Building simulation models credibility: what gain can we expect from test-simulation data fusion in solid mechanics?

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Abstract

Ensuring the credibility of simulation models is imperative for justifying cost reductions in testing and expediting the development of innovative structures. However, enhancing model credibility with limited test data necessitates the establishment of robust model validation metrics and toolboxes. This presentation will discuss the challenges associated with implementing data fusion techniques, especially when dealing with measurement techniques of diverse nature, exploring how they can significantly bolster model reliability.

Moreover, we will delve into the integration of Digital Image Correlation (DIC) technology, a pivotal tool aiding in the acquisition of additional test data for enhancing model credibility. DIC is a kinematic (displacement and strain) field measurement technique that relies on the analysis of images of the test specimen. It facilitates the extraction of detailed strain and deformation information by analysing these images, providing valuable insights that contribute to more comprehensive model validation. Nevertheless, it also makes matters more complicated as no modern platform automates the comparison operations for all these measurement devices, even less so when including DIC, which makes a lot of manual operations necessary to perform an exhaustive comparison. Some dedicated platforms exist that allow validation of models for specific tests types (such as experimental modal analysis [1] with accelerometers and displacement sensors or fatigue life estimation [2]), but do not always extend to more generic usage or other experimental data types, and especially fiber optics or DIC [3].

The discussion will highlight how data fusion and DIC technology can interconnect, addressing the hurdles and showcasing the rewards they bring to the table. By exemplifying these concepts, we will present a case study involving a test-simulation dialogue of a large-scale structure, the Dual Launch Structure, built by ArianeGroup for the Ariane 6 launcher. The application of data fusion and DIC technology in this real-world scenario will underscore their effectiveness in optimizing model validation processes and toolboxes,

ultimately enabling the development of reliable simulation models for complex structures. The goal of building model credibility being ensuring a test is no longer necessary, this presentation will address ArianeGroup's approach to do so, thus limiting the necessary number of costly scale-1 tests.

1. Introduction and objectives

Simulation models play a pivotal role in justifying cost reductions and expediting the development of innovative structures. However, ensuring the credibility of these models, especially with limited test data, poses significant challenges. Testing itself is still mandatory for innovative structures and materials; but to limit the number of tests needed in a test campaign, robust model validation metrics and toolboxes are also essential for addressing these challenges effectively.

This presentation focuses on the implementation of data fusion techniques to enhance the reliability of building simulation models. Additionally, it explores the integration of Digital Image Correlation (DIC) technology for acquiring supplementary test data, to further increase confidence in simulation modelling. The objective is to highlight the application of these techniques through a real-world case study involving a large-scale "Dual Launch Structure" (see Fig 1) constructed by ArianeGroup for the Ariane 6 launcher. Through this exploration, we aim to showcase how data fusion and DIC technology can optimize model validation processes, ultimately facilitating the development of reliable simulation models for complex structures.

Figure 1: Ariane 6's Dual Launch Structure (left) and location within the launcher (right)

2. Challenges in Application of Data Fusion Techniques to the Dual Launch Structure

The Dual Launch Structure is a critical component in the Ariane 6 launcher project, and a key structure of one of the launcher's configurations. With a height of about 9 meters, its primary purpose is to facilitate the simultaneous launch of two similar payloads. A test was conducted at ArianeGroup facilities to validate its behaviour at maximum loading and identify possible discrepancies between the FEA and real-life test results.

Data fusion techniques encompass methodologies for integrating disparate data sources to enhance the reliability and accuracy of simulation models. In the context of the Dual Launch Structure, data fusion involves amalgamating data from various sources, such as DIC measurements, but also about 200 strain gauges, fiber optics, force and displacement sensors, as well as optical markers tracking. The underlying principle is to leverage the complementary nature of these datasets to gain a more comprehensive understanding of the structure's behaviour. In practice, managing such test data is complex, particularly when attempting to extract the exact counterpart in a CAE environment. One simple example is virtual strain gauges, which do not have a single natural definition on the CAE side. More complex examples involve fiber optics or DIC, which are far from being standards of virtual sensors.

The scale and complexity of the structure required robust methods for processing, analysing, and interpreting a large volume of test data with respect to their FEA counterpart. In particular, a procedure should be defined for each kind of sensor to take into account positioning (and respective errors), measurement uncertainties, and interpolation on the FEA dataset. For instance, a standard procedure should be defined to calculate virtual strain gauges (ie the FEA version of the physical strain gauge) and how to take into account the various error sources the comparison procedure implies.

Finally, resource constraints, such as limited time, budget, and computational power, impose challenges in efficiently utilizing available resources for model validation: traditional spreadsheet-based FEA validation can be extremely long to set up in the case of large test datasets, and most of the test data is often discarded for lack of time. Indeed, it has been shown than on previous comparable test campaigns, data management already amounted to about 40% of the simulation engineering time that had been dedicated to the project. This is linked to the fact that this is a very instrumentation-heavy test (see Fig. 2), and that proper care is needed to organize the data in a safe manner. This kind of process very often leads to unused data, but is also prone to human errors, since a lot of "manual" data management operations are involved.

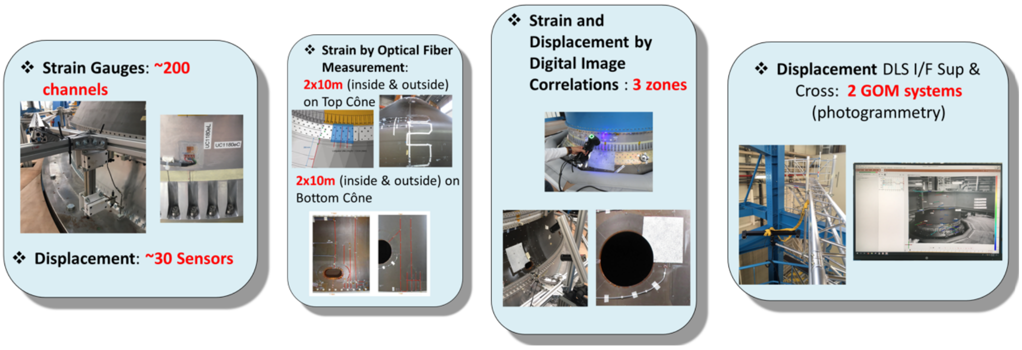

Figure 2: Instrumentation list for the Dual Launch Structure test.

3. Processing

Addressing these challenges required the development of tailored solutions and adaptations. Within the MUTATION collaborative project, a "Smart testing framework" was developed to seamlessly incorporate diverse data sources into simulation models, enabling comprehensive validation against real-world observations (see Fig 3). In this framework, the FEA mesh has been defined as a center geometric reference, around which all measurement devices can be positioned and put in reference to the simulation result.

During this project, an existing toolbox was extended to make processing this test possible. Robust preprocessing techniques were employed to standardize both FEA and test data formats, resolve inconsistencies, and eliminate outliers, ensuring compatibility and coherence among disparate datasets. The Altair H3D file format was chosen to contain all simulation information, regardless of the solver used, for its capability to hold various model information, and being easily imported within the EikoTwin platform. This is a needed preprocessing on the FEA side to be able to use a model within the toolbox.

The main challenge in assembling the test result datasets onto the simulation model resided in the fact that these test datasets were not originally aligned with a 3D model or synchronized with original simulation predictions.Alignment tools have been developed to allow adaptation of the sensor types that were needed in the project:

- Strain gauges (3D position+orientation)
- Displacement sensors (3D position)
- Optical fibers (end points and computation of the surface path between these points)

- DIC results (key fiducials are used to align images and FE mesh).

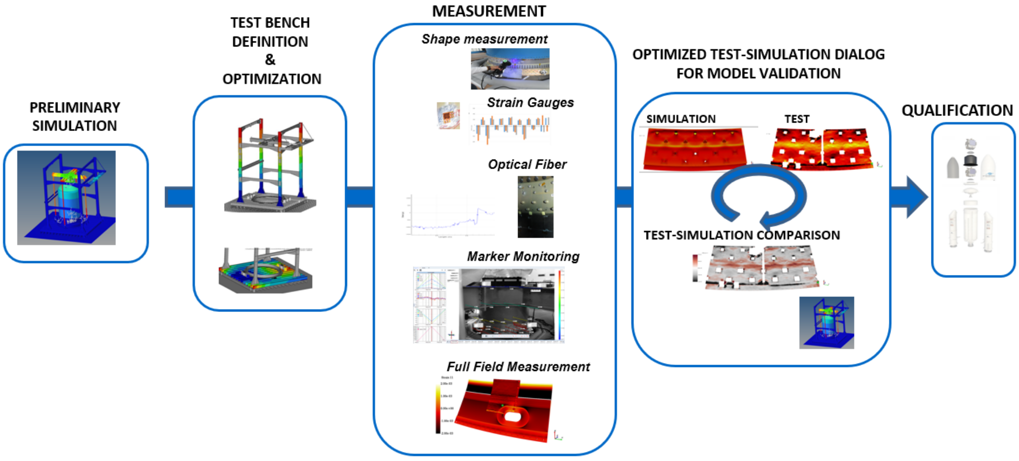

Figure 3: Smart testing framework for the Dual Launch System

When alignment is performed, though, the issue remains of correctly interpolating data from the FE simulation model. For each sensor type, an adapted and documented procedure has been set into place to automatically calculate the equivalent data for virtual sensors:

- For strain gauges, integration of the surface displacement data within a virtual strain gauge;
- For displacement sensors, dispalcements are interpolated at a given locationof the surface mesh;
- For fiber optics, a segment of the fiber is discretized with 100 smaller segments that each calculate their mean strain value by using displacement maps at the surface of the mesh;
- For DIC, a global DIC method is used to directly measure displacement fields by using the surface elements of the FE mesh, ensure a one-to-one comparison of displacement and strain fields.

Furthermore, efforts have been made to automate the physical data import, based on the native exports of test rigs, to cut some of the processing time for CAE engineers, and reduce possible human errors. This also goes for prediction of virtual sensors, that can be automatically exported before testing has started to set min/max limits for the test bench control.

Virtual sensors can then be compared to their physical counterparts automatically within the platform. Specific procedures were implemented to detect outliers and facilitate processing of large number of sensors. More specific procedures were also implemented per sensor following ArianeGroup's specifications, such as the capacity to estimate the uncertainty that comes from the mis-positioning of a strain gauge.

4. Results and Conclusion

Having a data fusion framework facilitated the integration of disparate datasets, offering a comprehensive understanding of the structure's behaviour. DIC technology, as well as optical fibers and more traditional sensors, provided detailed insights into structural deformation, validating simulation predictions and identifying areas for optimization. High-resolution techniques in particular, such as DIC and fiber optics, proved more effective when dealing with stress/strain concentrations, while traditional techniques covered homogeneous deformation zones. Markers tracking were also an important technique that helped monitor the structure's top part's rigid body movement. This allowed to make sure everything was going according to the plan during the test, but also to later compare the simulation's boundary conditions to the actual loading of the DLS. The complementarity between these techniques in the same platform was a strong motivator for this work and is key to develop a robust argument twords certification agencies that the model can be used to develop further versions of the structure.

This new process has been implemented and tested along with the traditional post-processing procedures. It has been confirmed that all sensors could be processed in this new platform in an automated way, thus shortening considerably the data management time for this particular test (about 75% of data management time could be saved, which is tens to hundreds of hours depending on the cases).

Besides efficiency, it's also important to state that the effort to make the model more credible was also attained by the project team. Although not entirely dependent on this new process, the notion of credibility can be worked on by implementing data fusion techniques, since the insurance of a using robust platform makes it easier to help CAE and test engineers exchange information. Such efforts participate in increasing the model maturity assessment score and presenting a robust case for management or certification authorities.

In conclusion, through collaborative efforts and a "Smart testing" framework, challenges in validating complex structures were effectively addressed, resulting in an overall validation of the FEA model for future test-less developments. Key lessons include the importance of robust data preprocessing and convenient tools to aggregate datasets coming from different sources to a 3D model. These insights will guide future endeavours in building models for the DLS, but also ensuring the development of reliable validation methodologies for complex structures in general.

References

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