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Virtual Testing Project Feasibility Study

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Introduction

The objective of this document is to set the framework for building a high fidelity *virtual testing* system for gas turbine engines taking into account the primary and secondary flow path, their interaction and the interaction with the surrounding structural elements.

This would thus allow for simulations leading to performance predictions, aeromechanical response, and thermal and heat transfer predictions in one single simulation. The programme will build on existing successful experience of large scale modelling of entire engine components such as the modelling of the entire compressor and the entire turbine.

The resulting virtual testing system can be applied in at least two modes.

The first mode is to be used in the design cycle, cutting down the number of rig and engine tests and allowing for increased number of design cycles while still at the drawing board. This will lead to larger steps in improved designs to achieve the main target of larger steps in development. The system will be particularly useful in reducing the cost and time requirements for major design modifications to engines resulting from the anticipated introduction of new fuels.

The second mode in which the system can be used is test mode, where the system can be used in the post-design for both performance analysis as well as in-service problem investigations. It would be impractical to suggest a complete re-write of existing codes as all OEMs, operators and other parties involved in the design, manufacture and operation of gas turbines have invested significant amounts of money and effort in the development and validation of numerical tools and their incorporation in their design systems over the past decades. Instead, it is proposed that the virtual system will be built from existing validated codes with the flexibility of keeping the standard routes for the development of those codes open. It is also proposed to allow interchangeably of component codes so that each partner in the program can use their preferred codes as will be described below.

Project rationale

The impact of power generation on the environment is arguably the most serious challenge facing the industry for the foreseeable future. Other important issues are the security of supply and sustainability in the long term. A substantial proportion of the electricity generated in Europe uses gas turbine based power stations. Concerted research and development efforts are being conducted across Europe motivated by the EU 2020 targets to reduce CO2 emissions on various fronts including those of alternative fuels, carbon capture and storage technologies in addition to improving energy efficiency. The cost and time required to develop new gas turbine technologies needed to meet the future demands on fuel flexibility, low or zero emissions and commercial viability is considerable. In order to reach the targets significant step changes in technology are required (normally over longer periods) as the usual small incremental changes would not be sufficient. In the past two decades, there has been a dramatic increase in the use of computer based models in the design process of power plants, leading to significant design improvements at a much reduced cost and with a shorter design time scales than the traditional methods. It is becoming increasingly apparent that the trend towards reliance on numerical methods is leading to what is termed as *virtual testing* techniques. These techniques are expected to further cut the cost of the design process, leading to more reliable and efficient power plants and more importantly in the current context, reduced emissions.

State-of-the-art and beyond

The standard has been to use a single numerical code for the large scale simulation of engine components, however recently it has become increasingly apparent that specialised codes based on possibly different numerical models need to be used for the different components. For example, the main flow path in the compressor and turbine can be simulated using Reynolds Averaged Navier-Stokes (RANS) codes, as it is not practicable in the foreseeable future that Large Eddy

Simulation (LES) will be used for those components. Meanwhile, LES seems to be the more appropriate tool for modelling the combustion system and possibly, some of the secondary flow path components. Additionally, if heat transfer is to be modelled correctly, heat conduction models might need to be integrated within the system, an approach known as "conjugate methods".
Significant investments have been made in specialised codes to tackle these problems, therefore it is proposed to set up a virtual testing system based on the existing tools. While the final set up of the proposed system will be left for discussions with potential partners, it is envisaged to be constructed around the idea of the use of existing validated CFD, combustion, structural dynamics, and aeroelasticity codes as the major building blocks, while developing new features in these codes as needed. The CFD codes can be a mixture of RANS, LES or possible DNS codes.
A top level system (figure 1) which will manage the integration and communication of the various sub-models and facilitate the division of the computational resource and the computational work will be set up The physical domain will be divided into regions simulated by the appropriate codes that communicate with each other at predefined interfaces. Each sub-block will be running at multiple processors allowing for fast simulations. The system will be designed in a modular fashion allowing for sub-components to be interchanged for either comparison or replaced with more advanced components in the future. Data handling and post-processing techniques will be adapted and developed not only to use the data after the simulation, but also to allow for direct monitoring of the test as it is being conducted, similarly to actual tests.

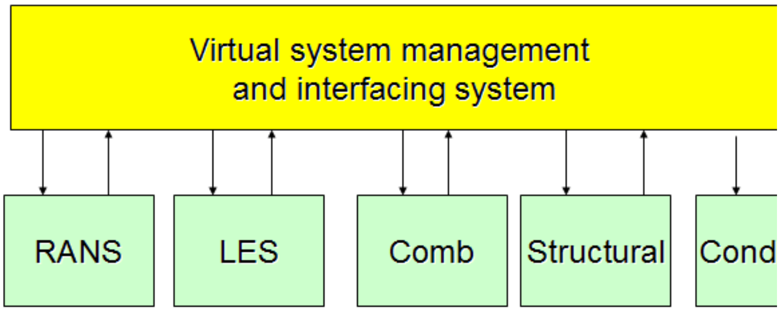

Figure 1: Block diagram of the proposed system

Research and Demonstration Tasks
On the technical level, the main research and development areas required to realise the system are:

Domain Structure
1. Dividing the physical domain into sub-domains where the most appropriate numerical models are used in each sub-domain.
2. Defining interfaces between sub-domains where appropriate data can be exchanged during the simulations. Devicing appropriate data transfer techniques particularly when different numerical models are used such as LES and RANS poses a significant research challenge. Additionally, temporal discretisation can be significantly different and research on appropriate synchronisation techniques is needed. Finally, interfaces between structural domains and solid thermal analyses domains and flow domains need to be developed.

Parallelisation of Simulations
3. It is implicitly understood that such simulations can only be handled using massive parallelisation. When a single solver is used in certain domain, usually domain decomposition is used and load balancing is relatively straightforward. However, for the proposed virtual system, different spatial and temporal discretisations are going to be used throughout the domain. Load balancing becomes a serious challenge and significant research needs to be done in this area.
4. Massive parallelisation requires research into the most appropriate computer architectures to host the virtual testing facility in addition to research on ensuring load balancing while minimising cross processor communication to achieve computational efficiency. While whole component

simulations currently can take days or even weeks on standard parallel clusters, it is aimed to achieve quick turnaround simulations with costs at a fraction of the cost of real tests. This will pose another major research challenge.

Handling of Data

5. Simulations at this scale require handling complex geometries for discretisation partitioning and defining interfaces. It also produces significant amount of data as a result of the simulations. A major challenge is to effectively handle the input data to produce a workable environment for the simulations and to intelligently store, reduce and extract meaningful data from the resulting simulations. Research is required across the spectrum of these issues, requiring expertise from CAD's and CFD specialists, numerical analysis and computer specialists.

6. While significant amount of rig and engine data are available in the public domain for validation of the system components, a database needs to be built to validate an integrated virtual testing facility. This requires either gathering and analysing and compiling existing test data or designing and conducting new tests for the purpose of validation.

7. One of the objectives of the proposed system is to provide a self-adapting and versatile numerical virtual testing environment. Since different numerical models are going to be used in different parts of the domain, the system will be designed such that building blocks are interchangeable. This allows for replacing a certain component by either an up-to date component, a modified component, or even a component of totally different numerical modelling level, without requiring any changes to the rest of the system. To achieve this, research and development is required to produce data standards to govern the communications allowing for future developments without major disruptions to the system

Ideal consortium

It is proposed to set up a consortium to build the essential blocks of the virtual testing system and put them together. The research and development programme will build on significant experience of partners in the fields of Computational fluid dynamics, turbomachinery aerodynamics, structural dynamics and aeroelasticity, parallel computing, large data-set handling and post-processing methods.

The consortium is expected to have groups from academia and industry providing the following:

- RANs CFD
- LES and DNS
- Structural dynamics and aeromechanics
- Combustion
- CAD and meshing
- System integration
- Engine test data
- Validation experiments
- Turbomachinery aerodynamics
- Parallel computing
- Computer architectures
- Data acquisition, handling and post-processing