Integration of on-board systems preliminary design discipline within a collaborative 3rd generation MDO framework

INTEGRATION OF ON-BOARD SYSTEMS PRELIMINARY DESIGN DISCIPLINE WITHIN A COLLABORATIVE 3RD GENERATION MDO FRAMEWORK

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Abstract

The integration of the on-board systems design discipline in a collaborative Multidisciplinary Design and Optimization (MDO) framework is presented in this paper. The collaborative MDO framework developed within the context of the EU funded H2020 AGILE project is selected as reference. The technologies developed or made available in the context of the AGILE project are employed for the integration within the MDO framework of ASTRID, an on-board systems design tool owned by Politecnico di Torino. The connection of the tool with a common namespace (i.e. CPACS) and its implementation within two Process Integration and Design Optimization (PIDO) environments are described. An application study is eventually presented, showing the benefits and the potentialities of the integration of the on-board systems design discipline within a collaborative MDO framework.

1 Introduction

The aircraft design is a complex process that encompasses several disciplines. The integration of the design disciplines within an aircraft development process is not a trivial task, due to all the contrasts and conflicts among them. In this regard, many studies of the international community are addressed to the Multidisciplinary Design and Optimization (MDO) research field since the last decades. MDO techniques indeed aim at overcoming the contrasts among all the design disciplines, eventually determining the optimal design solution, which represents a compromise among all the disciplinary solutions [1].

Due to the high potentialities of MDO, lots of initiatives are currently arising targeting the conception and development of MDO frameworks. MDO frameworks tackle the integration of several disciplinary tools within an MDO context. Potentials of MDO frameworks are promising in academic and industrial contexts. Piperni *et al*. discuss the importance but also the challenges associated to the adoption of MDO frameworks within the aerospace industry [2]. Several examples of MDO frameworks are available in literature, for instance PrADO [3], OpenMDAO ([4], [5], [6]) and MICADO [7]. In particular, Ciampa *et al*. underline an evolution of the MDO frameworks [8]. The authors claim that newer MDO frameworks – which according to the paper belong to the 3rd generation – tackle the integration of a higher number of disciplinary competences. Therefore, these kinds of frameworks would include hundreds of specialists belonging to different specialized organizations. However, 3rd generation MDO frameworks are affected by several non-technical barriers, which hamper the collaborative design. As presented by Belie [9], non-technical barriers encompass the management of large quantities of data, the complexity and size of the MDO problem, the difficult collaboration among experts with different idioms, culture, education and skills.

In this context, the EU funded H2020 AGILE project [10] targets the realization of a 3rd generation MDO framework, tackling many of the aforementioned collaborative challenges. The AGILE collaborative MDO framework encompasses several disciplinary competences owned by European, Russian and Canadian partners from the academia and industry. Several disciplines are included within the framework, e.g. aerodynamics, structures, propulsion, flight mechanics, mission simulation, costs and emissions. One of the novelties of the AGILE project is the integration of the preliminary on-board systems design discipline within the MDO framework. The on-board systems discipline is indeed deeply influenced by the other design disciplines. In turn, the on-board systems discipline impacts the main results of the Overall Aircraft Design (OAD). In this regard, it is worth noting that about 30% of the aircraft Maximum Take-Off Mass (MTOM) is represented by the on-board systems masses ([11], [12]). A significant impact at aircraft-level is represented by the secondary power, i.e. electric, hydraulic and pneumatic power taken from the engines to supply the on-board systems. In general, the fuel burnt for the generation of secondary power off-takes represents up to 5% of the total mission fuel. Furthermore, the on-board systems design discipline impacts aerodynamics (e.g. due to flap fairings), aircraft geometry, flying qualities, Reliability, Availability, Maintainability and Safety (RAMS) considerations, costs. It is therefore important to perform a more detailed on-board systems design within an OAD context since the earliest phases of the design process [13]. With this aim, several MDO frameworks are present in literature addressing the preliminary on-board systems design within a multidisciplinary context. Among all these frameworks, it is worth mentioning here the solution proposed in [14], which aims at investigating some effects at aircraft-level – e.g. masses, fuel consumption, aerodynamic drag – due to both conventional and innovative on-board system architectures (e.g. More/All Electric aircraft). Another example of integration of the on-board systems design discipline within an OAD framework is proposed by Lammering [15]. In this case however, more emphasis is put on the multidisciplinary aspect of the aircraft development process, as a tool for the on-board systems preliminary design is integrated within MICADO environment. Analogously, other MDO frameworks that deeply focus on the on-board systems design results at aircraft-level are described in [16] and in [17]. Nevertheless, all these cited frameworks are realized by on-board systems design specialists. A lot of emphasis is put on the on-board systems design module, while the other disciplinary tools are generally represented by low-fidelity codes. For instance, the fuel burnt for the generation of secondary power is typically evaluated employing empirical equations (e.g. [18]) and simple physics-based algorithms (e.g. [19]). Alternatively, higher-fidelity tools are employed, as GasTurb ([20], [21]). However, the correct setup of the tool and interpretation of the results should be made by a propulsion expert. Therefore, a 3rd generation MDO framework would bring to an enhancement of the OAD process and better assessment of all the impacts of on-board systems design at aircraft-level.

The integration of the on-board systems design discipline within the AGILE's collaborative 3rd generation MDO framework is therefore the main and original contribution of the present paper. In particular, the entire process followed to correctly connect the on-board systems design with all the other disciplines is hereunder presented, facing all the related challenges due to the inclusion of several experts into the development process. An overview of the AGILE's 3rd generation MDO framework is presented in Section 2, while a deeper description of the on-board systems design discipline is provided in Section 3. Section 4 is entirely devoted to the integration of the on-board systems design discipline into the AGILE's collaborative MDO framework. A demonstrator of the described integration is then provided in Section 5. The paper eventually is concluded presenting future improvements of the proposed work (Section 6).

2 AGILE's collaborative 3rd generation MDO framework

As previously introduced, the H2020 AGILE project aims at developing next generation aircraft MDO processes, targeting the reduction of the time-to-market and development costs, and addressing the design of more cost-effective and more environmentally friendly solutions [22].

In particular, the AGILE consortium is developing techniques that would enhance the collaborative aircraft design and optimization among a distributed team of disciplinary experts belonging to different organizations. All these techniques are collected within an original methodology developed during the project: the AGILE Paradigm. All the main elements composing the AGILE Paradigm will be described in the following Section.

2.1 The AGILE Paradigm

The AGILE Paradigm consists of two main elements: the Knowledge Architecture (KA) and the Collaborative Architecture (CA).

The KA is deeply described in [23]. It formalizes the overall aircraft development process as a hierarchical layered-structured process. In more details, the KA defines the levels and the interfaces among them needed to the setup and execution of collaborative design and optimization tasks performed by multiple teams of experts.

The CA instead provides the methods and the tools enabling the multi-experts and cross-the-nation MDO process [24]. In particular, multiple are the technical solutions made available to the AGILE consortium for the enhancement of the collaborative process. These technical solutions are employed in this work for the integration of the on-board systems design discipline into the collaborative framework.

First of all, a product data model schema is adopted as common language among the different experts for the sharing of aircraft data (e.g. requirements, specifications). The Common Parametric Aircraft Configuration Scheme (CPACS) [25] developed by the German Aerospace Center (DLR) is employed as product data model schema. The CPACS is an .xml file needed to provide the disciplinary tools with the input required for their execution. Once the tool have completed the analyses, the obtained results are saved into the CPACS file. In this way, the interfaces among all the disciplinary tools are drastically decreased, and the exchange of data is standardized.

The second element needed to setup a collaborative 3rd generation MDO framework is represented by a PIDO (Process Integration and Design Optimization) environment. The PIDO environments enable the implementation and execution of the workflows containing the disciplinary tools. Within the AGILE project, two PIDO environments are employed. The former is the “Remote Component Environment” (RCE) developed by DLR [26]. The latter is the software Optimus, provided by NOESIS [27].

Another technology made available to the AGILE consortium is a module aimed at interconnecting disciplinary tools owned by different disciplinary specialists and hosted in different locations, complying with all the IT security constraints. This interconnection module is named BRICS [28], and it has been developed by the Netherlands Aerospace Centre, NLR.

The last technical solution is a data server accessible by all the project partners for the exchange of data obtained through the disciplinary workflows. Within the AGILE project, a dedicated Microsoft SharePoint server has been set up for this purpose. This server is named AGILE Teamserver.

2.2 Agents participating in a collaborative MDO framework

The collaborative aspect of the 3rd generation MDO process entails the joint effort of different experts with different development tasks.

Therefore, five types of agents involved within a collaborative MDO framework are identified in AGILE, each one performing a dedicated role.

The customer is one of the five agents. He is the primary user of the MDO framework. The customer is responsible of defining the design task, determining the Top Level Aircraft Requirements (TLARs).

Another agent is represented by the architect, who is in charge of collecting all the required design competences and defining the dimension of the design space to be investigated.

The deployment and management of the design and optimization processes are responsibility of the integrator.

The fourth agent is the collaborative engineer, who is responsible of connecting all the various competences and making them accessible to the framework.

Eventually, the disciplinary analyses and simulations are performed by the competence specialist. The authors belong to this category, as they provide their expertise on the preliminary design of aircraft on-board systems. The present paper is therefore mainly focused on the tasks performed by this agent of the collaborative MDO process.

3 On-board systems design discipline

The importance of the on-board systems design in a multidisciplinary context has already been stated in the introductive Section.

Before the integration of the on-board systems design into a MDO framework, it is important to investigate on how much the on-board systems design influences the other design disciplines. Analogously, the impact of the design disciplines on the on-board system design should be investigated as well.

Therefore, the following Sections assess the integration of the on-board systems design discipline into a multidisciplinary framework. Moreover, a brief overview on an in-house tool aimed at preliminarily designing the on-board systems is provided.

3.1 Integration of the on-board systems design into a multidisciplinary framework

The integration of the on-board systems design discipline into a multidisciplinary framework requires first of all a qualitative assessment of all the main impacts of the aircraft systems discipline on all the other design disciplines. Many are indeed the on-board systems design variables impacting the other design disciplines, as described in [29]. However, the current Section is limited to only three on-board systems: Ice Protection System (IPS), Environmental Control System (ECS) and Electric Power Generation and Distribution System (EPGDS).

The main design choice of the IPS is represented by its technology. Several options are possible for this on-board system. Conventional IPS solutions are characterized by a pneumatic configuration (aerothermal or with inflating boots), while innovative systems are electric. In both cases, the propulsion system is affected by the power demanded by the IPS, due to the hot airflow bled from the engine compressors or the additional electric generation required by the electric resistors of the innovative system. The aerodynamics and thus the flight performance might be influenced by the IPS technology, as well. In particular, aerodynamic drag of the wings can be obviously incremented by inflating boots [30].

As well as the IPS, the ECS is deeply influenced by the system technology. In particular, new "bleedess" configurations aim at increasing the efficiency of the propulsion system, therefore reducing the needed quantity of mission fuel and consequently the Direct Operating Costs (DOCs). However, this innovative solution negatively affects the aerodynamics of the airplane, as additional drag is generated by the dedicated air intakes of this innovative solution [31]. Also the structural design and the maintenance operations are influenced by the ECS, more specifically by the level of the cabin air pressure, as it influences the comfort inside the cabin but it affects the fatigue life of the fuselage [32]. The passengers comfort is also negatively affected by the percentage of cabin air recirculation, as only part of the airflow is renewed [33]. However, the efficiency of the engines is improved by the percentage of air recirculation, as it entails a significant reduction of the extracted secondary power.

Finally, the attention in this paper is posed on the EPGDS. The main electric voltage (e.g. 115 V AC or 270 V DC or 235 V AC) influences the system weight, thus impacting on the structural design [11]. However, the increment of the electric voltage peculiar of newer solutions might impact the safety and the schedule of the maintenance operations. Also the costs of the electrical equipment are impacted, even if benefits at aircraft-level are commonly envisaged, as reduction of maintenance costs and improvements in reliability ([34], [35]). Furthermore, the number of distribution lines and the number of components – namely generators and hydraulic pumps – influence the aircraft empty weight, but also the airplane safety level and the maintenance tasks.

A summary of the on-board systems (IPS, ECS and EPGDS) design variables influencing the other design disciplines is reported in Table 1.

Table 1. Summary of disciplines influenced by IPS, ECS and EPGDS design [29]

On-board systems	Design variables	Design disciplines: Aerodynamics	Structural design	Flight control, stability	Propulsion	RAMS, costs
IPS	System technology (standard, innovative)	•		•	•	•
ECS	System technology (standard, innovative)	•		•	•	•
	Cabin pressure during cruise		•			•
	Percentage of recirculating air				•	•
EPGDS	Supply voltage		•			•
	Number of lines and generators		•			•

3.2 ASTRID: an on-board systems design tool

Several on-board systems design tools have been developed by the aeronautical community in the last years. Models for the preliminary estimation of conventional and innovative on-board system masses and power off-takes have been proposed by Liscouët-Hanke [36], Lammering [15] and Chakraborty [37].

A tool for the preliminary design of aircraft systems is being developed by Politecnico di Torino since the last years. This tool is named ASTRID (Aircraft On Board Systems Sizing and Trade-Off Analysis in Initial Design). A detailed description of the tool and the implemented design routines is provided in [38] and [29]. Nevertheless, the present paper focuses on the algorithms for the preliminary mass and power off-takes estimation of the IPS, ECS and EPGDS.

As previously claimed, ASTRID can be employed for the development of both conventional and innovative on-board systems. Therefore, in case of design of a conventional pneumatic aerothermal IPS, the airflow $\dot{m}_{ice}$ [kg/s] required by the system is computed by means of equation (1), where $\dot{q}_{tot}$=10 kW/m^2 is the heat flow per unit area [39], S_{ice} [m^2] is the area of the surface to be protected, c_p=1.005 kJ/(kg·K) is the air specific heat at constant pressure, T_{pn} (K) is the air temperature of the pneumatic system and T_{ice} (K) is the ice temperature.

$$\dot{m}_{ice} = \frac{\dot{q}_{tot} \cdot S_{ice}}{c_p \cdot (T_{pn} - T_{ice})} \quad (1)$$

An innovation of the IPS is represented by its electrification. In other words, the surface is protected by electrical resistors, identifying two areas (see Figure 1). Continuously heated areas are constantly de-iced, while the latter are cyclically warmed up. Two different flows per unit area characterize the two areas (Continuously heated areas: 18.6 kW/m^2 [40] or 11.82 kW/m^2 [41]. Cyclically heated areas: 34.1 kW/m^2 [40] or 27.25 kW/m^2 [41]).

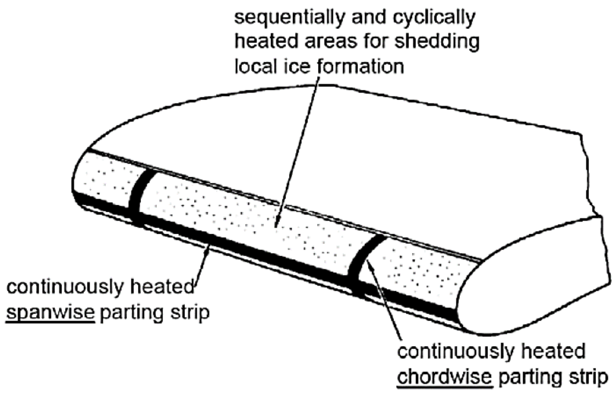

Figure 1. Electrically protected areas on the wing surface [41]

Regarding the IPS mass, algorithms for the mass estimation of conventional aerothermal systems are available in literature (e.g. [42], [43] and [44]). However, these methodologies can't be employed for the innovative electric IPS. Therefore, its mass should be estimated if the density of the conductive layer is known. Otherwise, to a first approximation the mass of the electric IPS can be assumed equal to 60% of the mass of the equivalent aerothermal system, relying on the results estimated in [45].

The procedure for the dimensioning of the ECS instead starts from the estimation of the total thermal load (w_{TOT} [kW]) inside the cabin. The method proposed by Martinez [46] can be adopted for this purpose. Given the total thermal load, the temperature of the air entering inside the cabin (T_{ic} [K]) and the target temperature in cabin (T_{cab} [K]), the airflow ($\dot{m}_{ECS}$ [kg/s]) required by the system is computed:

$$\dot{m}_{ECS} = \frac{w_{TOT}}{c_p \cdot (T_{ic} - T_{cab})} \qquad (2)$$

The obtained airflow is then employed for the estimation of the airflow ($\dot{m}_{PN}$ [kg/s]) that should be extracted from the engines compressor – in case of conventional system – or provided by dedicated compressors (for "bleedless" configurations). This airflow is calculated through equation (3), where the percentage of recirculation $\%_{rec}$ ranges between 0% and 50%, according to the technological level of the ECS.

$$\dot{m}_{PN} = \dot{m}_{ECS} \cdot (100 - \%_{rec}) \qquad (3)$$

Furthermore, it should be noted that the result of equation (3) shall guarantee a minimum of 0.00415 kg/s of fresh air per person on board, in compliancy with the regulation [47]. In case of innovative "bleedless" configurations, the airflow $\dot{m}_{PN}$ is employed for the sizing of the electric-driven dedicated compressors, determining the required electric power ($P_{ECS_{compr}}$ $[kW]$) according to:

$$P_{ECS_{compr}} = \frac{\dot{m}_{PN} \cdot c_p \cdot (T_{fc} - T_{ext})}{\eta_{compr} \cdot \eta_{elect}} \qquad (4)$$

where T_{fc} [K] is the air temperature after the compression, T_{ext} [K] is the external air temperature and the efficiencies η_{compr} and η_{elect} are relative respectively to the compression and the transformation from electric to mechanical power.

Similarly to the IPS, the mass of the ECS can be estimated by means of [42], [43] and [44]. For the preliminary design of innovative ECS, the methodologies can be adapted adding the weight of the dedicated compressors and the electric motors, given the proper power-to-weight ratios.

The last system considered in the present paper is the EPGDS. The electrification of the aircraft systems has brought to an introduction of new electric voltages, with the aim of reducing the masses of the conductors. Therefore, other the standard voltages 28 V DC and 115 V AC (400 Hz), new systems are characterized by 115 V AC variable frequency, 270 V DC and 235 V AC variable frequency. As described in the previous Section, the introduction of new electric voltages, as well as the adoption of new electric machines (e.g. Switched Reluctance Machines – SRMs), entails significant benefits in terms of system weight, despite the large increment of the generated and distributed power. Again, the total mass of the conventional EPGDS can be estimated by means of the methodologies available in literature, i.e. [42], [43] and [44]. The mass of innovative systems instead can be calculated substituting the conventional electric machines with newer components, knowing the power-to-mass ratio. Also the mass of the conductors depending on the electric voltage can be evaluated. The weight reduction due to the electric voltage increment can be evaluated through the Ohm's law, considering constant the material of the conductor (same density and same electric resistivity ρ_{electr} [Ω·m]), the length of the conductor l_{cond} [m] and the distributed electric power:

$$Vol_{cond} = \rho_{electr} \cdot l_{cond}^2 \cdot \frac{i}{V} \qquad (5)$$

Therefore, the voltage increment for instance from 115 V to 270 V would ideally and to a first approximation bring to a weight saving of around 80%.

4 Integration of on-board systems design discipline within AGILE's framework

The integration of the on-board systems design tool within a collaborative MDO framework requires a procedure aimed at making the entire design process fully automated and exchanging with the other project partners only disciplinary results, preserving the intellectual property of the tool.

The present Section describes this procedure. In the first step, the tool is made user-independent, i.e. once launched, the tool shall execute autonomously all the coded routines without requiring the interaction with the specialist. Hence, all the tool inputs shall be provided before its execution. The disciplinary tool is therefore integrated within a PIDO environment located within the specialist's administrative domain. Only the coupling variables, e.g. inputs/outputs exchanged with the other disciplines, are shared. In this regard, a common namespace can be employed.

4.1 "CPACS-ization" of ASTRID

As stated in Section 2, the integration of different disciplinary models within an MDO framework requires a common namespace for the correct exchange of data among the tools. The common namespace employed in the AGILE project is the CPACS.

Therefore, it is necessary to connect all the disciplinary tools with the common namespace. In other words, all the tools shall be able to extract the needed inputs from the CPACS file. Once the tools have been executed and results have been obtained, the outputs shall be stored into the CPACS file. For instance, the external temperature T_{ext} required by equation (4) depends on the flight altitude. The flight altitude is a mission parameter stored within the CPACS file. In more details, the branch of the CPACS file storing this value is:

cpacs/missions/mission/segments/segment/constraints/constraintAltitude

Figure 2 shows a CPACS file with highlighted the location storing the flight altitude.

Analogously, the value resulting from equation (4) is saved into the output CPACS file, within the proper branch.

The management (e.g. reading, writing) of the CPACS data is supported by dedicated functions, named TIXI and TIGL. More details are reported in [48]. Therefore, each tool shall be "CPACS-ized", i.e. properly adapted to be connected with a CPACS file. TIXI and TIGL functions are therefore implemented within ASTRID for the extraction from the input file of all the required inputs and for the saving of the obtained results into the output file. For instance, the following command line coded in ASTRID entails the extraction from the CPACS file of the aircraft MTOM:

MTOM=tixiGetDoubleElement(tixi_h, '/cpacs/vehicles/aircraft/model/analyses/massBreakdown/designMasses/mTOM/mass')

```
<?xml version="1.0" encoding="UTF-8"?>
<cpacs xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance" xsi:noNamespaceSch
 <header>
 <vehicles>
 <missions>
  <mission uID="">
   <name>name</name>
   <description>description</description>
   <fromRunwayUID>fromRunwayUID</fromRunwayUID>
   <toRunwayUID>toRunwayUID</toRunwayUID>
   <segments>
    &lt;segment uID=""&gt;
     <name>name</name>
     <description>description</description>
     <controlInputs>
     <thrustMode>IDLE</thrustMode>
     <constraints>
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      <constraintMach mapType="vector">constraintMach</constraintMach>
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      <constraintAltRate mapType="vector">constraintAltRate</constraintAltRate>
      <constraintCASRate mapType="vector">constraintCASRate</constraintCASRate>
      <constraintLength mapType="vector">constraintLength</constraintLength>
      <constraintESI>constraintESI</constraintESI>
     </constraints>
     <exitConditions>
     <holdingMode>
    &lt;/segment&gt;
   </segments>
   <flightPath>
  </mission>
 </missions>
 <airports>
 <fleets>
 <toolspecific>
</cpacs>
```

Figure 2. Example of CPACS file

4.2 Integration of ASTRID within a PIDO environment

The "CPACS-ized" tool shall make available its results to the other disciplinary models of the collaborative framework. For this purpose, the tool shall be integrated within a PIDO environment.

Two examples of PIDO integration are proposed in the present Section. The former refers to the implementation of ASTRID within Optimus software, while in the latter example the tool is integrated in RCE.

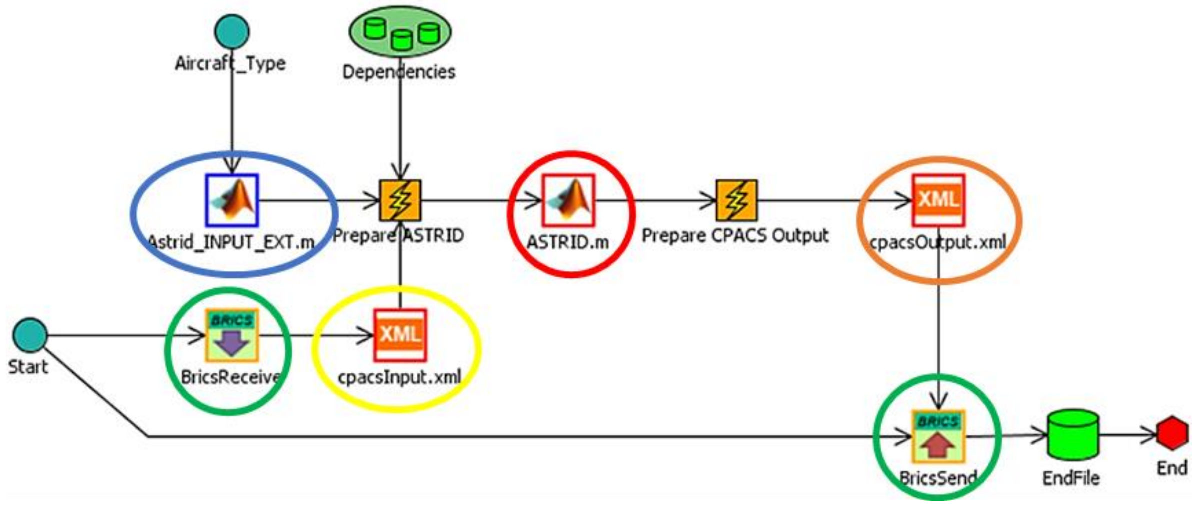


Figure 3. Integration of ASTRID in Optimus

Figure 3 shows the integration of ASTRID in Optimus. The tool is represented by the central block with the red circle. The tool receives inputs from the CPACS file, through the block circled in yellow. Additionally, specific inputs of the on-board systems design discipline – e.g. the hydraulic system pressure – are collected in an external file owned by Politecnico di Torino (see the block with the blue circle). The results computed by ASTRID are then saved into the CPACS file, which is circled in orange. The entire workflow is connected with the MDO framework through the BRICS interfaces, identified with the green circles. The BRICS interfaces download and upload the input and output CPACS files from and to the AGILE Teamserver.

Analogously, ASTRID is integrated within RCE, as depicted in Figure 4.

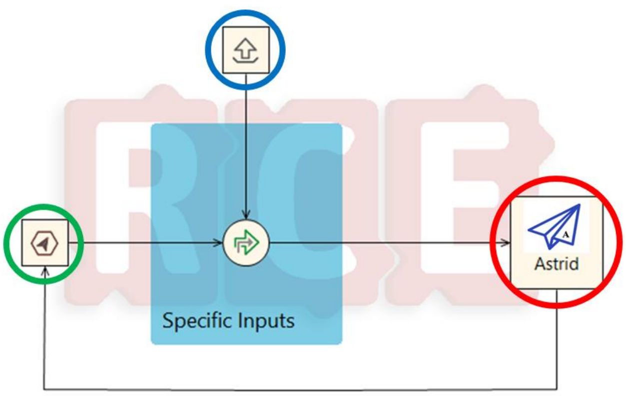


Figure 4. Integration of ASTRID in RCE

Though at first glance the integration in RCE looks much more condensed than in Optimus, all the main elements of the previously described workflow are still present. The ASTRID tool is again circled in red. Before its execution, ASTRID merges the specific inputs (block with blue circle) with those contained in the CPACS file, which is downloaded from the AGILE Teamserver through the BRICS interface encircled in green. The same BRICS block is employed for the upload of the CPACS output file to the AGILE Teamserver, once ASTRID has finished the execution.

The employment of the two described workflows is analogous. An e-mail is firstly received by the competence specialist, sent by the integrator and requiring the execution of the disciplinary workflow. The e-mail contains the so-called "Task ID", a code identifying the proper input file to be downloaded from the AGILE Teamserver. Moreover, within the e-mail is included the proper folder of the server where the input file is located. This folder is relative to each test case under design. An additional instruction reported in the e-mail refers to the type of execution. The tool can perform a single-task, when only an execution is required. Otherwise, several iterations might be needed, in case of converged Multidisciplinary Design Analysis (MDA), Design Of Experiments (DOE) and optimization problems. In this case, a multi-task is required by the integrator.

5 Demonstrator: influence of on-board systems technology on OAD

The development of an innovative concept is chosen as case study of the present paper. In particular, a Strut-Braced Wing (SBW) airplane is selected as reference aircraft. Several studies have been conducted on this kind of configuration (e.g. [49], [50], [51]), as it entails significant benefits in terms of aerodynamic efficiency and structural weight savings.

The selected reference aircraft has been defined by the AGILE consortium to test the technologies developed within the context of the research project. A 3D model of the reference SBW aircraft is depicted in Figure 5, while the TLARs are collected in Table 2.

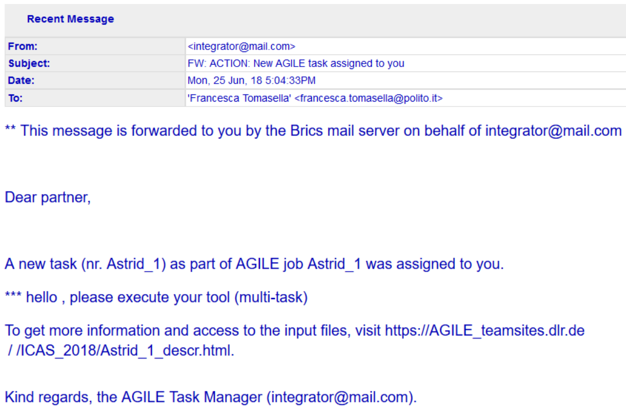
Figure 5. 3D model of the reference aircraft

Table 2. TLARs of the AGILE reference SBW aircraft

AGILE SBW aircraft	
Cruise altitude	41000 ft
Range	3600 km
Number of passengers	150
Payload	18500 kg
Take-off field length	< 2000 m
Cruise Mach number	0.76

An innovative all-electric on-board systems architecture is chosen. The selected architecture is characterized by the “bleedless” configuration and removal of the hydraulic system. Therefore, all the on-board systems traditionally supplied by the pneumatic and the hydraulic systems – i.e. Flight Control System (FCS), landing gear, IPS and ECS – are electric.

The here proposed case study refers to a 20-point DOE, set up to investigate the variation of wing span. The MDO problem is formulated by the integrator, which requests all the involved disciplinary experts to execute the own tools. Therefore, an e-mail is sent for this purpose, stating the task ID, i.e. “Astrid_1”. As the MDO problem is a DOE, a multi-task is required (Figure 6).



Recent Message

From:	<integrator@mail.com>
Subject:	FW: ACTION: New AGILE task assigned to you
Date:	Mon, 25 Jun, 18 5:04:33PM
To:	'Francesca Tomasella' <francesca.tomasella@polito.it>

** This message is forwarded to you by the Brics mail server on behalf of integrator@mail.com

Dear partner,

A new task (nr. Astrid_1) as part of AGILE job Astrid_1 was assigned to you.

*** hello , please execute your tool (multi-task)

To get more information and access to the input files, visit https://AGILE_teamsites.dlr.de / /ICAS_2018/Astrid_1_descr.html.

Kind regards, the AGILE Task Manager (integrator@mail.com).

Figure 6. E-mail requesting the tool execution

Therefore, the local workflows implemented in the PIDO environments (see Figure 3 and Figure 4) are properly setup and executed. For instance, Astrid integrated in RCE is executed through the window reported in Figure 7, where the task ID and the user’s credentials for the access into the AGILE Teamserver are filled in.

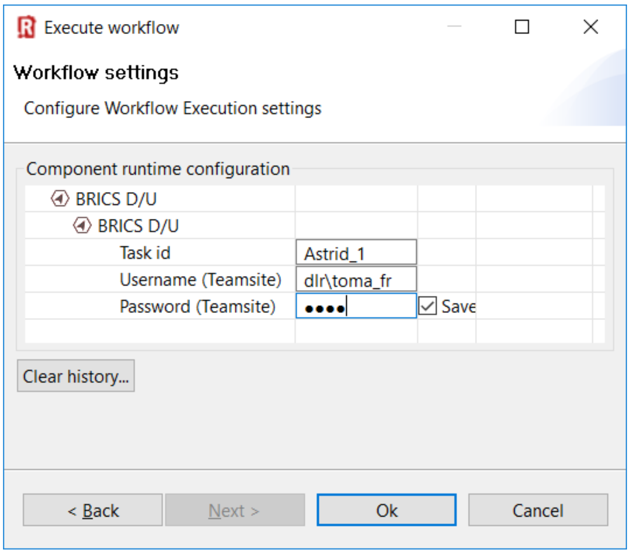


Figure 7. Execution of the workflow in RCE

At the end of the execution, several results are obtained. Part of them is discussed hereunder. The diagram in Figure 8 plots the mass of the IPS of the 20 designed aircraft characterized by different values of wing span, from 28 m to 42 m. The wing span directly influences the area of the surface to be protected from ice accretion (S_{ice} of equation (1)). It can be noted that the IPS mass increases with the increment of the wing span. Notwithstanding, this variation is not linear, as shown by the red line. All the experiments are characterized not only by different values of wing span, but also by different values of wing chords. Therefore, the points depicted in Figure 8 are ordered by wing span and not by the area S_{ice}, which depends also on the wing chords.

It is worth noting that higher values of wing span would increase the benefits of the SBW configuration, especially in terms of better aerodynamics. However, the increment of IPS weight for higher values of wing span should be taken into account when varying the wing dimensions. This fact underlines the importance of the integration of the on-board systems design discipline into a MDO framework.

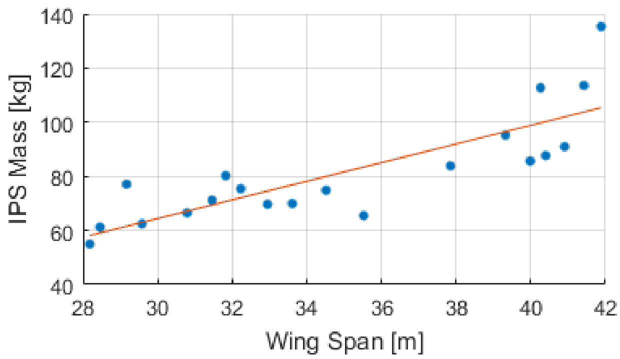


Figure 8. IPS mass varying with the aircraft wing span

The graph in Figure 9 shows instead the variation of the total electrical power for all the experiments characterized by different values of MTOM.

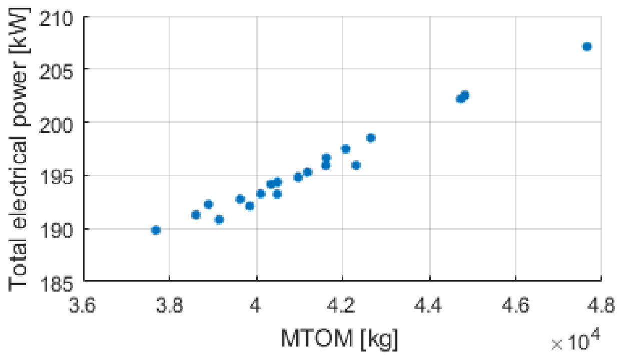


Figure 9. Total electrical power varying with the MTOM

The MTOM is indeed a coupling variable of the MDO problem, i.e. it is the output of a disciplinary model and meanwhile an input of other tools. It is worth noting that the MTOM is one of the main design variables driving the on-board systems sizing process. Therefore, the increment of MTOM entails a roughly linear increase of total electrical power.

6 Conclusion

The importance of the integration of the on-board systems design discipline within a collaborative 3rd generation MDO framework is claimed in this paper. An on-board systems design tool owned by Politecnico di Torino is integrated within the innovative MDO framework developed in the H2020 AGILE project.

A test case demonstrating the potentialities of the treated topic has been presented. Furthermore, several other papers have been published by the authors, presenting other application studies of the here described integrated on-board systems design discipline, e.g. [52], [53], [54] and [55].

Future works will address the integration of the on-board systems design tool with further design disciplines and the development of other different aircraft concepts.

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