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COMPUTATIONAL MODELLING: A TOOL TO ADD ECONOMIC VALUE TO THE INDUSTRIAL PRODUCTION

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Abstract. The scientific-technological development is essential for the sustained growth of our regions; the production of quality goods with high added value is an important step forward when compared with the production of raw materials. Computational Mechanics is an essential tool for the development of new technologies and for the optimization of the existing ones [1].

The industry faces technological problems increasingly more complex, and the numerical simulation of those technological problems induces scientists to computational developments of greater complexity.

Since technological decisions are reached based on the results provided by numerical models, it is evident that these models have to be highly reliable. Therefore, it is essential that sophisticated modeling techniques are used; that highly qualified engineers develop models and that the results are validated experimentally using industrial or laboratory determinations [2].

The examples used to illustrate this article are taken from real applications developed for industry: the structural verification of the communications satellite ARSAT-1 and the modeling of rock fracturing processes.

1 INTRODUCTION

The scientific-technological development is essential for the sustained growth of our regions; the production of quality goods with high added value is an important step forward when compared with the production of raw materials. Computational Mechanics is an essential tool for the development of new technologies and for the optimization of the existing ones [1].

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The modeling process must follow the following steps:

- Identification of the physical phenomenon to be analyzed.
- Formulation of the mathematical model: determine the system of differential equations that best represents the physical phenomenon, defining the appropriate domain, border conditions, initial conditions, etc. At this stage it is necessary to decide what physical aspects are indispensable to take into account in the model and assumptions about the response of the material, loads, friction, etc.
- Development of the numerical model: in most of the cases it is necessary to solve the system of equations in an approximate way, using numerical methods, as for example the method of finite elements (method in which we will focus on this work) [3].
- Verification: in the verification process it must be proved that the equations are resolved correctly, and therefore this is a mathematical step [2]. In this step it must be proved that the numerical scheme is convergent and stable. It is important to notice that the verification process is not related only with a numerical procedure but also with its effective implementation in software, either commercial or developed in/house.
- Validation: The process of validation must demonstrate that the right equations are solved, and therefore is an engineering step [2]. It is validated neither a formulation nor software, but the use of verified software when used by a design analyst in the simulation of a given process. It is necessary to validate the complete procedure.

2 FROM THE PHYSICAL TO THE MATHEMATICAL MODEL

The analyst must understand the physical phenomenon that must model and have enough information on the subject, to include the most relevant features in the model. The expertise of the analyst and a clear definition of expected results are fundamental to the definition of an appropriate mathematical model.

Due to geometric or material nonlinearities most of the models describing physical phenomena of technological importance are non-linear.

In the analysis of a solid under mechanical and thermal loads, some of the nonlinearities found in the formulation of the mathematical model are [4]:

- Geometric nonlinearities

The equations of equilibrium must be fulfilled in the unknown solid deformed configuration and not in the unloaded known configuration. If these settings are very similar, this nonlinearity can be omitted. An intermediate step would be to consider the balance in the deformed configuration but assuming that deformations are very small. This is also an important simplification in the mathematical model.

- Contact conditions

Contact conditions are unilateral restrictions, contact forces are distributed in an area that is initially unknown to the analyst.

- Material non-linearities

Elasto-plastic material models (metals), phenomenon of creep with high temperatures, non-linear elastic materials (polymers), fragile materials, changes in phase in solid state, etc.

In the case of fluids or heat transfer, some of the involved nonlinearities are:

- Non-constant viscosity or compressibility: rheological materials and turbulent flows.
- Convective terms of acceleration.
- Temperature-dependent thermal properties: for example changes of phase.

3 EXAMPLES OF TECHNOLOGYCAL APPLICATION

The examples used to illustrate this article are taken from real applications developed for the industry.

3.1 Structural models and mechanical tests in the development of a satellite

Computational models were developed to verify the resistance and orbital alignment of satellite Arsat-1, designed and built by INVAP S.E.

The results of computational models were used by the designers of the satellite to predict its dynamic behavior during environmental tests, check its structural integrity and its ability to withstand the thermal cycles in orbit.

Dynamic and thermal vacuum (TVAC) load tests were performed and the results of the simulations were compared with the experimental ones, in order to validate the computational-experimental qualification process of the satellite.

The objective of the dynamic tests was to check the structural integrity of the satellite during launch, while the objective of the thermal test was to demonstrate that the satellite's equipment are able to withstand the extreme operating temperatures, as well as to validate the thermal mathematical models used to predict in-orbit thermal maps. Finite element models where used to verify the structural integrity of the spacecraft during TVAC tests, and during its entire lifetime in orbit.

Figure 1 shows the geometry and the corresponding finite element model of ARSAT-1 protoflight model (PFM).

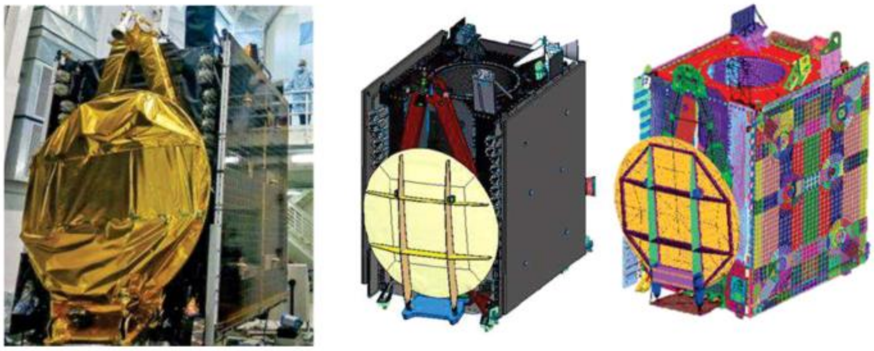

Figure 1. Satellite ARSAT-1 PFM, geometry and finite element model.

Figure 2 presents the dynamic test model and the obtained bending second mode. Comparing with the experimental test it was found an excellent correlation between both results (in the order of 5% for structure fundamental modes).

Figure 2. ARSAT-1 PFM. Test configuration and prediction of the second bending mode

In figure 3 it can be observed the temperature data in each sector of the satellite and the respective thermal model data, used to perform the termo-elastic analyses.

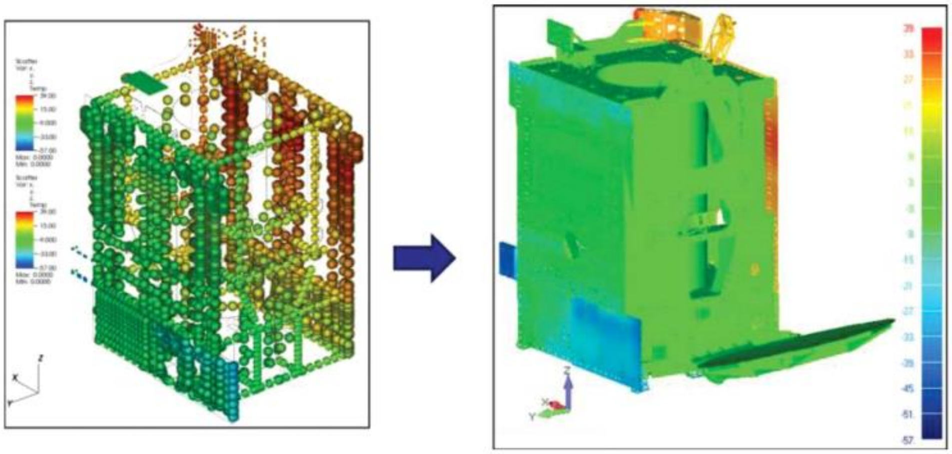

Figure 3. Termo-elastic analysis of ARSAT-1. From temperature data to finite element model

3.2 Simulation of hydraulic fracture

The objective of this work is to develop the ability to model hydraulic fracture processes.

As the first case of validation, the Brazilian test (diametric compression of a cylindrical sample) was simulated, with a central notch [6, 7].

Different failure criteria were implemented, and the results are shown in figure 4, which compares cracking trajectories obtained experimentally with the numeric ones. The Maximum Tension criterion gave the best results, as it is shown in the figure. The ratio between the numerical failure load and the experimental one is 0.97; therefore this stage was validated.

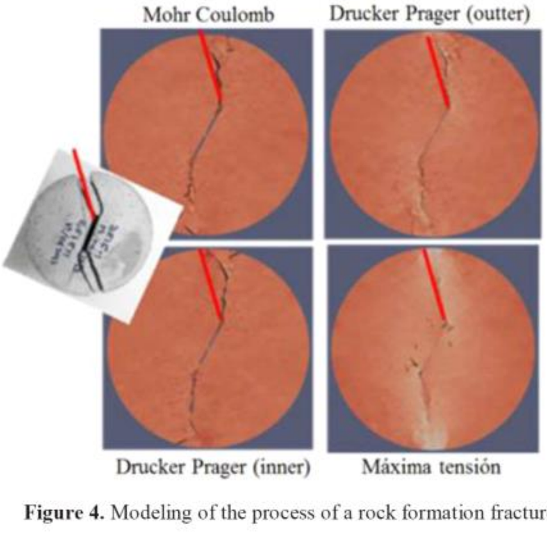

Figure 4. Modeling of the process of a rock formation fracture

The next stage was to model a rocky massif, loaded with the weight of the rock which is above (figure 5), and to model the hydraulic fracture; figure 6 shows the progress of the fracture.

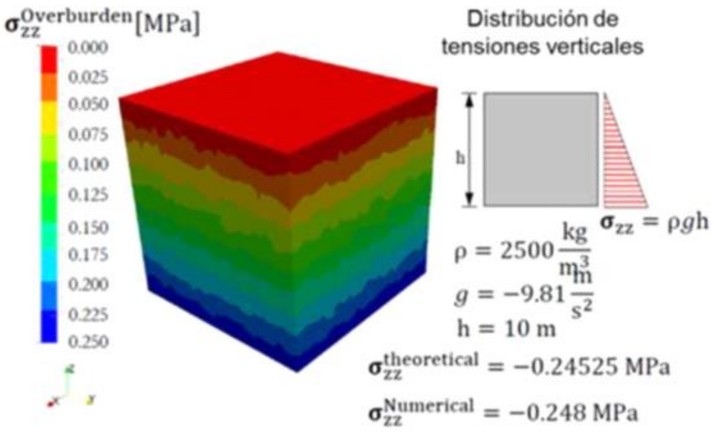

Figure 5. Vertical stresses

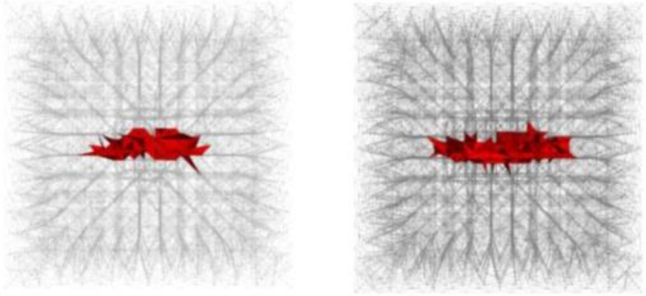

Figure 6. Pattern of fracture hydraulic pressure (horizontal and vertical plane)

12 CONCLUSIONS

The presented results show that the numerical simulation is a powerful tool in the industry to "add innovative value" to products and processes. The reliability of the models is of utmost importance, so it requires a strongly trained professional to understand the phenomenon, design the model, and judge, with the results, the validity of the assumptions and used models. The experimental validation of the model is indispensable to have a really reliable tool to make technology decisions.

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