Improving design and maintenance by modelling a fail-safe electromechanical actuator

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New generation products as well as the resources at our disposal are constantly evolving, reaching ever higher levels of complexity. Consequently, the methodologies and techniques conventionally used to develop new systems must also evolve to accommodate the demands of innovative products or processes. This technological effort by industry has recently resulted in the introduction of the Digital Twin (DT), which represents the current trend in industrial innovation processes.

A DT is a virtual model developed and implemented to replicate a physical product or process accurately and reliably. It is connected to the physical model for the sharing of data and information in real time [1]. A DT connects and uses three completely distinct parts: a physical asset, a digital model, and a platform for communication and data transfer [2]. It allows the functional integration of operational data from the field, CAD drawings, numerical simulation models, and meta-models thereby allowing the functionality and performance of the real system to be virtually replicated, and new design solutions to be explored.

A digital model can also be a virtual representation of a complex multi-physical system. As a multi-domain, multi-physical system model, it enables the prediction of system response, the monitoring of the phenomena affecting the system, and the evaluation of operational parameters such as performance and remaining useful life. It also supports the optimization of the design process and of asset management.

By allowing new maintenance formats such as predictive and condition-based maintenance to be explored, it can also be used for maintenance planning.

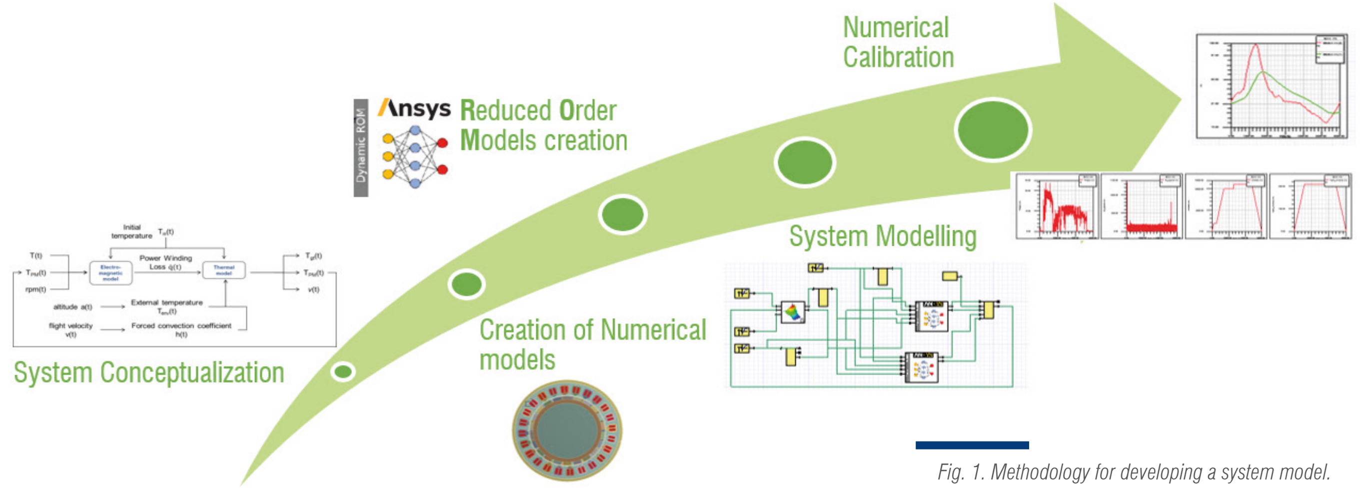


Fig. 1. Methodology for developing a system model.

The implementation and use of a DT for industrial applications yields both high- and low-level (i.e. managerial and technical) benefits. At the managerial level, it can help: to increase turnover and margins, to manage design and process costs and final product costs in general, and to retain competitive advantage. At the technical level, on the other hand, a digital model can reduce the computational resources required, enable rapid and simplified visualization of 2D and 3D results, and support advanced analysis and decision-making.

Digital model of a mechatronic product

The objective of the LUBFORLIFE research project was to integrate components and technologies that never require lubrication during their operational life into recirculating ball electromechanical actuators to control aircraft and UAVs. Eliminating the need for lubrication, which is usually essential for safety and to reduce maintenance costs, required a redesign of the system and sub-systems to ensure functionality and efficiency over the entire lifetime of the parts.

Within this context, EnginSoft developed a system model using a Simulation Based Digital Twin methodology. The system model was then used to create a Digital Twin of the system itself, and to develop predictive lifetime models using reduced order models (ROM). The Simulation Based Digital Twin was developed and implemented using company know-how and data shared by the various project partners. The aim was to develop a virtual system to replicate the behaviour of an electromechanical actuator designed to last infinitely in order to improve safety, monitor utilization, enable rapid decision-making, and track the system loads to be withstood.

There are five steps to the methodology used (Fig. 1):

1. Conceptualize the system
2. Create numerical models of the individual domains
3. Use reduced order models
4. Integrate with the multi-physical system model
5. Calibrate and validate

The first step involves conceptualizing the entire system. More specifically, a system engineer has to define the physical field of each phenomenon to create a logical process that replicates reality. As part of a more complex project, this first step conceptualized the system from an electromagnetic and thermal point of view to evaluate and characterize the increase in system temperature due to the loss of winding power typical of brushless motors [3].

The loss of power of the electromagnetic motor, which drives the ball screw actuator, was assessed using the input values (extracted via sensors incorporated in the physical system) of torque and rotational speed. Temperature changes were evaluated based on the loss of winding power and on boundary conditions (such as outdoor temperature, convection coefficient, etc.). The next step involved the definition and implementation of detailed numerical models to accurately and reliably solve the physical phenomena involved.
These detailed numerical models were then converted to ROM (Reduced Order Models) to reduce computational effort. Next, analytical, reduced order numerical models were integrated to obtain a multi-physics system model that replicates the behaviour and response of the physical asset. In the end, the system model was calibrated based on comparison with the results of full numerical models.

The numerical models were implemented from various tools available in Ansys Workbench.

The response surfaces and reduced order models were exported in FMU format to allow them to be used in Ansys Twin Builder, while the ROMs and analytical models were incorporated into a system model for use in real-time response prediction.

The input variables to the system model (shown in Fig. 2) were:

- axial force (which was converted into the torque required by the actuator and supplied by the brushless motor);
- stator stroke (which was converted to shaft rotational speed, which corresponds to rotor speed, which was converted to stator travel speed);

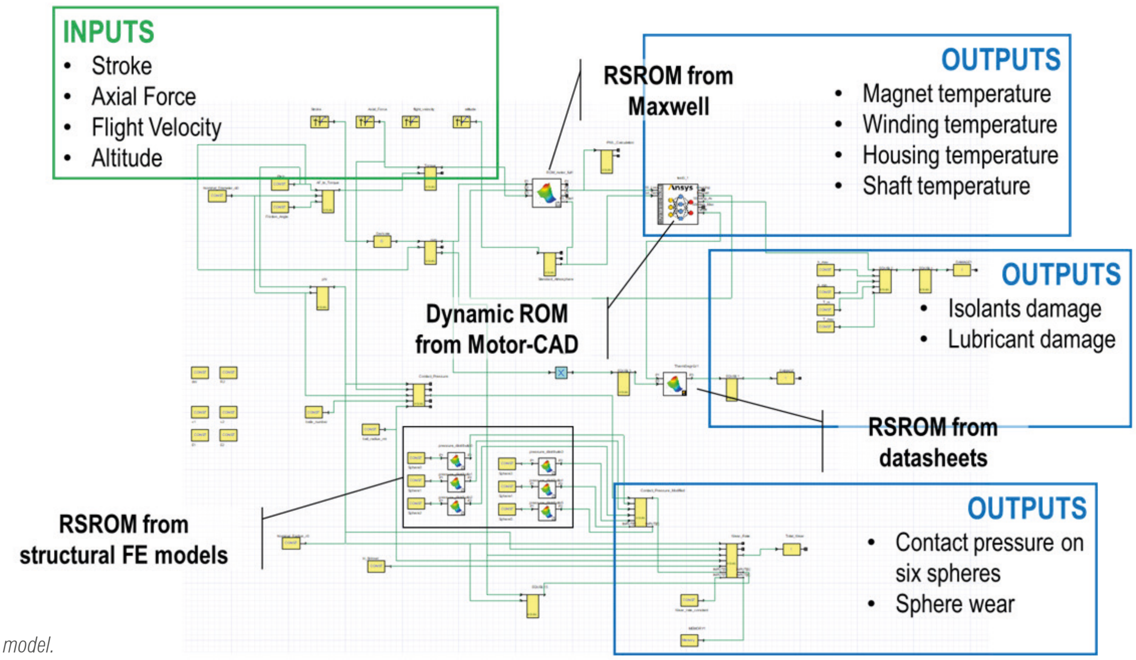


Fig. 2. System model.

- altitude (from which the outside temperature is calculated); and
- flight speed.

The outputs monitored are: the typical temperatures of the system (permanent magnets, windings, shaft, and housing); the contact pressure on the rolling elements; and some damage indices by which to assess the health of the system.

In the system model, input variables are defined as a function of time in order to replicate the data acquired by the sensors. The outputs are computed in the same way. In this project, different models share various input parameters related to a specific phenomenon or physics.

Therefore, multiple models, analytical or numerical, or ROMs can share the same information and data, enabling co-simulation. The system model developed can be used to minimize operating temperatures, and monitor lubricant viscosity and wear conditions, especially on the contact surfaces between balls and screws. The system model allows real-time evaluation of results. Specifically, the model allows missions of 1 hour and 40 minutes to be simulated in mere seconds for evaluation.

As mentioned earlier, a DT consists of a simulation and an IoT platform. The latter enables the exchange of information and data between the physical asset and its digital twin. This makes it possible, starting from the data acquired from the sensors embedded in the physical asset, to assess the health of the monitored system by detecting any anomalies or damage arising from the actual flight record of the mechatronic product. EnginSoft possesses the know-how and technologies to develop multi-physics numerical simulation and system models in this regard.

Benefits

The development and implementation of DTs of industrial technology requires companies to make a substantial investment in human hours and financial resources. However, on the other hand, the DT provides a projection into the future that generates technological and commercial benefits. Adopting the DT concept involves the use of a number of other digital technologies and innovations, which, in turn, can be key factors to stimulate innovation and new business in the enterprise.

Maintenance

The digital model can be used for the forecasting and prediction of the future state of real assets and the evaluation of possible critical issues during normal operation. The ability to detect and identify such issues in advance enables new frontiers in maintenance techniques to be explored,

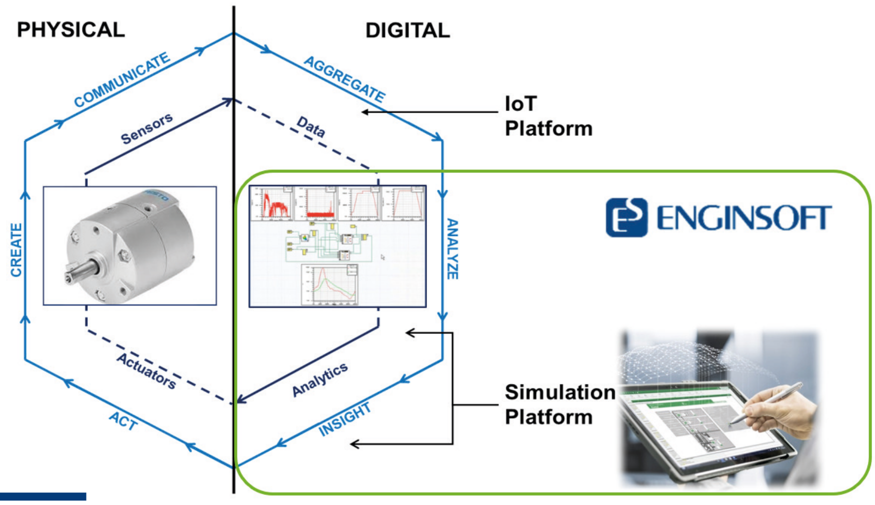
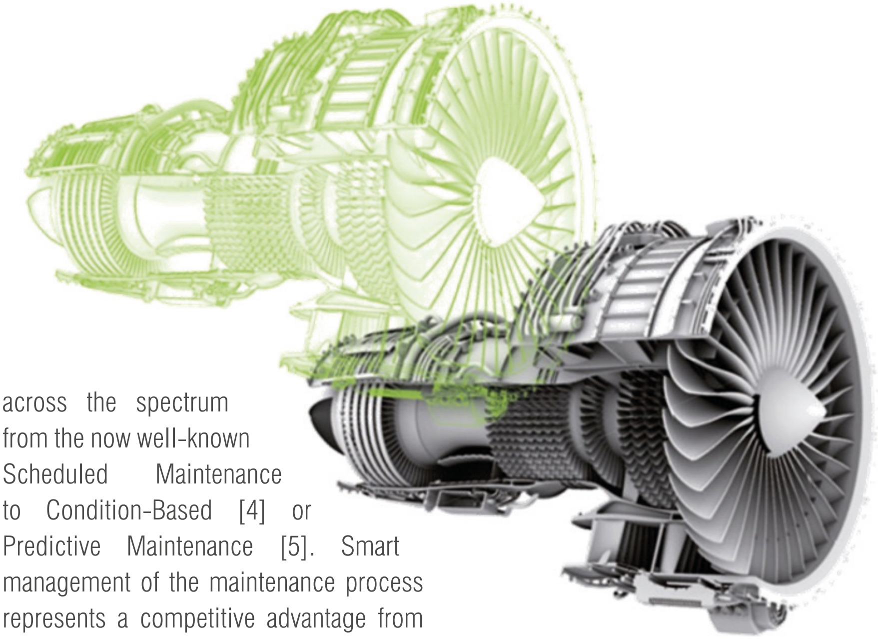


Fig. 3. EnginSoft's role.



across the spectrum from the now well-known Scheduled Maintenance to Condition-Based [4] or Predictive Maintenance [5]. Smart management of the maintenance process represents a competitive advantage from a cost perspective and in terms of the time and technical resources required. In the LUBFORLIFE research project, the ability to assess the condition of individual components in real-time enabled a 10-20% improvement in the management of the maintenance costs of a civil aviation aircraft or UAV.

In fact, continual monitoring of the actuator system's temperature field allows the wear rate and degradation of the insulating materials in the electric motor to be estimated and predictive maintenance programs to be adopted.

Design

Numerical simulation and system modelling are key enablers of continuous improvement that can also be used in the design and pre-design processes. In fact, the (calibrated and validated) digital model can be used during pre-design to optimize the performance of a new product.

The digital model of the actuator was parameterized geometrically (rolling element size, stator diameter, etc.) and topologically (number of turns, thread pitch, thread angle, etc.).

These input parameters can then be adjusted to reduce weight and overall dimensions, minimize power consumption, and generally maximize electromechanical performance. In the context of the research project, pre-design optimization resulted in an estimated performance improvement of about 30%. Pre-design optimization was found to be viable, rapid, modular, and scalable.

Characterization and testing

Professionally designed user interfaces allow interaction with the DT for scenario (what-if) analyses to identify the appropriate corrections in managing the actual system to maximize performance and remaining useful life. Specifically for the LUB4LIFE project, the costs and time required for characterizing lubricants and for testing the assembled product were reduced by 30-50%.

Time to Market

In all markets and industries today, products move from conceptual design to market release in increasingly short periods of time. Hence, development time is a key factor for a new product and for maintaining a competitive advantage over other industry players. DTs can play a key role in product development and rapid prototyping. The development of a parallel virtual model streamlines the development cycle in the business environment. Rapid prototyping and an improved development process make it possible to reduce time-to-market. With their abilities to conduct scenario analyses for different operating conditions, and to reduce the number of tests in the testing and experimentation phase, DTs can reduce the time to market of a mechatronic product by between 20-50%.

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