Our critical aeronautical and wind energy structures are ageing and deteriorating. As such, their maintenance and reliability has become an economic burden to our society. Acquisition of new ones is in many cases economically unfeasible. Corrosion, fatigue, overloads and usage, are just some of the reasons for their rapid deterioration. The structural community has spent millions of euros on regular inspections, training and instrumentation with the aim of maintaining safety and in many cases extending their useful life. In the field of Structural Health Monitoring (SHM), many of the parameters being monitored are local to some critical points on our assets. Structural engineers are then mandated to assess the life of the structure based on a series of single point measurements or in many cases only based on visual inspection. In the aeronautical industry, large-scale instrumentation programs are prohibitive, primarily due to the weight gain and cost associated with carrying all these sensors. As such, *Monitoring Aerospace Structural Shapes* (MASS) has developed numerical models with the aim to reduce this economic burden while maintaining safety standards for our aeronautical and wind energy assets.

Computer aided engineering and numerical tools have been present as part of our design process now for several decades. These tools are an essential part of our engineering curriculums in training our next generation of mechanical and aeronautical engineers in assessing the structural deformation of their designs. As part of the students' formation, instructors highlight the ability and inability of these structures to carry the required design loads. However, in many cases the environmental effects, the usage, and unforeseen loading conditions that are present are not always transferred to our computational models. Thus, our structural damage models don't account for the wear and tear of our structures. This lack of understanding on the degradation behavior of our materials necessitates the need for higher safety factors, a greater number of inspections and whenever possible, a greater number of sensors, thus increasing the overall maintenance budgets of those authorities mandated to maintain these critical structures.

Ageing of our structures requires a holistic approach that accounts for the synergistic effects that lead to the deterioration of our critical assets. However, this is an ongoing unresolved complex scientific challenge, that will require many generations of scientists working together to find a physics based approach to the understanding of failure of traditional and new materials. When damage is found in our structures, there are three main inputs that are needed by structural engineers to assess the remaining component life: (i) size of the damage; (ii) its location; (iii) and the loads acting on the damage site. The current instrumentation/sensors in some cases are not positioned at the damage sites. As such, MASS combines two important fields of research: (1) Load Monitoring; and (2) Computer Aided Engineering. Even though many of our critical structures are sparsely instrumented, the information provided by single point sensors in combination with computer aided engineering, and more specifically Finite Element Analysis, provides an incredible opportunity to obtain the load (strains) and global behavior of the structures. Many of our civil and aeronautical structures are rigid in nature as such, their deformation follows well known shapes. MASS makes use of this historical knowledge to predict strains/stresses in those locations that lack instrumentations.

Within MASS, the use of a fiber optic strain system has allowed structural engineers to surface mount or embed a single fiber optic line on complex structures. More importantly, these single fibers can capture thousands of deflection points along their path. In addition, non-contact optical techniques allow for accurate measurements of full field deformation of these structures in quasi-real time. As such, the question that lies ahead of us is:

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How can we merge the existing computational models that allow for the accurate prediction of the deformation of our complex structures with the sensing systems that can measure these deformations at specific locations, to obtain accurate global load distribution predictions in complex structures under realistic operational conditions?

The answer to this challenge is MASS. This Marie Curie Integration Grant has allowed the PI and his team to acquire the necessary instrumentation to monitor simple and complex structures under controlled loading conditions, in addition to developing the finite element and inverse Finite Element Methods (iFEM) required to perform the analysis. The results of these tests show how sensors can measure in quasi-real time and communicate directly with computational models to predict deflection (strains) even in locations were the structure has not been instrumented. The lack of sensing data on the structure is compensated by the predictive capabilities of the finite element methods. As such, it is envisioned that one day our instrumented critical structures will pass information seamlessly as inputs into our predictive structural algorithms, thus eliminating the need for structural analysts.

To prove this integration concept, the MASS team at Delft University of Technology performed a detailed analysis of sensing systems used to date for wind turbine applications. The team developed an in-house Finite Element (FE) code and an inverse FE code that could take as inputs data measured from a Rayleigh Backscattering distributed sensing fiber optic system, strain gauges, full field digital image correlation and photogrammetry. The iFEM code then made use of the measured data to determine the deformation and thus the strain/loads suffered by the structure. The results of this effort showed that while photogrammetry (displacement) data combined with the iFEM algorithm produced very accurate and representative strain fields, the use of solely sparse strain field data does not suffice for obtaining an accurate strain field prediction. The developed iFEM code accounts for both geometric and geometric nonlinear conditions. Furthermore, the original iFEM code developed by Dr. Alexander Tessler at NASA was primarily based on shell and triangular shell elements. The MASS team has augmented these capabilities by adding solid elements which are commonly required for thicker structural assets, such as those found in the wind energy industry.

The algorithms are still being evaluated and tested under different conditions. However, it is envisioned that once the developed algorithm has been fully created, it will be released as an open source code to allow for greater scientific and social economic impact of this method. The current algorithm is being shared on a per individual basis with the aim of creating a community around this technology. Collaboration with full scale testing is being sought out both in Europe and North America, to test this methodology and other sensing systems in determining full field strain and stress distributions of critical assets. Public and private organizations will be able to make use of the code to perform global load monitoring of their assets, thus saving money on our taxation system which has been heavily burdened by our ageing infrastructure.

Finally, the work performed as part of this project has been disseminated through a series of journal papers and peer review conference proceedings. The PI would like to acknowledge the financial support received for development of the MASS project. This funds received allowed for acquisition of hardware, assist in the funding of 1 full faculty member, 1 Post Doc, 2 Ph.D and 2 M.Sc. students at Delft University of Technology. For further information on this project, please do not hesitate to contact Dr. Marcias Martinez at, m.j.martinez@tudelft.nl

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