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DIGITAL TWINS IN SPACE RESEARCH: THE CASE OF STASIS, EXTREMA'S ATTITUDE SIMULATION PLATFORM

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Introduction

Digital Twins (DT) are emerging development philosophies that have the potential to revolutionize the way engineers and designers approach the design, development, and operation of complex systems. A digital twin is a digital replica of a physical system, process, or product that can be used to simulate, analyze, and optimize the performance of the system in a virtual environment. Digital twins can be used to streamline the design of a physical system, predict its behavior under different conditions, and monitor and control it in real-time.

At Politecnico di Milano, the digital twin approach is being used to enable research on autonomous GNC systems in the context of the EXTREMA project. In particular, the methodology will be presented for the case of **STASIS (SpacecrafT Attitude SImulation System)**, an attitude simulation platform [1]. STASIS will be employed in the **EXTREMA Simulation Hub**, an integrated facility in which algorithms and systems to enable deep-space CubeSats with autonomous guidance, navigation, and control (GNC) capabilities will be tested [2].

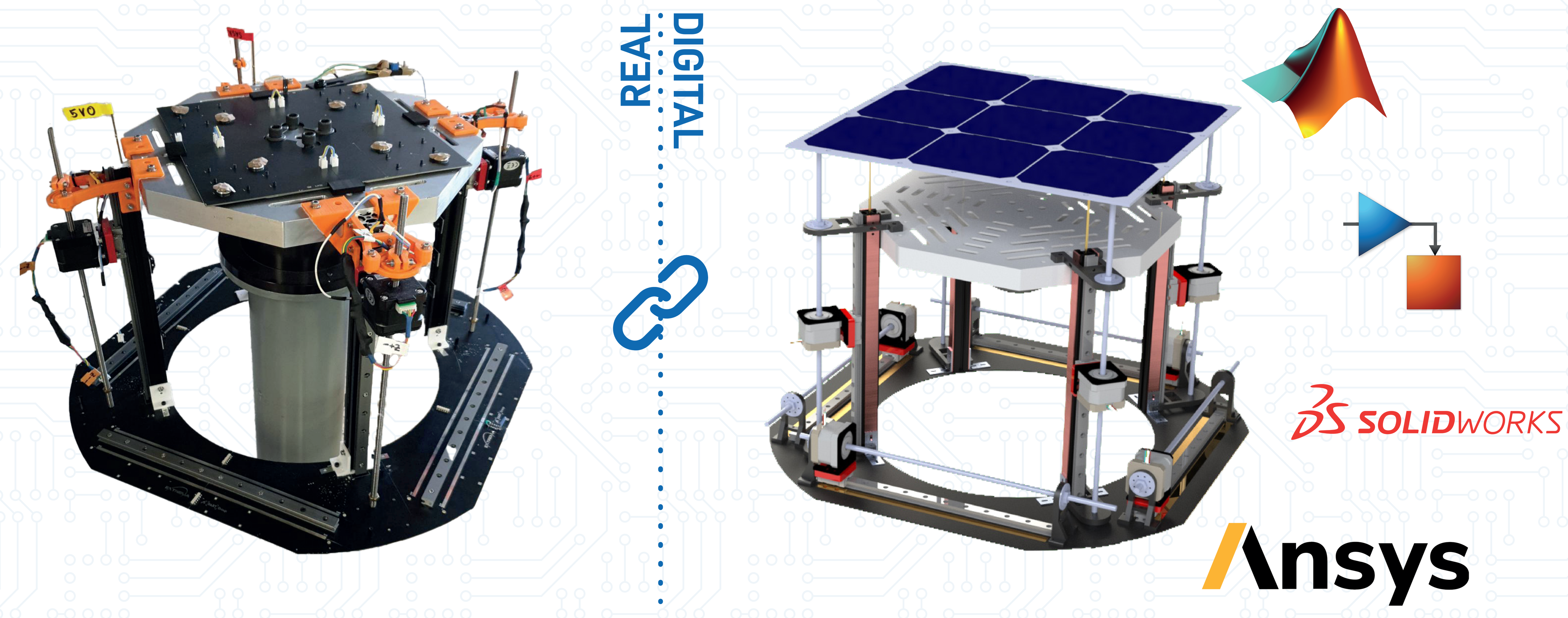

Figure 1: STASIS in development at PoliMi on the left; some of the engineering tools associated to its digital twin on the right

Growing up together: DTs for design and development

The utility of DTs span all phases of the product lifecycle [3]. As a matter of fact, the DT was developed to design and develop the STASIS' **balancing** and **power generation and management** subsystems. In the first case, multiple procedures - differing for the number and type of actuators and the control and estimation laws employed - were tested, converging towards a batch estimation procedure involving the positioning of **8 moving masses** to tune both the center of mass of the platform and its inertia tensor (Figure 2) [1].

In the second case, the requirements indicated the simulations in which STASIS was expected to take part to span multiple days. In order to avoid big, heavy batteries, a **power beaming solution** involving an array of high-power LEDs with narrow-beam optics and an array of photovoltaic cells was designed [1]. The DT was employed to assess the effect of non-uniform illlumination at different platform orientations (Figure 3), and to build a dataset of expected irradiation data to tune the maximum power point tracker algorithms to maximize the conversion efficiency of the system.

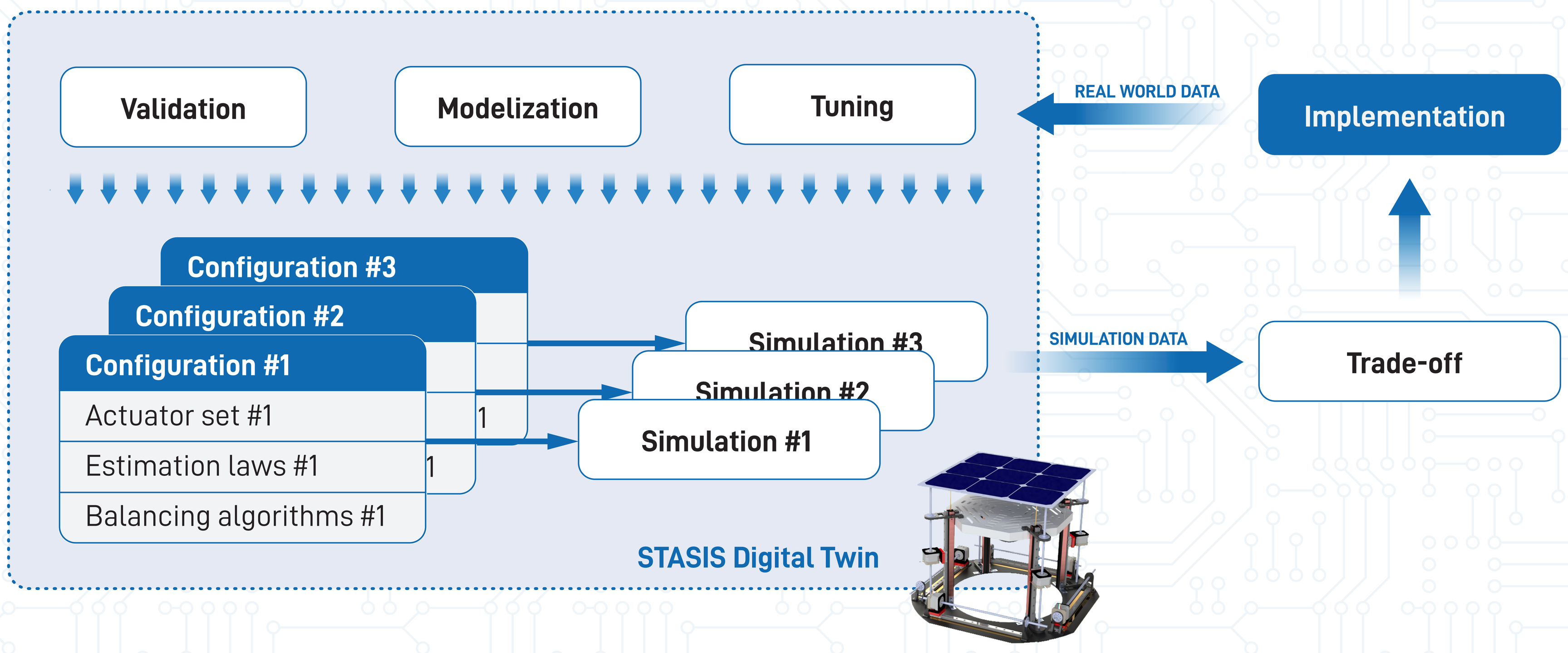

Figure 2: Design and simulation flow within the digital twin approach employed for STASIS

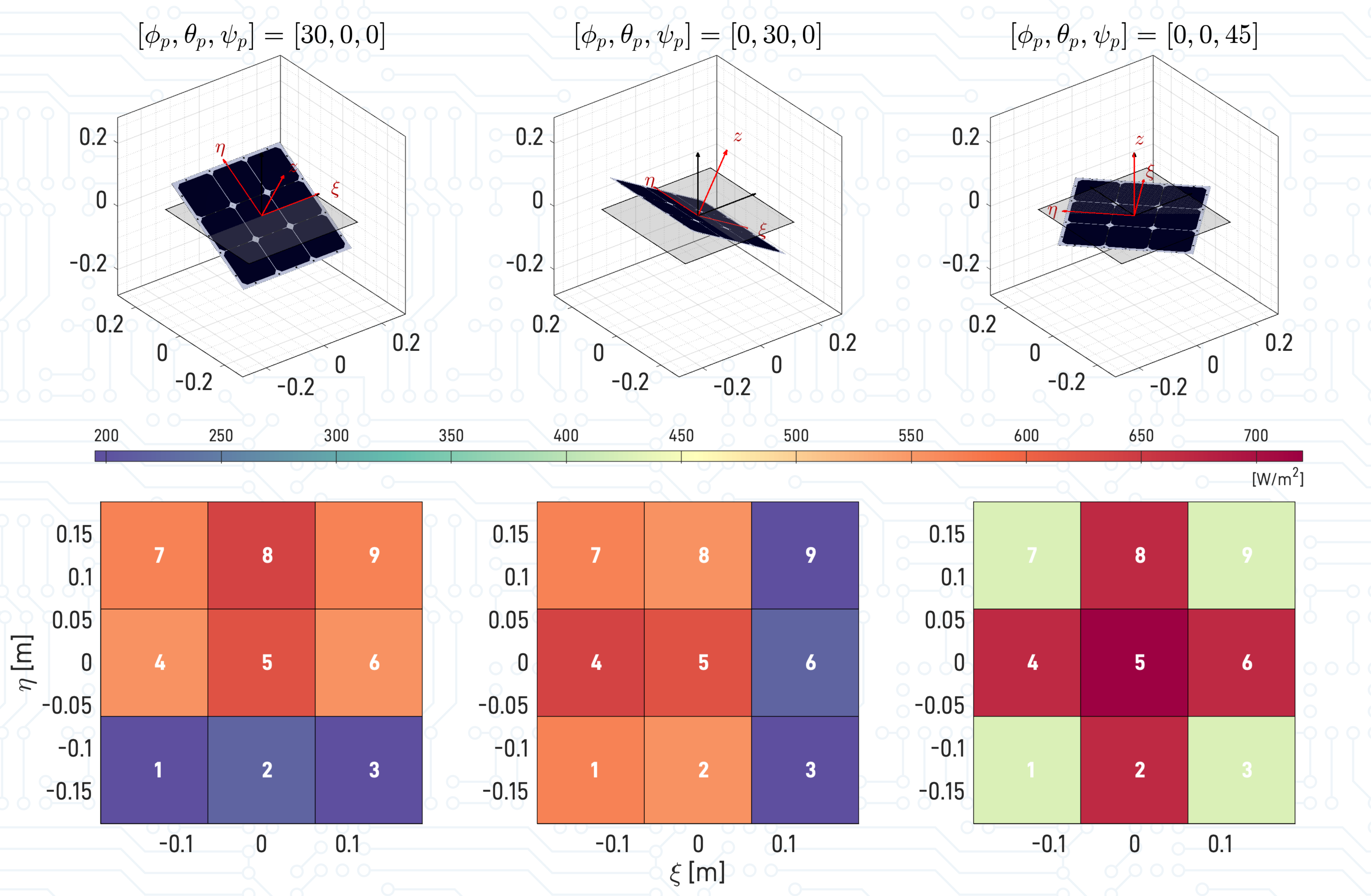

Figure 3: Beam irradiation distribution for different platform orientations, 9-cell configuration

Two is faster than one: DTs for rapid prototyping

The availability of a digital twin is advantageous also in the context of rapid prototyping. In order to perform preliminary simulations of slew and attitude maneuvers, the platform was thought to be equipped with a COTS momentum exchange device, such as a reaction wheel. In particular, **COMAT lent the DART lab an engineering model of its CubeSat RW40 reaction wheel** [4].

Before implementing the actuator on the platform, it was interfaced to the platform DT. The exact code for the ADCS control unit to command the RW40 was tested within a HiL simulation, in which the wheel was actuated on a table-top and its speed was relayed back to the Simscape environment to analyze the effect on the platform orientation.

Then, the control algorithm was deployed on the OBC with minimal modifications and succesfully executed in the context of the **EXTREMA Dry Runs**, broader HiL simulations involving additional components and facilities.

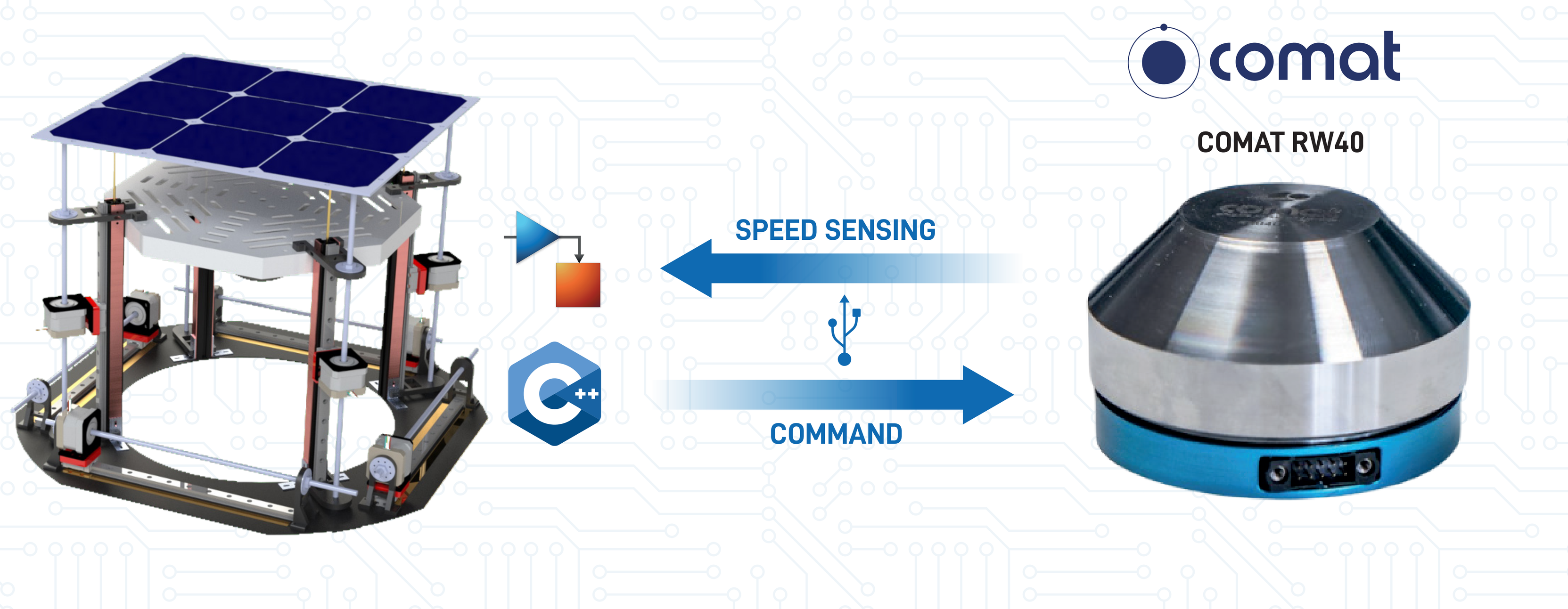

Figure 4: The digital twin of the platform was augmented with ready-to-deploy C++ code to be interfaced with the RW40 reaction wheel from COMAT. The speed data as read from the RW40 were fed back to the multi-physics simulation to investigate the performances of different attitude maneuvers

Leveraging digital assets for performance

We leveraged the digital assets of STASIS' digital twin - in particular, the CAD model of the platform - to carry on a set of **CFD simulations** of the platform. The high-fidelity CAD model was reduced to a simplified one that was easier to mesh and use in ANSYS Fluent.

The analysis showed that the current configuration of the platform has multiple stagnation points whose interaction with the surrounding air resulted in **significant pressure drag torque**. Improvements are currently envisioned to reduce such effects.

Moreover, a dataset of the estimated drag torques at different angular speeds and orientation is currently being built. After proper validation, such dataset will be employed with a fast interpolating algorithm to estimate the drag torque in real-time and compensate it with dedicated micro-actuators.

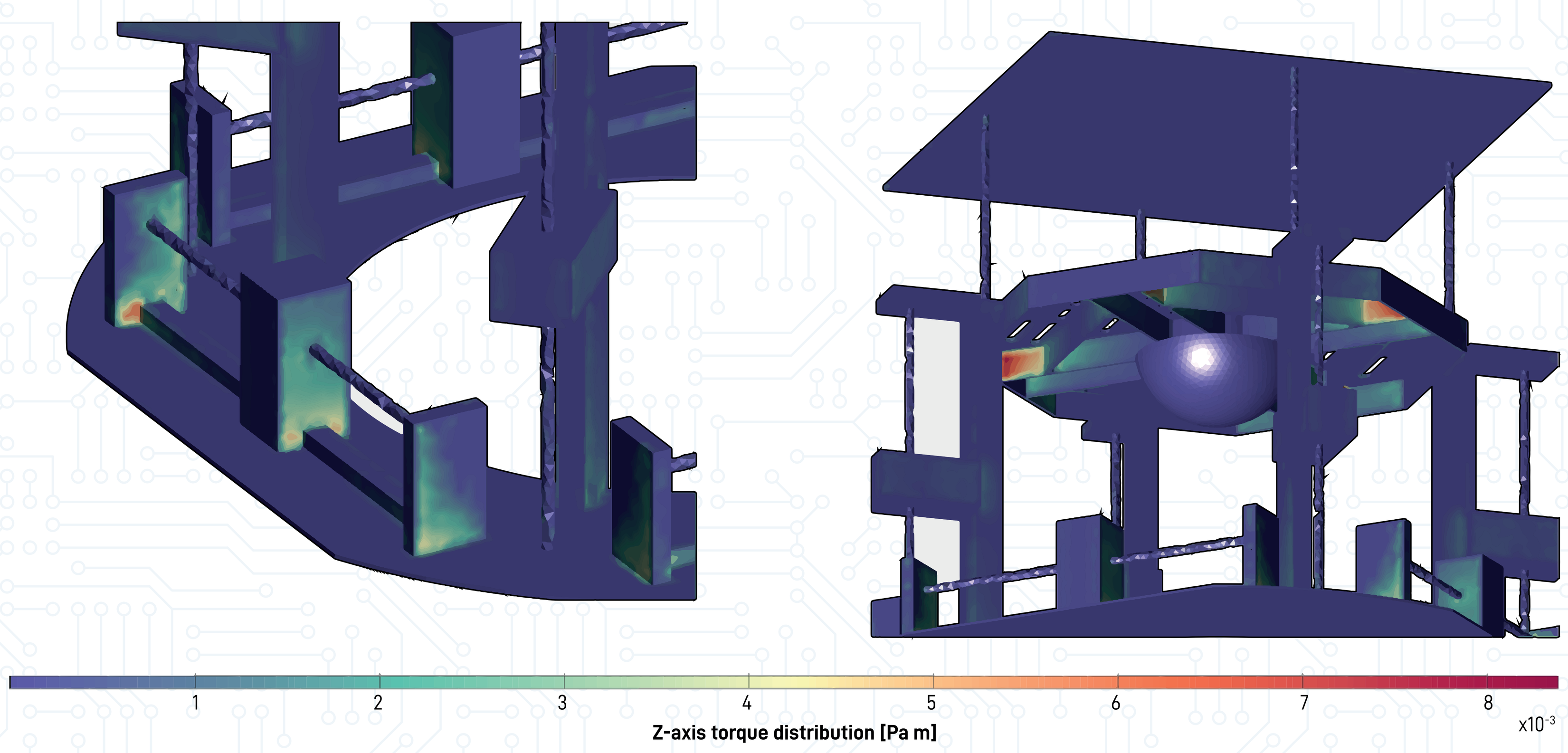

Figure 5: High pressure torque areas on STASIS identified through the CFD simulations

REFERENCES

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