A multiphysic approach to improve helmets comfort and reduce time and costs in design process

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MATHEMATICS FOR INNOVATION

MODELLISTICA E CALCOLO SCIENTIFICO
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Longoni Matteo[1], Formaggia Luca[2], Ferrandi Paolo[1]

[1]Moxoff Srl, Via D'Ovidio 3, 20131 Milano, Italy

[2]MOX - Modeling and Scientific Computing

Dipartimento di Matematica "F. Brioschi", Politecnico di Milano, Italy

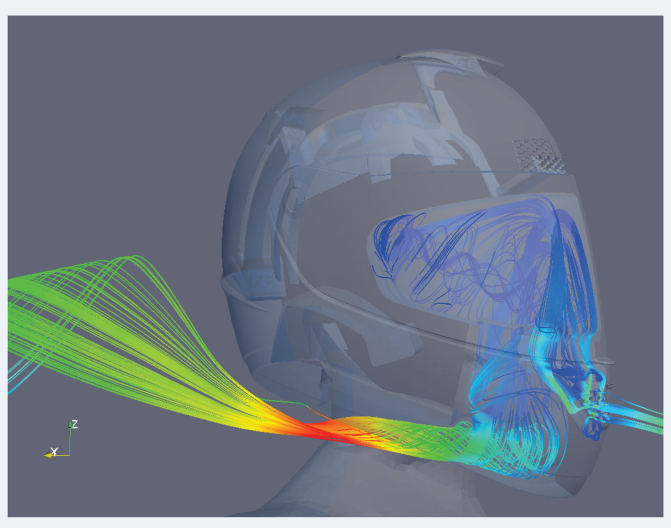
Motivation

- Improve helmet comfort in every-day conditions
- Key issue: pleasure of driving and safety

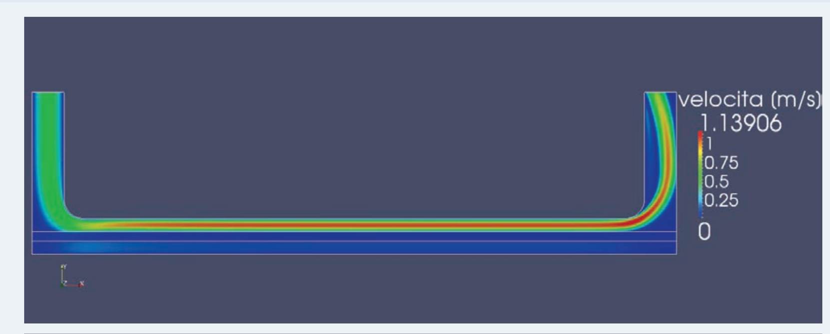
Goal

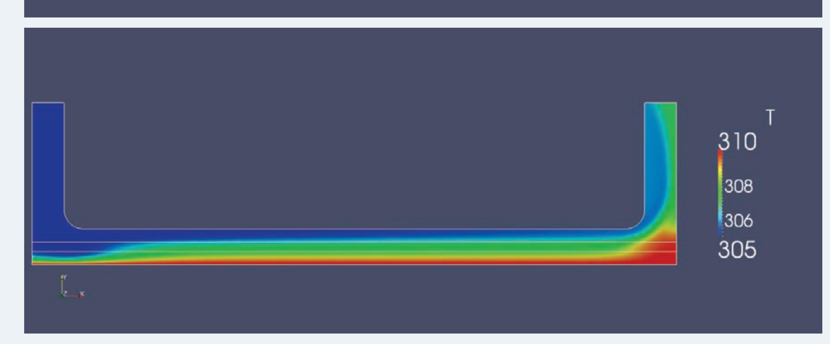
- Develop a support design tool for engineers
- Simulate helmet performances efficiently

Technology



- Starting point: very latest research works
- Handling of real and complex CAD geometries
- Model coupling: aerodynamics 3D, thermofluid 2D and vibroacoustics 3D
- Multiphase (water/vapour) flows in porous media (comfort tissue/human hair)
- Human head sweating model for heat generation
- Advanced numerical methods
- Improvement and development of robust simulation codes





Mathematical model

ThermoFluid dynamic problem

- Navier–Stokes coupled with Darcy–Forchheimer: Penalized NS

$$(\rho(\mathbf{u}\cdot\nabla)\mathbf{u} - \mu\Delta\mathbf{u})\,\chi_{\Omega_f} + \nabla p + \left(\frac{\mu}{k}\mathbf{u} + \frac{\rho C_F}{\sqrt{k}}|\mathbf{u}|\mathbf{u}\right)\chi_{\Omega_p} = \mathbf{0}$$

- Temperature T: $$\frac{\partial T}{\partial t} + C_f\mathbf{u}\cdot\nabla T = \nabla\cdot(\lambda_p\nabla T) - l_e s(h,w,T)$$
- Humidity h: $$\frac{\partial h}{\partial t} + \mathbf{u}\cdot\nabla h = D_h\Delta h + s(h,T,w)$$
- Sweat content w: $$\frac{\partial w}{\partial t} = \nabla\cdot(D_w\nabla w) - s(h,T,w)$$
- Evaporation rate s: $$s(h,T,w) = E\sqrt{\frac{M_v}{2\pi RT}}\,(p_{sat}(T) - p_v(h,T))\,\chi_{w^+}$$

$\Omega_{f,p,w}$ = *fluid, porous, wet domain*
ρ = *air density*
$\mathbf{u}$ = *flow velocity*
t = *time*
μ = *dynamic viscosity*
p = *pressure*
k = *permeability*
D_h = *water diffusivity*
χ = *indicator function*
C_f, λ_p, l_e = *thermodynamics*
M_v, R, p_{sat}, p_v = *psychrometrics*
C_F, D_w, E = *coefficients*

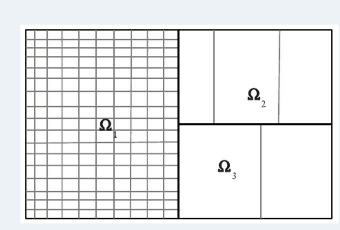
Vibroacoustic model - WIP!

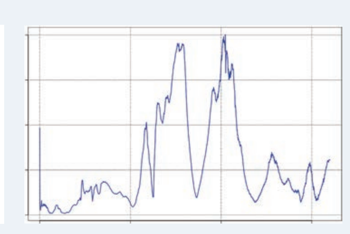
- Elastodynamics equations:

$$\begin{cases} \rho\partial_{tt}\mathbf{u} - \nabla\cdot\underline{\sigma}(\mathbf{u}) = \mathbf{f}, & \text{in } \Omega\times[0,T] \\ \mathbf{u} = \mathbf{0}, & \text{on } \Gamma_D\times[0,T] \\ \underline{\sigma}(\mathbf{u})\cdot\mathbf{n} = \mathbf{t}, & \text{on } \Gamma_N\times[0,T] \\ \text{non-reflecting b.c.}, & \text{on } \Gamma_{NR}\times[0,T] \\ \partial_t\mathbf{u} = \mathbf{u}_1, & \text{in } \Omega\times\{0\} \\ \mathbf{u} = \mathbf{u}_0, & \text{in } \Omega\times\{0\} \end{cases}$$

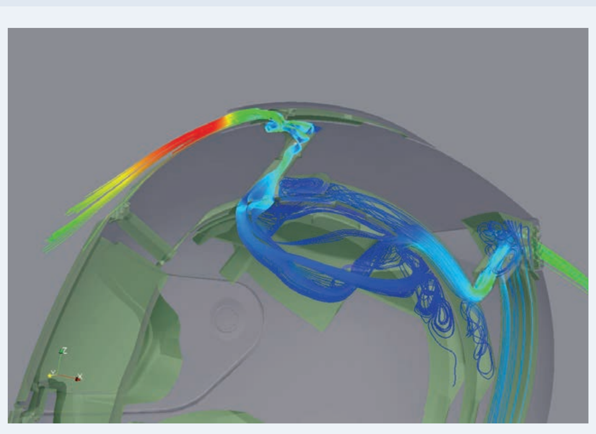
$\mathbf{u}$ = *displacement*
t = *time*
$\mathbf{n}$ = *unit normal*
$\underline{\sigma}$ = *stress tensor*
$\mathbf{u}_{0,1}$ = *initial conditions*
$\mathbf{f}$ = *external force*
Ω = *3D domain*
Γ = *boundaries*

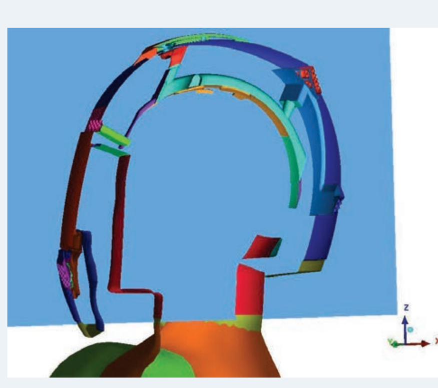
- Discontinuous Galerkin formulation
- Space–Time formulation
- Multi-domain formulation
- 3D hexa mesh

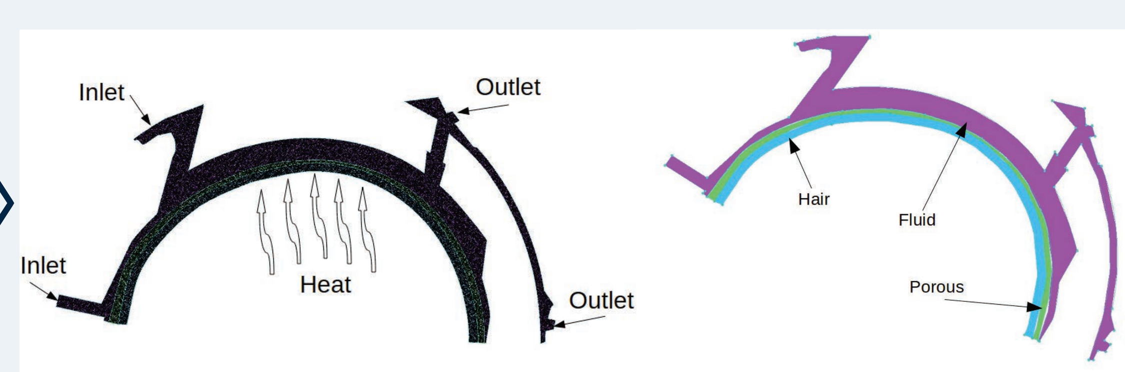


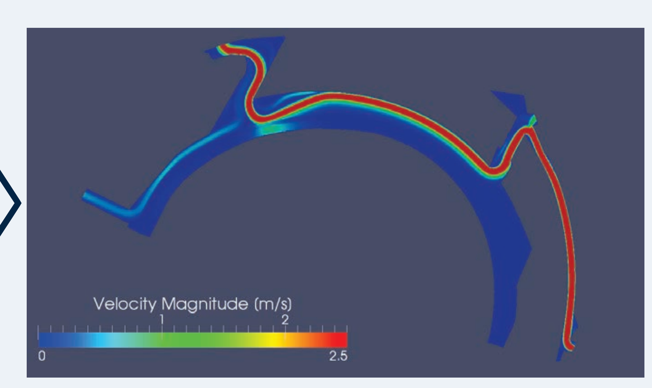


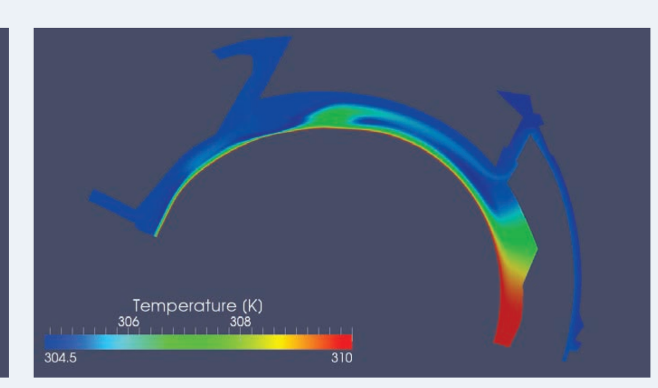
Multiphysic approach





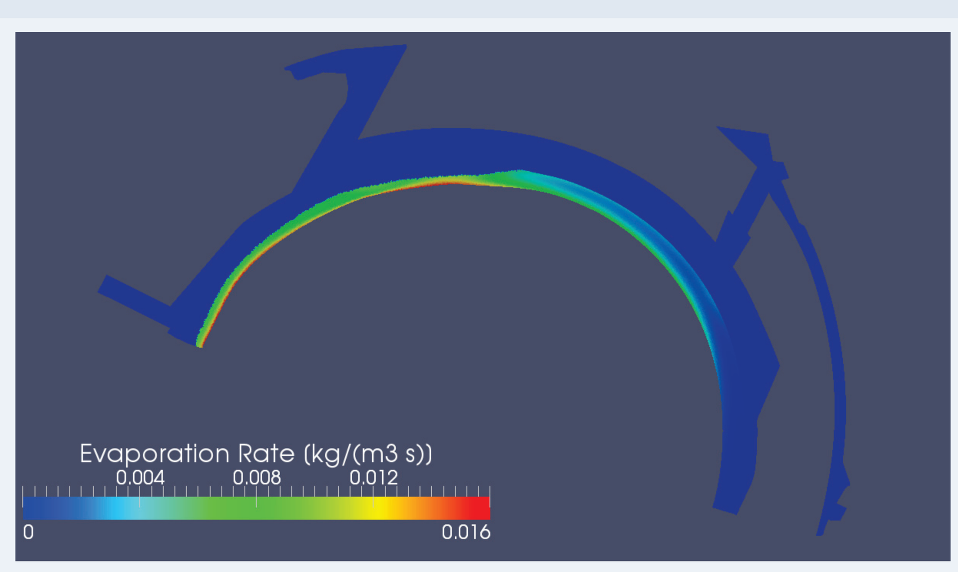


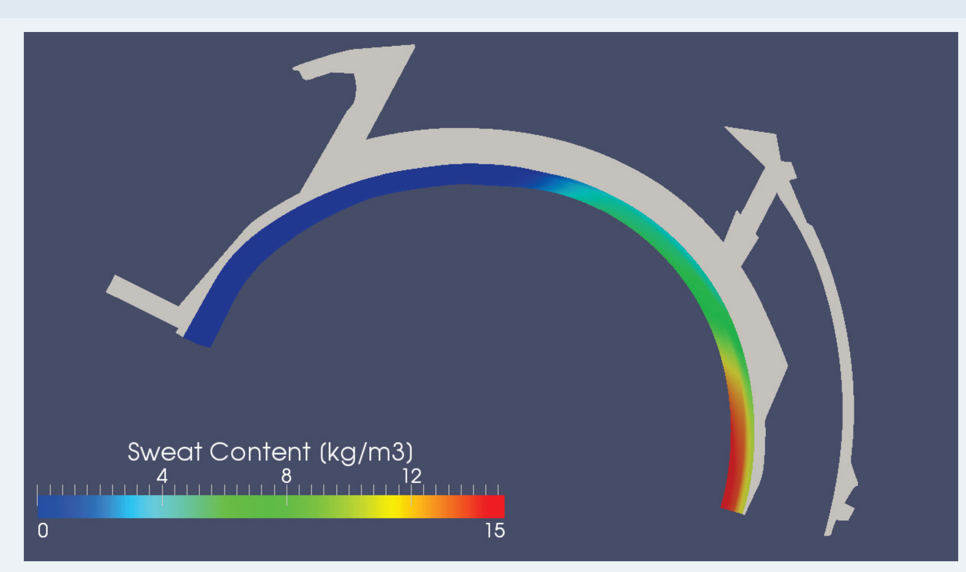


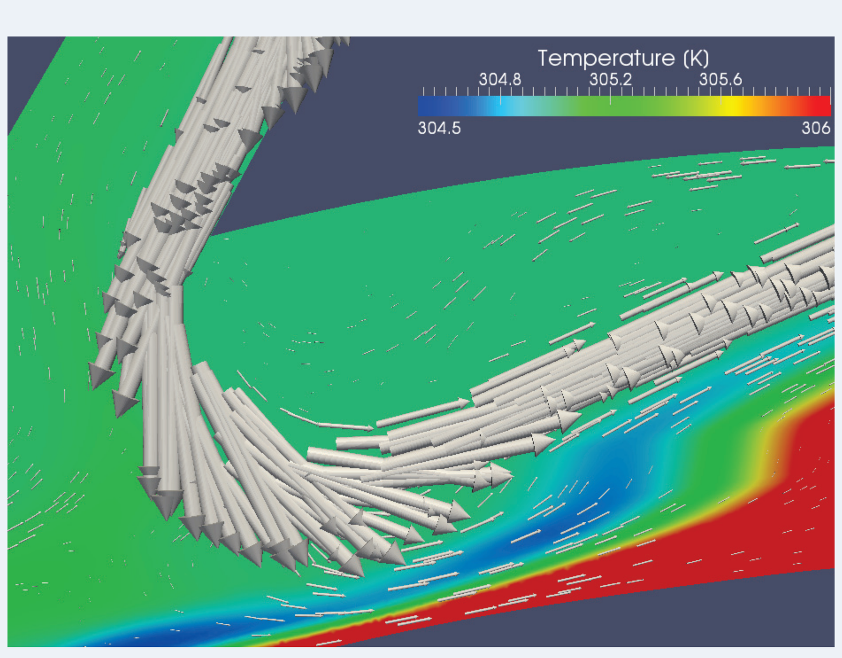


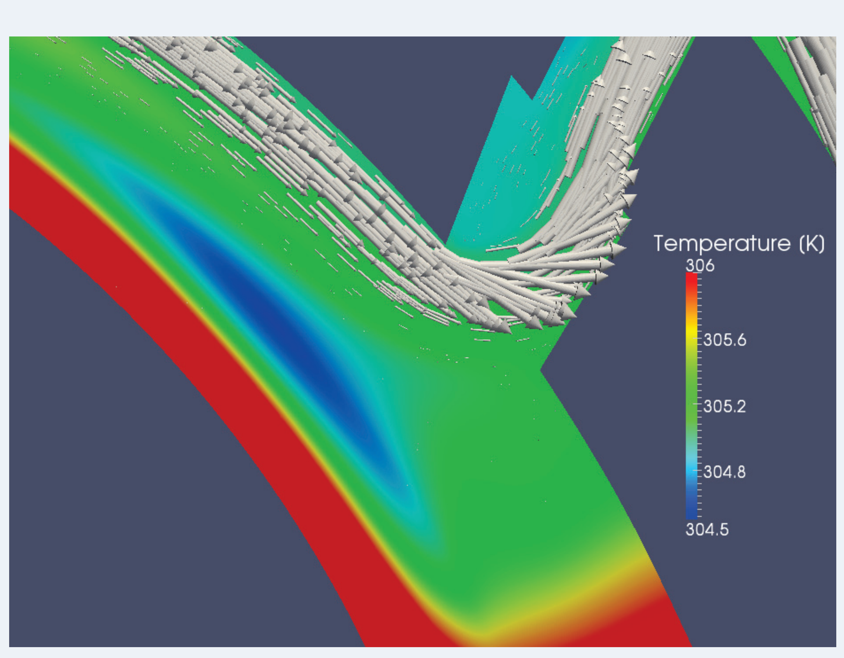
Results

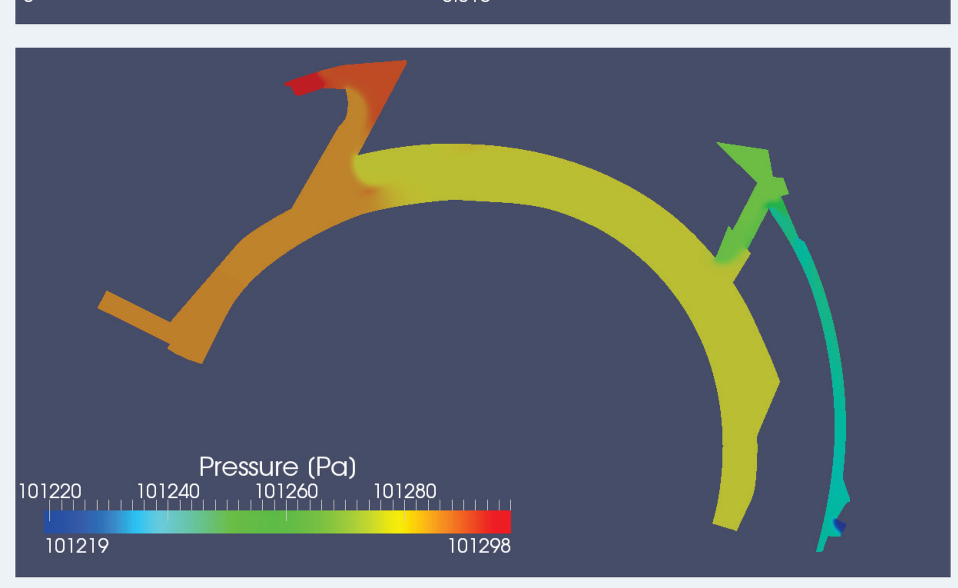
- Accurate and efficient simulations of the physics involved
- Evaluation tool for engineers to explore different design solutions
- Time and costs of the overall design process drastically improved
- Optimized process satisfying comfort requirements for a successful product.

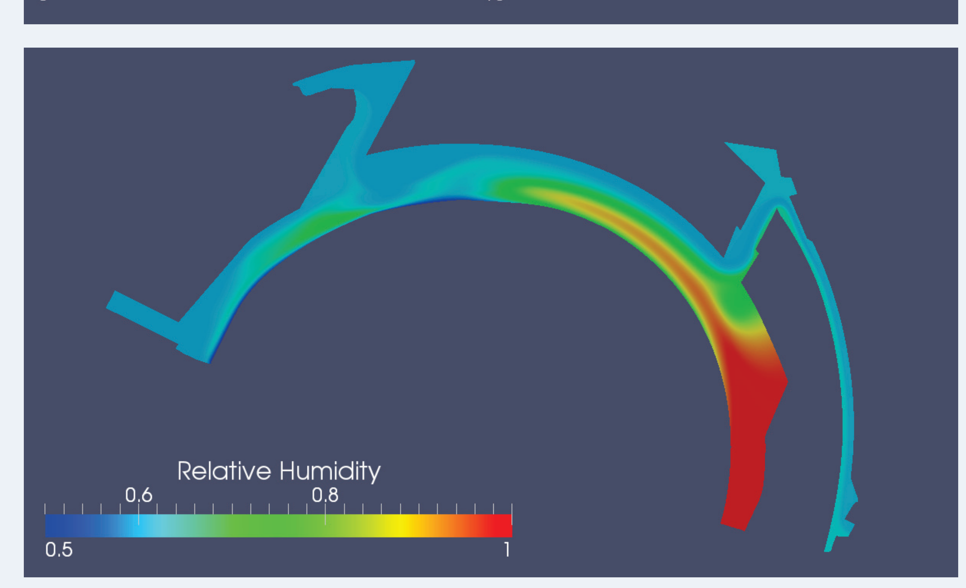












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