# Automated Selection of Airliner Optimal On-board Systems Architecture within MDO Collaborative Environment

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## ABSTRACT

The test case described in the paper is a multidisciplinary, distributed, design optimization aimed at the identification of the best on-board system architecture for a regional airliner on the basis of its production and operative costs.
A key requirement was to integrate in a collaborative, multidisciplinary environment the analysis modules needed to investigate the effects of the chosen architecture on engine performance and actuator fairing design. The final objective is to determine if the higher installation and development costs of innovative architectures are paired by a lower operative cost due diminished fuel consumption (function of engine configuration and aerodynamic properties).
The collaborative MDO has been implemented using a commercial PIDO, Optimus by Noesis Solutions; this has been used to connect four different analysis tools (developed and operated by Politecnico di Torino, Leonardo Aircraft-Alenia and CIAM) adopting the communication protocols developed within the European Project AGILE. Only the integration platform, the connection protocols and the design tools are described in the paper; the complete distributed MDO is currently in the validation phase.

**KEYWORDS:** *Automated Design; Design Optimization Environment; MDO; On-Board Systems Design; Surrogate Model.*

**NOMENCLATURE**

AEA – All Electric Aircraft
AGILE - (Aircraft 3rd Generation MDO for Innovative Collaboration of Heterogeneous Teams of Experts)
CPACS - Common Parametric Aircraft Configuration Scheme
DLR – German Aerospace Center
DOE – Design of Experiment
EM – Engine Module
MEA – More Electric Aircraft
MDA – Multidisciplinary Design Architecture
MDO – Multidisciplinary Design Optimization
OBS – On-Board System
PIDO – Product Integration and Design Optimization
SFC – Specific Fuel Consumption
SM – Surrogate Model
SOA – Service Oriented Architecture
SOTA – State Of The Art

## 1 INTRODUCTION

Current aircraft designers have to address new competitiveness and environmental constraints aimed at the design of less noisy and expensive, as well as of more fuel-efficient, airplanes: these considerations have influenced not only engines, structures and aerodynamics, but also the on-board systems [1].
Thanks to the development of new technologies, innovative concepts like "More Electric Aircraft" (MEA) and "All Electric Aircraft" (AEA) have enriched the on-board systems design discipline. These new architectures potentially offer significant advantages over conventional ones [2], however evaluate their effectiveness is far from trivial due to the number of influenced global aircraft design elements [3] as engine performance, additional fuel weight, installation volume of the implants, aircraft reliability and safety, required electric, hydraulic and pneumatic power and their conversion, aerodynamic friction on engine nacelle, air-intakes and actuator fairings [4].
In order to be evaluated, all these aspects require different specialists with detailed competences and analysis tools. Parametric models and interaction schema commonly applied to the preliminary design phase [1] are typically tailored on convectional OBS architectures, thus they cannot fully describe the much more in-deep changes introduced by the switch from conventional to MEA or AEA.
Furthermore, only large companies and organizations have the financial resources required to maintain internal design teams able to cover all the engineering aspects associated to an airliner development; in most of the cases, sub-contractors or research institutes have to be involved to assess specific tasks [5].
This cooperation makes modern aircraft development a collaborative and multi-organizational design process that would benefit from the creation of standardized integration platforms and protocols; the development of these collaboration methodologies is one of the main objective of the AGILE project [6][7]. Once completed, the 3-years long project will enable the 3$^{rd}$ generation of multidisciplinary design and optimization through efficient collaboration among international, multi-site, aircraft design teams.

The interfaces and discipline-connection technologies assessed within the AGILE project by the end of its second year have been used to set up the current test case, specifically dedicated to investigate the OBS architecture fall-outs. To this end, 4 analysis tools dedicated to OBS, engine, external aerodynamic and costs have been improved and connected. Once validated, the constructed MDO will allow analysing the impact of the chosen on-board system architecture on the overall aircraft design with a higher fidelity than traditional conceptual design tools. It will also permit the identification of the most affordable solution considering the full extent of the airliner foreseen lifetime.

The test case relies on existing state of the art analysis tools and the focus has been put on their integration in a new, flexible, collaborative architecture, able to capture the significant aspects of the OBS-engine design influence since the conceptual stage of the aircraft development. The modularity of the implement approach will also allow for the future, independent development of the design tools to improve the accuracy and the validity of the performed analysis.

The paper has been organized as follows: section 2 describes collaborative MDO and existing problems, section 3 briefly reports how these challenges have been addressed in AGILE, section 4 introduces aircraft OBS and their effect on aircraft design, section 5 presents the implemented collaborative MDO test-case, section 6 illustrates the preliminary results achieved and section 7 anticipates the undergoing and future developments.

## 2 COLLABORATIVE MDO

The setup of a collaborative MDO is a key step in order to ensure the success of the design phase [7]. In the easiest scenario imaginable, all the design tools have been purposely build for the specific MDO problem, thus they are available within the same environment, have been developed by cooperating teams with well-defined competencies using the same architectures and methodologies, therefore there are limited issue related to communication between teams, or information exchange among tools. This scenario is also extremely unlikely: due to the time and effort required to develop and validate analysis tools and models, most MDO problems are addressed using a combination of general-purpose (often customized) and in-house developed software created for wider range of objectives by heterogeneous teams.

Two main cross-influencing communication issues emerge: between experts and between their tools. It is mandatory to efficiently bridge not only the product models and simulation capabilities but also to merge the competences of the different experts [7]. This include the arrangement of compliancy with regulations; the conclusion of contracts to define the costs and work distribution, hierarchies, responsibilities and communication lines; and agreements on the disclosure of information and knowledge, dissemination of the results. Then more human related aspects of collaboration have to be addressed, which include communication issues, differences in technical background and methodologies, variations in perceived priorities, naming conventions and unit of measurements, lack of awareness of each other's specific competences. All these aspects have to be acknowledged; pretend to solve all the listed issues would not be reasonable and often only mitigation strategies can be implemented [8].
Then the technical level of the multi-designer collaboration can be taken into care. Engineers will have to agree on set-up of joint models; connect possibly heterogeneous working environments and operating systems; coordinate the simulation campaigns; define data exchange formats, tools connection protocols. These challenges have been already investigated in other EU-funded projects, such as VIVACE [8], CESAR [9] and CRESCENDO [10] which had, among their objectives, the development of methods to support efficient multi-engineer collaboration.

A still existing obstacle is represented by the dynamic IT environments; organizations are constantly increasing their self-protection implementing layers over layers of security constraints as network restrictions, proxy servers, and firewalls that, in spite of agreements and contracts, make the set-up of a collaborating environment extremely difficult and resource-consuming [8].

## 3 AGILE FRAMEWORK

AGILE [6] (Aircraft 3rd Generation MDO for Innovative Collaboration of Heterogeneous Teams of Experts) is an EU funded project under the research schema Horizon 2020 and coordinated by the German Aerospace Center (DLR). AGILE is developing the next generation of aircraft Multidisciplinary Design and Optimization processes, which target significant reductions in aircraft development costs and time to market, leading to cheaper and greener aircraft solutions [6]. The aim of the project is to create a collection of methodologies and software to facilitate the communication among the design

teams and to integrate heterogeneous tools in a flexible, collaborative, multidisciplinary design environment.
The project is structured into three sequential, one year-long, phases, each targeting design campaigns with increasing levels of complexity while the framework is being built and upgraded. During Phase 1 and 2 the distributed MDAs for 2 regional turbojets have been developed and tested, while Phase 3 is dedicated to the application of the Paradigm to non-conventional configurations (as blended-body wing aircrafts, advanced turboprop, drones and Prandt-wings).
The project is intended as a technology demonstrator; the objective is to develop methodologies to efficiently and reliably create executable multidisciplinary, distributed, design architectures. The operation of the MDA and the optimization of the aircraft design itself are not the main objectives. For the same reason, included analysis tools were already available and, although some of them have been improved during the project [11][12], this was not the main purpose.

### 3.1 Framework approach

The AGILE development framework is based on a system-wide approach of Service Oriented Architecture (SOA) in order to improve the integration of engineering services within development workflows. This implies that every specific activity, from the run of a simulation tool to the post-processing of the results, has to be wrapped to create a module with standardized interfaces and access protocols, thus making it possible to develop complex functionalities by connecting these simpler 'building blocks'.

In collaborative MDO several types of participants can be identified, according to their role, each operating within a specific step of the overall development. This arbitrary function-based separation within the AGILE project has led to the identification of the participative agents illustrated in Figure 1.

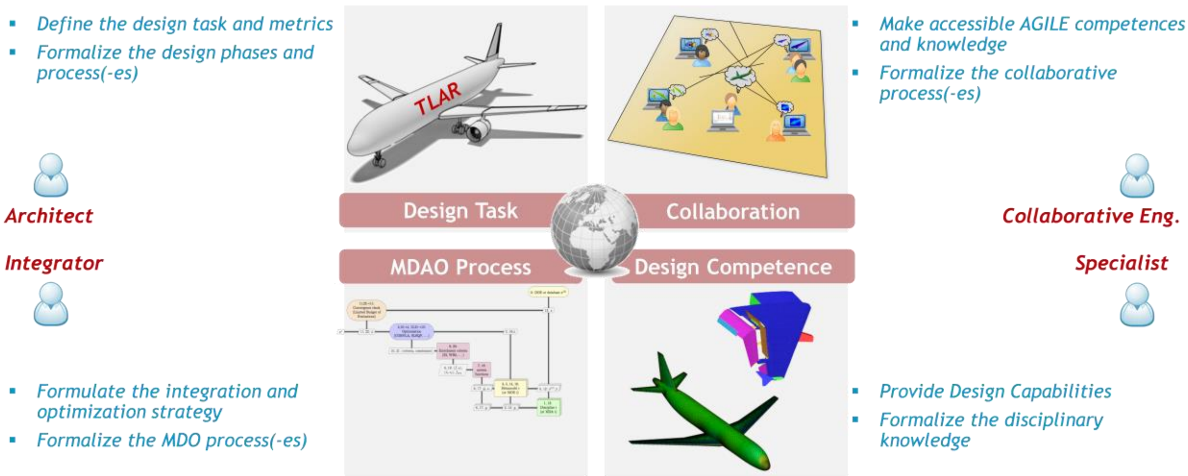



**Figure 1: Participative agents identified within AGILE.**

- *Architect*. Responsible for specification of the design case in the AGILE framework, such as collecting the required competences, defining the design phases and the dimensionality of the design space to be explored.
- *Integrator*. In charge for the deployment of the design and optimization (sub-) processes, and for the management of such processes within the AGILE framework. IP protection is also administrated.
- *Collaborative engineer*. Responsible for providing the integration within the framework, necessary to connect the various competences and making them accessible to the framework. It includes the secure integration of software apps in different networks.
- *Competence specialist*. Responsible for providing design competence within the framework, such as a simulation for a specific domain, or an optimization service. Specifications of the competences are managed in the AGILE development framework.

A fifth role, not included in Figure 1, is required in order to set-up and run the collaborative MDO: the *Customer* (and primary user of the framework), who is responsible for defining the design task, top-level requirements, and available development lead-time. It interacts during the operational phases, for instance to access the final or partial results, and to participate to the decision making process.

A mandatory precondition to enable the collaborative MDO is that every simulation capability is wrapped as an automatically executable engineering service. This provides the means to efficiently perform integrated design studies using distributed simulation workflows. The encapsulation procedure is aimed at avoiding the non-creative, repetitive, and error-prone manual data conversion steps, tool executions, and data exchange. The overall objective of the SOA implementation is to generate modular systems where every component can be interfaced, reused, upgraded and replaced independently.

### 3.2 Connection Protocol

In the AGILE Paradigm, procedures has been defined both to request a particular service execution (needed to integrate the service in the MDO) as well as to provide the service itself (by the design specialist). The two scenarios have been schematically depicted in Figure 2.
In this example, the process integrator (left) defines and deploys a design and optimization workflow in the *administrative domain 1*, characterised by 3 *local services* located within the same domain and 1 *remote service* (e.g. another organization network). The connections represented by means of arrows depict the data exchange between the services.
The *remote service*, indicated in green, represents an engineering capability within *administrative domain 2* (right). The input and output data needs to cross administrative domains when a remote design competence is included in the workflow. To allow for this data to be securely exchanged, a neutral domain is established, consisting of a central data server (that enforcing authentication and access-control mechanisms prevents the potentially confidential design information from being accessed by third-parties) for the instantaneous exchange of data.

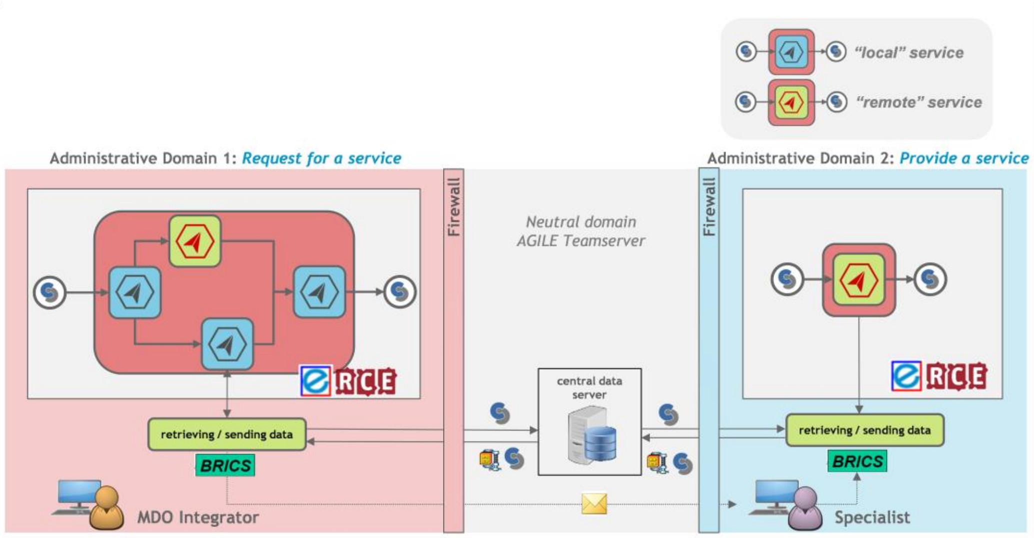



**Figure 2: AGILE Collaborative Architecture. Service oriented scenario.**

When the remote service is triggered, the required input data is uploaded to the central data server and the specialist receives a notification informing him/her that a single run/multiple runs of his/her tool is/are needed. The execution of the service is not automatically started as the control of the tool itself is always retained by the specialist. Only when the execution is started, data is automatically downloaded from the central data server and provided to the tool under consideration. After

execution, the enhanced results are automatically fed back to the central data server and automatically retrieved within *administrative domain 1*.
In AGILE this interconnection capability is provided by the NLR's software Brics [9][13]. It comprises protocols and middleware that facilitate remote execution of sub-processes from within a process, independent from the local PIDO environment being used.

### 3.1 Data exchange format

In order to minimize the number of interfaces between the services a common language has been selected to descript the MDO product. The AGILE project is aircraft dedicated, thus a non-completely neutral format has been selected, named Common Parametric Aircraft Configuration Scheme (CPACS)[14]. It has an xml-like structure which can be used to extract the input for the multiple design competences as well as to provide the output from the design competences. Although each design competence may provide additional data, in proprietary formats or other standards, the exchange between services is only via CPACS.

### 3.1 MDO implementation

The overall MDO structure could be implemented using almost any available scripting language; however such approach would result in cumbersome, time consuming, hard to debug and not easily understandable codes that could be adapted to different scenarios (as tools replacements or change in optimization strategy) only with a significant effort.
Process Integration and Design Optimization (PIDO) have been preferred to compose the MDO process. The exploitation of a common data format and a neutral communication protocol allow for implementations on different platforms to coexist in the same collaborative architecture as there are no direct links neither between different tools, not between design processes and MDO. Thanks to the dedicated PIDO interfaces it is possible to re-configure almost effortlessly existing design problems, adding, removing or exchanging tools. They also enable to analyse and explore the design space in order to gain the critical insights of the dynamics of the virtual design problem. Additional technologies, to enable the automatic construction of the MDA from tool input and output knowledge and architecture are under development [15].

## 4 AIRCRAFT ON-BOARD SYSTEMS DESIGN

The availability of more accurate, reliable and faster software and the progresses in IT infrastructures has made possible the execution in a reasonable time of complex analysis not just during the detailed design but also during conceptual and preliminary phases. This improved capacity has only partially influenced the definition of the OBS which, during conceptual design phase, are mainly considered for their weight using parameterized formulas based on literature data [1]; only from the subsequent preliminary design phase, architecture, required power and volume are taken into consideration.
However, in order to obtain a more integrated and optimized design since the conceptual phase, parameters and cross-influences traditionally considered only in later development phases are now at least partially [16] evaluated also during conceptual design. In the on-board systems case, these include (but are not limited to) supplementary fuel weight needed to supply them, installation volume, impact on aircraft reliability and safety, influence on performances.
In the last years, several technologies related to OBS have been developed, making new architectures a feasible alternative to traditional ones; the general trend is toward the electrification of the services, from actuators to air-conditioning. As shown on the left side of Figure 3, for SOTA architecture, the systems require hydraulic, electric and pneumatic power. The first two are derived directly from the mechanical power gathered from the engine (or the APU) by accessory drive gearbox whereas pneumatic power is generated using bleed air from engine compressor stages. Innovative architectures implement several variations of the concept presented on the right side of the same figure, characterised by a shift toward electric powered systems. The final users are still activated by the same power used in the SOTA architecture, but the mechanical power is the only one taken

directly from the engine and then converted into electric power. Electric motors are used to generate the non-electric power where needed. The rationale that justifies this approach is to minimize the impact on engine design (thus cycle efficiency [17]) with air bleed off-takes [18][19. Additionally distribution systems for electricity are lighter and safer than for pressurised fluids.

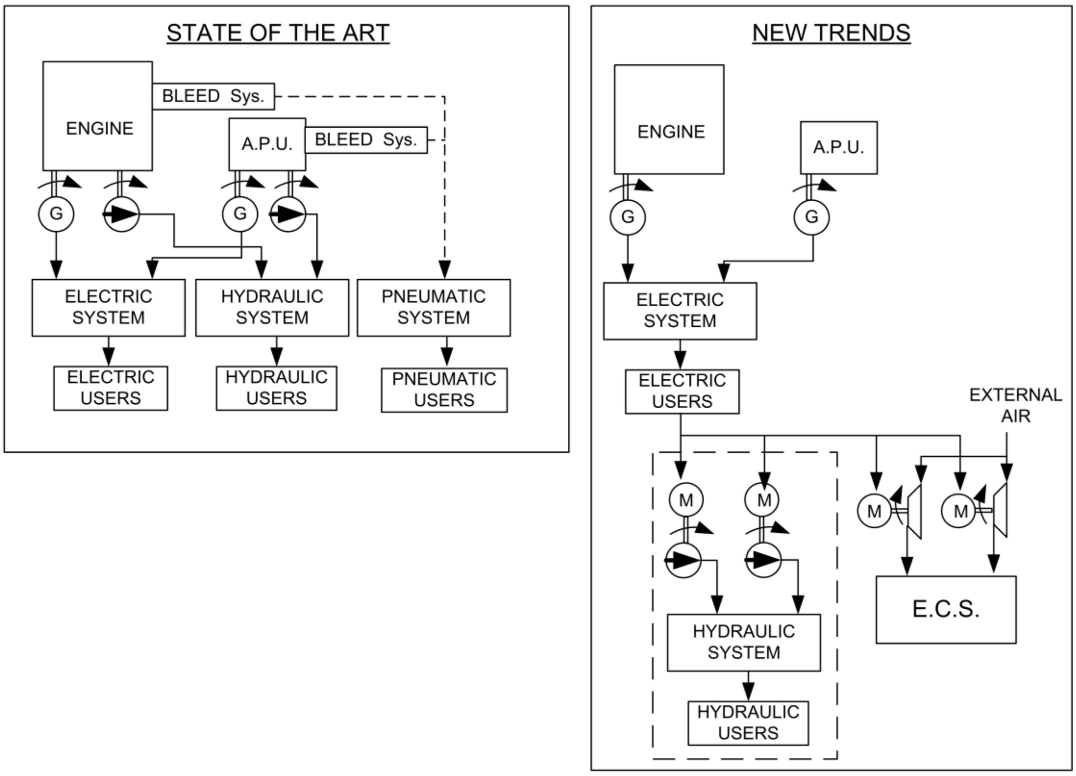



**Figure 3: State-Of-The-Art and New trends On-Board systems architectures.**

Regardless the power conversion strategy used, the starting point is always the engine, in the form of non-propulsive power that has to be extracted and converted. The specific architecture determines the magnitude of the following influences:

- Amount of additional fuel that has to be carried to ensure the engine capacity to operate as power source.
- Engine specific fuel consumption (affected by mechanical power off-takes and bleed air extraction [18] [19]).
- Engine configuration.
- Systems weight.
- Aircraft reliability and safety (due to the number of redundancy lines for electric, pneumatic and hydraulic power systems)
- Operative costs (logistic reliability).

In order to extract mechanical power from the shaft and pressurised air from the compressor stages, the engine has to be equipped with adequate interfaces; these have a direct impact on the engine efficiency. Consequently to maximize the performance, the engine designer has to consider the on-board system architecture; bleed-less configuration airliners like the Boeing 787 have purposely developed engines, based on conventional engines [19].
The balance between the three types of non-propulsive power, the sequence used to generate them, and the served utilities, determine the hardware configuration; e.g. an AEA is likely to be more fuel efficient and less maintenance intensive, but heavier due to the limitations of SOTA electrical actuators in force over weight ratio [19]. The total fuel consumption is affected too, due to variations in induced drag (related to systems weight) and in friction drag (affected by air intakes, nacelles and fairings size) [18]. In turn, fuel consumption and systems weight could lead to a cascade effect on structures, available volumes, lifting and control surfaces etc.

In force of the highlighted effects, depicted in Figure 4, it is essential to select (or at least to streamline) the candidate OBS architecture(s) as earlier as possible in the aircraft design process. The comprehensive evaluation of the afore-mentioned dependencies leads to a multidisciplinary design problem in order to be correctly assessed.
In this study, as the objective is to test and validate the collaborative MDO approach on a simplified, but still representative test case, only the direct influences on engines, aerodynamic and performances with respect to a nominal configuration have been included. This is not to be considered a limitation as, due to the modular nature of the approach adopted, additional elements could be added in the future.

The multidisciplinary design architecture (MDA) itself has been developed with the support of Leonardo Aircraft (formerly -Alenia Aermacchi) due to their expertise in aeronautical industrial design processes. A short description of each tool (dark grey blocks) is reported hereafter:

- ASTRID, in-house software conceived and realized by Politecnico di Torino, is a Matlab-based tool aimed at the preliminary design of the aircraft on-board systems. ASTRID inputs define the systems characteristic (like hydraulic pressure value, landing gear or control surfaces actuator technology, de-icing method) and estimates weight, mechanical shaft power off-takes and bleed off-takes. It includes methodologies to evaluate masses and secondary power requests both for conventional and innovative systems, such as MEAs and AEAs. Other details about ASTRID and the implemented design modules are reported in [20].

- The Engine Module (EM) developed by CIAM is based on the commercial software GasTurb v12 [21]. It is capable of running engine design and performances simulation with variable level of details. The preliminary design achieved using the EM includes constraints and aircraft generic information to perform engine cycle design, off-design simulation and engine overall geometry and mass assessment. The results of the EM feature the estimated engine deck properties (installation losses, flight envelope, intake pressure recovery description, thrust reverser ability, technical deliveries, performance for different operating conditions, dimensions description, sizing rules, automatic handling of air bleed). A comprehensive description of the engine model can be found in [22].

- Leonardo Aircraft developed an aerodynamic module, based on the reference aircraft, to evaluate the variations in viscous friction due to changes in actuator fairing surface and systems air intakes size. The CFD simulation is based on a reference aircraft and is adapted to match the different designs produced by the other tools. Due to the complexity and time required to update and re-mesh the model, the tool has not been integrated in the MDA as remote service. Instead, a fixed number of simulations for different combination of the input parameters have been performed off-the-loop and the results have been used to create a surrogate model.

- The cost module, a Matlab script, estimates the acquisition and operating costs of the proposed architecture considering on-board systems weight and additional fuel quantity for secondary power [23]. It has been developed by Politecnico di Torino.

As illustrated in Figure 4, the general inputs that characterize the reference aircraft are provided to ASTRID along with a specific set on data that defines the OBS architecture. Upon evaluation, the estimated systems volume, systems power/bleeded offtakes and systems mass are forwarded to the other modules. The drag variation module calculates the additional drag due to actuator fairings and systems air intakes. The drag data, combined with aircraft description and systems power/bleeded off-takes are used to investigate the engine performances; the engine module is able to assess both additional fuel required for power the systems and to produce the additional thrust required because of the drag increment. The engine parameters as geometry and total thrust are considered fixed inputs.

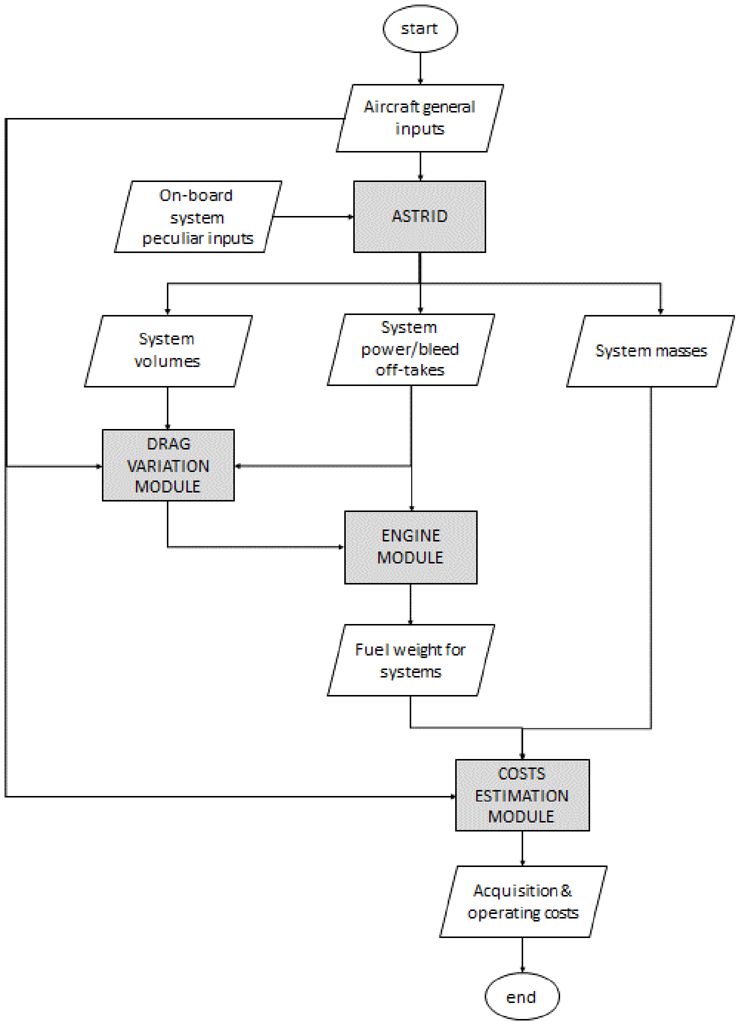



**Figure 4: Interaction schema of the MDA components.**

Finally, the total fuel required by aircraft systems, the engine fuel consumption and the systems weight are used by cost module to estimate the systems acquisition and operative costs.

## 5 COLLABORATIVE MDO IMPLEMENTATION

The MDA depicted in Figure 4 has been implemented into a functional workflow using the collaborative MDO methodology developed in AGILE; the objective was to convert the abstract connection schema into an actual collaborative workflow as in Figure 5. The identified agents involved were:

- *Architect*: Politecnico di Torino and Leonardo Aircraft
- *Integrator*: Noesis Solutions
- *Collaborative engineer*: Noesis Solutions
- *Competence specialist*: Politecnico di Torino, CIAM and Leonardo Aircraft

Politecnico di Torino also acted as main *Customer*.
The design starting point is a reference aircraft used in AGILE named DC-2 (from Design Campaign 2, a model that has been created to test the effectiveness and the reliability of collaborative MDO). In terms of size, configuration and performances is a regional airliner: range 3500 km, 90 passengers, design payload 9180 kg, cruise Mach .78, maximum take-off mass of 45046 kg, wing span 28.4 m [6].

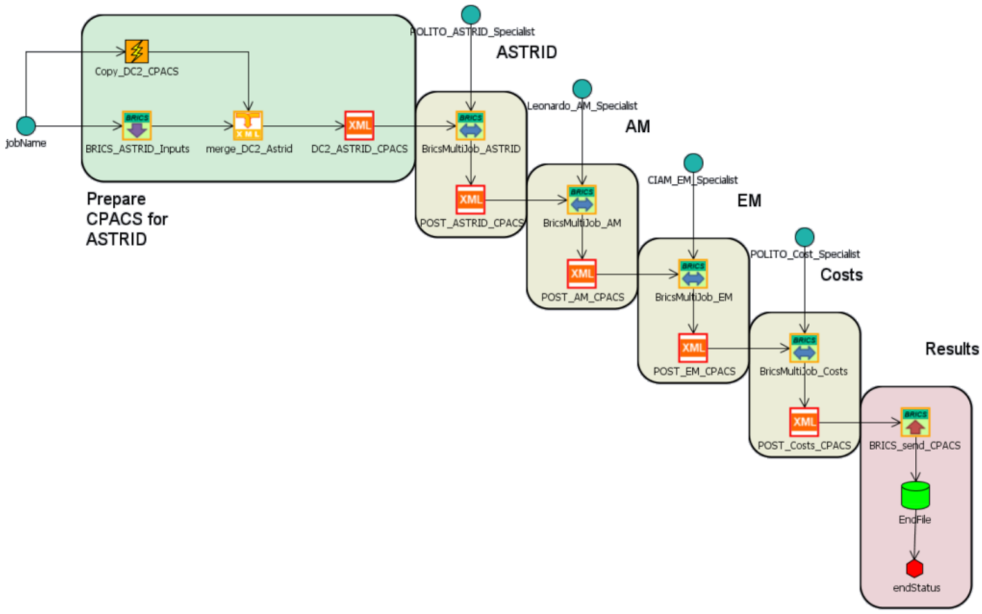



**Figure 5: Implemented MDO workflow.**

With their leading role of architects, Politecnico di Torino and Leonardo identified the relevant influences between the on-board systems choice and the other disciplines. The input/output relationships reported in Fig. 4 as connection lines, looks less articulated in the collaborative, Fig. 5. This is permitted by the common data format, CPACS, that collects the results and increases the stored knowledge: with this approach, ASTRID, although not connected explicitly with the cost module as in the conceptual MDA, is still able to provide information to it. The collaborative MDO has been built by the integrator (Noesis) that acted also as Collaborative Engineer. Politecnico di Torino created Optimus workflows to embed its tools whereas the two other involved disciplines (EM and Leonardo CFD) resulted to be computationally expensive and not easily automatable; in order to reduce the execution time, both have been replaced with functional models.
The entire MDO has been set up to be operated with Brics and CPACS not just to trigger the tools execution: the workflow exchanges information with the Customer using the collaborative protocol. Thus the complete MDO can be operated as a service and therefore integrated into a larger MDA.

### 5.1 MDO Disciplines

The disciplinary tools required minor adjustments to be executed as services: the information had to be retrieved from the CPACS file and mapped to the tool-specific input format and the Brics connection had to be established; to this end, template Optimus workflows have been used.

The en-capsulated ASTRID workflow has been reported in Fig. 6; the tool-specific components are those within the yellow box. The two Brics interfaces connected to it are required to perform the download and final upload of the enhanced CPACS file. The orange blocks map the data between Optimus and CPACS. Aircraft general inputs, such as Top Level Aircraft Requirements, airplane dimensions and geometries (e.g. fuselage length, wing area), design weights as maximum Take Off and Operative Empty are among the extracted data that are forwarded to the OBS design module. The values for engine power off-take, bleeded air and total estimated OBS mass are specified in the returned CPACS file.

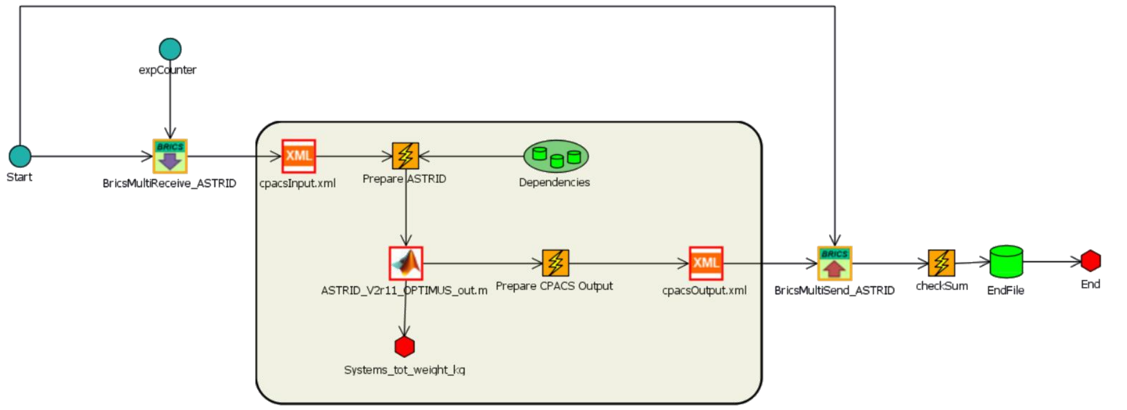
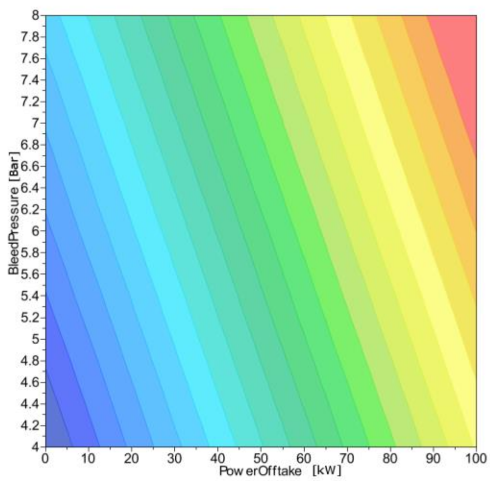



**Figure 6: ASTRID tool wrapped using Brics interfaces.**

The Aero Module is able to calculate the additional drag due to on-board systems. The two main contributions are due to wing actuator fairings and air intakes necessary to cool down the systems. The additional drag due to actuator fairings is related to the fairings dimensions hence, the actuators dimensions. The air intakes drag is calculated starting from OBS power off-takes. Statistically a certain part of the power produced by subsystems is lost in heat. Therefore, some external air is required and it is provided by means of several air intakes. Their dimensions and quantity (i.e. their additional drag) can be estimated staring from the systems power off-takes.
Due to the complexity of automatic mesh generation, the module was replaced by a surrogate model. A preliminary analysis using ASTRID was performed to determine the domain of the AM input variables; the information was used to build a DOE to extract the significant aspects of the AM. The evaluations performed were used to construct an interpolated SM that was wrapped using Brics to be executed upon call from the MDA.



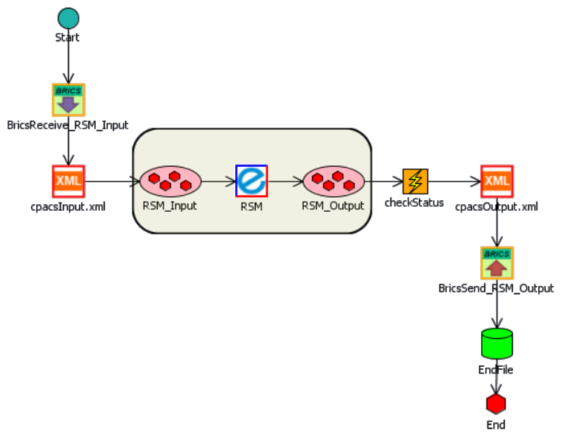




**Figure 7: Engine Model, Specific fuel consumption variation (left) and implemented collaborative workflow (right).**

Similarly to the Aero Module, also the Engine Module was replaced with a SM, Fig. 7. The engine surrogate model was modeled in Optimus by importing the DOE data and using one of the already available interpolation models [16]. The model was validated before its deployment using both cross-validation and comparison of predicted and off-point calculated values (from samples not included in the model construction). The EM surrogate was embedded into a workflow with Brics and CPACS compatibility. The inputs extracted from the CPACS are altitude and Mach number, power off-take, bleeded-air pressure and flow. The specific fuel consumption and the fuel flow required to supply power to the systems are included in the output file.

The last module is the cost model, which, given the systems weight and the fuel quantity for secondary power, estimates the acquisition and operating costs of each system architecture. This model is based on the costs estimation methodology proposed in [15] modified and updated to consider the inflation and the acquisition cost of novel technologies. This depends on the technology level of the sub-system, their "quantity per aircraft" and the number of production units. Concerning the operating cost, the implemented module evaluates only the fuel cost overlooking the other items of the direct operating cost in this conceptual design phase. To balance the acquisition cost with the operating cost, the model is set to calculate the operating cost considering the entire life cycle (about 120000 flight hours).

In this test-case, the main design parameters used to define the on-board system architectures have been identified as:

- Power supply (electric or hydraulic) of Flight Control System, Landing gear (retraction, steering, braking).
- Hydraulic system pressure (207 or 344 bar).
- Braking system pressure, (207 or 344 bar).
- Electric voltage (115 VAC or 235 VAC).
- Primary electric machine (Integrated Drive Generator or Permanent Magnets Alternator + AC/DC converter).
- Pneumatic system architecture (bleed air off-take or bleedless configuration).

These parameters allow for a good characterization of the OBS; the total number of possible combinations is 512. It is not required to explore all of them as some are either equivalent or not relevant: if all the users have electric actuators, the pressure of the -not installed- hydraulic system is unimportant. The 16 unfeasible combinations have been identified and reject rules have been implemented in the Optimus workflow in order to rule them out.

## 6 COLLABORATIVE MDO EXECUTION

The collaborative MDO is currently under validation. Preliminary evaluations have been performed in order to test the validity of the approach and its real capability to investigate the impact of the different architectures. The results achieved are in line with those previously obtained using a non-collaborative workflow, without CPACS, Brics components and the Aero module [25][26]. The information exchange between ASTRID and the EM was performed using Optimus-native variables with the output knowledge stored in dedicated local files. This customized procedure, although easier to implement for MDA characterised by few tools, suffers from limited readability and when applied to complex problems could result in hidden bugs and inconsistencies. Additionally the lack of Brics interfaces, or other equivalent technologies, demanded that all the tools were on the operated workstation. The development of methodologies to address these limitations would not have been possible without a dedicated workgroup as the AGILE project.

In spite of the lack of definitive results about optimal on board system architecture, several lesson have been learned:

- The collaborative MDO methodology developed within AGILE allows for a significantly higher degree of flexibility. The exploitation of the CPACS as unique file grants both a compact data storage and a more understandable sequential information enrichment process. It also allows for easier replacement of a specific tool with no changes in the MDO.
- The collaborative MDO has faster construction and re-configuration times and grants connection with any matching tool; this largely outmatches the execution overhead caused by the Brics interfaces (a remote execution using the automated data upload and retrieval takes about 10 seconds more than the equivalent local one).
- Leonardo as industrial partner with experience in aircraft design highlighted the necessity to validate not just every step of the MDA construction procedure but also the analysis results.

In particular during the execution the specialists must have the possibility to inspect both provided inputs before analysis and results before CPACS upload. The rationale is that even when the communication protocols and integration methodologies are executed correctly, it is still possible that unforeseen interactions between the tools generate results that are either wrong or non-relevant. This is particularly true during DOE when the extremes of the design variable domains are explored. Design tools used in the industry have to pass a rigorous validation and certification procedure. The same philosophy has to be applied to the combination of tools, as the MDA. This is a considerable obstacle to the deployment of the framework into in an industrial contest.

- The neutral domain used to exchange file was not accessible by partners with particularly strict IT infrastructures or restrictions about information exchange without a clearance. To this end, the exploit of surrogate model allowed to (partially) overcome these limitations.
- Developed Surrogate Models required versioning and metadata association to keep track of the specific simulation parameters used to generate them.

## 7 FUTURE DEVELOPMENTS

The current test-case has to be considered as the starting point for more a comprehensive evaluation of the impact of the on-board system architecture on the aircraft performances. Previous analysis [25][26] have highlighted that estimated acquisition and operation cost for different configurations can be similar, thus efforts will be dedicated to investigate the accuracy of the cost tool and its sensibility to the specific components that define the architecture. In parallel the updated AGILE methodologies will be integrated in the current framework.

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