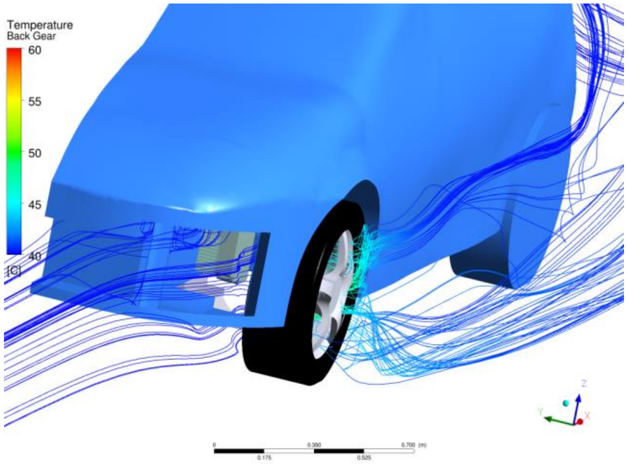
Why 3D CFD:

- **High specific power densities**
- Highly **complex 3D flow**

How:

- **Affordable** mesh sizes






⇩

**Complexity** of the geometry and domain size can lead in **huge mesh**

⇩

**Careful** control of the mesh **resolution**

# Introduction, how?

Why 3D CFD:

- **High specific power densities**
- Highly **complex 3D flow**

How:

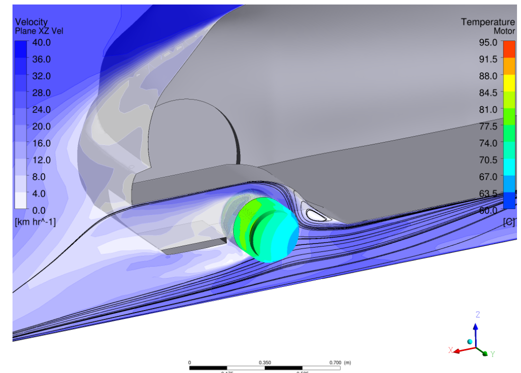
- **Affordable** mesh sizes
- Highly **automatization** of mesh generation

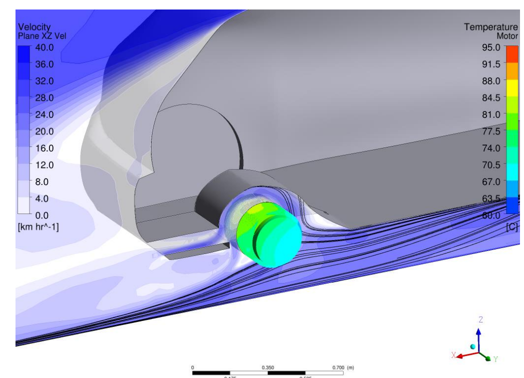
⇩

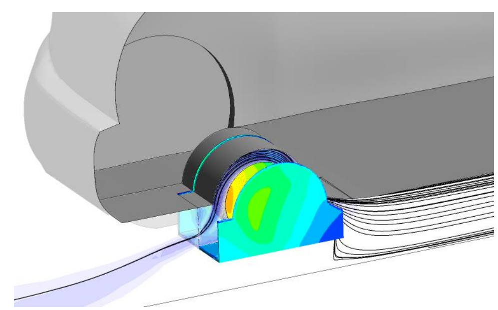
Many **different solutions** have to be tested (not just optimization)

⇩

Highly automatized **workflow** from the CAD to the CFD mesh



# SyrNemo project

- We are an international consortium of eight partners employing more than 15,000 people and we have built innovative electric drives for years.
- We are part of the automotive industry and we are actively involved in the international R&D community as well as in standardization bodies.
- Together we develop an **innovative synchronous reluctance machine (SYRM) with higher power density and higher driving cycle efficiency at lower cost** than state-of-the-art permanent magnet (PM) synchronous machines for automotive traction drives.

AUSTRIAN INSTITUTE OF TECHNOLOGY TOMORROW TODAY

AVL

CRF CENTRO RICERCHE FIAT

Leibniz Universität Hannover

tecnalia Inspiring Business

THIEN eDrives

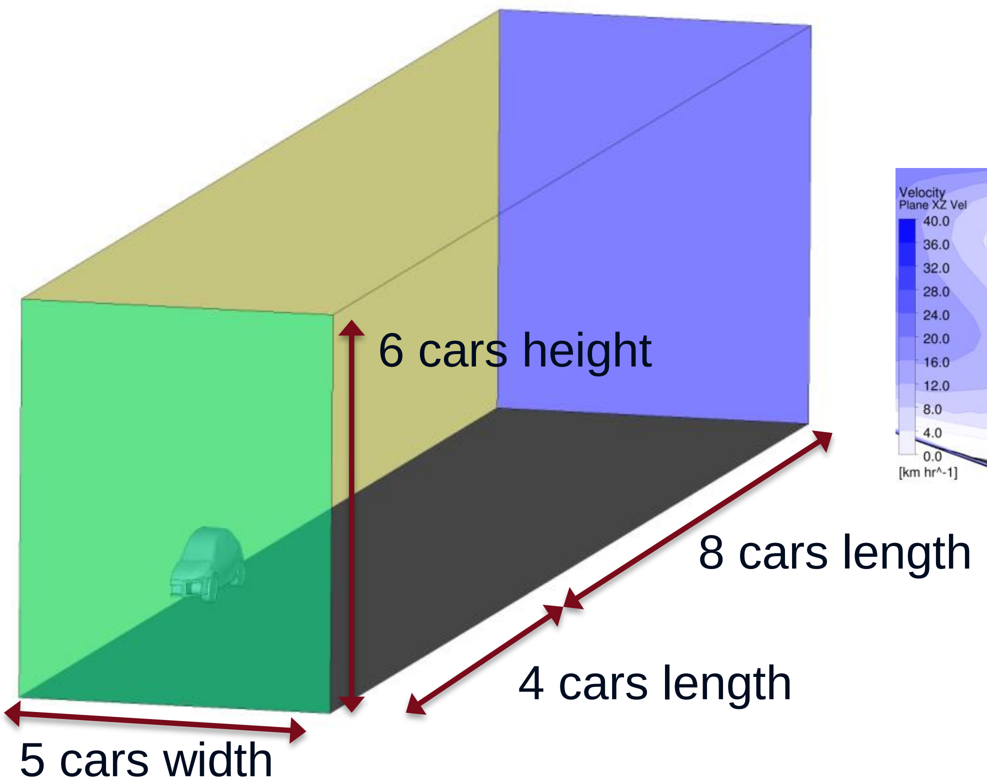
ALMA MATER STUDIORUM UNIVERSITÀ DI BOLOGNA

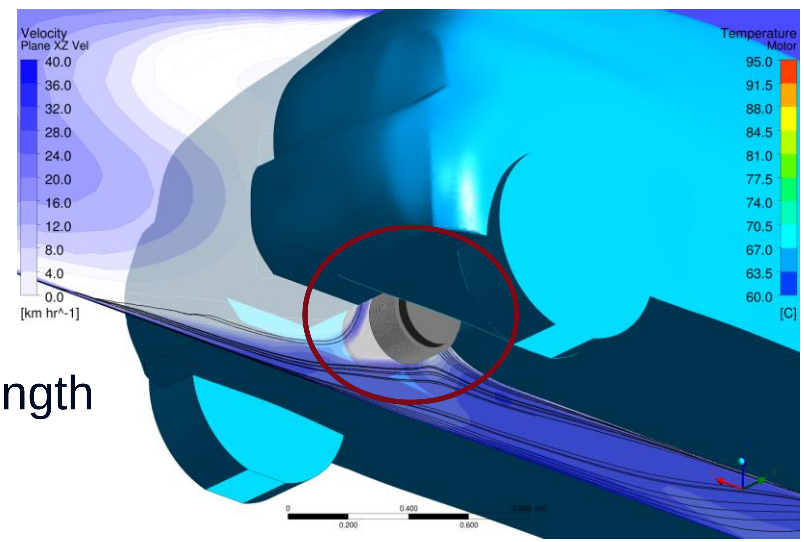
Vrije Universiteit Brussel

# Numerical model

## Numerical domain

- Half vehicle modelled (symmetry)
- Solid parts included (aluminium):
  - Motor external shell
  - Inverter heat sink



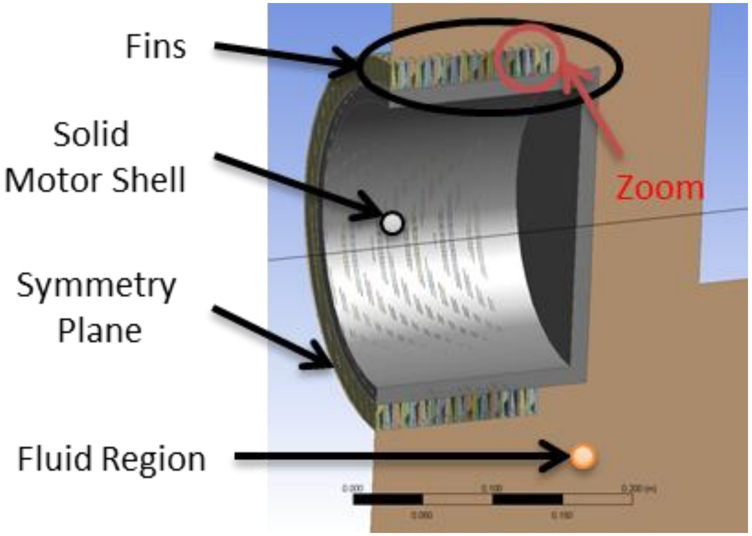
# Numerical model

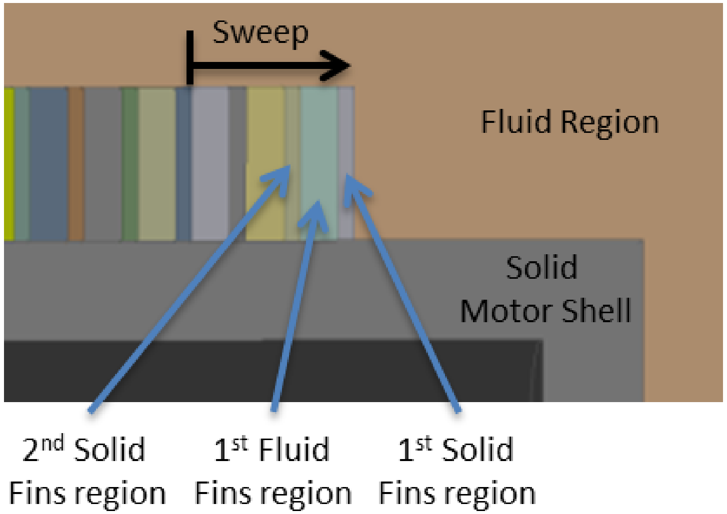
## Mesh generation details

- 10 prismatic layers for the car bodyworks (Automatic inflation)
- Sweeping technique for the fins (instead of automatic inflation)

⇓

This allows **high control** of the number of layer between in the fins (both in the solid and in the fluid region) and to **limit the number of cells** of the numerical model.



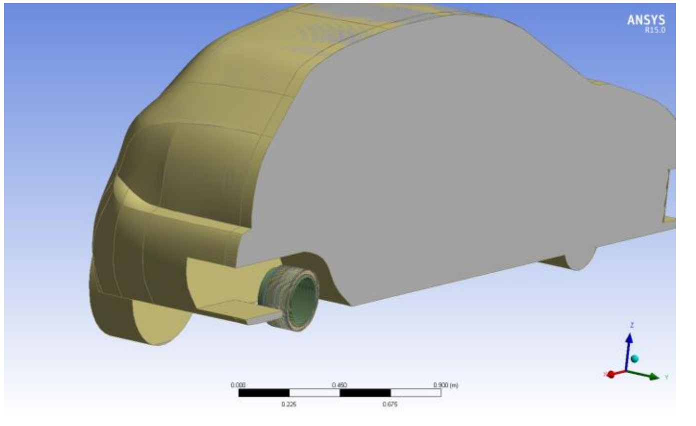
# Numerical model

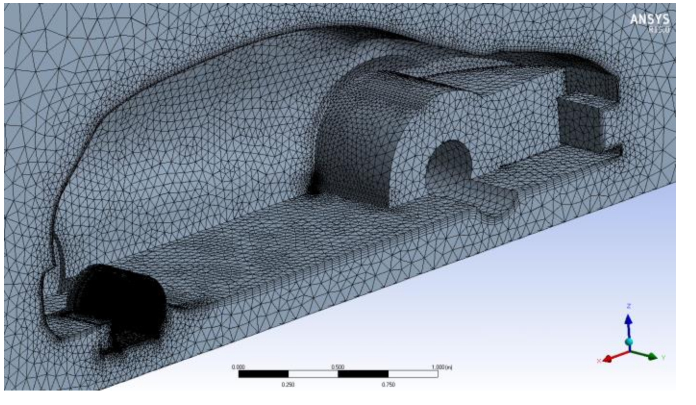
## Mesh Generation workflow, Ansys Workbench

- The solid/fluid domains are modelled by using Ansys DesignModeler.
- Meshed with Ansys Meshing.
- Mesh converted to polyhedral.
- Solver: Ansys Fluent
- Post processing with Ansys CFDPost

⇩

**Change in the design** requires a **minor** interaction of the user to evaluate the **new performance**



# Numerical model

## Boundary Conditions, fluid & solid

**Predesign, only motor** (no inverter)

- Car speed = 38 km/h
- Side wall: 0 W
- Circular wall: 1352 W

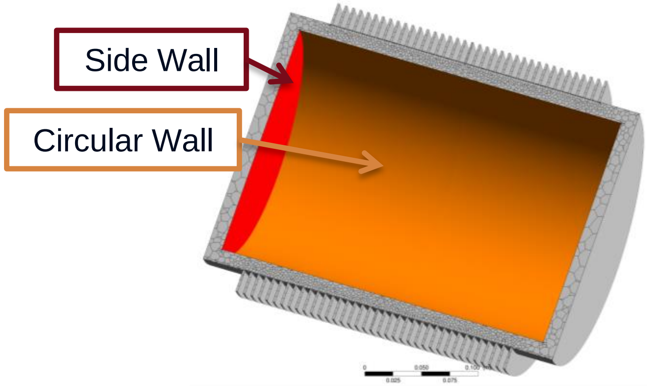
**Inverter integration**:

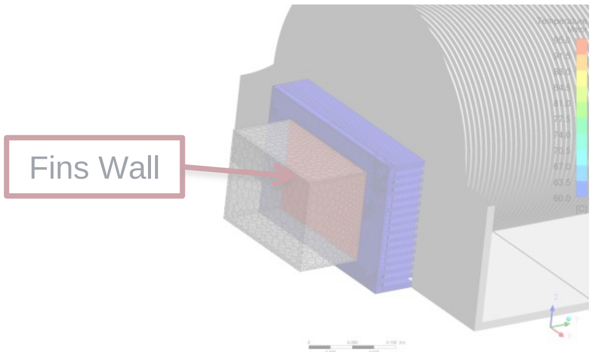
- Car speed = 38 km/h
- Side wall: 0 W
- Circular wall: 1352 W
- Fins wall = 588 W

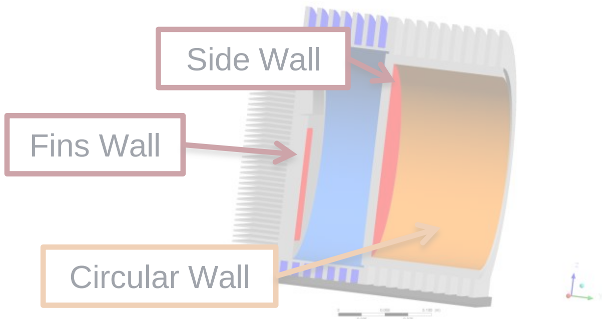
**Final design**:

- Car speed = 33.6 km/h
- Side wall: 190 W
- Circular wall: 760 W
- Fins wall = 588 W

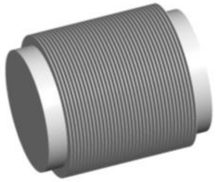
Fluxes imposed as computed by using **1D model**



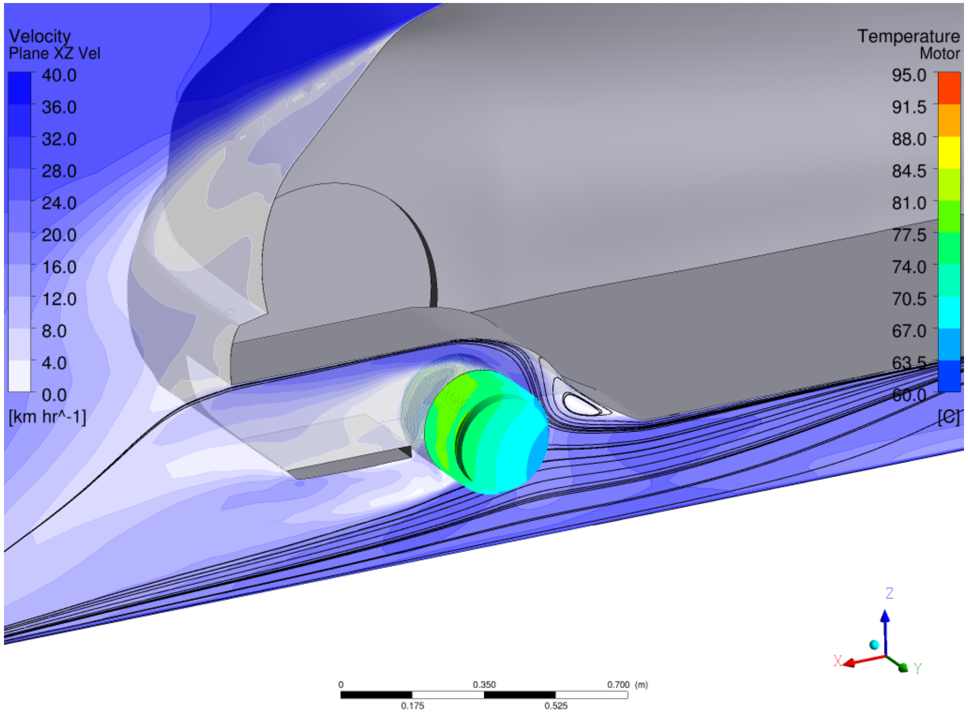



# Predesign



- Power electronic not included
- Cylindrical fins distribution, aligned with the air flow

Design driven by Reducing impact of the e-drive on the car bodywork

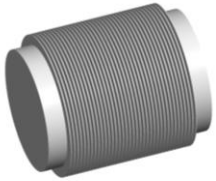



Motor circular wall:

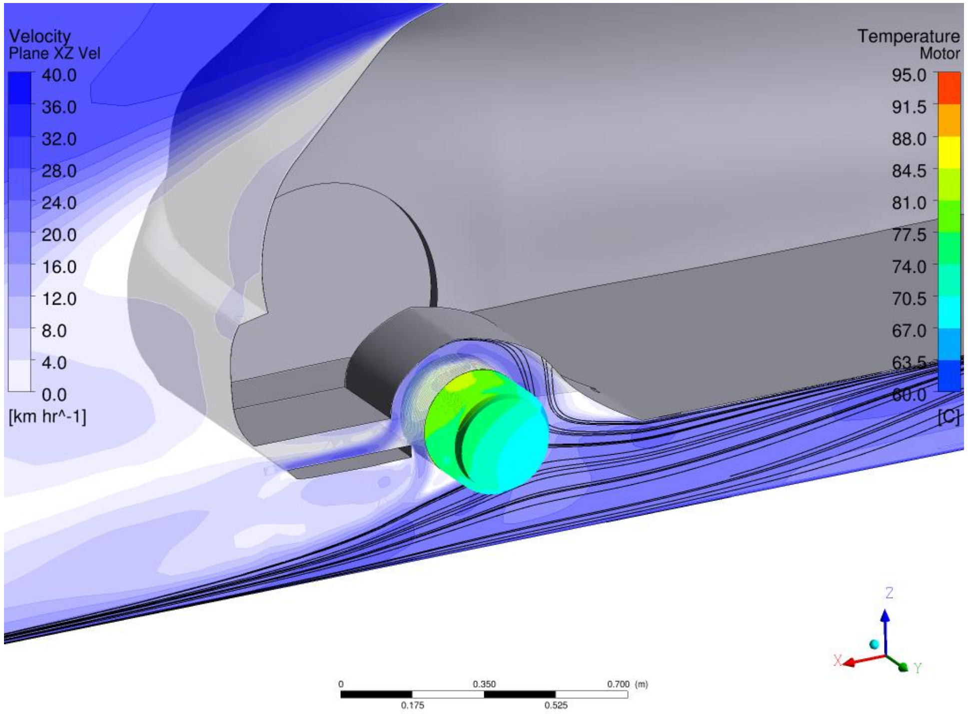
- Max temperature ≈ 81ºC
- Internal maximum ΔT ≈ 17ºC

# Predesign

- Power electronic not included
- Cylindrical fins distribution, aligned with the air flow



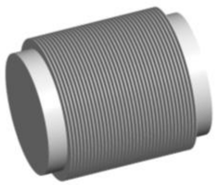
Design driven by Reducing impact of the e-drive on the car bodywork




Motor circular wall:

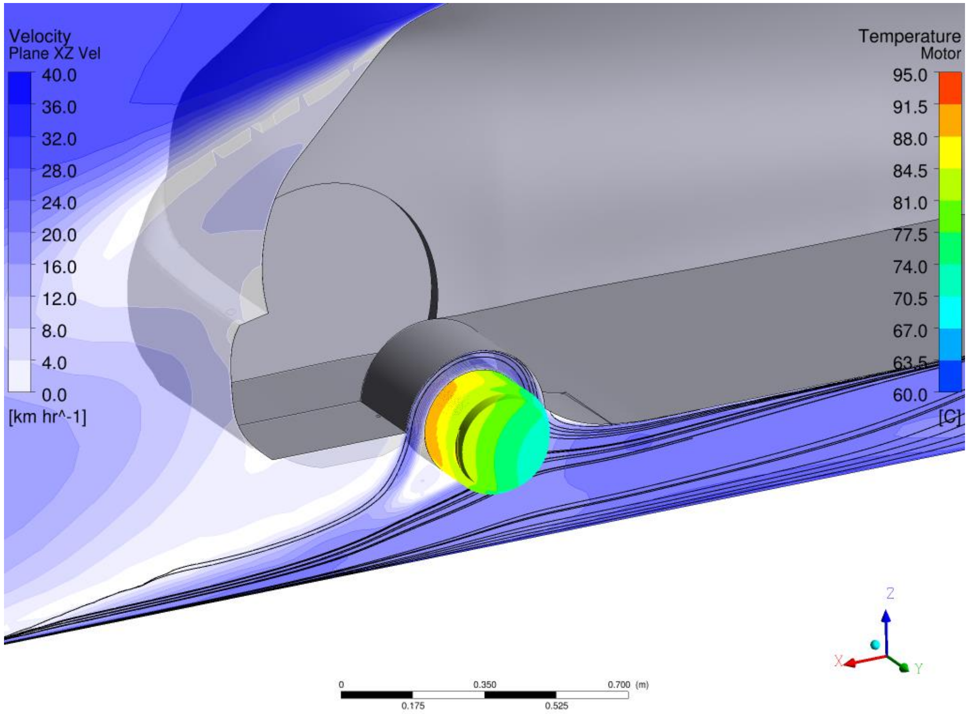
- Max temperature ≈ 80ºC
- Internal maximum ΔT ≈ 16ºC

# Predesign



- Power electronic not included
- Cylindrical fins distribution, aligned with the air flow

Design driven by Reducing impact of the e-drive on the car bodywork




Motor circular wall:

- Max temperature ≈ 93ºC
- Internal maximum ΔT ≈ 25ºC

# Numerical model

## Boundary Conditions, fluid & solid

**Predesign, only motor** (no inverter)

- Car speed = 38 km/h
- Side wall: 0 W
- Circular wall: 1352 W

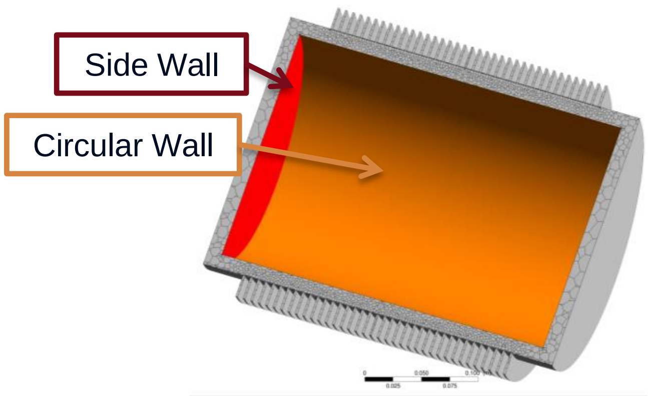
**Inverter integration**:

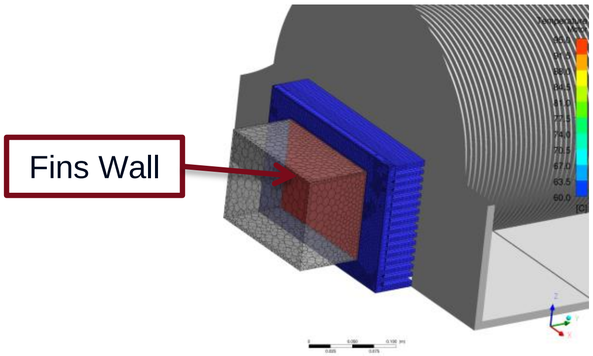
- Car speed = 38 km/h
- Side wall: 0 W
- Circular wall: 1352 W
- Fins wall = 588 W

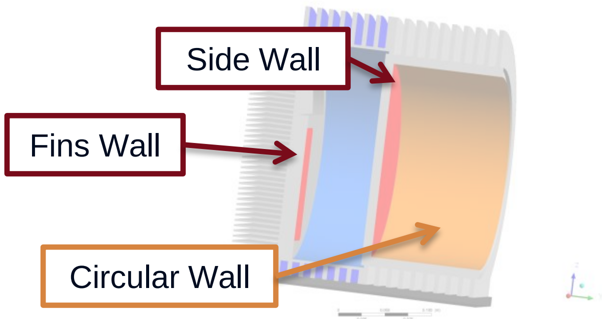
**Final design**:

- Car speed = 33.6 km/h
- Side wall: 190 W
- Circular wall:  760 W
- Fins wall = 588 W

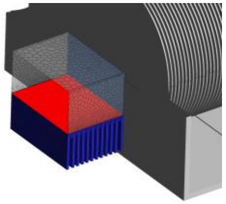
Fluxes imposed as computed by using **1D model**



# Inverter integration



- Commercial heat sink placed different positions
- Considered both Thermally **connected and disconnected** to the electric motor

Fins Wall:

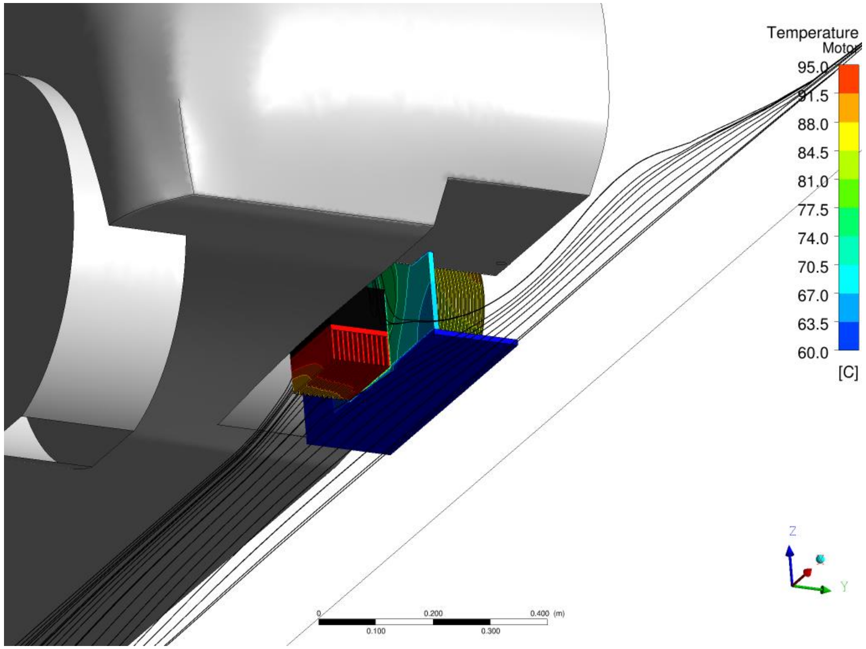
- Max temperature ≈ 111 ° C

Motor circular wall:

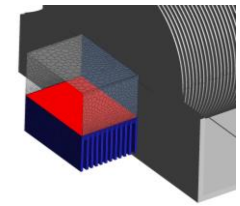
- Max temperature ≈ 93 ° C
- Internal maximum ΔT ≈ 23.5 ° C

⇩

Temperatures **above** the maximum allowed



# Inverter integration



- Commercial heat sink placed different positions
- Considered both Thermally **connected and disconnected** to the electric motor

Fins Wall:

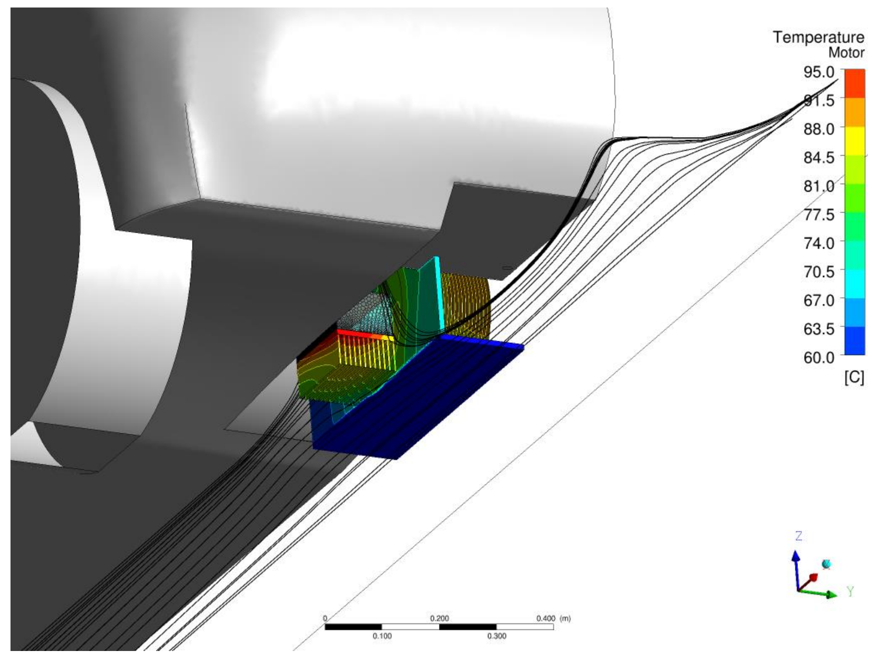
- Max temperature ≈ 97 ° C

Motor circular wall:

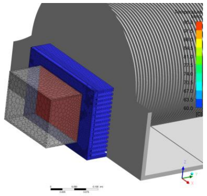
- Max temperature ≈ 99 ° C
- Internal maximum ΔT ≈ 25.5 ° C

⇩

Temperatures **above** the maximum allowed



# Inverter integration



- Commercial heat sink placed different positions
- Considered both Thermally **connected and disconnected** to the electric motor

Fins Wall:

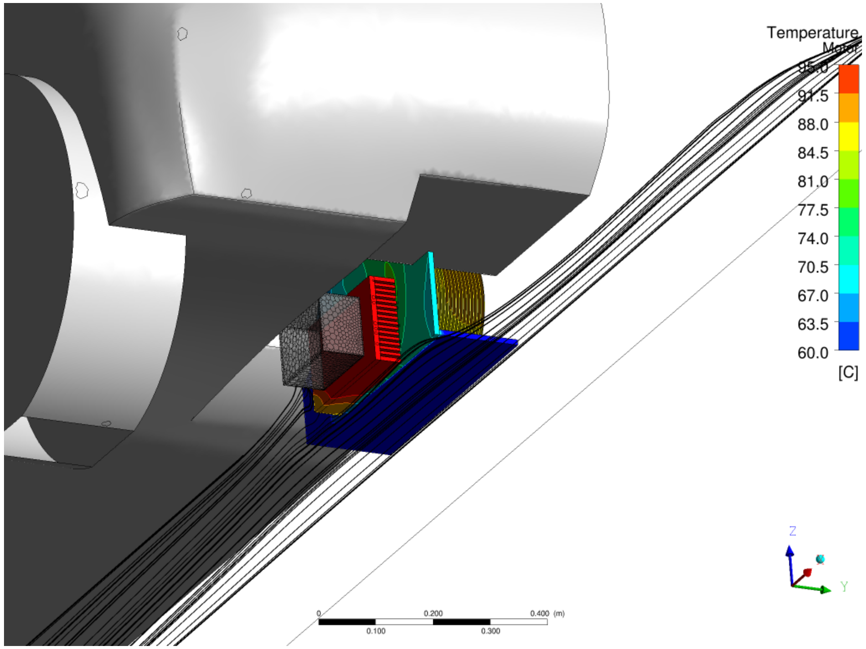
- Max temperature ≈ 99 ° C

Motor circular wall:

- Max temperature ≈ 99 ° C
- Internal maximum ΔT ≈ 25.5 ° C

⇩

Temperatures **above** the maximum allowed



# Numerical model

## Boundary Conditions, fluid & solid

**Predesign, only motor** (no inverter)

- Car speed = 38 km/h
- Side wall: 0 W
- Circular wall: 1352 W

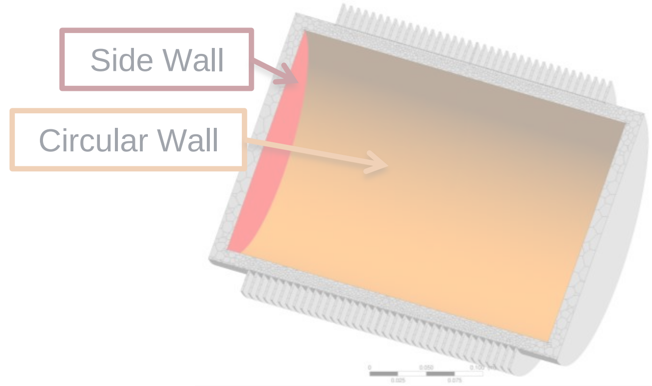
**Inverter integration**:

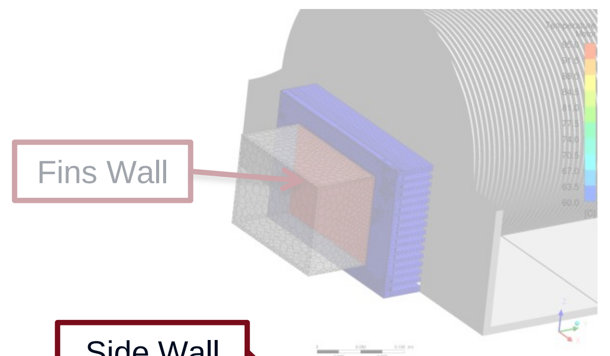
- Car speed = 38 km/h
- Side wall: 0 W
- Circular wall: 1352 W
- Fins wall = 588 W

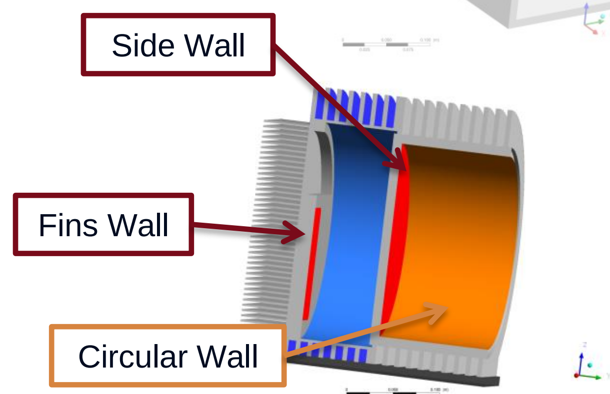
**Final design**:

- Car speed = 33.6 km/h
- Side wall: 190 W
- Circular wall: 760 W
- Fins wall = 588 W

Fluxes imposed as computed by using **1D model**

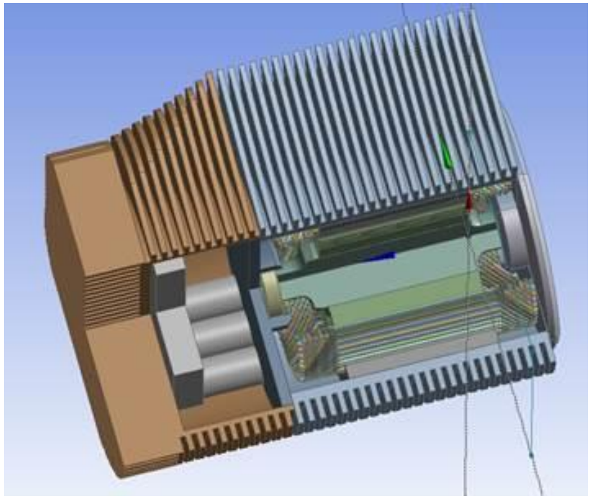


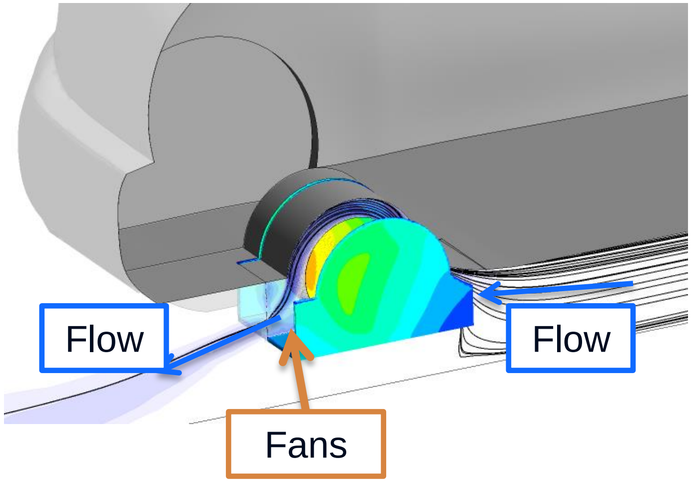



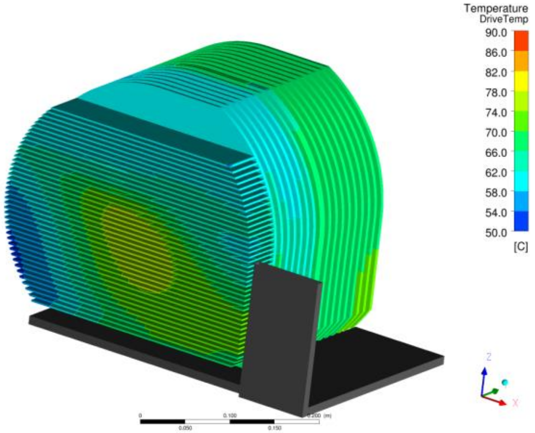



# Final design

- Increased **compactness** of the E-drive system
- Fins designed to have higher area of exchange in the low flow velocity regions: reduced DT between front and back of the motor
- **High thermal inertia** to reduce invert temperature peaks under severe unsteady loads
- **Efficient fans integration** for boosting/supply cooling flow





# Final design

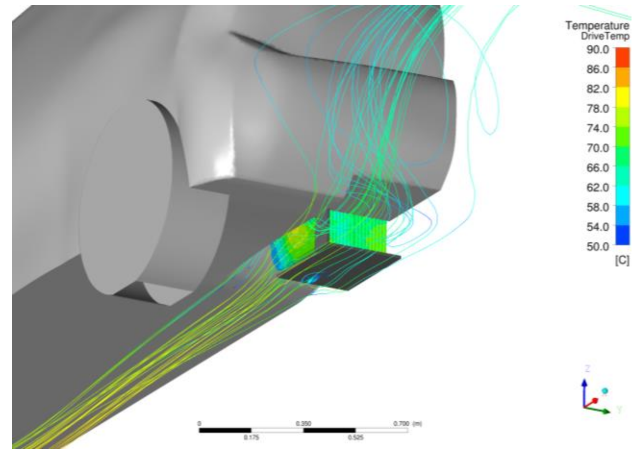
WP1, running car

Fins Wall:

- Max temperature ≈ 83 °C

Motor circular wall:

- Max temperature ≈ 73 °C
- Internal maximum ΔT ≈ 7 °C



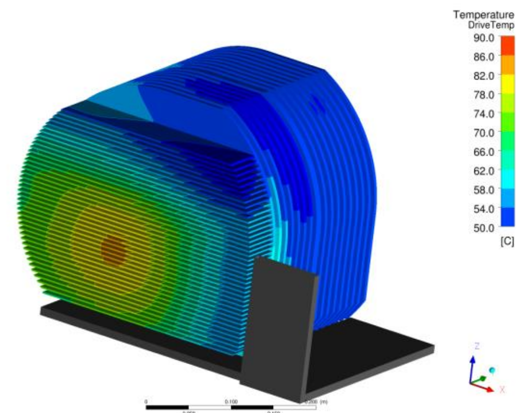

Standing car, cooling fans on

Fins Wall:

- Max temperature ≈ 87 °C

Motor circular wall:

- Max temperature ≈ 57 °C
- Internal maximum ΔT ≈ 4 °C




Temperatures **below** the maximum allowed

# Eco-design and Validation of In-Wheel Concept for Electric Vehicles

*Project acronym: EUNICE*

**Grant agreement no.:** 285688
**Call:** FP7-2011-GC-ELECTROCHEMICAL-STORAGE

www.eunice-project.eu

**Main Objective**: Design, Development and validation of a **complete motor in wheel.**

- Analytical and experimental evidences will be generated by the EUNICE consortium to demonstrate the feasibility of the solution on an existing **B segment vehicle**.
- Expected technology readiness Level 6, with demonstrated engineering feasibility of the solution.

SEVENTH FRAMEWORK PROGRAMME

European Commission

**PARTNERS**

tecnalia, pininfarina, MAGNETI MARELLI, CIE Automotive, DENN, IVL, Infineon, aic, AIT, HAYES LEMMERZ, EVO ELECTRIC / GKN, CLEPA, EVO ELECTRIC

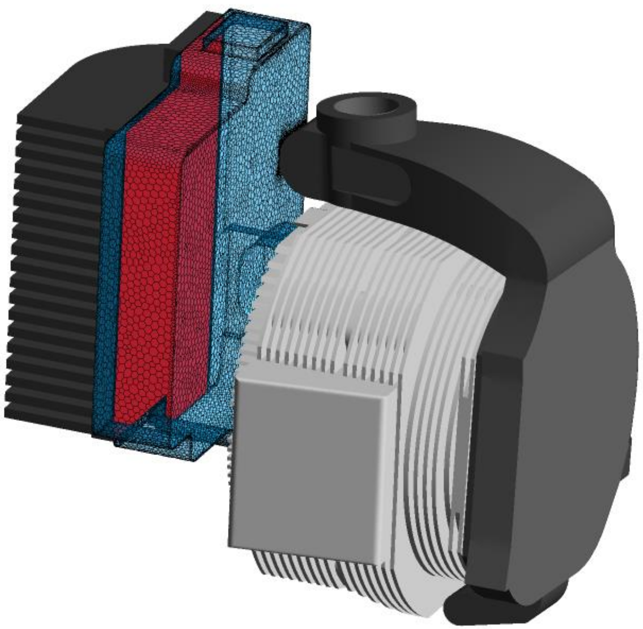


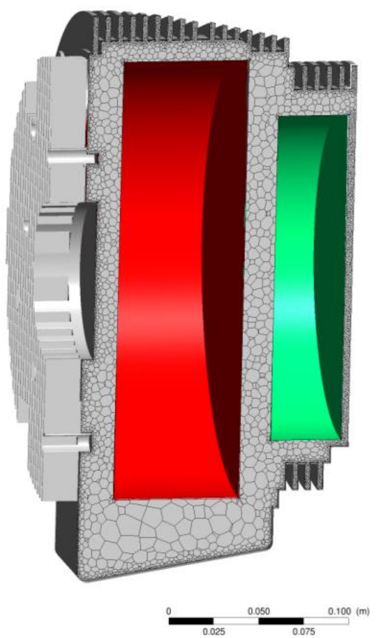

FP7 SEVEN FRAMEWORK PROGRAMME THEME: GC.NMP.2011-1, GC.SST.2011-7-7, ICT

# EUNICE cooling concept design

Tasks:

- Development of detailed CFD model for cooling concept design
- Define fins distribution and orientation to meet temperature constrains

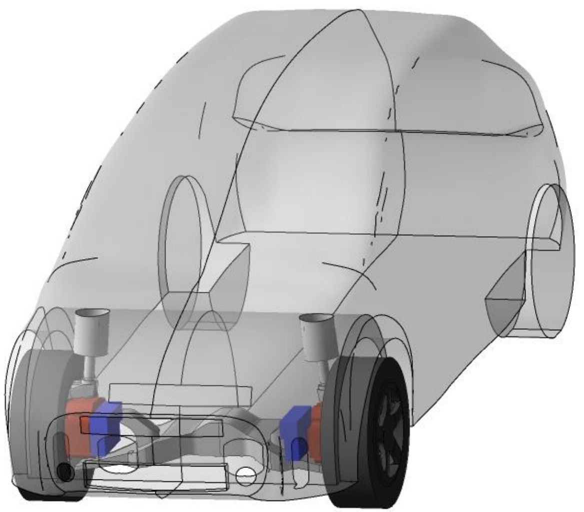


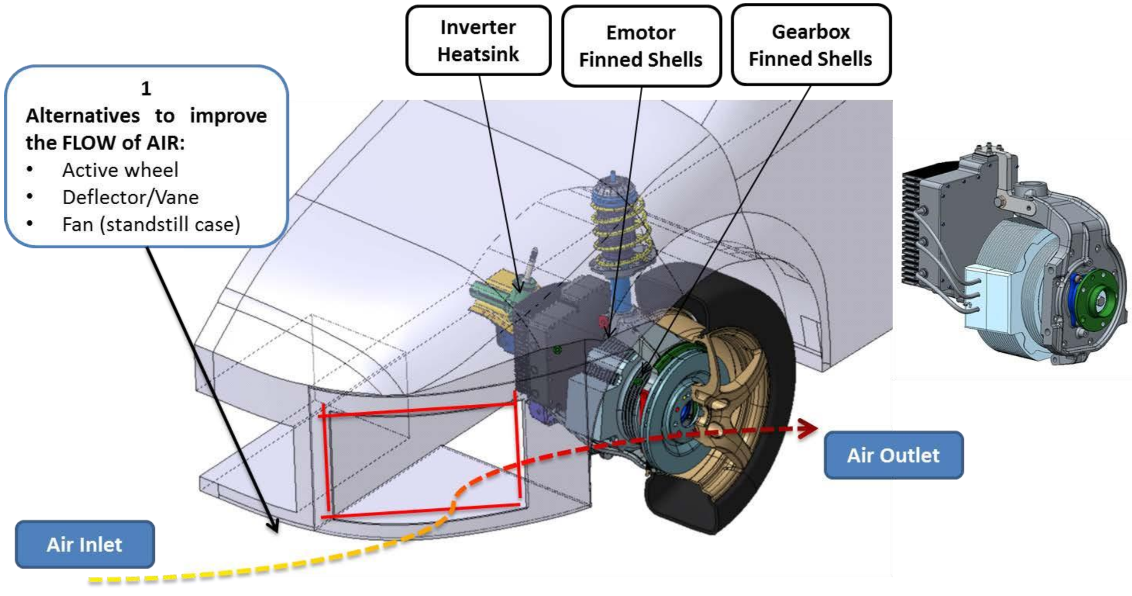


# EUNICE cooling concept design

Tasks:

- Development of detailed CFD model for cooling concept design
- Define fins distribution and orientation to meet temperature constrains
- Define required cooling channel in the car bodywork to evacuate heat generated





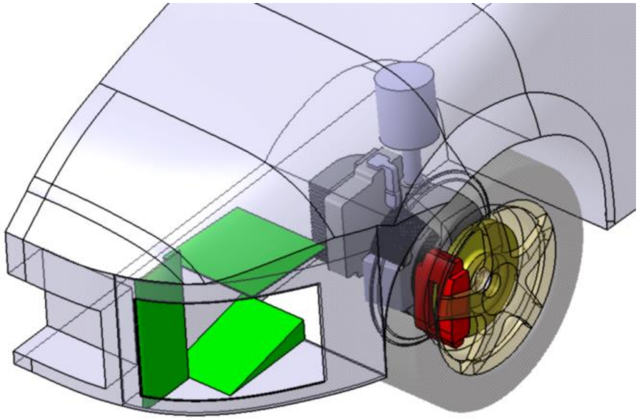


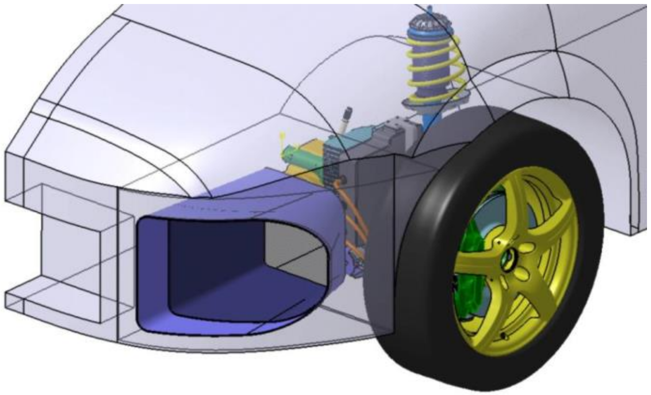


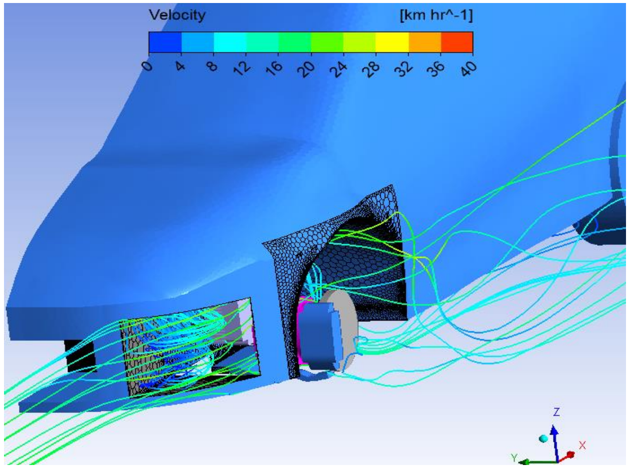
FP7 SEVEN FRAMEWORK PROGRAMME THEME: GC.NMP.2011-1, GC.SST.2011-7-7, ICT

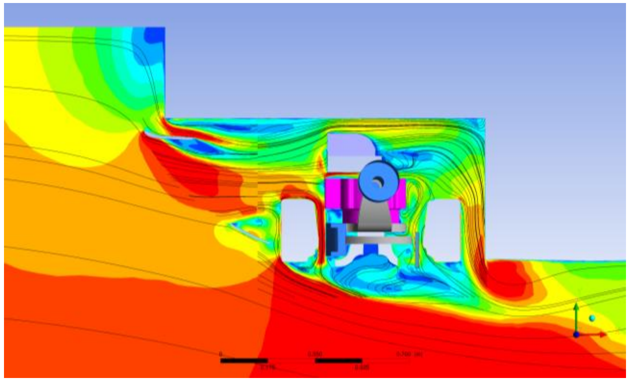
# EUNICE results

- Design and evaluation of different cooling channels







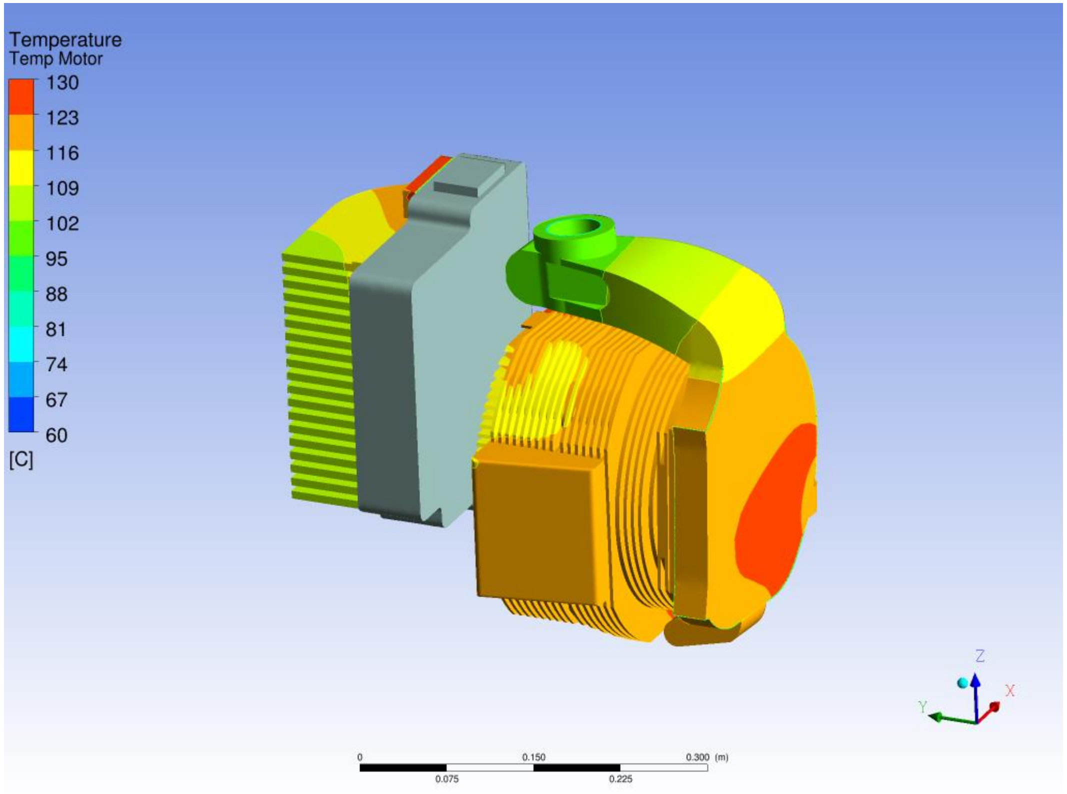






FP7 SEVEN FRAMEWORK PROGRAMME THEME: GC.NMP.2011-1, GC.SST.2011-7-7, ICT

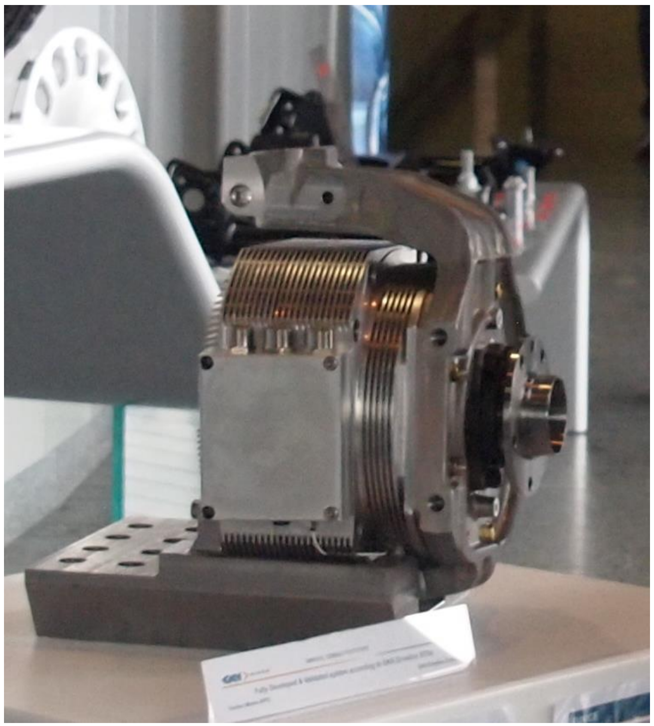
# EUNICE results

- Design and evaluation of different cooling channels
- Fins geometry/distribution design and temperature evaluation of components



# EUNICE Prototype

In-wheel motor and car





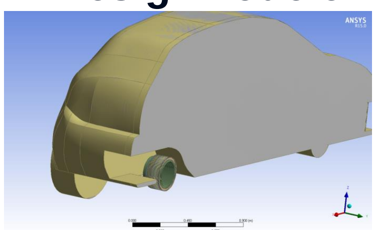

FP7 SEVEN FRAMEWORK PROGRAMME THEME: GC.NMP.2011-1, GC.SST.2011-7-7, ICT

# Conclusions

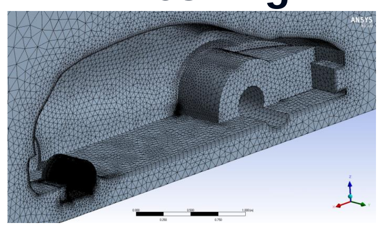
- How we are using Numerical Simulations to design Air Cooled Electric Drive

  - **Change in the design** requires a **minor** interaction of the user to evaluate the **new performance**

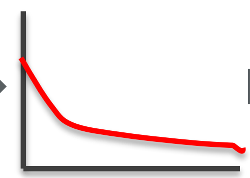
**DesignModeler**



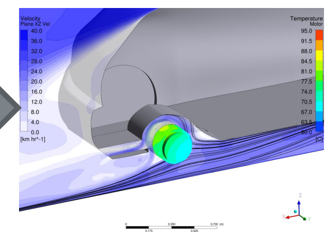
**Meshing**



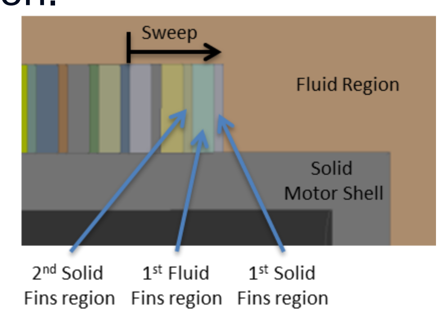
**Solver**



**Post**

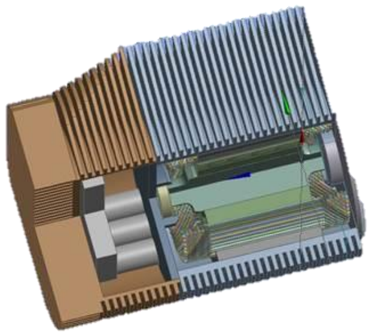


  - **High control** of the mesh **resolution** to reduce computational burden allowing a realistic fluid flow prediction.



# Conclusions

- How we are using Numerical Simulations to design Air Cooled Electric Drive
- Speed up the design and virtually test the cooling concept for two air cooled electric drives:



**SyrNemo:** Innovative synchronous reluctance machine.

**EUNICE:** Validation of In-Wheel drive concept.

# Acknowledgment

The authors are grateful to the European Commission for the support to the present work, performed within the EU FP7 project SYRNEMO (Grant Agreement 605075) and EUNICE (Grant Agreement 285688).

Dr. Alessandro Zanon

Alessandro.Zanon@ait.ac.at