The digital transforming of the CAE world:
A 60-year status and some perspectives

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Preamble

To mark the occasions of 30th anniversary of PUCA – ESI Forum Japan – and the 40th anniversary of the formation of ESI Germany, I reflected on the multi-decade journey that brought to life virtual prototyping and its notable economic and social contributions: from electro-nuclear and automotive safety to environmental impact. This letter starts in the past, but then leaps to the future: I am convinced we are just at the beginning of enthralling new contributions, and I am excited to share with you today the views of ESI's Founder and Chairman on this acceleration.

Cristel de Rouvray – Chief Executive Officer

Summary

The world of engineers became computer aided (CAE) with scientific computing in the early 1960s. In industry the world of designers was thoroughly ingulfed into computer aided design (CAD) to create the 'digital mockup' to represent the shape and functionalities of new products and manage the related documentation. As CAD became a pre-requisite to CAE, both got entangled into driving the development cycle of new products, known as the 'Product Lifecycle Management' or 'PLM'. The Design of Experiments (DoE) complemented the process based on 'trial and error' around 'real' (hardware) prototypes and tests.
Decades later, PLM and CAE, long interdependent and complementary, have started to grow apart, as CAE transformed into virtual prototyping and virtual testing, gradually eliminating real tests and prototypes. Furthermore, the need has grown for industry to anticipate beyond launching and be held accountable for the full life usage of their product in-Service ('Outcome economy').

So, the manufacturing industry is now gradually compelled to extend the management efficacy of their product lifecycle from the limited development and certification phase (PLM) to its full life

performance ('Outcome') as a solution and 'asset' in-Service, from launch to repair and retirement, now referred to as 'Product Performance Lifecycle' (PPL)TM.
How CAE had been driven to evolve and transform from analysis and simulation to the extended virtual prototype and to culminate into the disruptive 'Hybrid-TwinTM ' is the story recalled here (see Narrative).

It may be that the new perspective offered by the 'hybridization' of the 'predictive' rational virtual prototype with the empirical digital twin of big data and Artificial Intelligence, leveraged with the amazing potential of coupling 'Model Order Reduction' and hyper (quantum) computing and the cloud, will create a new era where CAE will drive 'real time – physics based' design, independently from a legacy of preferred CAD subservience.
In perspective, as the sustaining exponential technology growth is constantly and increasingly interfering with the constraints and opportunities of the asset performance and the outcome value, their synergies are creating a whole new PPL/CAE world for us to strive for and thrive on, in order to deliver technologically better and socially smarter products and solutions, hopefully responsibly developed and monitored during their full life, be they assisted or autonomous.

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Narrative

A voyage through the CAE world of past, present and future

Computer Aided Engineering (CAE) came into existence with scientific computers some 60 years ago, driven by the wide spread adoption of the Finite Element Analysis/Method (FEA/FEM), mostly originated in the USA and materialized with the funding in the mi-sixties by NASA of the NASTRAN FEM software package to support the structural design and analysis of aerospace structures.
ESI France was created in 1973, soon followed by ESI GmbH in 1979, to promote highly innovative CAE projects, in Defense, Aero-Space and Electro-Nuclear industries.

The First PLM Phase: CAD/CAM/CAE – 1970 / 2000 – 'Realistic Simulation'

- The PLM key challenge was to help engineering designers to perform mechanical design and analyses on realistic (complex) geometries as generated by CAD designers, using numerical computation. Practically for CAE purposes the CAD detailed geometric data were discretized into small pieces (finite elements) and fed into the FEA solvers to deliver the stress and strain distribution through the whole structure.

The expected benefit was geometric and loading accuracy for simple (linear) operational behavior.

- As technology improved exponentially both in computer performance and software functionalities, nonlinear material and structural behavior became the next challenge.

The expected benefit was the anticipation of the structural response for complex nonlinear behavior resulting from exceptional extreme and accidental loading conditions; Though for some decades there was little confidence in the accuracy of the numerical results.

The main rationale for industry to steadily invest and promote CAE and FEA, despite increasing hardware and software costs, high modeling complexity and sophisticated user expertise, was the clear advantage of providing a rational numerical 'autopsy' of real tests used in large numbers for design requirements validation, mostly for normal (linear) operating conditions. So, combining real experiments with FEA duplication became standard practice.

- In 1984, a threshold was crossed when the VW Group launched an initiative to simulate the regulatory frontal crash test, for its Polo car crashworthiness certification, which succeeded in 1985 with a joint team of ESI France and ESI GmbH led by Dr. E. Haug, using ESI's newly developed PAM-CRASH software run on a new Cray-Research 'High Performance super Computer' (HPC). ESI's software main technological innovation was the use of the explicit FEM allowing path and time dependent solutions, as opposed to the implicit FEM limited to boundary-controlled behaviors, as used by the legacy industrial software at the time (Nastran, Abaqus, etc.).

The expected benefit was predictive virtual testing, to anticipate through numerical simulation the effect of design parameter variations on complex time dependent events such as explosive loadings, projectiles and target design and crashworthiness.

NB: This Polo virtual crash test event is now recognized as epoch making for the CAE world, as exposed in the Mountain View Computer History Museum in the Silicon Valley, CA.

- From then on, the critical source of innovation and industrial benefit was to extend and enrich the 'circumstances and limits' of 'predictive' numerical simulation to represent more closely the reality of design and regulatory testing. This meant for example for crashworthiness to add the modeling of regulatory barriers for more realistic car body kinetic energy absorption, and next to focus on passenger safety with virtual models for airbags, seat belts and various regulatory human dummy mock-ups.

The Second PLM Phase: CAE/VP - 2000 / 2020 - 'Predictive Virtual Prototyping'

- By 2019, spectacular progresses in CAE modeling and solving had been achieved, first of all by the automotive industry relentlessly led by the VW Group (Audi, etc.). Other OEMs followed suit, as recently illustrated by the announcement by Renault of the successful predictive numerical pre-certification of its new Clio car model, fully achieved through virtual simulation, i.e. without any new real crash tests, and confirmed by winning 5 stars with top grades and reducing the CAE development time by half.

– This exponential rate of technological progress has led the innovative manufacturing industries into a multi decade prudent but steady methodological 'digital transformation' of their CAE practice, gradually replacing the real tests required for design evaluation by 'realistic' numerical simulations, step-wise per engineering domain (e.g. crash, safety, comfort, durability, aerodynamics, climate, etc.), per component and sub-system (e.g. frame, seats, suspension, etc.), up to the virtual modeling and testing of full systems (e.g. power train) and assembled product (e.g. body with trim and power train). Eventually this patient but exerting transformation has given rise to the present age of predictive 'Virtual Prototyping' (VP) for virtual 'pre-Certification', applicable to many industries, such as automotive and transportation, heavy industry, energy, aerospace and defense, etc.

– This multi decade long stream of digital innovations to develop the predictive VP approach, has focused on realistic numerical modeling at each stage of design, analyses, assembly and testing of the full product, and at all levels of details of its parts, systems and components, to ensure the proper assembly and linkage of all its elements, maintaining the 'circumstances and limits' guarantying the full validity of the modeling and assembly process and underlying assumptions.

– For ESI, the software delivery is its 'Smart VP Platform', encompassing its process management and the delicate multi-materials characterization for multi-solver specific modeling.

– A typical example of the spectacular progress thus achieved in the Auto industry is the extension of Virtual Prototyping to cover routinely multi-domain performance, such as combining crashworthiness and occupant safety as well as passenger comfort (postural, thermal, acoustic, riding, etc.), including detailed fabrication, assembly and joining effects, and using multi-million element explicit/implicit numerical models on massively parallel computer clusters and networks.

– The expected benefit of this accelerated digital transformation is the generation of massive savings in time and costs resulting from largely forsaking 'real' for 'virtual' testing in the lab and in the field.

The new PPL (Product Performance LifecycleTM) Phase: CAE/XVP – 2020 / 2025 – 'Extended Virtual Prototypes'

Product Performance LifecycleTM (PPL) is the next generation of the digital transformation in the Manufacturing industries. PPL relies on physics-based information and focuses on product performance from launching to end of life. And its stems naturally from the success of the Virtual Prototyping phase, when confidence in the model allows to go beyond pre-Certification to evaluate the product operational performance in-Service.

-When Virtual Prototypes describe realistically and reliably the 'cause and effect' scientific relationships between design parameters of complex assets, then it becomes possible to evaluate, improve and predict its behavior in operation. However, this requires extending the 3D-4D VP model with an effective 0D-1D representation of the asset control systems (i.e.: mechanical, hydraulic, electrical, etc.), in order to model with this 'Extended Virtual Prototype' (XVP) the interactions with the operational environment (e.g. 0D-4D models of wind, water, obstacles, etc.).

- Impressive examples of such XVP performance in hypothetical operation have now been routinely achieved for example: With offshore wind mill farms; with a field of giant umbrellas opening and closing in variable winds; or with a landing gear under various approach and tarmac conditions.

- The expected disruptive benefit of the PPL/XVP is to understand and anticipate the in-Service behavior of innovative products and operational industrial solutions beyond the limited circumstances of the legal Certification process applied to the brand-new product, and to investigate rationally beyond the realistic possibilities of pre-launch real testing or without the excessive costs and risks of post launch recalls.

The Nascent OPL (Outcome Performance Lifecycle) Phase: CAE/XVP/Hybrid-TwinTM - 2020 / 2025sq - 'Outcome Virtual Performance'

'Outcome Performance Lifecycle' (OPL) will likely become the next CAE frontier when:

- the individual asset status (i.e., wear, tear and repair) becomes known and continuously monitored in-Service,

- and the description of the actual operational environment is also known and continuously monitored.

This is the age of the Big data, IoT, A.I. and the Cloud. The 'pattern recognition' algorithms and generated empirical results will be called upon to update the science based rational XVPs, in order to create by 'hybridization' the live Hybrid-TwinTM of the as-built, as-used asset in-Service.

'Model Order Reduction' and real time XVP

However, to make it practical and effectively implemented in industry, there needs to be a meaningful time to response of the Hybrid-TwinTM: This is now achieved with the exponential progress of the condensation methods of 'reduction' of complex 3D-4D numerical models, referred to as 'Model Order Reduction' (MOR /PGD).

-Impressive examples have been recently demonstrated in various industrial size solutions of relevant complexity (mostly still industry confidential at this time).

The Future OPL Phase: The CAE/XVP/Hybrid-TwinTM – The Perspectives

- Open Source software and digital commoditization

Equations and text-book scientific algorithms may be evaluated like connections in brain neurons and synapses, or computer microprocessors, and may be electric power; i.e. their relative value contribution to innovative solutions tends to surely and steadily decrease to correspond to the actual cost of continuous validation, user support and maintenance.

However, the need to build ever more elaborate 'Extended Virtual Prototypes (XVP)' and to control and pilot their mechanical interactions with their operational environment (Hybrid-TwinTM) will continuously increase in cost and value.

The savings in the democratization of scientific algorithms and multi-physics solvers, can be effectively re-invested into smart modeling processes and integrated solutions to virtually describe and experience the future world we want to build and live in.

The recourse to 'open source' quality software may help to accelerate the commoditization of CAE software, and to promote on a large and global scale collaborative and synergistic innovation, industrial validation of realistic and predictive solutions.

- ESI's Hybrid Material LabTM (HML) and VDSS Platform for CAE Integration

At the source of all real life and of the manufacturing industries which strive to serve practical and social needs in the growing global 'Circular Economy', lies the 'engineering materials' and fabrication processes used to build any products and under constant pressure to innovate.

But these engineering materials also need to be created, fabricated, used, aged, repaired and ultimately recalled and tentatively recycled. This is to date a new challenging frontier to develop realistic and predictive material models, which can be reliably injected into increasingly complex multi-physics solvers and transported across sophisticated chains of multi-domain/multi-trade models, all the way to the whole XVP immersed into its operational environment.

Coupling design and analyses, multi-domain engineering optimization, together with fabrication and repair multi-trade manufacturing processes, will concentrate most CAE innovation and industrialization efforts on the foreseeable future.

Therefore, understanding, creating and utilizing smartly new materials and new processes for innovative purposes will be a continuous source of progress and economic and social value.

In all these aspects, collaborative efforts across multi disciplines and economic sectors, will require new ways to evaluate the creation of value and to share smartly its benefits like assisted and autonomous piloting of products (cars) and machinery (assembly lines).

- Designing with real time physics

Exponential progress in extended virtual prototyping, model order reduction, cloud based real time collaboration and empirical data feed, has now open the way to a new design paradigm. Using massive parametric optimization of reduced order but physically realistic virtual and hybrid models, running on the new generation of hyper performance ‘quantum’ computers, it becomes foreseeable to design, develop and innovate using accelerated evolutionary algorithms, systematically reducing the ‘ignorance’ of our fancy models, to best fit product and solution features to whatever behavior the environment and society may require, i.e.: some numerical adaptation of Darwin’s generation and adaptation of the ‘fittest’, created in accelerated virtual time rather than requiring eons of biological time.

I wish you a successful ESI Forum in Japan and much success in your exciting empirical and rational creative endeavors, and:
Let’s ‘Get it Right’ faster and better together!

Alain de Rouvray
Founder and Chairman, ESI Group