Multiphysics-Multiscale Mechanical Design
for Plasma Facing Materials

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Abstract
My research topic is developing an advanced multiscale-multiphysics approach for mechanical design optimization of complex systems. Multiphysics simulation approach needs to be improved for solving physically coupled systems in a more efficient and accurate way. For the multiscale approach, I'm going to incorporate elasticity, dislocation-based plasticity and fracture mechanics in a single computational framework with a step-by-step zoom in process.

Status Quo

- Many problems in engineering and science involve some level of coupling between different physical fields.
- The available macroscale models are not accurate enough, while the microscale models are not efficient enough.

Research Goals

- Provide reasonable coupling and optimization strategies to solve complex and real world engineering problems, quickly and effectively.
- Develop an advanced multiscale-multiphysics mechanical design methodology to get more accurate simulation results with relatively high efficiency by incorporating elastic, dislocation-based plastic and fracture mechanics analysis.

Research Impact

- The multiscale-multiphysics analyses provide deeper insight into the performance of designs, leading to more economical and safer products.
- Develop useful tools and strategies for improvements in packaging performance derived from the simulations during the entire design cycle.

Model Summary

- Typical multiphysics problems

Fluid-Structure Interaction (FSI)
This kind of problems involves the interaction between general nonlinear structures and general Navier-Stokes fluid flow all tightly integrated in a single program.

Thermo-Mechanical Coupling (TMC)
In this class of problems, the temperature distribution affects the structural deformation and the structural deformation may affect the temperature distribution.

Thermal-Fluid-Structural Coupling (TFSC)
The fluid flow changes the temperature in the system and this change of temperature causes mechanical deformation changing the boundary conditions for the flow, thus affecting the flow.

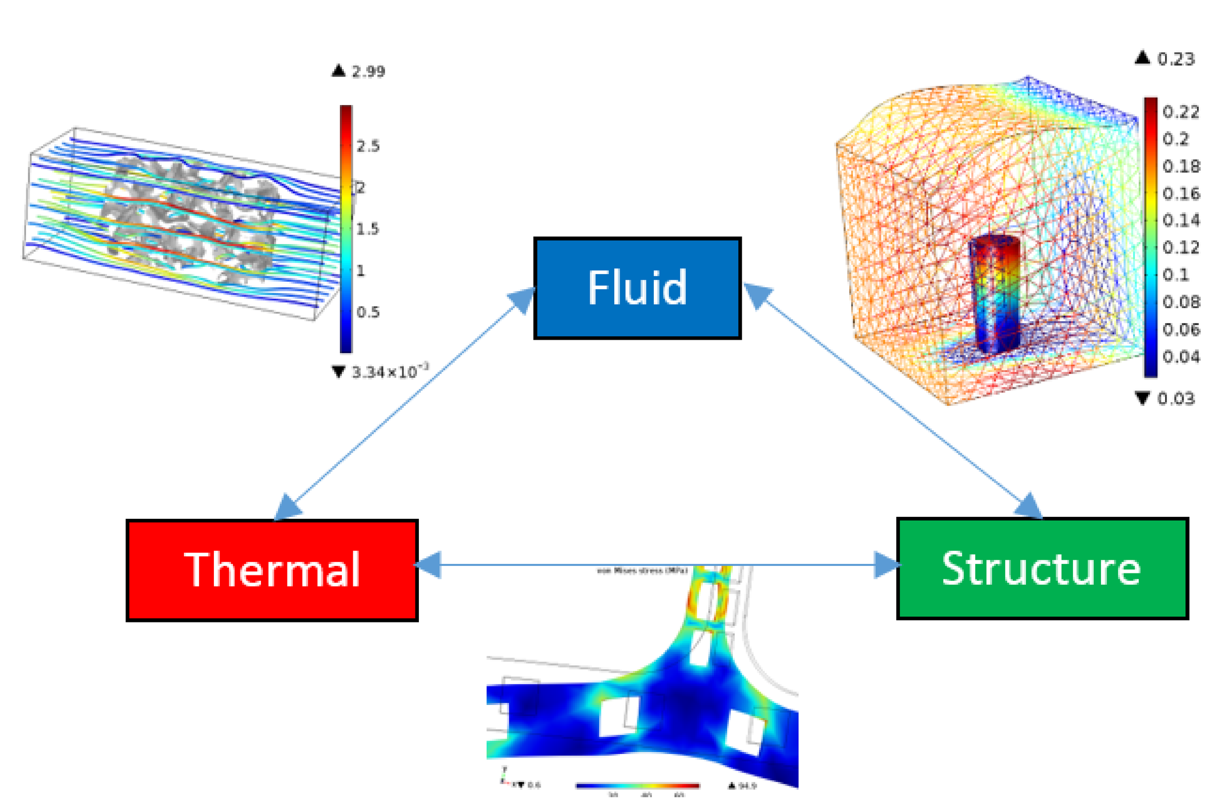

Figure 1: Examples of typical multiphysics problems

- Simulation Process

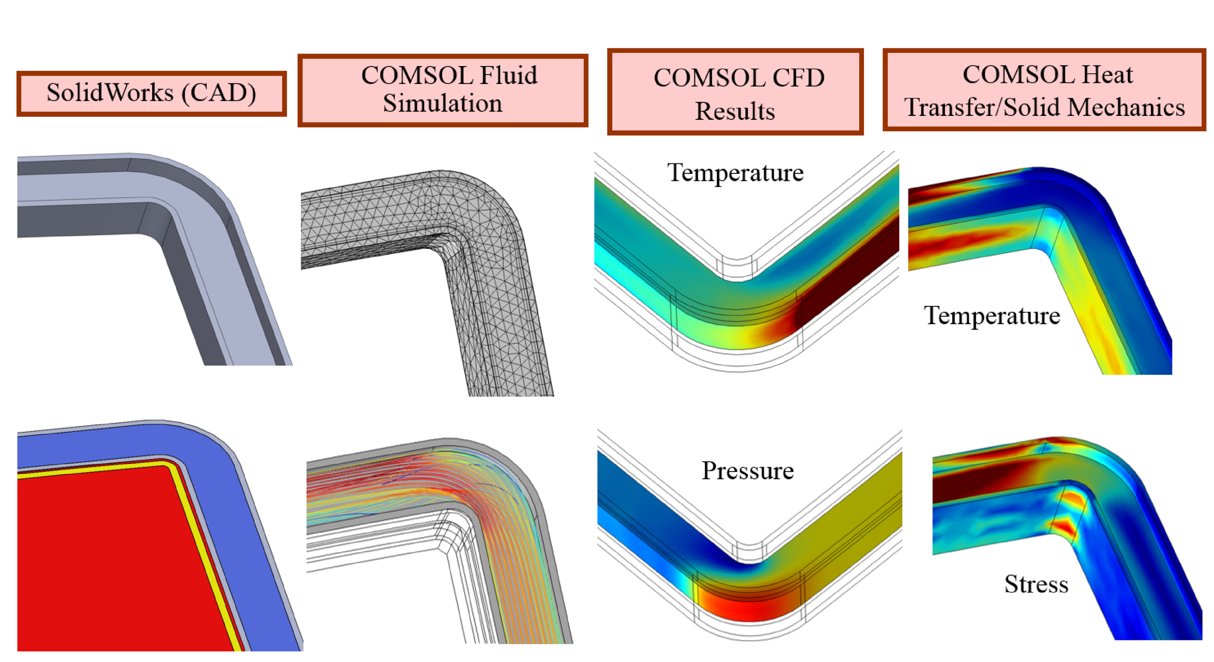

Figure 2: Summary of the multiphysics simulation process sequence

Results

- Inboard Blanket

A multiphysics modeling process is applied on the dual coolant lead-lithium (DCLL) inboard blanket, which is utilized in the Fusion Nuclear Science Facility (FNSF) conceptual design in order to optimize the design and achieve long life time and high reliability. The multiphysics aspect of the design is demonstrated via coupling of Computational Fluid Dynamics (CFD), heat transfer in solids and fluids and structural mechanics.

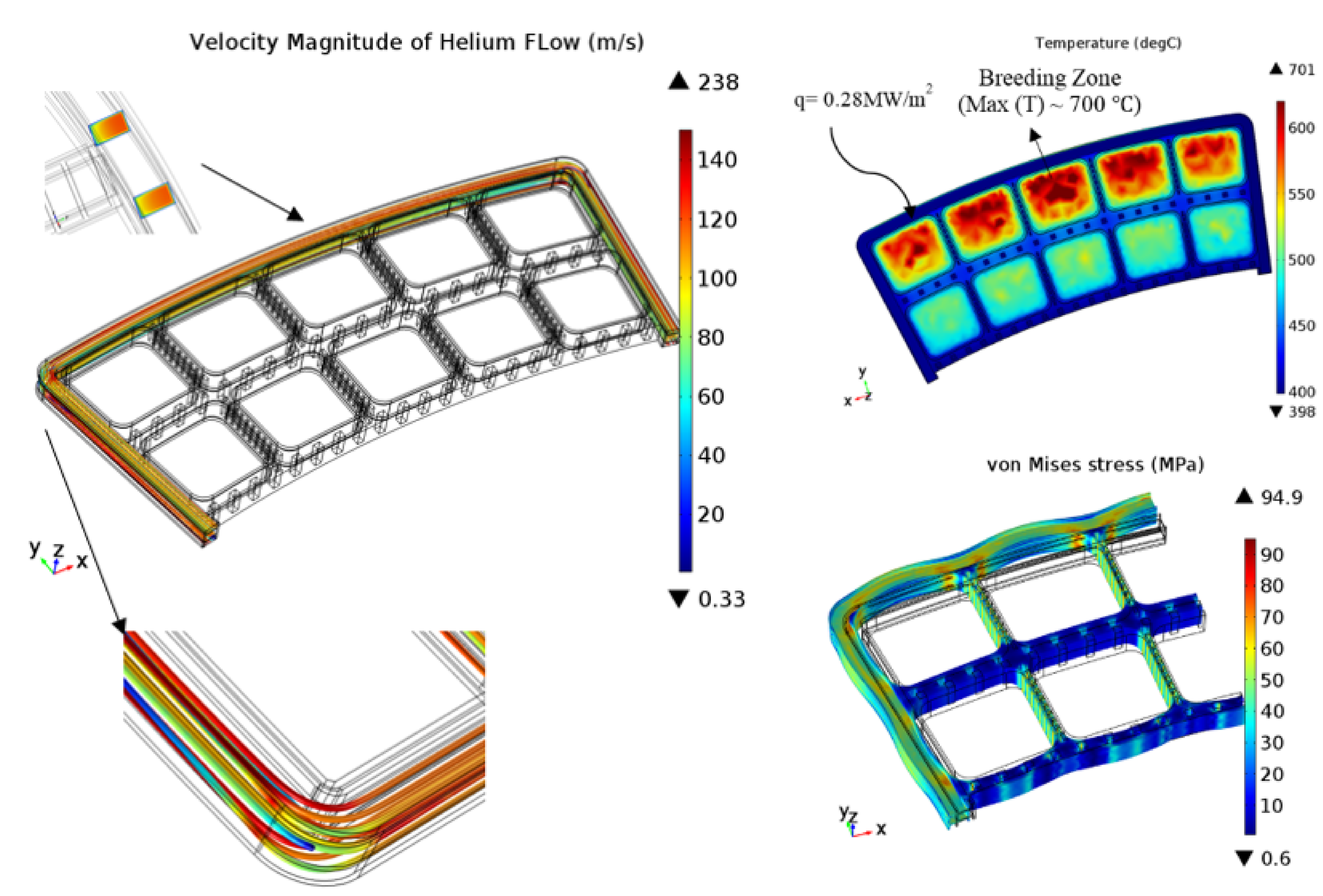

Figure 3: Velocity, Temperature and stress fields of the FW/B structure of FNSF

- Divertor

Divertor in fusion power plant is a typical high heat flux component which is usually designed to accommodate a high heat flux of 10 MW/m^2. Turbulent flow model is coupled with heat transfer to provide velocity and pressure field results of helium coolant for following time-dependent transient analysis.

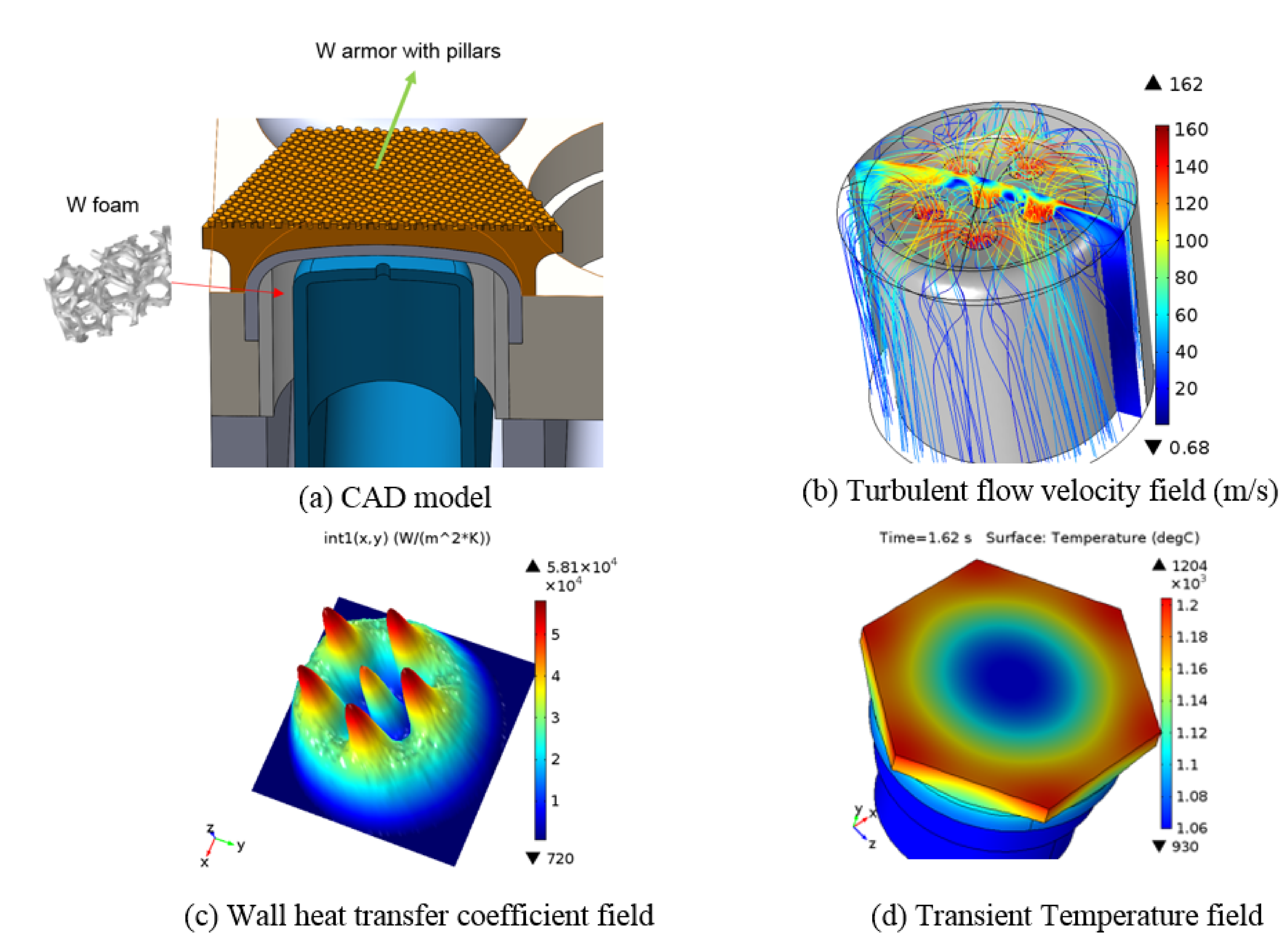

Figure 4: He-cooled Finger W-Divertor Preliminary Results

Forthcoming Research

- Provide design guidance on multiphysics design optimization of complex systems, especially for the ones under high temperature and high heat flux.
- Couple dislocation-based plasticity model to a tool capable to treat elastic mechanical problem, for example, with a finite element code.

References

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