Methods Supporting the Efficient Collaborative Design of Future Aircraft

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ABSTRACT

The paper describes the need for and advantages of efficient and effective collaboration within the aircraft development supply chain. It discusses the barriers on the organisational, human and technical levels that hamper efficient collaboration. One of the focal points of the European Horizon2020 project AGILE is the creation of technical solutions for resolving the challenges that come with collaboration. In this light, the paper focuses on two methods being investigated and developed for supporting multidisciplinary teams from different organisations in collaborative aircraft design. The first method concerns the realisation of cross-organisational workflows for multidisciplinary design of aircraft. The workflows support the definition and smooth application of multiorganisation collaborative product development analyses. The second method concerns the deployment and management of surrogate models, which support efficient collaborative multidisciplinary aircraft design while dealing with intellectual property issues and computational speed limitations. After the introduction of the methods, two representative use cases which are successfully supported by the methods are highlighted. An important observation is that efficient collaboration is not straightforward when engineers from different and usually geographically dispersed organisations attempt to achieve a common design target. Once the collaboration methods are in place however, investigation of novel aircraft configurations is enabled by optimally leveraging the dedicated disciplinary knowledge of all involved experts.

KEYWORDS: *collaborative engineering, design of more competitive aircraft, cross-organisation workflows, surrogate model repository*

1 INTRODUCTION

Global air travel is doubling every 15 years (e.g. [1]). Meanwhile, green, safe and secure operations are required and passengers' demands for easy, fast, cheap, and comfortable travelling must be taken into account. To keep up with these needs, airlines continuously extend and modernise their fleets. Consequently, the aircraft industry and its supply chain must constantly innovate. They have to manage the growing needs for cost-efficient and complex aircraft that respond to the societal and passenger needs and that meet a non-fixed set of requirements. The innovations include application of new advanced technologies, such as additive manufacturing, virtual testing, factories of the future, big data, cloud, internet-of-things and digital twin technology. The innovations also involve exploration of novel concepts such as high-bypass ratio engines, hybrid electric propulsion or blended wing-body aircraft. Quick evaluation of promising new technologies and concepts is required to facilitate a short time to market. Innovations usually require many experts and are generally costly and risky. At the same time, the aircraft industry inevitably faces certification, global competition, economic fluctuations, scarcity of non-renewable energy sources, staff turnover, and aging people. Increasing the level of collaboration within the aircraft industry and its supply chain is considered as a good step forward in order to face the challenges described above. Step changes are required to develop modern aircraft in an increasingly cost and time efficient manner in a collaborative set-up.

Developing aircraft has evolved over the past century from pioneering by a single man building a simple and small aircraft in a shed, into a modern and well-established engineering process for designing and building aircraft as complex, safe, sustainable, comfortable and competitive products. Today, new or derived aircraft types, systems and components are developed by large numbers of multidisciplinary teams of experts from many different organisations, which are often located in several countries. To keep up with the growing demand for more complex and innovative products in shorter time and in higher volumes, the industry digitises rapidly. The highly advanced aircraft industry more and more applies innovative design approaches based on digital modelling, simulation and optimisation technology to take design option decisions as early as possible and hence to develop state-of-the-art aircraft more timely and cost efficiently.

Efficient collaboration within the aircraft development supply chain is considered essential for developing an aircraft today and it will be even more in the future. The development of disruptive technologies and unconventional solutions cannot be achieved without integration and optimisation on system-level, applying the appropriate fidelity of physics based analyses. Additionally, the distribution of work and risk along the supply chain is changing fundamentally. The ongoing trend of outsourcing, combined with increasing technical responsibility of suppliers, clearly shows that the successful suppliers of tomorrow must be able to access, operate at and contribute to system-level analysis and optimisation. At the same time, the specific disciplinary expertise need to be accessible by the product integrator, which could make early use of these to perform the analysis in support of the overall architecture evaluation. This increases the need for a collaborative design approach.

The development of a "more competitive supply chain" is the key-enabler to deliver innovative products in a time and cost efficient manner. The overall project objective of the EU-funded Horizon2020 AGILE project [2] targets the significant reduction in aircraft development costs, by enabling a more competitive supply chain able to reduce the time to market of innovative aircraft products. AGILE focuses on the reduction of the aircraft development time at the early stages of the design process, pronouncing the synergies between the heterogeneous disciplinary experts and the overall product architect, thereby addressing all the components of the supply chain network. In AGILE, multidisciplinary design analyses and optimisations are performed in a collaborative way by multiple organisations located in several countries, see Fig. 1.

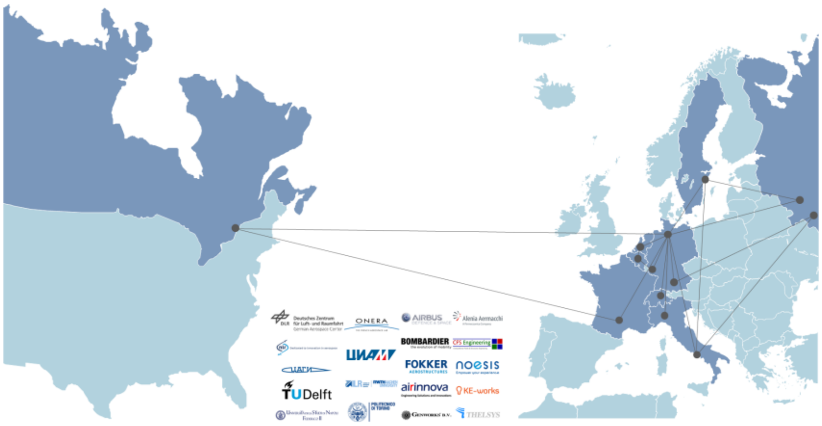

Figure 1: Cross-organisational and cross-country integration of competences made possible by the collaborative architecture being developed in the AGILE project

This paper focuses on the developed and applied methods for efficient collaboration in aircraft design. Section 2 describes the challenges in collaborative aircraft design, in particular among the engineers from different disciplines, organisations, and countries. Sections 3 and 4 detail two methods investigated and developed in the AGILE project to face particular challenges supporting efficient collaboration. Section 5 describes use cases in which the methods are applied successfully. Section 6 summarises and concludes the work.

2 EFFICIENT COLLABORATION: GENERAL CHALLENGES AND APPROACH

Although collaboration may seem a straightforward method of working, it unfortunately is not trivial. Through experiences in practice, experiences in previous research projects on collaborative aeronautic design (e.g. the EU projects VIVACE [3], CRESCENDO [4] and TOICA [5], and the DLR-lead project FrEACs [6], [7]), a dedicated working session held at the kick-off of the AGILE project and from literature on the subject (e.g. [8], [9], [10]), the authors have identified many barriers which hamper collaboration between aerospace engineers. These barriers exist on the organisational, human, and technical levels and are summarised below.

- Organisation level. On the organisational level, barriers are mainly caused by resource and property protection as well as managerial complexity. To protect resources and intellectual property most organisations have extensive security policies. Measures resulting from these policies usually make the exchange of information among collaborating engineers inside and outside the organisation – if possible at all – a complex and time-consuming activity. The managerial complexity is caused by factors such as political choices, export control regulations, non-aligned strategies, operating procedures, and measures, lack of centralised and overarching management, and inflexibility towards changes to established organisational systems and processes on behalf enabling collaboration. Such factors complicate collaboration, and certainly reduce the efficiency of collaboration.
- Human level. Human background and behaviour is also seen as the cause of several collaboration barriers. In collaborations, people need to work together, which may be challenging. Cultural differences, differences in languages and applied nomenclature between the involved disciplines, the "not invented here" syndrome leading to a lack of trust, aversion to changes that would support collaboration, lack of sufficient knowledge sharing (resulting in making the same errors, unnecessary double actions, overlapping results, and lack of a global picture of available resources and results), and lack of common interest hamper efficient collaboration.
- Technical level. Technical barriers that impede efficient collaboration include the lack of adequate information systems for organising the data and activities in a collaborative set-up, over-conservative security measures that implement complex security policies, heterogeneity of computing infrastructures and tools, dynamic – both organisational and IT – environments causing difficulties in guaranteeing a presently working solution to also work in the future, licensing issues prohibiting use of an organisation's commercial tools or computational

resources by others, trust in the integrity of available information and resources, and computational delay of processes.

With reduction of the lead-time and increase in quality of the design and optimisation process as major goal, the AGILE project establishes solutions to the barriers commonly encountered in collaborative aircraft design activities.

As described in the introduction, the project develops innovative methods to support efficient collaborative design of conventional and future aircraft configurations. Guiding the developments, the AGILE paradigm has been established and published [11]. The components constituting this paradigm are depicted in Fig. 2. As explained in [12], the *knowledge architecture (KA)* on the bottom left of the figure formalises the overall product development process as hierarchical layered process. It describes how the multitude of design competences can be connected in automated simulation workflows and embedded in the overall development process. As described in [13], the *collaborative architecture (CA)* on the bottom right of the figure formalises the collaboration approach within the product development process. It defines how the different stakeholders and processes interact within the paradigm. The CA enables the cross-organisational and cross-the-border connection of all partners within the design process.

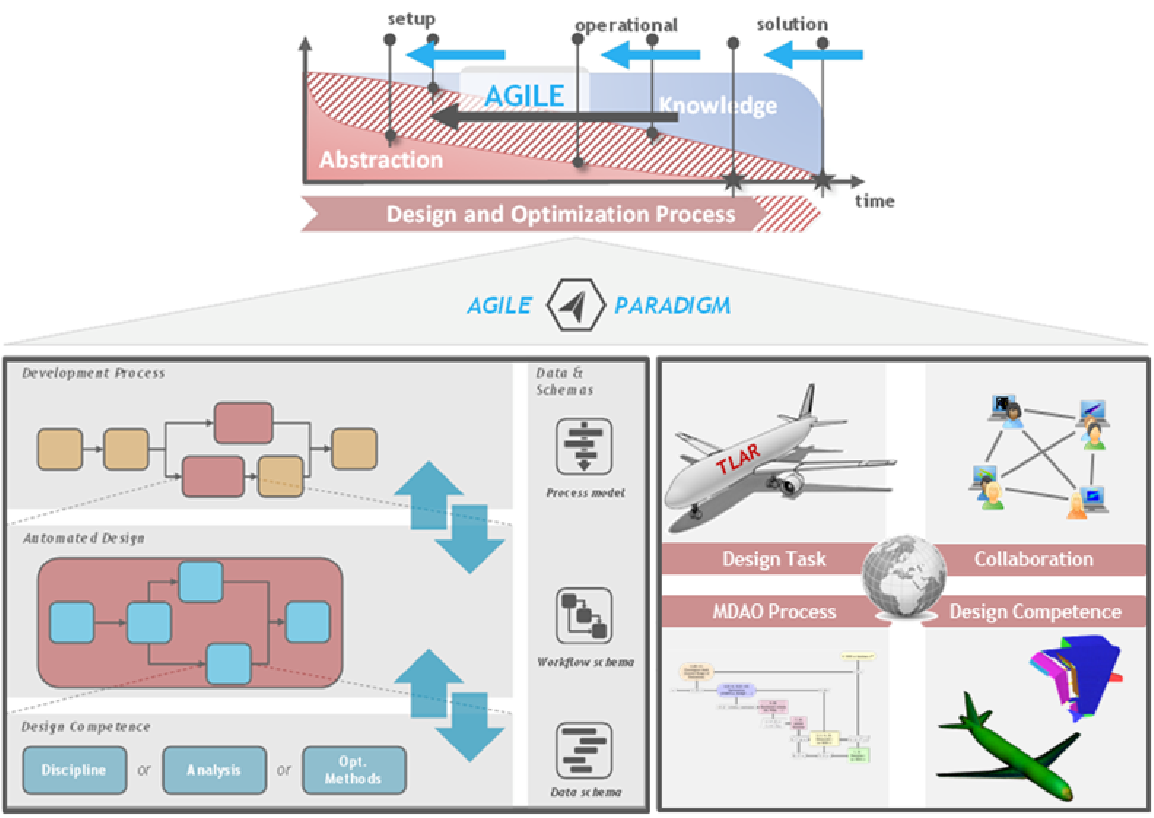

Figure 2: Components of the AGILE paradigm

The components of and roles within the collaborative architecture are introduced in detail in [13]. The key components which are relevant for the present paper are:

- The central XML-based data exchange format "Common Parametric Aircraft Configuration Scheme (CPACS)" [14] as common language for the exchange of aircraft design and tool specific information across the available engineering services.
- Common Multidisciplinary Design Optimisation (MDO) Workflow Schema (CMDOWS, [15]), as common XML-based workflow definition schema for integrating and connecting MDO services.
- The Process Integration and Design Optimisation (PIDO) environments RCE [16] and Optimus [17] for the integration of the available design competences and the orchestration of the design process using simulation workflows.

Based on the principles of the collaborative architecture and in conjunction with the knowledge architecture, two collaboration methods are identified as promising resolutions for dealing with the most common technical barriers and the Intellectual Property (IP) barrier: the *cross-organisation workflow* method supporting multipartner MDO studies using interconnected engineering services, and the application of a *surrogate model repository* for sharing knowledge using surrogate model representations in a clear and managed way. Both methods are elaborated in the subsequent sections.

3 CROSS-ORGANISATION WORKFLOWS

One of the pivot concepts identified as supportive to efficient collaboration is the cross-organisation workflow. In general, workflows serve to define, execute and automate processes where the tasks and the information involved are passed between the actors according to procedural rules. In the field of aeronautical design, workflows support and increase the efficiency of the design activities performed by multiple collaborating engineers from the different disciplines. More specifically, workflows are commonly used for implementing and automating MDO scenarios. Workflows orchestrate the design activities, the execution of tools, and the flow of information among a team of aeronautical design engineers and available computing resources.

In present-day aeronautical design, the engineers, activities, tools, information and other resources involved are often dispersed across the organisations of the participating partners. Consequently, the aeronautical design workflows may have to "cross" organisation borders. Even if organisational and human barriers have been resolved by contracts, common agreements, and team building activities, the realisation of cross-organisation workflows is not straightforward and involves issues that are not commonly observed in their "local" counterparts. These issues mainly comprise the technical barriers as described in the previous section and experienced by the design engineers involved in the execution of cross-organisation workflows. Barriers such as firewalls, proxy servers, and bans on the free exchange of files by email seem to hinder the seamless and automated execution of the cross-organisation workflows. Simply avoiding or removing such technical barriers is difficult or even impossible, basically because these result from the organisations' well-established policies, procedures and security measures that cannot be by-passed or adjusted.

From the viewpoints of the collaborating engineers, the cross-organisation workflows ideally run as seamless and efficiently as possible across the organisations' borders. At the same time, the workflows must comply with the prevailing policies, procedures and security constraints of the organisations involved. In addition, these shall exhibit the required level of security as defined for the collaborative work.

While considering the identified collaboration barriers, the realisation of cross-organisation workflows raises the following main technical challenges:

- Complying with the IT and security policies and measures of the collaborating organisations. Security measures serve to enforce a security policy, e.g. to protect an organisation's assets, intellectual property, and network. Although security measures are in some cases over-conservative, they cannot be by-passed. For example, organisations generally do not allow by-passing of proxy servers or opening particular communication ports. To allow for collaboration, however, organisations commonly provide means for data-file exchanges, in particular for use in commercial projects. Such mechanisms are usually highly secured and may involve use of dedicated tools, additional authentication steps, special file-exchange servers and communication channels. Although engineers on the shop floor experience these mechanisms as barriers, because of the required complex and time-consuming procedures and tools, file exchanges may be allowed and technically feasible. This obviously does not imply using deficiencies in software and security systems to enable collaboration!
- Dealing with the heterogeneity in the organisations involved in collaboration. The heterogeneity includes different ways of working, workflow tools, IT systems, and IT and security policy. In particular in research projects, organisations cannot be forced to install particular software or to use standard tools to enable collaboration.
- In collaboration, most organisations permit tools and other resources being used by collaborating partners only under full control of the organisations' own personnel.

- Managing the use of potentially unsafe communication channels via the internet, while reaching or preserving a certain level of security. IT technologies exist and can be exploited to establish secure data exchanges.
- Dealing with the dynamic operational context. As indicated in the previous section, a presently working cross-organisational workflow cannot be guaranteed to also work in the future.

In AGILE, the established "Brics" concept is applied to cope with the challenges in realizing cross-organisational workflows. Developed by NLR, Brics comprises a protocol and supporting middleware for creating cross-organisation workflows as federations of native and legacy local workflows, tools and scripts. Thereby it resolves many technical barriers of collaboration across organisations while complying with the prevailing security constraints. The working principle is based on a long history and track record of developing cross-organisation workflows in various multipartner set-ups, varying from loosely coupled and unsafely internet connected partners to federated networks and virtual enterprises (see e.g., [18], [19], [20]).

A key aspect of Brics is that it keeps the specialist in the loop. When a service is requested as part of a collaborative workflow, the specialist is notified and approves usage of the service, while the rest of the service may be automated. As such the specialists retain full control over their resources. Brics is non-intrusive and independent from particular process integration or workflow software. It allows the collaborating experts to use the engineering and workflow tools they are familiar with in their organisations, and it does not disturb the experts' usual way of working or the organisations' business flows. The concept is easy to comprehend and easy to explain to IT security experts and compliancy officers. The supporting middleware can be easily integrated with well-established workflow systems, data exchange servers, engineering workflows, various script languages, and technical security measures. In AGILE the Brics concept is seamlessly integrated within the PIDO tools RCE and Optimus.

Brics is based on a simple protocol that supports single or repetitive remote execution of a tool or workflow from within a local workflow or script [21]. It facilitates the definition and implementation of cross-organisation workflows by interconnecting local workflows through "links". A link enables a workflow to act as a "client": to request for an external service by calling another workflow as if the other workflow is a single local tool. While executing the linked workflows, Brics takes care of the notifications and data-file exchanges involved. A link may cross organisational borders: the called workflow may be located remotely, at another organisation. A link also enables the implementation of a "server" workflow supporting a competence provided and called as an external service. At execution of collaborative workflows, the links cater for the smooth flow of control and data between local workflows. The schematic in Fig. 3 depicts a client-server setup between two local workflows. Practical applications of cross-organisation workflows using a close connection between Brics and the introduced PIDO tools are described in section 5.

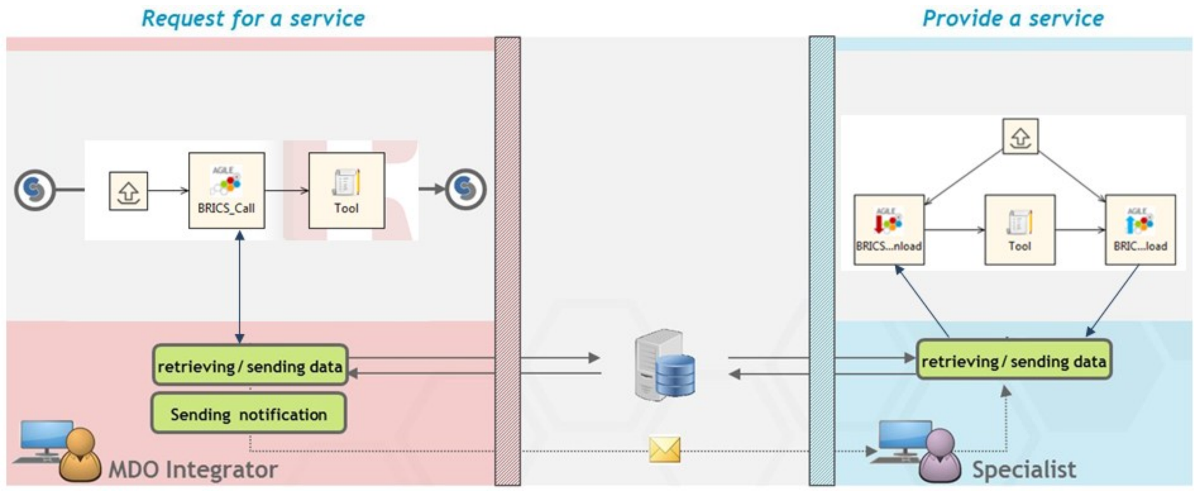

Figure 3: Depiction of a cross-organisation workflow comprising two local workflows located at different organisations. The client workflow is depicted on the left, and the server workflow is depicted on the right.

4 SHARING SURROGATE MODELS

Surrogate modelling is an important method in engineering design studies. A surrogate model (SM) is an analytical formula that replaces a complex model, or even a design analysis workflow, by means of data fitting. Consequently a surrogate model requires only small computation time, which is particularly useful for capturing complex analysis methods and applying them multiple times as part of a global optimisation. NLR has a long and extensive experience in developing and applying surrogate models. Descriptions of methods for constructing and applying surrogate models are described in [22] and [23].

Surrogate models are used in MDO studies instead of high-fidelity, high-quality, precise models and mid-fidelity models requiring too much computational resources, time and costs or if IP protection prohibits the use of the original models.

Especially in collaborative design studies during the early aircraft design phases, surrogate models are valuable to support the collaborative analysis of as many design alternatives as possible in short times and at low cost, preferably with as much knowledge of the systems under consideration as possible. Suppliers of aircraft parts and systems may collaborate with the aircraft Original Equipment Manufacturer (OEM) by providing surrogate models without exposing their IP, in contrast to high-fidelity models which may represent a company's proprietary knowledge. Vice versa, the aircraft OEM can provide surrogate models based on (preliminary) aircraft design analysis that may be relevant for the suppliers. An aircraft level surrogate model can provide useful information for the suppliers in such way that they can take into account the effect of aircraft design variations into their own preliminary design analysis. If several surrogate models (e.g. representing different design analyses) are exchanged between OEM and suppliers, this exchange needs to be performed in a managed way.

Moreover, surrogate models must be applied with care. The bounds of the allowed input space of the surrogate model need to be clearly specified (e.g. to avoid extrapolation). Furthermore the prediction accuracy of the outputs of the surrogate model must be specified, so that the user has a clear idea of its applicability, quality and limitations.

Many surrogate models of different types have been developed in the AGILE project, e.g. to support efficient optimisation and partner collaboration. The question then arises how to manage, i.e., document, register, deploy and share these surrogate models? Various aspects need to be taken into account in answering this question, such as:

- IP issues: can the surrogate model be shared or does it still contain intellectual property that is considered confidential information?
- Quality, traceability and usability aspects: is the surrogate model good enough (and well-documented) to be used successfully in studies by others?
- Ease/smoothen the collaborative process. Sharing surrogate models will facilitate the collaborative development process. Easy access and guidelines for successful usage are needed.

Based on the above question a Surrogate Model Repository (SMR) has been developed within AGILE. The SMR is defined as central broker for registration, storage, deployment, sharing, and usage of surrogate models so that these may be shared and reused in collaborations in a managed way.

The SMR stores meta-information with a surrogate model. The meta-information allows properties to be assigned to a surrogate model. The meta-information also facilitates easy usage of surrogate model e.g. by being searchable and cross-referencing the source dataset, fitting method, IP owner, etc. The meta-information includes the following items:

- *General Information*: creation date, creator (e.g. name, company, email), owner (may be different from the creator), operator (envisaged user of the surrogate model), version, status (draft/final);
- *Description*: guidelines of usage, reference to the data set from which the SM was derived, description of original (high-fidelity) model(s) or analysis used for creating the data set (including version and owner) as well as fitting method (including related surrogate modelling tools that have been applied to create the SM);
- *Input and Output variables*: name, description, physical unit, type (e.g. float), bounds (for input only);

- *Verification*: verifier (e.g. name, company, email), verification date, method, result: output prediction error metric and value per output variable;
- *Execution information*: downloadable executable or "available as-a-service" (also provided online through SMR).

With respect to the sharing of surrogate models different cases are considered in the frame of the SMR:

- *Full share*: Share all of the compiled binary code of a SM to support its use by others. In this case the complete SM implementation is uploaded to the SMR with meta-information describing its usage. The SM is used by downloading its code and running it.
- *Partial share*: Share only the usage of a SM: others may use the SM 'as a service' while the code remains at the owner's site (or developer's site). In this case only the meta-information of the SM is uploaded to the repository. In addition, the SM may be securely stored at the repository without permission for others to access the code. The SMR provides a user interface to directly use this SM by calling the remote service. Furthermore, the SMR can export a neutral XML format (i.e., CMDOWS [15]) that supports usage of the SM as part of a workflow system without further intervention of the SMR.

The set-up of the SMR is modular in order to be flexible to support integration of different services. The modular architecture is depicted in Fig. 4. A separation is made between the front end, which provides the main functionality of the SMR, including the web interface, web server, registration and broker functionality, and the various back ends providing storage and execution capabilities. The back ends may be located remotely with respect to the front end. The back ends provide the services for storage and remote execution of surrogate models.

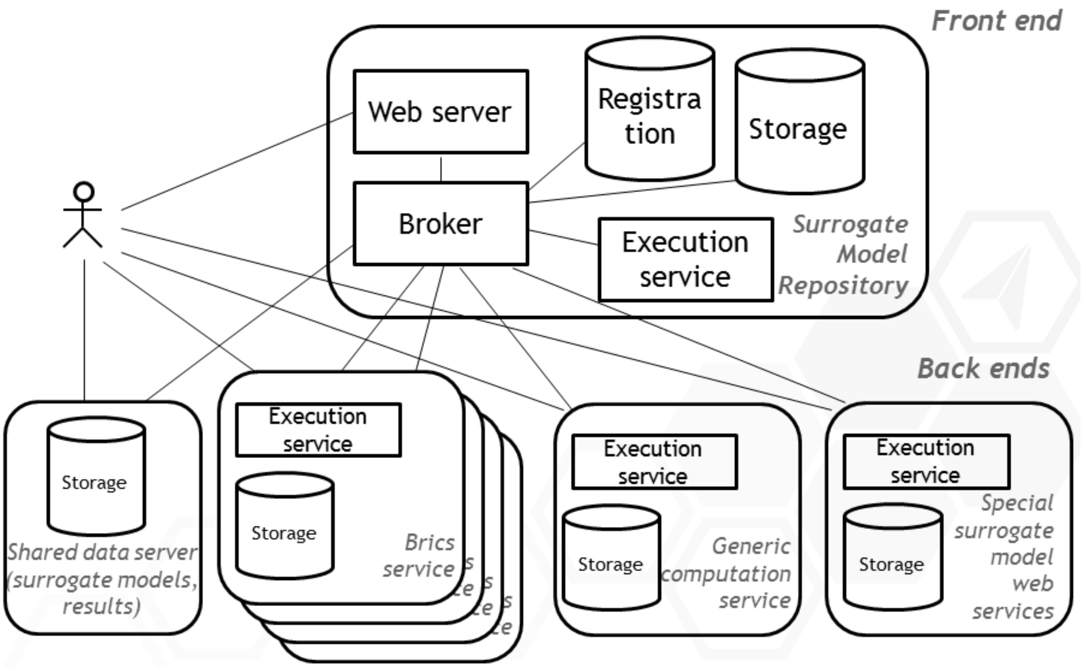

Figure 4: Architecture of the SMR implementation.

5 USE CASES

5.1 Multipartner aircraft system-of-systems design workflow

This use case shows an application of the cross-organisational workflow concept as introduced in section 3. By interconnecting local workflows through "links" using the Brics concept, the legacy workflows of multiple disciplinary experts are connected. Fig. 5 depicts an implementation of the workflow concept for a system-of-systems analysis in aircraft design. For an existing aircraft topology; the matching on-board systems layout (architecture and power requirements), engine (performance and dimensions) and nacelle are obtained for the objective consisting of reducing fuel usage, emissions and cost.

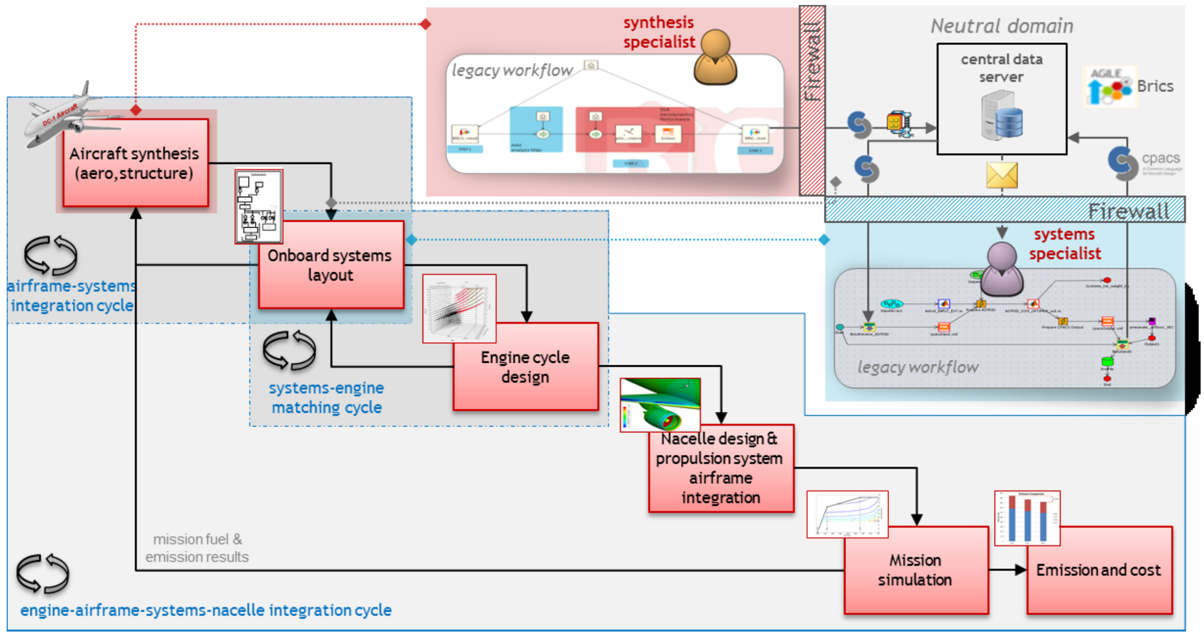

Figure 5: The cross-organisational workflow concept illustrated by a systems-of-systems approach in aircraft design. The legacy workflows of the individual specialists are connected using Brics. The CPACS files are automatically exchanged through a central data server in a neutral domain

After triggering the master workflow, three cycles of analysis are iteratively executed:

- Within the airframe-systems integration cycle, the legacy workflows of the synthesis specialist and of the aircraft systems specialist are connected. The result of this cycle is a schematic layout of the on-board systems with their corresponding mass properties and power requirements, fitting the aircraft concept. Within the synthesis, the effects of changing the systems layout on overall aircraft level are considered.
- Within the systems-engine matching cycle, an engine specification is obtained fulfilling the thrust requirements for the aircraft to be able to fly the required missions while providing the power for operating the on-board systems.
- With the engine dimensions and weight known, a corresponding nacelle specification is obtained and the resulting propulsion system is positioned according to the aircraft and systems layout. For the resulting configuration, the intended missions are simulated and corresponding emissions and costs are estimated. The resulting masses (fuel and propulsion system) are fed-back to the synthesis specialist, closing the engine-airframe-systems-nacelle integration cycle.

Every discipline block within the master simulation workflow depicted in Fig. 5 represents a legacy process of a partner within the AGILE project. Within each cycle, these legacy workflows are loosely coupled using the cross-organisational workflow principle. The first of the cycles – in which the airframe and on-board systems layouts are coupled – is depicted in the upper right of the figure. A legacy workflow of the synthesis specialist is highlighted in red. A legacy workflow of the systems specialist is highlighted in blue. The involved engineering routines as well as the simulation workflow controlling the execution of these routines remain within full control of the specialists and are located within their individual administrative domains, i.e. their local networks. To overcome the technical interconnection barrier of having to exchange product information between these administrative domains, the central data server in the neutral domain (grey background in Fig. 5) is set up and the Brics principle is applied. The moment the synthesis specialist has finished his/her task, the result is automatically uploaded to the central data server, and the systems specialist is notified by email. After approving the calculation request, the required data is retrieved automatically from the server in the neutral domain, the systems layout legacy workflow is executed and results are uploaded to the server. This principle is then continued in a cascading manner, triggering respectively the engine cycle design, nacelle design, mission and emission analyses. In fact, every arrow connecting the major disciplines involved represents a connection through the neutral domain. To speed-up the

iterative analysis process, specialists have the opportunity to allow for repeatedly performing similar calculations using their legacy workflows on their dedicated servers for an overall design session. When the complete design session is finished, e.g. since the results have converged, the workflow is automatically terminated.
For further details and actual results of the application of the depicted system-of-systems analysis workflow, the interested reader is referred to [24].

5.2 Collaborative aircraft rudder multilevel optimisation using surrogate models

This use case illustrates potential collaboration between the aircraft manufacturer and a supplier through the sharing of surrogate models. The use case involves the multilevel optimisation (MLO) of an aircraft rudder. Details on the optimisation method can be found in [25]. In this collaborative design case the choices in the aircraft design may impact the rudder design, e.g. through the rudder planform sizes that follow from the aircraft design and by the applicable rudder forces that result from the design load cases. It may be beneficial to the rudder supplier if he or she can analyse the impact of different aircraft configurations on the rudder design already in the early design phases. As such the supplier will be prepared for different potential future specifications. Such impact analysis could be performed with surrogate models resulting from aircraft conceptual design studies.
In AGILE two surrogate models have been developed that represent the aircraft level design analysis in the context of aircraft rudder MLO. The first surrogate model has been derived from data calculated with an Overall Aircraft Design (OAD) analysis capability provided by DLR [26]. The second surrogate model has been derived from simulations with a tool for aircraft load calculation provided by NLR: AMLoad [27]. Details on the surrogate model derivations can be found in [25]. The surrogate models are shared and deployed as-a-service through the SMR. In this way other partners such as the rudder supplier can use the surrogate models to test potential impact of changes in aircraft design on the rudder design and anticipate on that. In practice, typically the aircraft OEM could control such surrogate models and the supplier could use them to anticipate to potential sensitivities of certain design changes on aircraft level.
Another surrogate model has been developed that represents the rudder design. A surrogate model has been derived that predicts optimal rudder mass as a function of specified rudder sizes and loads (cf. [25]). This surrogate model is also shared and deployed as-a-service through the SMR. In practice, typically the rudder manufacturer could control such surrogate model and the aircraft manufacturer could use it in order to integrate the rudder component optimisation (including detailed design knowledge from the supplier side) into the overall aircraft design.
Both the aircraft level and the rudder level surrogate models and their interactive context are depicted in Fig. 6. Fig. 7 provides a schematic in which the SMR is used to retrieve the information of a surrogate model (in this case the OAD surrogate model) and to request an online calculation with the surrogate model. This online calculation is provided as-a-service, using the same Brics technology as was also applied in the context of cross-organisation workflows (see sections 3 and 5.1).

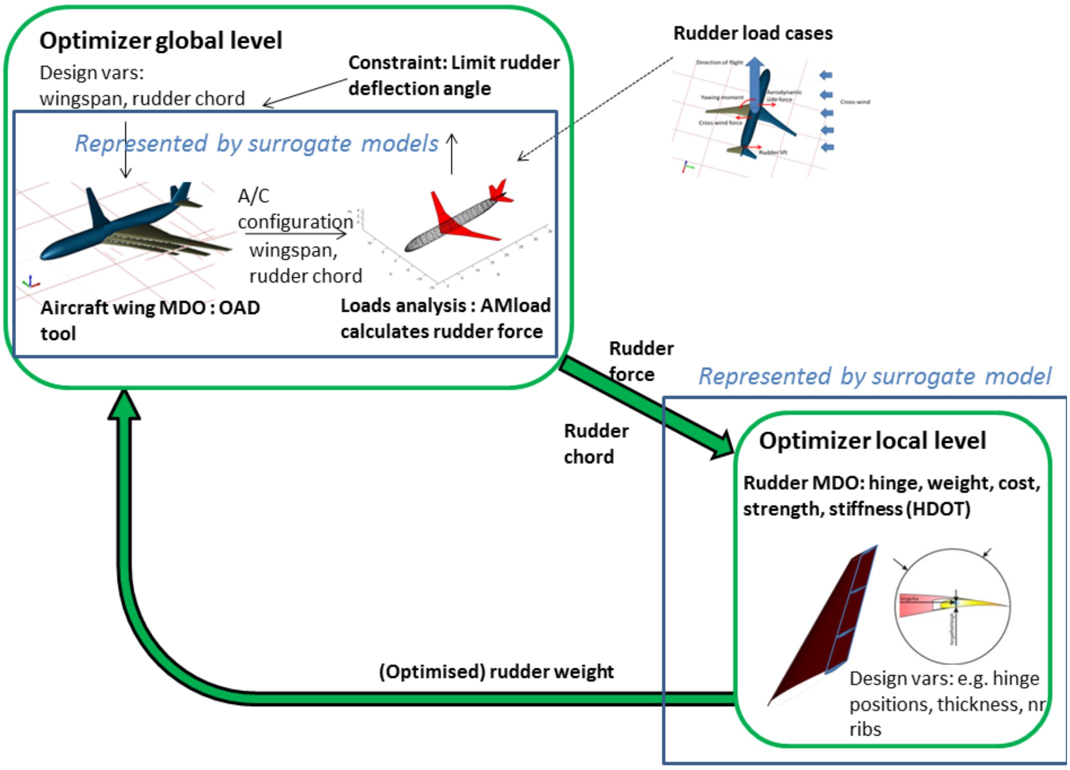

Figure 6: Depiction of aircraft level and rudder level surrogate models and their interaction in the context of a multilevel aircraft rudder optimisation.

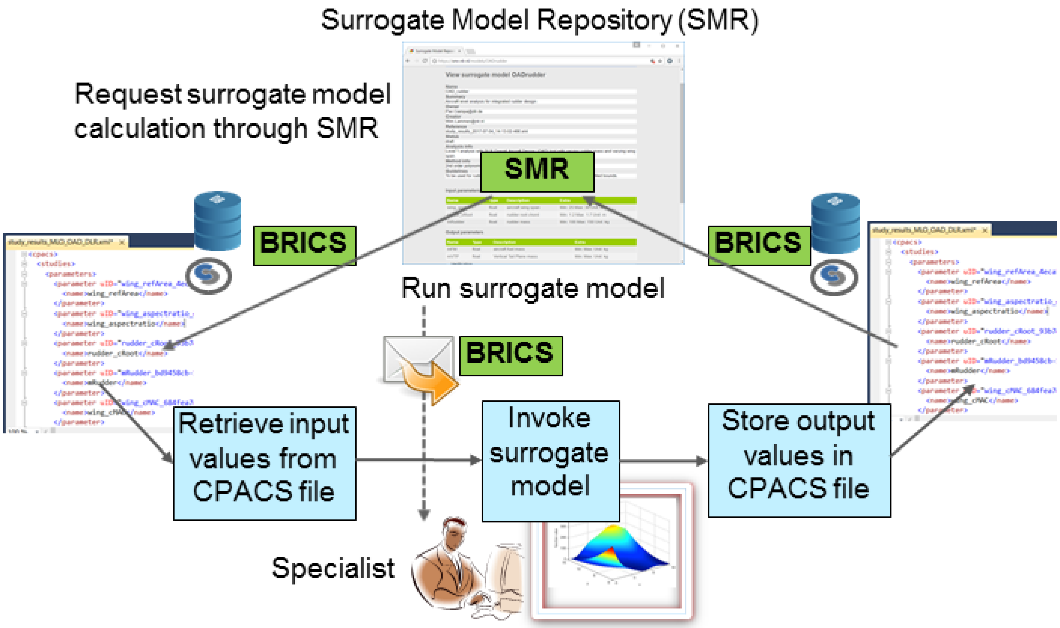

Figure 7: Illustration of the SMR enabling a (remote) calculation with a surrogate model as-a-service, with Brics integrated technology and input and output data implemented in CPACS (XML) files.

The input and output data of the surrogate model are stored in CPACS [14] format, using the specific CPACS 'designStudy' object. As such a list of several combinations of design parameter values (the inputs) can be processed by the surrogate model in one step. The corresponding CPACS files can be both loaded and generated using the SMR. The user can specify the input values manually via the SMR user interface or select and load a specific CPACS file to provide a set of input values. The results of the calculations with the surrogate model (the outputs) are presented to the SMR user interface.
The rudder design has been chosen as example, as this is an AGILE use case. However, the same collaboration method could be extended to any other OEM–supplier relation.

6 SUMMARY AND CONCLUSION

Collaboration within the aircraft development supply chain is essential to face today's challenges of staying competitive and delivering aircraft timely and cost-efficiently. However, many barriers exist that impede the efficient collaboration required by the aircraft industry and its suppliers. The EU-funded H2020 project AGILE investigates and develops technical solutions for facing collaboration challenges.
This paper has presented two practical methods for efficient collaboration. The first method supports the realisation of cross-organisational workflows. The method has been proven to be an effective approach to face the most common collaboration barriers. Its non-intrusive character has facilitated easy integration of different analysis competences implemented within heterogeneous IT environments of multiple partners. Since within this concept the specialist retains full-control over his or her capability, IP protection concerns have been alleviated. Furthermore, automating processes where possible further adds to the efficiency. It reduces the chance of miscommunications and corresponding rework. The underlying Brics technology has been integrated in several PIDO systems, including the RCE and Optimus systems applied in the AGILE context. The resulting cross-organisational workflows have been successfully applied in multiple collaborative design use cases, of which the aircraft systems-of-systems analysis has been illustrated in the current paper.
The second method supports the sharing of design knowledge represented as surrogate models by means of the surrogate model repository (SMR) and provides a complementary approach for efficient collaboration. The SMR specifically takes into account IP issues and facilitates smooth collaboration, e.g. by providing online surrogate model calculations as-a-service and by providing guidance in deploying a surrogate model. Surrogate models provided and managed by the SMR could be used to shield the IP of both OEM and supplier. This would allow for a better collaboration in situations where contracts have not been signed and IP issues can be sensitive. Just as for the cross-organizational workflow method, the application of surrogate models has been shown in multiple collaborative design use cases.
Being part of the collaboration architecture, both collaboration methods follow the AGILE paradigm while also complying with the AGILE knowledge architecture. They provide important building blocks, which can also be combined easily, to enable a more competitive supply chain. Together they address collaboration barriers on the three levels: organisational, human and technical.
In general it has been observed that efficient collaboration is not trivial when engineers from different and usually geographically dispersed organisations attempt to achieve a common design target. Once the collaboration methods are in place, investigation of novel aircraft configurations is enabled by optimally leveraging the dedicated disciplinary knowledge of all involved experts. In the context of use cases being implemented in the AGILE framework, successful and satisfactory applications of the collaboration methods are observed, enabling the aircraft design engineers to join their forces and to accumulate their potentials.
Contributing to the AGILE paradigm and being part of the AGILE framework, the methods will be applied to a multitude of design challenges in the remainder of the AGILE project. Since the application is done through a well-documented and well-established approach, the methods are likely to become adopted in future projects in which a more efficient air transportation system is found through effective collaboration of specialists across all involved disciplines.

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