Dedicated to innovation in aerospace

NLR-TP-2016-377 | October 2016

Streamlining cross-organisation product design in aeronautics

CUSTOMER: European Commission

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EXECUTIVE SUMMARY

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Streamlining cross-organisation product design in aeronautics

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NLR-TP-2016-377

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Problem area

Thermal behaviour has become a crucial topic in the development of modern aircraft. This is due to factors such as an increasing number of complex systems required by modern, more electric commercial aircraft, the introduction of hotter engines with higher by-pass ratios, the increased use of composite material in aircraft structures, and confinement of highly dissipative equipment and systems in smaller areas to earn space for passengers and cargo. New advanced techniques to manage the aircraft thermal behaviour at the early stages of development are essential to take the right configuration decisions while meeting market demands. In particular, the thermal analyses require collaborative effort from the supply chain involved in the development of modern aircraft. Collaborative analyses may be hampered by company intellectual property rights and security policies and by differences in simulation objectives in the supply chain. Effective and efficient technologies are needed to deal with these issues.

Description of work

The TOICA research and technology development project carried out in the Seventh Framework Programme funded by the European Union, focuses on the creation and management of new aircraft architectures, including collaborative thermal analyses and trade-off studies of the architectures. The partners, being members of the supply chain, have jointly defined, implemented and validated methods for supporting design activities. The size and complexity of the aircraft programmes, the market demands and the contexts of competition require the collaboration to be effective and efficient as well. NLR has continued the development of NLR's Brics software tool that supports definition and streamlined execution of cross-organisation modelling and simulation workflows.

Results and conclusions

The work has resulted in an extended version of Brics that has been validated in the context of a pylon design study. In combination with other collaborative design methods, Brics supports the required effectiveness and efficiency of joint design activities across organisations. It responds to the challenges in multi-disciplinary and multi-partner engineering teams achieving cross-organisational simulation workflows while dealing with intellectual property rights and security constraints of the involved organisations.
In the context of the pylon design study, Brics was successfully applied and demonstrated in a multi-partner distributed multi-disciplinary design optimisation workflow, comprising optimization and thermal, aerodynamic and structural analysis running at various partners and locations.

Applicability

Through its support for cross-organisational simulation workflows Brics contributes to effective and efficient collaboration among the supply chains. The capability enables NLR in supporting collaborative modelling and simulation for high level of integrated aircraft design in general, which increases the competitiveness of the Dutch and European aeronautics industry. Brics has been and is being applied successfully in the national TAPAS2 and in the EU Horizon2020 AGILE projects to enable Dutch aircraft industry to participate in national as well as international collaborative engineering workflows.
The generic character of the capability suggests investigating the applicability in other areas, such as automotive and ship-building.

GENERAL NOTE

This report is based on a presentation held at the 6th EASN International Conference on Innovation in European Aeronautics Research, Porto, Portugal, October 18-21, 2016.

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Summary

Aircraft development programmes generally involve collaboration in engineering between different organisations, in order to develop innovative products efficiently, to involve necessary skills from the supply chain, and to spread risks and costs among the partners. The size and complexity of the programmes, the market demands and the contexts of competition all require the collaboration to be effective and efficient. Advances in information technology provide many new capabilities to support collaborative design but a step change is needed to harness and coordinate this support to be effective and efficient.

The extended enterprises in which the collaborative engineering activities take place span the partner organisations. Engineers wishing to cooperate are however facing security constraints. For example, technical security measures such as fire walls and proxy servers hamper smooth exchange of engineering data and seamless execution of collaborative workflows. The restrictions assist organisations in protecting their assets and in remaining compliant with legislation and regulations. From a programme technical point of view, effective and efficient collaboration in this world full of security and the resulting connectivity constraints is a major challenge.

In this paper, we describe the usefulness and necessity of collaboration between multi-disciplinary specialists in aerospace engineering, and the challenges that aerospace engineers are confronted with in this collaboration. We then present a technology that supports aircraft manufacturers and their supply chains in facing the challenge and in performing analyses of innovative aircraft designs collaboratively. This technology has emerged from past research projects, and has been further developed and successfully demonstrated in the TOICA project, a research and technology development project carried out in the Seventh Framework Programme funded by the European Union. We illustrate the developed technology in the context of a multi-partner analysis and optimisation study, which has been conducted as part of a pylon design that is subject to thermal constraints.

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Contents

Abbreviations

ACRONYM	DESCRIPTION
COTS	Commercial Off The Shelf
EU	European Union
FP7	Seventh Framework Programme (funded by the EU)
FTP	File Transfer Protocol
IT	Information Technology
MDO	Multi-disciplinary Design Optimisation
NEO	Airbus' A320 New Engine Option program
NLR	Netherlands Aerospace Centre
PLM	Product Lifecycle Management
SFC	Specific Fuel Consumption
TOICA	Thermal Overall Integrated Conception of Aircraft

1 Introduction

Global air traffic has increased over the past years and is expected to further increase in the next decades (European Commission 2011; Airbus 2016; Boeing 2016). In addition to the growth of air traffic, aviation is facing other issues such as globalization and (world-wide) competition, climate change, societal demands for safety and security, scarcity of resources, and passenger demands for comfort, service and low prices. To deal with the issues, airlines need to accelerate fleet extension and replacement under more and more regulations, requirements and demands. Consequently, aircraft manufacturers and their supply chains are facing a growing need for aircraft combined with a progressive set of challenges that continuously stimulate, or even require innovations. These challenges include increasingly efficient, fast and cost-effective development and manufacturing of more and more complex innovative products while being competitive, being flexible with respect to evolving and changing technologies and requirements, and at the same time taking care of the environment and the reduction of operating costs for airlines.

To accept the challenges and hence to develop innovative products efficiently, to spread risks and costs among the partners, and to involve necessary skills from the supply chain, the organizations involved in aircraft development programmes need to collaborate in engineering. The size and complexity of the programmes, the market demands and the contexts of competition all require the collaboration to be effective and efficient.

Whereas collaboration in computer-aided design is already practiced in the supply chain, the trade-off of designs based on collaborative analysis is only recently emerging, in particular when this involves simulations. Advances in information technology (IT) have already provided many new capabilities to support collaborative analysis of designs in extended enterprises but a step change is needed to harness and coordinate this support to be effective and efficient in realistic industrial use cases. Support for effective and efficient collaborative trade-off, analysis, and simulation has been addressed in the TOICA (Thermal Overall Integrated Conception of Aircraft) project, a research and technology development project carried out in the Seventh Framework Programme (FP7) funded by the European Union (EU) by a consortium of 32 parties under the leadership of Airbus.

The TOICA project focused on the creation and management of new aircraft architectures, including collaborative thermal analyses and trade-off studies of the architectures (TOICA Consortium, 2016). Thermal behaviour has become a crucial topic in the development of modern aircraft. This is due to the increasing number of complex systems required by modern, more electric commercial aircraft, the introduction of hotter engines with higher by-pass ratios, the increased use of composite material in aircraft structures, and the confinement of highly dissipative equipment and systems in smaller areas to save space for passengers and cargo. New advanced techniques to manage the aircraft thermal behaviour at the early stages of development are essential to take the right configuration decisions while meeting market demands. In particular, the thermal analyses require collaborative effort from the supply chain involved in the development of modern aircraft. In TOICA, capabilities have been developed and applied to support the thermal trade-off studies as well as the collaborative efforts from the partners.

Collaborative engineering activities and workflows span the partner organisations that constitute the extended enterprise. Unfortunately, engineers wishing to cooperate smoothly are facing restrictions resulting from security constraints in practice. For example, fire walls and proxy servers hamper seamless execution of collaborative workflows. The restrictions assist organisations in protecting their assets and in being compliant with legislation and regulations. From a programme technical point of view, however, effective and efficient collaboration in an extended enterprise full of security and connectivity constraints is a major challenge.

In section 2, we outline the context of collaborative exchange in aerospace engineering between multi-disciplinary specialists, highlight the issues, and explain the elements needed for an effective approach. In section 3, we describe a technology that streamlines cross-organisation collaborative workflows, and as such that supports aircraft manufacturers and their supply chains in jointly performing analyses of innovative aircraft designs as has been demonstrated in the TOICA project. In section 4, we illustrate the validation of this technology in a TOICA multi-partner distributed analysis and optimisation study of a pylon design that is subject to thermal constraints. In section 5, we summarise and conclude.

2 Collaborative Engineering in Aerospace Development Programmes

Engineering state-of-the-art aircraft, aircraft systems and components in the context of the challenges described in the previous section requires efforts from multi-engineer, multi-disciplinary, multi-site and even multi-organisational teams. The joint result of a team is not just simply a matter of adding the individual results but requires collaboration, which comprises the coordination and use of the available expertise and capabilities to achieve the joint result. In addition, today's demand for being competitive and maintaining industrial leadership requires the collaboration to be effective and efficient, which is a challenge with today's security constraints.

The TOICA project took up this challenge. The project aimed at introducing thermal constraints at the global aircraft level in the early design phases of modern aircraft and at allowing aircraft architects to take into account such constraints during trade-offs between aircraft architectures. Thermal analyses based on simulation of thermal behaviour are therefore already needed in early design phases. Analysis of thermal behaviour of aircraft is inherently multi-disciplinary involving fluid simulation, structures simulation, and systems simulation disciplines. With an increase of the involvement of the supply chain also the accuracy and optimisation performance can be increased considerably. This new way of working has raised specific collaboration issues. TOICA has therefore empowered collaboration between architects, academic and industrial simulation experts from various disciplines, equipment suppliers and IT solution providers.

The new, collaborative way of working exemplified in the TOICA project is based on the creation and management of new aircraft architectures via a so-called "Architect's Cockpit" as depicted in Figure 1. The Architect's Cockpit provides an architect with the ability to define and manage virtual architectures, to set-up and orchestrate studies, to collect and integrate study results, and finally to evaluate the concepts and take decisions. To enable the trade-off studies to be carried out effectively and efficiently, a step change has been required in the way the multi-disciplinary teams in an extended enterprise carry out the studies, which comprise modelling and simulation processes. The TOICA project has developed advanced capabilities to support conducting effective and efficient collaborative studies initiated and controlled from the Architect's Cockpit. The capabilities have been validated on realistic industrial use cases. One of these use cases is the New Engine Option (NEO) use case, which is described in section 4 of this paper.

Although TOICA and advances in IT have provided many capabilities to support collaborative studies, the joint efforts from multi-disciplinary, multi-organisational and multi-site engineering teams in aeronautical industry are commonly hampered by security constraints and protection of intellectual property. It turns out that, despite the available communication and resource sharing capabilities, organisations are protective with respect to access to their own assets. For example, collaborative workflows that involve tools, data and information from different organisations, ideally run seamlessly across the networks of these organisations. With the current complexity of design, analysis and simulation tools and workflows it is, however, difficult to be compatible with the varying security settings and the variety thereof. Engineers are facing unintended security restrictions due to organisational security rules, fire walls and proxy servers, and participation of a partner in a cross-organisation simulation workflow is difficult or even impossible. In some cases, old-school phone calls, e-mail messages, and FTP servers are still used for exchanging information and data, and for triggering the next engineer in the chain, but these are inefficient in view of the increased level of interactions necessary between the collaborating engineers.

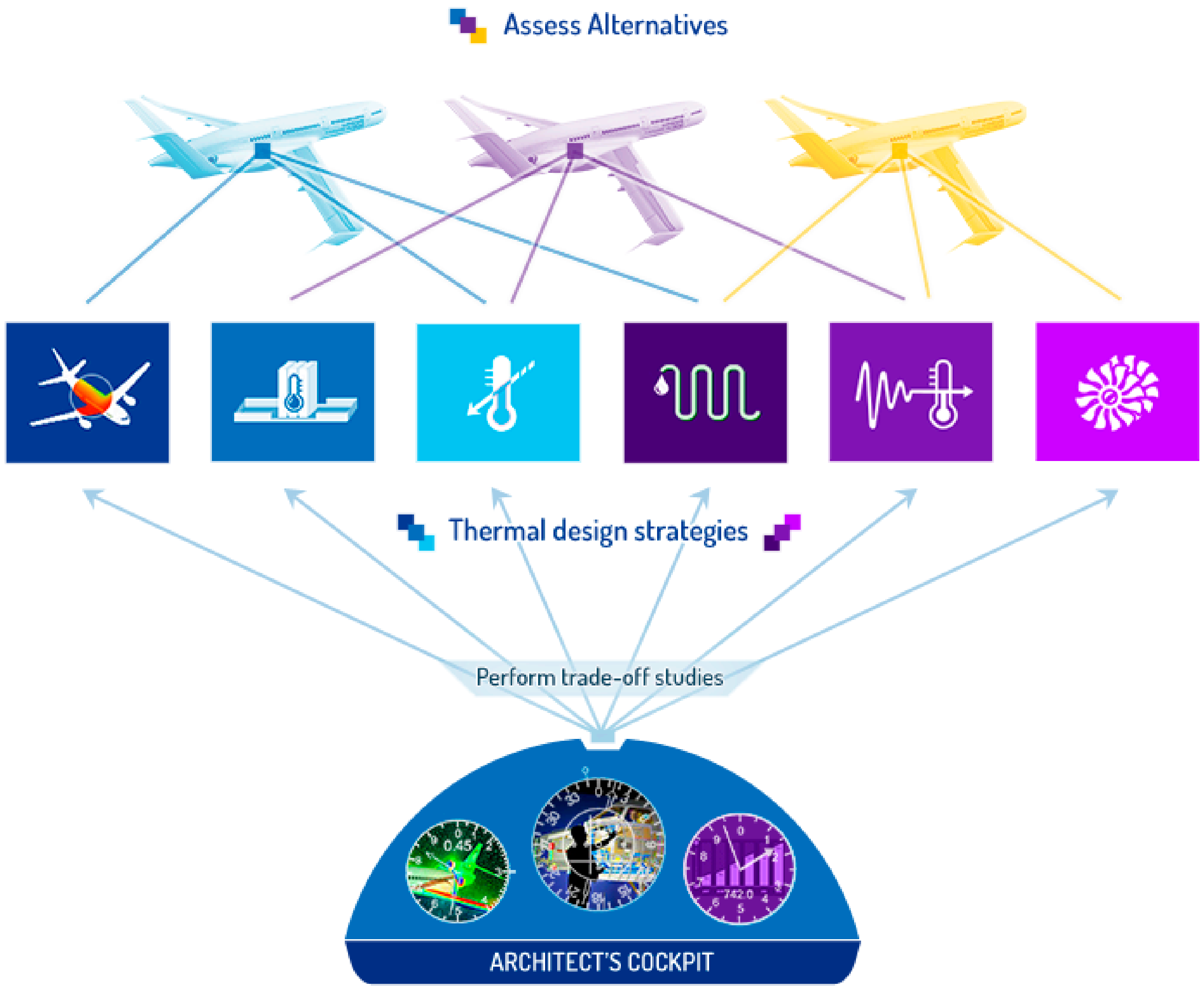

Figure 1: Depiction of the TOICA Thermal Architect's Cockpit that enables collaborative thermal trade-off studies, which include collaborative simulations. Source: TOICA Consortium (2016)

One of the main challenges addressed by TOICA in this respect was to facilitate and streamline the execution of cross-organisation workflows while dealing and complying with the security policy and rules of the involved organisations. In addition the challenges included the requirements to permit the use of independently preferred software tools by each organisation, efficiencies in single-task or multi-task protocols, and high speed data exchanges necessary to support multi-disciplinary analysis optimisations. The technology developed for these – known as Brics - is described in section 3. Its application in the TOICA NEO use case is described in section 4. This NEO use case concerned the design of a modern pylon in a thermally more challenging environment. In this complexity the use case was therefore comparable to a global thermal aircraft analysis to which TOICA was mainly directed. In the context of this NEO use case, many collaboration issues were tackled and solved by application of Brics.

3 Cross-organisation Collaborative Engineering complying with Security Constraints

The issue of cross-organisation activities being hampered by security constraints and measures is not new. Over the years, the issue has been addressed in multi-partner research projects such as CESAR (Baalbergen *et al.*, 2009), VIVACE (Kesseler and Guenov, 2010), CRESCENDO (Coleman *et al.*, 2012), in which solutions for particular collaboration situations have been developed, deployed, and demonstrated. Solving the cross-organisation issues in workflow execution, however, has generally received only marginal attention. Commercial workflow management systems and product lifecycle management (PLM) systems may support collaboration but generally put heavy demands on the interconnectivity of the systems and organisation networks involved. In addition, such systems usually also require the collaborating partners to install and use the same tool, which is generally impossible or at least not appreciated. However, as the demand for effective and efficient collaboration is emerging and consequently the need for streamlined cross-organisation workflows (including optimisations) is growing while the security policies and resulting technical barriers are evolving, there is need for a step change.

NLR has a long history of experiences in supporting cross-organisation engineering activities and workflows, for example in the abovementioned research projects. The knowledge, expertise and reusable solutions developed in the research projects have been collected in an easily deployable technology called ‘Brics’ (Baalbergen *et al.*, 2012; Soemarwoto *et al.*, 2014). Brics is key technology for achieving efficient and secure cross-organisation collaborative engineering, while complying with the security constraints of the collaborating partners. It supports definition and streamlined execution of cross-organisation collaborative workflows, and it bridges the gap between the collaborative workflows on the one hand and the IT and network technologies and tools, security constraints and other cross-organisation issues on the other hand. Brics has evolved “on the job” for more than ten years in several research and industrial projects. Its development has been - and still is - driven by needs and requirements from stakeholders, projects, use cases, and engineering teams that face more and more cross-organisation collaborative engineering efforts being subject to increasing and varying security constraints.

Brics comprises protocols and middleware that enable definition and execution of collaborative workflows. Brics facilitates easy transformation of separated local workflows into collaborative workflows that span the organisations of the collaborating partners. It manages the orchestration of the distributed tasks in the extended enterprise, including the notification of remote engineers and the exchange of data among the tasks. It enables all engineering partners to participate, even if they are “network-access restricted” because of security measures (Baalbergen *et al.*, 2012). Brics allows each partner to have full control over its own computing resources, on-line data, and software tools used on behalf of the collaborative workflow. This means that organisations do not have to put their resources under management of Brics, any cross-organisation workflow or any external coordinating body. The resources may be deployed on behalf of cross-organisation workflows only under full control of the organisation’s own employees. To support this, Brics caters for a “man-in-the-loop”, as is shown in Figure 2.

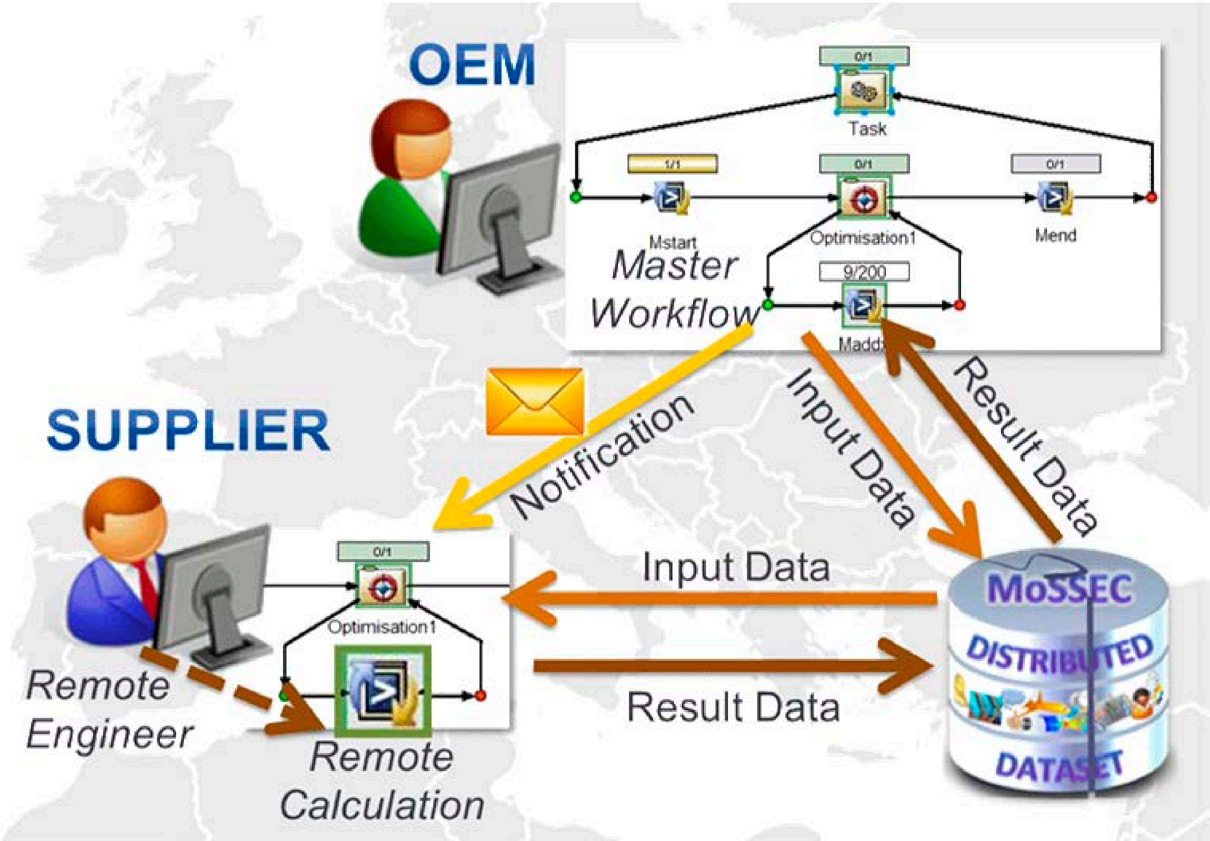

Figure 2: Schematic overview of the basic idea behind Brics: performing a remote calculation from a "master" workflow by sending a notification to a remote engineer, who may decide on whether or not perform an action or a series of similar actions. Brics in addition facilitates the orchestration of the remote job and the data exchanges involved.

Brics is based on a simple protocol that arranges the execution and data flow between an orchestrating (or 'master') workflow in one organisation and a remote engineer in another organisation who is assigned to execute a tool or a part of the workflow. The protocol includes the uploading of the remote task's input files, sending a notification to the remote engineer requesting the execution of the remote task, the synchronisation with the remote task, and the downloading of the remote task's output files; cf. Figure 3. The 'single-task' protocol is suitable for the execution of a single remote task. If the same protocol were applied in a loop, the remote engineer would repeatedly be notified to execute the same task again with slightly different input data. The handling of a consecutive series of similar notifications is cumbersome, time consuming and error prone. Brics has an extended protocol for gracefully dealing with such multi-task jobs. The 'multi-task' protocol centralises the triggering of the remote engineering into a single notification, requesting the remote engineer to execute a series of equal tasks. The protocol furthermore deals with handling the series of equal tasks and the graceful termination thereof. The protocols are described in detail in (Baalbergen *et al.*, 2013).

Being based on Java technology, Brics is operational on a variety of operating systems, including Windows, Linux, and UNIX. Its Java packages and encapsulating tools allow easy integration of its capabilities into Java applications and proprietary, COTS and open source engineering tools and environments, including workflow management, PLM and optimisation platforms. The encapsulating tools include Brics command interpreters that cater for interactive use as well as batch use from within script languages such as UNIX and Linux command scripts, Windows BAT scripts, Python, and Matlab. To support data exchange, Brics is capable of interacting with a variety of data and file servers. Examples are FTP, Microsoft SharePoint, Share-A-space, and shared file systems. Interfaces to other, including new and organisation-specific data exchange services, such as Airbus' FTS+ service, have been and can be added easily at the Brics developer's level. Brics' default mechanism for notifications is e-mail. Brics has provisions for integration with product-specific notification mechanisms.

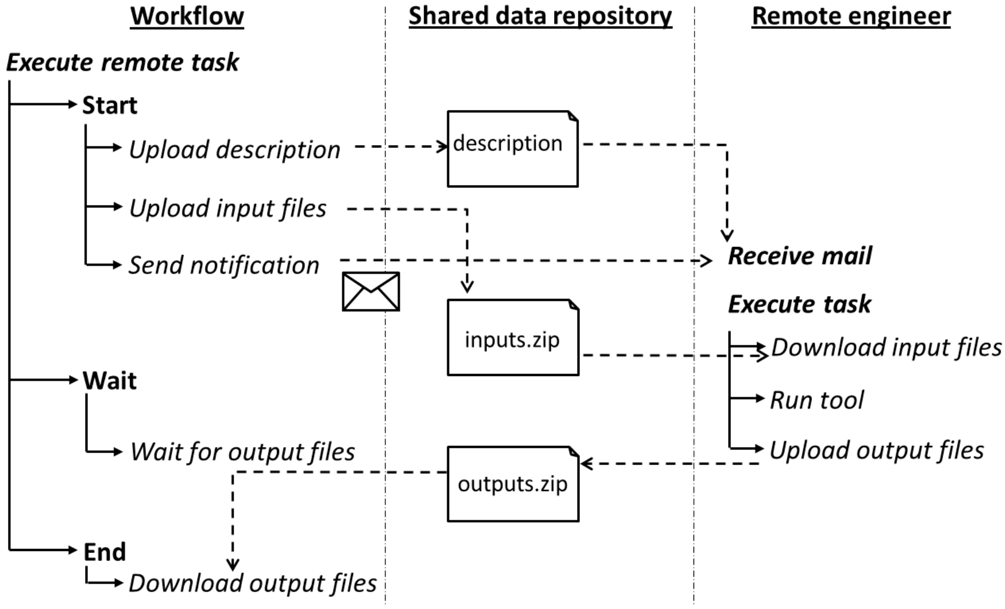

Figure 3: Simplified sequence diagram of the Brics single-task protocol

Brics uses default and standard network protocols, tools and facilities. Application of Brics has minimum so-called connectivity requirements: being able to send and to receive e-mail messages and to upload and to download files to a file or data server that is accessible to at least one other partner. To avoid common misunderstandings, Brics does not "penetrate" fire walls and does not exploit known bugs in networking software or other security means. The communication involved with execution of Brics-enabled cross-organisation workflows is fully transparent and can be explained easily to the involved IT departments and security officers upon request.

Brics can be used in conjunction with existing engineering tools and workflows, and does not require changes of tools, methods, and processes in organisations. Being light-weight, easy-to-install, highly configurable and easy-to-deploy in existing tools and workflows, Brics enables partners to experience collaboration in a flexible and easily accessible way, even in early stages of collaboration and collaborative workflows development, as has been demonstrated in the TOICA project (e.g. Baalbergen *et al.*, 2016), in particular in the use case described in the next section.

4 Distributed Multi-Disciplinary Optimisation to Support Pylon Sizing under Thermal Constraints

4.1 Motivation and background

Recent engine design, for example in the context of Airbus' A320 NEO ("new engine option") program, tends to increase by-pass ratio in order to increase efficiency and to reduce jet noise. Higher by-pass ratios however result in larger engines closer to the wing to preserve ground clearance, and thus in smaller pylon boxes (cf. Figure 4). The enhanced efficiency of new engines also leads to hotter engines. Combined with the usage of new materials with reduced maximum operational limits, the thermal constraints for both structure and equipment installation become critical. In today's aircraft design, complex multi-physics analysis involving multiple disciplines such as thermal, aerodynamics and structural sizing are checked during the detailed design phase. Any issue raised at this stage of the aircraft lifecycle may lead in the worst cases to redesign or to delays and hence to additional costs in aircraft program.

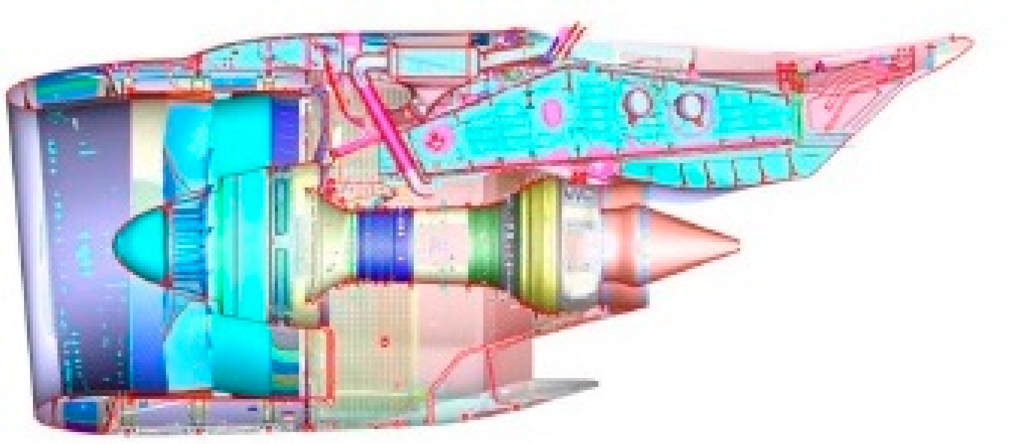

Figure 4: Pylon illustration

The objective is therefore to set up a framework to anticipate such issues in early design phases and to mitigate risks related to late redesign. The framework should provide pylon architects with capabilities to rapidly assess a given design thereby taking constraints from the multiple disciplines into account.

In the EU FP7 project CRESCENDO, a bi-level optimization for aerodynamic and structural sizing of a pylon was set up to balance structural weight and drag count in the pylon design process (Remouchamps *et al.*, 2011). CRESCENDO featured successful demonstrations of collaborative simulation scenarios, with solutions (e.g. Brics) for secure management of distributed data, processes and infrastructures (Coleman *et al.*, 2012). The new constraints emerging from new engine technologies gave rise to taking thermal constraints into account in the pylon sizing process in the early design phases of an aircraft programme.

An environment enabling to conduct an architecture trade-off collaboratively involving multiple disciplines is operated from the aforementioned Architects' Cockpit and is described by Tabaste and Campguilhem (2016). In this section, we focus on the execution of the Multi-Disciplinary Optimisation (MDO) process introduced in that paper. We describe a solution to actually implement and test a multi-objective, multi-disciplinary optimization of a pylon sizing process involving partners in the extended enterprise taking into account structural, aerodynamic and thermal constraints available in the early design phase.

4.2 Implementation of the distributed MDO process

In TOICA, an MDO process was set up to perform a trade-off study of a pylon design, including its thermal influences (Barron *et al.*, 2016). The three disciplines involved in the MDO problem studied were thermal, aerodynamics and structural sizing. The MDO process is illustrated and comprises the steps indicated in Figure 5.

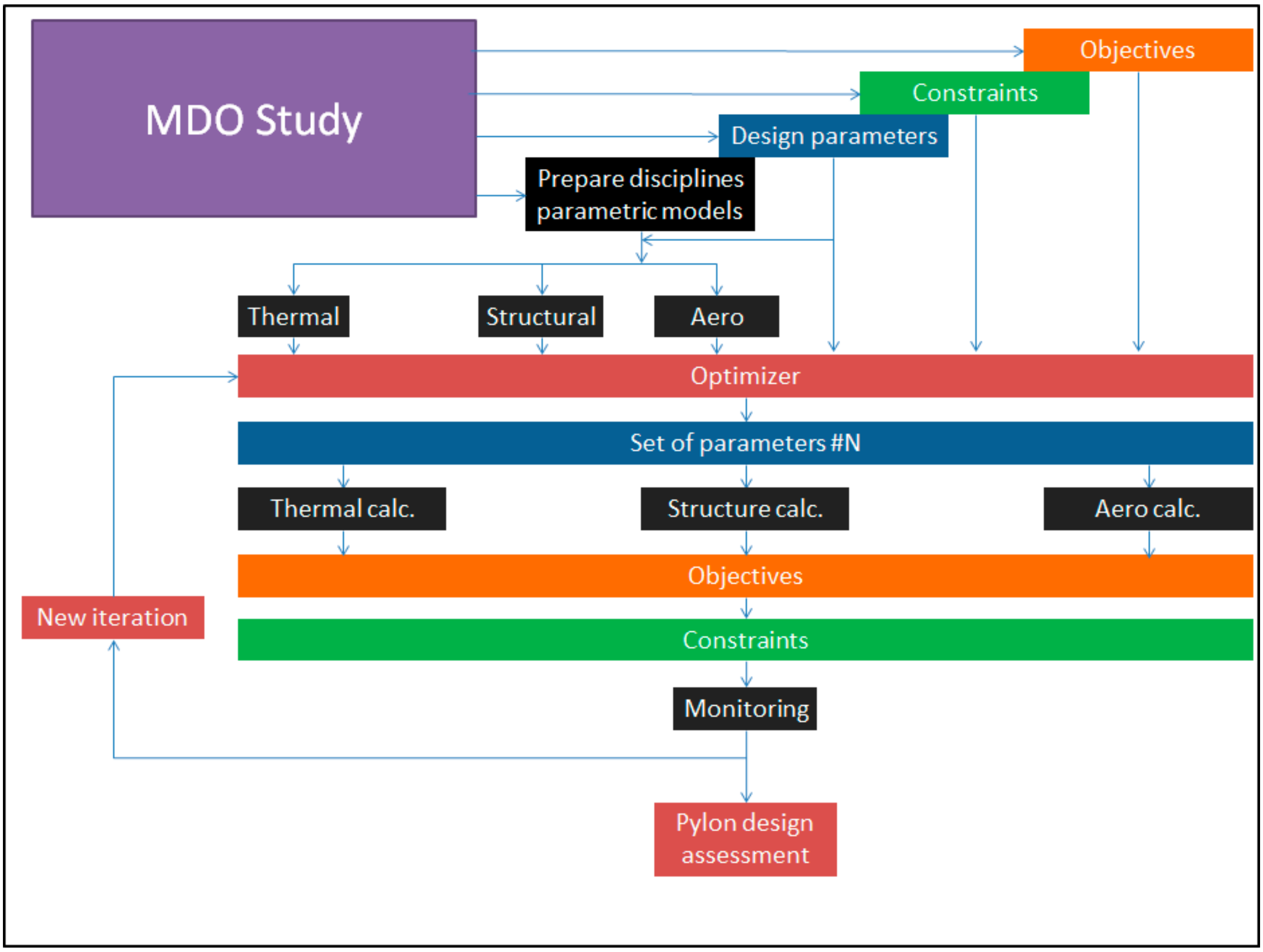

Figure 5: Overview of the overall MDO process that was set up to perform a trade-off study of a pylon design

The trade-off to be performed is identified and a request is sent to a simulation expert. The request enables the simulation expert to set-up the trade-off study. The simulation expert is in charge of preparing the trade-off, by (1) selecting the MDO objectives, (2) selecting the MDO constraints, (3) selecting the MDO parameters, and (4) requesting the experts of the involved disciplines to prepare their models (cf. Figure 6) to be used in the MDO process.

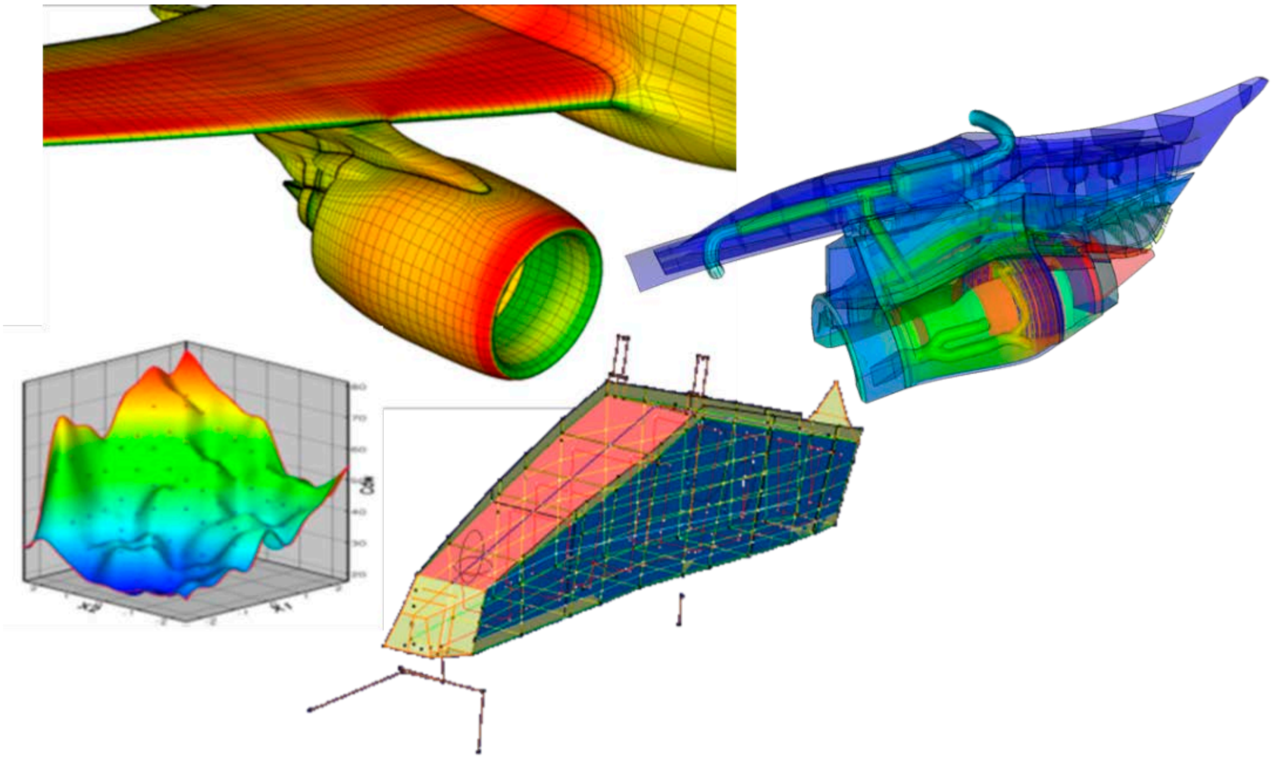

Figure 6: Illustration of models used

In the context of the TOICA project, the trade-off study was formulated as follows:

1. Selecting the MDO objectives: Three objectives were defined: the pylon primary structure weight, the Specific Fuel Consumption (SFC) and the drag. This multi-objective problem could only be solved by involving the three relevant disciplines: the thermal analysis to assess the thermal protection weights and SFC penalties, the aerodynamic analysis to assess the pylon shape drag penalties, and the structural analysis to assess the pylon primary structure weight penalties.
2. Selecting the MDO constraints: Two multi-disciplinary constraints were defined in the MDO formulation - both of them being thermal constraints. In addition, each discipline had its own constraints integrated in its modelling.
3. Selecting the MDO parameters: Five multi-disciplinary design parameters were defined in the MDO study. In addition, similarly to the overall constraints, each discipline also had its own set of local design parameters.
4. Requesting the discipline experts to prepare their models for the MDO process: This process was generic in the sense that all the discipline parametric modelling activities were prepared with their own sets of tools and methods with the required levels of fidelity (from surrogates to state of the art 3D physical models).

The MDO simulation study for the sizing of a pylon is a distributed process. The study involved three disciplines with specific simulation tools and methodologies from different partners across different sites. The workflow to orchestrate the simulations and the iterations needed for the optimisation process is depicted in Figure 7. Brics was used for managing the distribution aspects of the simulation workflow.

In Figure 7 the workflow is initiated by the simulation expert who is in charge of setting-up the MDO study. The study is launched by first notifying the involved discipline experts through Brics notifications sent as e-mail messages requesting the tasks. A task is initiated by, for example, launching a parametric model or by starting the optimizer.

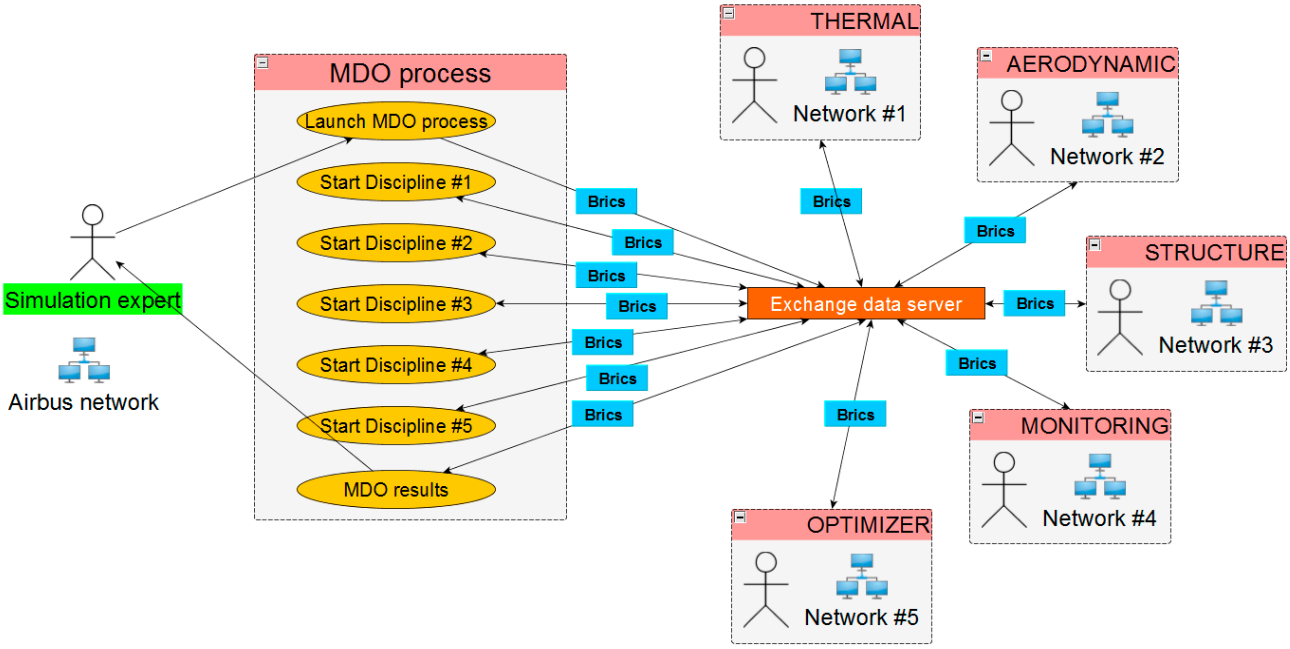

Figure 7: Distributed workflow process diagram for the pylon MDO

Next, Brics manages the task orchestrations and data exchanges involved, by exchanging the input and output data between the distributed tasks, for example, by sending the input parameters from the optimizer to the disciplines and by collecting the discipline results for the optimizer. These high-frequent and fast data exchanges are performed iteratively, for all optimisation loops, and take place via a dedicated data storage and exchange server that is capable of managing the required concurrency and speed of data exchanges.

During the development of the MDO process, several distributed configurations of the MDO process were implemented to identify the best choice for the Exchange data server and its communication with the partners through their firewalls. The partners involved in the several configurations were Airbus (for running the top-level MDO process, monitoring, and the parametric models, in several departments), ONERA (for running parametric models), Cenaero (for running the optimizer). NLR provided Brics and several Exchange data servers. Other Exchange data servers were provided by Airbus and Eurostep. The choice for the Exchange data server was mainly constrained by the required speed of data exchanges and by the security policy of the partners as implemented in their firewalls and the work to make this choice was affected by the limitations in the sharing of information on these communication and security matters. In parallel to these IT aspects of the MDO process, the exchange of the pylon and optimisation technical data of the MDO process was defined and therefore it was useful to be able to test parts of distributed MDO process in earlier configurations.

Finally, the workflow in Figure 7 may be extended with a link to the Product Lifecycle Management (PLM) system to obtain the MDO input data and to store the MDO results in compliance with the overall high level process described by Tabaste and Campguilhem (2016). Brics also provides an interface for exchanging data with PLM systems. This interface has been tested in another TOICA use case, but has not been deployed in the implementation of the distributed MDO process.

The multi-disciplinary workflow has been distributed among the different partners involved in the study and complied with the security constraints of the involved organisations. It enabled all partners to work in their own working environments and according to their own methodologies so that they could manage their own models, data and resources. Brics enabled the workflow being automated from the initial notifications of the experts involved up to the results collection.

4.3 Experiences

The distributed MDO process required the involvement of all discipline experts to perform trade-off analyses, and it gave all partners the freedom to select the best level of accuracy for their analysis with the insurance to be protected against industrial intellectual property issues by keeping their modelling details at their own premises and exchanging only the relevant data for the analysis under their own control. Moreover, it gave the discipline experts the possibility to assess the results of their own models and then properly to validate the outcomes of the study.

The solution developed to obtain the distributed MDO process was non-intrusive, which allowed the selection of whichever methods and tools that were preferred at the discipline levels and for the optimizer. It also allowed the choosing of any preferred technical solution for the orchestration and exchange of data, although requiring some specific developments to exchange the data between the partners. It should be noticed that the security constraints addressed by each partner were difficult to overcome in a cross-organisation study context. Thanks to the flexibility of Brics to adapt to different technologies for data exchange (and the Brics protocols and middleware that was already available for several technologies) it was successful. However security measures are of course subject to evolve and change due to the continuing appearance of new security threats to companies. Hence organisational and policy-related collaboration issues remain to be addressed.

In general, Airbus and other industrial partners are reluctant to share information. Any connection with the external world is perceived by security departments as a potential security breach that can be exploited by competitors. These issues might be perceived as “extreme” and counter-productive for engineers, and may be challenged next by aeronautics. The organisational collaboration issues in aerospace and defence are also addressed in global initiatives, e.g., in the Transglobal Secure Collaboration Program (TSCP) initiative (TSCP, 2015, 2016).

The distributed MDO process for the pylon has benefits both for the aircraft development process and for the aircraft as product. The present way of conducting trade-off analyses during early phases of design is based on sequential processes. Discipline experts work on their side and commit their progresses at identified milestones to provide the architects with the overall view for their design assessment. This way of working is acceptable as long as the right level of expertise and experience from previous programs is satisfied. When architects face a new technical challenge, such as disruptive changes, for which the experience is limited and a constraint becomes a first order for the first time, the risk to have late re-design increases. This collaborative MDO, with direct involvement of the discipline experts from the supply chain in their familiar environments, is a promising way to identify sooner any design issues and improve the technical solutions.

From a process point of view, the distributed MDO process thus contributes to:

- Reducing lead time of aircraft derivative developments by earlier assessment of design risks and by avoiding issues requiring late redesign.

- Increasing design efficiency by permitting a wider range of design options to be considered in the time available – leading to the possibility of selecting a more optimum design.
- Increasing design efficiency by permitting higher fidelity disciplinary analyses to be performed in the time available – leading to reduced design margins.
- Implementing a better traceability in the design process

From a product point of view, the distributed MDO process contributes through its increased design efficiency to improving the performance of an aircraft in terms of payload and range in an early stage of development.

The result of the MDO process is the selection of the best pylon design compromise, regarding the architects' constraints and taking into account the thermal influences. From an industrial point of view, Brics has proven to be a valuable approach for the realisation of the 'distribution' aspect of the MDO process:

- Brics has been applied successfully in the realisation of the distributed MDO process in cross-departmental set ups in a single organisation as well as in cross-organisation set ups.
- Brics provides a non-intrusive solution. It does not require updating simulation tools or the optimizer.
- Brics is flexible as it enables setting up the right scenario which can be as complex or as simple as needed.
- Brics is also flexible in the sense it can use multiple technologies to exchange data, varying from general purpose data-file exchange solutions such as FTP to specific and dedicated PLM systems and data management tools.

5 Summary and Conclusions

In this paper, we have described the need and the context of collaboration among multi-disciplinary specialists in aerospace engineering, and we have highlighted that inevitable security constraints often appear to hamper the collaboration by company-dependent limitations on data exchange. We have described the Brics technology that supports aircraft manufacturers and their supply chains in running collaborative workflows as part of joint analyses of innovative aircraft designs, thereby dealing with the security constraints.

We have summarised that Brics comprises protocols and middleware that enable definition and execution of collaborative workflows. Rather than being an "ivory tower" product, Brics has evolved on the job, driven by needs and requirements from stakeholders that increasingly face cross-organisation collaborative engineering. With these protocols and middleware the data exchange between partners in collaborative workflows can be built quickly, while respecting the security constraints. Brics has been further developed and successfully applied for realistic industrial use cases for thermal trade-off analyses in the EU FP7 project TOICA. We have illustrated the application of the technology in the context of a multi-partner distributed optimisation study and trade-off analysis by simulation of the behaviour of a pylon design that is subject to thermal constraints. We have identified the benefits for the aircraft development process and for the aircraft as a product.

We conclude that collaborative thermal analysis by simulation offers significant benefits to master thermal challenges for new (derivative) aircraft developments, to reduce development risk, to increase design efficiency and to improve aircraft performance. This innovative and more intense collaborative way of working between discipline experts for architects requires new tools. The collaboration has to cope with constraints at the companies due to their solutions to handle their issues with the digital world, such as intellectual property protection, security leaks prevention and compliance with export control rules enforced by governments. Within these changing and company specific digital environments Brics has proven to ease the collaboration for discipline experts. It brings a solution enabling each discipline to focus on its own methods and tools while exchanging their technical results in a streamlined manner. Architects can then combine the experts' engineering results with actual product constraints to better assess the overall performance of the product as per high level requirements and objectives.

Collaborative analysis by simulation is not only beneficial to master thermal challenges but is beneficial for new aircraft designs with increasingly interacting systems/equipment/parts and multi-disciplinary assessments. Organisational and policy-related collaboration issues remain important, company-dependent and subject to change due to on-going security developments. Further application and development of Brics is therefore continued in new consortia with other aircraft development applications such as in the H2020 AGILE project that targets multidisciplinary optimisation using distributed analysis frameworks with realistic overall aircraft design tasks for conventional, strut-braced, box-wing and blended wing body configurations as use cases (AGILE, 2016).

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