Open PhD position 2023-2026:

# High Performance Digital Image Correlation for the characterization of lattice structures.

**Supervisors:**

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**Attachment:** ICA UMR CNRS 5312 (collaboration with IMT Toulouse and LIP6 Paris).

**Funding:** ANR project AVATAR, including 2 PhD theses and 1 postdoc, and gathering IMT, ICA, LIP6 and EPFL.

**Key words:** Computational solid mechanics, data assimilation, digital image correlation, lattice structures, additive manufacturing.

## General context

This research internship takes place in Project AVATAR funded by the french National Research Agency (ANR) involving universities in Toulouse, Paris and Lauzanne (CH). This projects builds on the advent of Additive Manufacturing (AM) and digital imaging tools that are currently revolutionizing the area of mechanics of materials. Metal AM (*e.g.* Selective Laser Melting (SLM) process) now allows the fabrication of industrially-relevant high-performance products (see Fig. 1(a)) with unprecedented weight savings, which is particularly appealing for cleaner mobility and space [1].

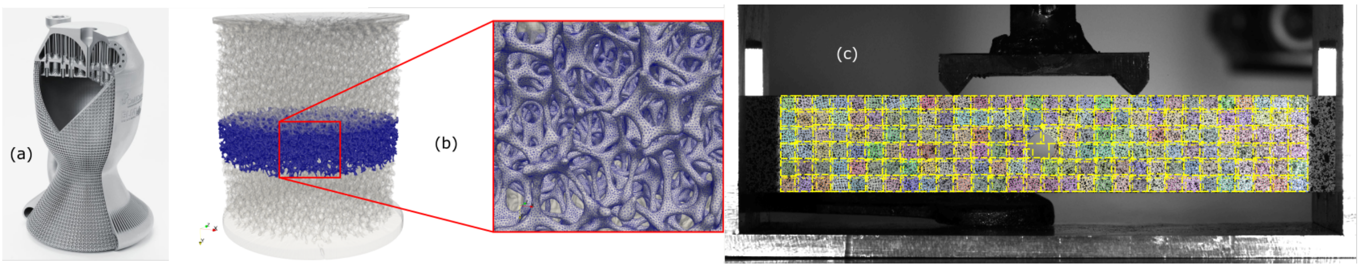


Fig. 1. (a) 3D printed (SLM process) thrust chamber of a rocket engine (cellcore3d.com), (b) image based FE mesh used for FE-DVC [3], (c) domain decomposition approach in FE-DIC.

The incredible design freedom that is now offered by metal AM comes at the cost of process complexity, which unfortunately generates strut-level defects with respect to the initial Computer-Aided Design (CAD) geometry elaborated by engineers. Hence, important mechanical behavior variability occurs between the idealized, defect-free, CAD model (*i.e* representing the "as-designed" geometry) and the model incorporating the real, imperfect (*i.e.* "as-manufactured") geometry [2].

The characterization of the mechanical impact of the strut-level defects requires to perform *in-situ* experiments on real lattice samples. Indeed, X-ray Computed Tomography (CT) provides a three-dimensional insight into specific specimens, which now enables the analysis of inner structures right down to a micro-meter level at different loading stages.

To analyse these series of volume images quantitatively and extract mechanically relevant fields from them, we develop 3D image registration techniques (often called Digital Volume Correlation (DVC) [3,4] in the field). Since, en the end, these measurements open the door for calibrating numerical models, the displacement solution is sought in an analysis-suitable numerical framework using Finite Element or Isogeometric Analysis [4,5].

## Challenge

These volume images contain a huge amount of data (as an example, current tomographic images can reach $2000^3$ voxels). The development of registration methods adapted to these large amounts of data seems crucial. Meshes, which are used to accurately describe the displacement of materials with such complex architectures, also have a complexity that can become limiting, see Fig. 1(b) and [6]. The few existing methods for registration of large volume images by analysis-suitable meshes are insufficiently efficient (not scalable) which strongly limits the dialogue between images and models in this context of architected materials.

The objective of the present master internship is to develop and implement a computational algorithm based on domain decomposition methods [7] in order to be able to solve the problem of global digital images correlation in parallel. The strategy will thus allow to cumulate the advantages of Global-DIC (continuity of the solution, coherence of the approach with physics, direct link with the simulation) with those of the subset methods (parallelization) in the spirit of [8], see Fig. 1(c).

Domain decomposition methods naturally lend themselves to parallel computing on distributed architectures [6]. Eventually, the algorithms developed during the internship may be deployed on massively parallel machines of the regional HPC facility CALMIP.

## Supervising team

This intership is based on **interdisciplinary research** that bridges applied mathematics, computational solid mechanics and high performance computing. Therefore, the supervising team is composed of different researchers from the laboratories of solid mechanics (ICA, Toulouse) (J.C. Passieux and P. Oumaziz) ; mathematics (IMT, Toulouse) (R. Bouclier) and computer sciences (LIP6, Paris) (P. Jolivet). The PhD student will be hired at INSA Toulouse.

## Job

The student will (i) develop numerical methods halfway between mechanics and digital image analysis; and (ii) implement them in parallel by writing computer codes mostly in Python.

## Profile sought

Master's degree with significant research experience. Specialization: computational mechanics and/or applied mathematics. Skills in finite elements, numerical analysis, optimization, programming languages (Python...).

**Application:** CV, covering letter, to be sent to passieux@insa-toulouse.fr and pierre.jolivet@lip6.fr.

### References

[1] Blakey-Milner, B., Gradl, P., Snedden, G., Brooks, M., Pitot, J., Lopez, E., Leary M., Berto F., & du Plessis, A. (2021). Metal additive manufacturing in aerospace: A review. *Materials & Design*, 209, 110008.

[2] Korshunova, N., Alaimo, G., Hosseini, S. B., ..., & Kollmannsberger, S. (2021). Bending behavior of octet-truss lattice structures: Modelling options, numerical characterization and experimental validation. *Materials & Design*, 205, 109693.

[3] Bay, B.K. and Smith, T.S. and Fyhrie, D.P. and Saad, M. (1999) Digital volume correlation: three-dimensional strain mapping using X-ray tomography, *EXME*, 39(3)217–226

[4] Leclerc, H., Périé, J.N., Roux, S., & Hild, F. (2011). Voxel-scale digital volume correlation. *EXME*, 51(4), 479-490.

[5] Rouwane, A., Bouclier, R., Passieux, J.C., & Périé, J.N. (2022). Architecture-Driven Digital Image Correlation Technique (ADDICT) for the measurement of sub-cellular kinematic fields in speckle-free cellular materials. *IJSS*, 234, 111223.

[6] A. Rouwane, P. Doumalin, R. Bouclier, J.-C. Passieux and J.-N. Périé (2023). Subcellular scale kinematical studies in a cellular material undergoing crushing: measurement of struts buckling by Architecture-Driven Digital Volume Correlation. *Sudmitted*.

[7] V. Dolean, P. Jolivet, F. Nataf. An Introduction to Domain Decomposition Methods: Algorithms, Theory, and Parallel Implementation. Society for Industrial and Applied Mathematics (2016).

[8] R. Bouclier, J.-C. Passieux. A domain coupling method for finite element digital image correlation with mechanical regularization: Application to multiscale measurements and parallel computing, International Journal for Numerical Methods in Engineering (2016).