Internship proposition

Academic Year: 2026 – 2027 – February to June 2027.

Acronym: CRAFT

Project title: Modelling cranial vault response under impact: from elastic energy transfer to fracture

Supervisor

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Project description:

Context. The cranial vault plays a central mechanical role during head impact. Its geometry, local thickness, material organisation and constitutive properties govern how impact energy is absorbed, redistributed and transmitted towards the intracranial structures. At higher loading levels, damage initiation and fracture progressively modify this mechanical pathway. Understanding these transitions therefore requires a modelling framework able to represent both geometrical and mechanical variability.

CRAFT will address this challenge through the development of a parametrized finite element (FE) model of the cranial vault, in which geometrical, mechanical and impact-related parameters can be varied independently and systematically. The project will build directly on the experimental–numerical methodology developed by Siegel et al. (2022), who combined controlled impact tests with a simplified three-layer cranium FE model and direct comparison of experimental and simulated impact kinematics. Their work also identified image-based geometry, cranium-thickness variability and improved material laws as key next steps. CRAFT will extend this framework towards parametrized geometry and mechanics, damage and fracture.

Beyond this fundamental impact-biomechanics objective, the project is embedded in an unusual interdisciplinary collaboration with palaeontologists from PACEA (Université de Bordeaux), including Antoine Souron. A particularly emblematic application concerns the specimen KL 287-1, a 0.6-million-year-old Kolpochoerus majus cranium from Bodo, Ethiopia, displaying a depressed cranial fracture whose origin and timing have been debated for decades. CRAFT therefore offers the opportunity to combine modern impact mechanics and parametric modelling with the investigation of a genuine 0.6-million-year-old “cold case”

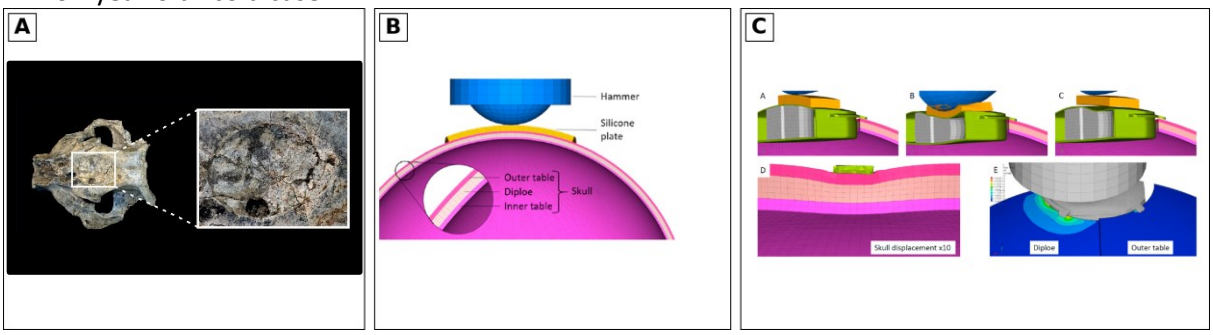


Figure 1 – From a 0.6-million-year-old cold case to an experimentally evaluated FE framework. (A) KL 287-1, a Pleistocene Kolpochoerus majus cranium cranium displaying a depressed fracture (photo © S. Frost, University of Oregon; reproduced in Fiz, 2024). (B) Simplified three-layer cranium FE model used to reproduce controlled impact tests. (C) Example of FE displacement and local cranial strain extraction during impact. Panels B–C adapted from Siegel et al. (2022).

Scientific question. Which geometrical, mechanical and impact-related parameters govern the response of the cranial vault under impact, from elastic deformation and energy transfer to the onset and propagation of fracture? Can a parametrized geometrical and mechanical FE model, evaluated against controlled drop-tower experiments, reproduce and explain the variability of cranial response observed under different impact conditions?

Aim. The aim of the CRAFT project is to develop and evaluate a parametrized finite element model of the cranial vault, integrating geometrical and mechanical variability, from elastic response to fracture. By comparison with controlled drop-tower experiments on fresh wild boar heads, the project will identify the main geometrical, material and impact-related parameters governing cranial deformation, energy transfer, damage and fracture.

Methodology. The project will first establish a parametrized geometrical model of the cranial vault from imaging data. In contrast with the simplified spherical-cap, constant-thickness representation

used in the initial Siegel framework, parameters describing cranial shape, local curvature, cortical/trabecular thickness, sinus development, and structural organisation will be introduced so that geometrical variability can be explored in a controlled manner. In parallel, the model will incorporate a parametrized mechanical description of cranial bone, including stiffness, heterogeneity, strain-rate dependence and damage/fracture properties.

The experimental–numerical workflow will adapt the methodology implemented by Siegel et al. (2022). Controlled drop-tower impacts on fresh wild boar heads will be characterised through impact and rebound kinematics, energy transfer and pre/post-impact imaging. Corresponding FE simulations will reproduce the experimental loading and boundary conditions. Comparison between measured and simulated impact duration, impactor kinematics, restitution/energy dissipation and, where available, local deformation will provide the basis for model evaluation and progressive calibration.

A systematic parametric and sensitivity analysis will then quantify the respective influence of three complementary families of parameters: geometry (shape, curvature, local thickness and architecture), mechanics (material properties, heterogeneity, rate effects and failure parameters) and impact conditions (location, direction, velocity, energy, effective mass and contact surface). Particular attention will be paid to the transition between elastic energy storage, local deformation, damage initiation and fracture propagation.

The most influential parameters will finally be combined within an explanatory and predictive framework able not only to reproduce experimental observations, but also to identify why a given cranial geometry and a given set of mechanical and impact conditions produce a specific response. Once evaluated on controlled experiments, the framework may also be explored for inverse problems, using observed fracture patterns to identify mechanically plausible impact scenarios, including selected palaeontological cases such as KL 287-1.

Deliverable. A parametrized geometrical and mechanical FE model of the cranial vault, evaluated and calibrated against controlled drop-tower experiments; a sensitivity analysis identifying the parameters that most strongly govern elastic energy transfer, damage and fracture; and a numerical framework capable of reproducing a range of experimentally observed impact responses. The project will also provide a first assessment of the potential of the model for reconstructing unknown blunt-force trauma scenarios.

Skills developed during the project. The student will gain experience in finite element modelling, impact dynamics, parametrized geometrical modelling, constitutive modelling of biological tissues, damage and fracture mechanics, model calibration and validation, sensitivity analysis and quantitative comparison between numerical and experimental data. The project offers an unusual interdisciplinary environment at the interface between biomechanics, numerical mechanics, experimental impact research and palaeontology.

Suggested readings

Siegel, A., Sauter-Starace, F., & Laporte, S. (2022). Insights into the mechanical interaction between an active cranial implant and the skull subjected to moderate impact loadings. Journal of the Mechanical Behavior of Biomedical Materials, 126, 105048.

Fiz, M. (2024). Percussion et découpe des têtes de cercopithécidés : combinaison de l'expérimentation et de la simulation numérique et implications pour un spécimen pléistocène. Master thesis, Université de Bordeaux / PACEA.

Hanon, R., Vanderesse, N., Sandoz, B., Persohn, S., Laporte, S., & Souron, A. (2026). Headstrong! A new experimental framework for characterizing hominid predation by blunt force traumas on large mammals. TAPHEN 2026.

https://tumourrasmoinsbete.blogspot.com/2026/04/cest-paleontologie.html (french)

Dutel, H. et al. (2021). Comparative Cranial Biomechanics in Two Lizard Species: Impact of Variation in Cranial Design. Journal of Experimental Biology, 224.