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AGILE academy initiatives & outcomes

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MDO Framework for university research collaboration: AGILE Academy Initiatives & Outcomes

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AGILE Project is developing the 3rd generation MDO processes, which will support the development of the next generation aerospace products. The establishment of effective collaborative design methodologies is currently acknowledged as the key enabler for future product development processes. At the same time, the need to introduce collaborative design techniques within educational activities is also well recognized by the Academic, Research and Industrial communities. AGILE project supported by European Commission's H2020 Programme, is setting the "AGILE Paradigm", a conceptual framework which contains all the elements to implement a multidisciplinary collaborative design network. The AGILE Academy initiative is conceived to infuse into the Academic organizations and educational environments the "AGILE Paradigm", and make available all the technologies developed within the AGILE Project, which support the implementation of such a Paradigm. This paper focus is on the inception, approach and results of the AGILE Academy participants from several universities around the world

I.Introduction

AGILE ACADEMY Activities: AGILE ACADEMY consists of a series of activities carried out in collaboration with the Academic institutions. Such activities will support educational activities, such as student's thesis and University workshops, in order to promote and to make available the AGILE technologies to the entire Academic and research community. Two main activities are proposed:

- **Phase 1 - AGILE Incubator**: One team of distributed students, collaboratively working on a common aircraft design task. Focused within the AGILE EU project partner community

- **Phase 2 - AGILE Challenge:** multiple teams of students, collaboratively working and competing on a single (or multiple) design task(s). Focused multiple universities and research organization across the globe

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II.The AGILE Academy

The AGILE Academy supports educational activities, such as student's thesis and University workshops, to promote the AGILE technologies and make them available to a wider MDO community. Two main activities have been realized (see Figure 1): AGILE Academy Incubator and AGILE Academy Challenge.
As direct impact to the project, the AGILE Academy initiative provides a step towards the setup of the AGILE Open MDO Test Suite that will be disseminated at the end of the project. The training and teaching materials assembled during the AGILE Academy, will provide the basic module for teaching activities related to the dissemination of the "AGILE Paradigm" [1], both for industry, research centers and academia. Both elements will contribute to establish the AGILE Paradigm as a new collaborative development methodology, and to exploit the project's results beyond the duration of the AGILE Project. Several case studies tested by AGILE consortium using AGILE Paradigm, conventional civil aircraft [2] and novel BWB aircraft design [3] experiences were made available to the students during the course of Agile academy.

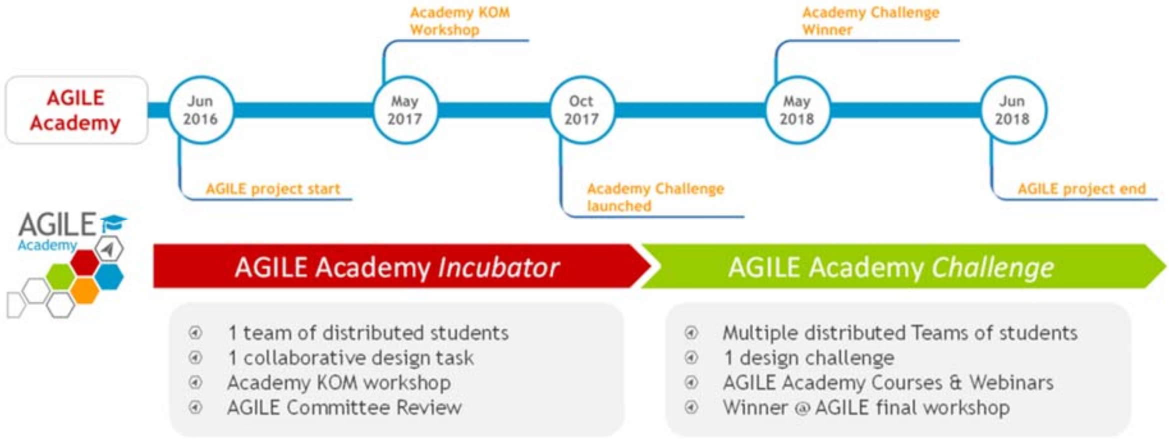


Figure 1 : AGILE Academy timeline

III.The Incubator phase

Target Group: Academic Organizations **within AGILE Consortium**. Final year students, thesis oriented, 1-2 students per organization: TUD, RWTH, POLITO, UNINA
General Initiative Setup: Independent Thesis works are carried out at Universities, with the aim to develop\extend any of the in-house design capabilities. The developed capabilities are applied to independent use cases, defined by the Universities and not necessarily connected to AGILE EU project.

In addition a **Collaborative MDO application**, which makes use of the "**AGILE Paradigm**", will be performed by the team composed by the distributed students. The capabilities developed during the independent works will be integrated into a collaborative design and optimization exercise. Complementarity in the roles and tools have to be discussed from the beginning and may reflect the AGILE competence distribution. Such application will be limited in time and scope, and it is part of first dissemination activities of the AGILE related Concepts.

A 2 days **AGILE workshop** was hosted by DLR Hamburg in May 2017 at the beginning of the Thesis works to have an introduction on the "AGILE Paradigm" and its components. The team successfully brainstormed how to being their thesis and tools developed together with the AGILE open source framework. Three day workshop also led to first preliminary run of framework (Figure 2), additional webinars are arranged successively on monthly basis to support the students' team with respect to the test case and AGILE framework.

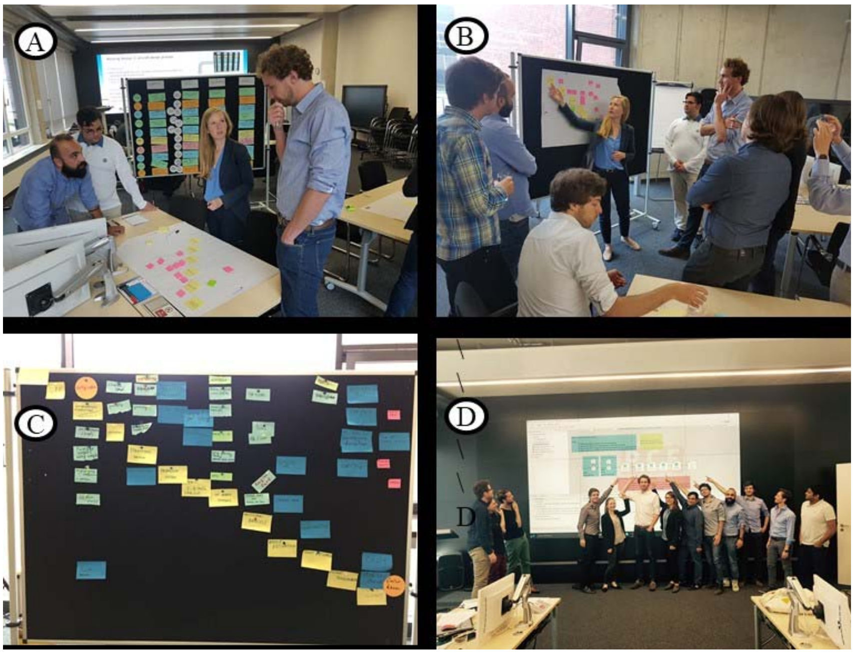


Figure 2. AGILE Academy workshop in May 2017. Fig A) Students brainstorming on their thesis tools, B) Students presenting their initial workflow, C) Academy Framework workflow, D) Preliminary Workflow implemented in AGILE framework: Students pointing towards individual developed tools in workflow

Use case:
Narrow Body 150 Pax TLAR and resulting aircraft may be used as reference, with technologies enhancements (e.g. hybrid electric version).

Link to the AGILE Eco-system elements:
In this first cycle of the AGILE Academy initiative, the following components of the AGILE environment will be distributed to the students' team for Educational purpose:

- Product model: the lower level of the AGILE Architecture → CPACS and tools
- Simulation workflow: mid-level → workflows manager, and MDO process representation
- Collaborative Architecture: cross-network implementation
- Disciplinary Competences: if required, a sub-set of competence available within the AGILE Consortium may be available for the completeness of the integration study.
- Visualization libraries
- IT support (e.g. tools server, etc.)

1. AGILE Academy Incubator stage team and Disciplinary analysis

A team of master's graduate students from multiple university participated in the incubator stage, bringing their master's thesis together. The Academy Scholars are

1. Jonas Kaminski (TU Delft University, Delft Neatherlands) - Initial Configuration Design
2. Guiseppe Torre (Naples University, Naples Italy) - Aerodynamics
3. Francesca Tomesella (Politechnico Di Torino University,Torino, Italy) - On Board Systems
4. Maximilian Nollman (RWTH Aachen University) - Engine Design
5. Nithin Kodalu Rao (TU Delft University) – Mission Simulation and Structures

2. AGILE Academy Incubator Stage Workflow Formulation

The team decided to create an MDA analysis for conventional narrow body Aircraft with 150 Pax. The geographically distributed students brought in their disciplinary analysis together using AGILE framework

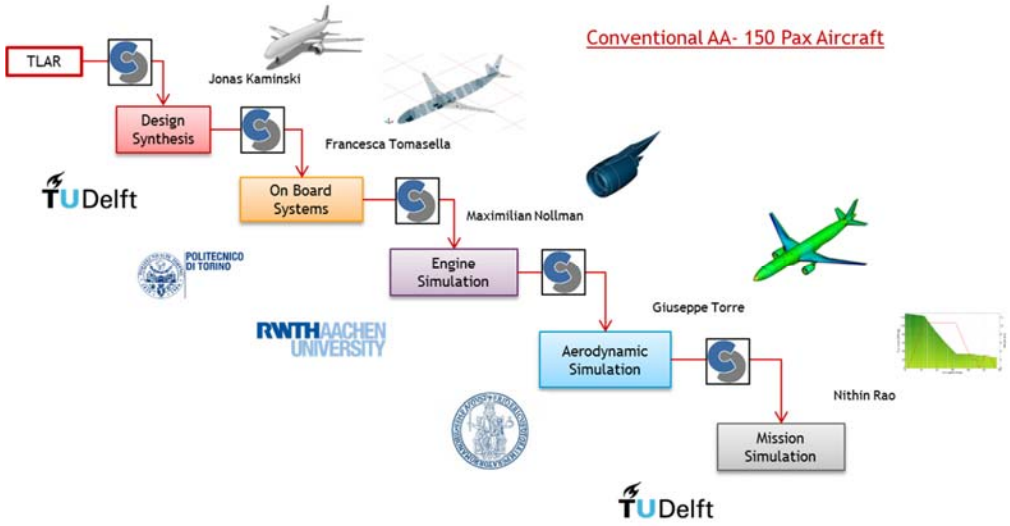


Figure 3. Collaborative MDA framework, AGILE Academy

The workflow formulation was translated to DLR MDO framework RCE. Each block you see in Figure 4 is a specific BRICS call (DLR: Initial Design, POLITO: On Board Systems, RWTH: Engine, UNINA: Aero, DLR: Mission simulation). BRICS is the software developed to collaborate across heterogeneous cross organization network. The University or research institute associated with the BRICS Call will run their respective disciplinary model or tool. The IT schema of the BRICS call is shown in Figure 5.

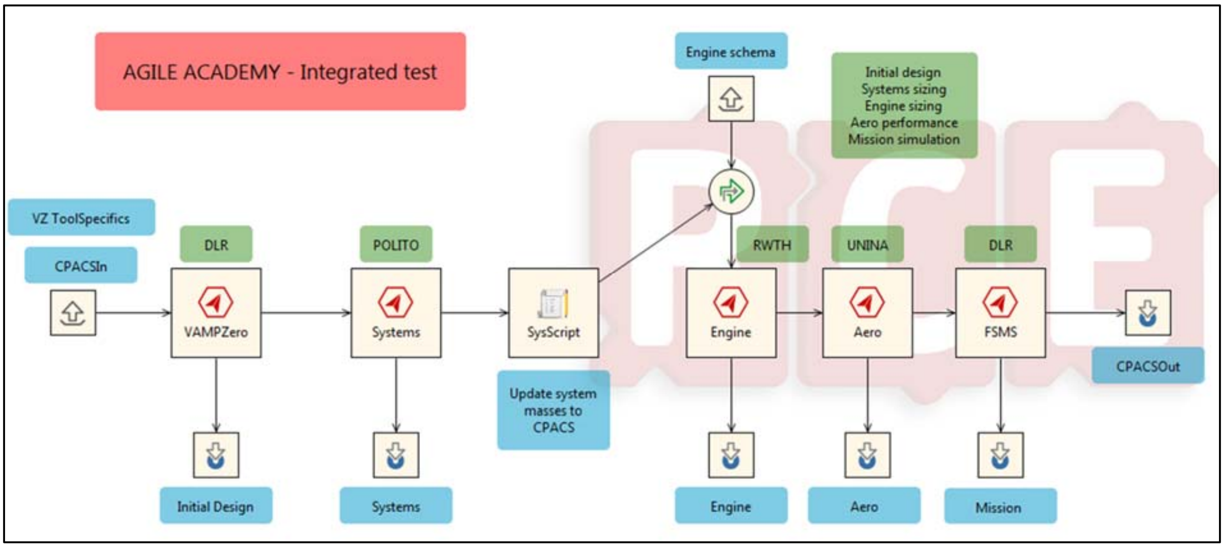


Figure 4. Workflow in RCE Framework

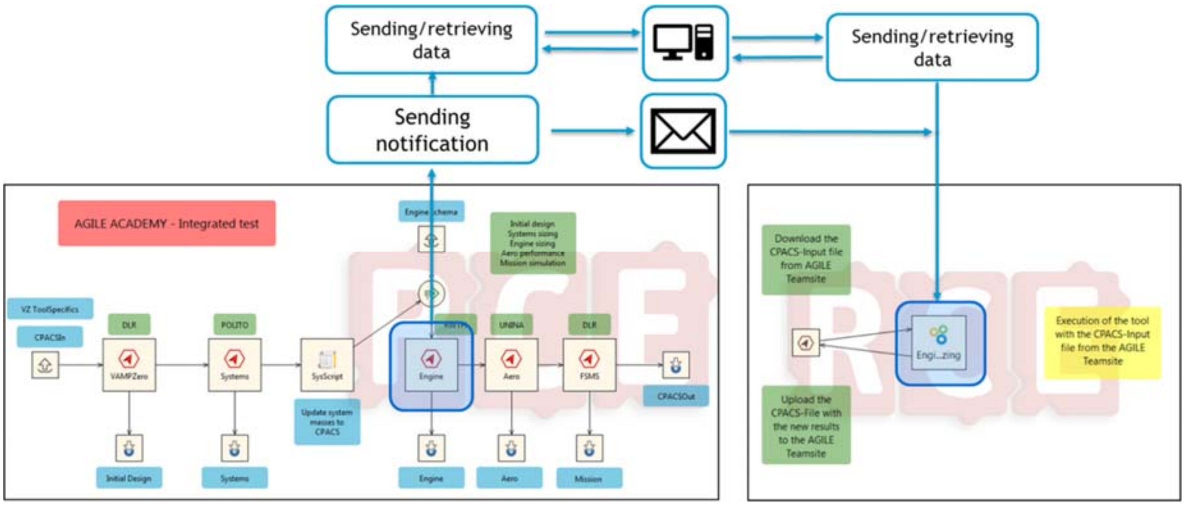
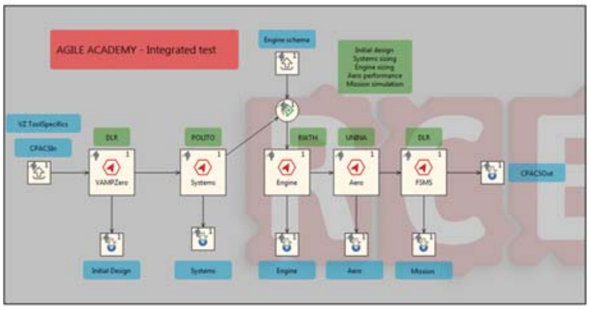


Figure 5 : Agile Academy cross organization data handling through BRICS, RCE and common central aircraft data Schema CPACS (www.cpace.de)

3. Results

The team run the workflow as shown in Figure 3 and Figure 4. The results are as per the Figure 6 below. The team with limited time available successfully collaborated, designed aircraft and understood the collaborative paradigm. Thus with more confidence in the framework, the challenge was expanded outside agile consortium.



Parameters	Empirical	Collaborative higher Fidelity	Difference
MOEM(kg)	49289	47550	-1738
Systems' Mass (kg)	12000	10261	-1436
Fuel Mass(kg)	11882	13318	1669
Payload Mass(kg)	13550	13550	0
MTOM(kg)	74720	74419	-301
Systems' Power Consumption	None	Systems' Shaft Power Systems' Bleed air	
Engine Performance	MaxThrust	Maps-Altitude, Mach, Thrust, Fuel flow rate	
Aero Performance	Mach,Re,Angle of Yaw, Angle of attack	Maps-Drag polar, moment coefficients	

Figure 6 : Academy Incubator workflow run and results

B. The Challenge phase

The AGILE Challenge open for universities and research centers outside the AGILE project consortium, with the aim to disseminate the "AGILE Paradigm". The initiative targets the integration of the "AGILE Paradigm" using lectures, projects, and other possible academic activities at the universities participating in the AGILE Challenge. The initiative has been promoted on the AGILE website, as well as during international conferences and meetings, reaching attention in several worldwide distributed organizations.

The main numbers of the AGILE Academy Challenge are summarized in Table I. A total number of 36 participants from 15 organizations, coming from 4 different continents have been registered to the challenge (see Table I). The participants have been assembled in three cross-university teams to compete with each other in three different tasks. The three teams are assembled as follows:

- **Team 1**: University Carlos II of Madrid, University of Tokyo, RMIT University, Chinese Aeronautics Establishment
- **Team 2**: RWTH Aachen University, Polytechnic of Milan, University of Southampton, General Aeronautics India, IRT SystemX
- **Team 3**: ISAE Toulouse, ONERA, University of Michigan, Concordia University, University of PISA

The three tasks are identical for all teams and are listed below:

- TASK A – Assemble one multidisciplinary workflow per team.
- TASK B – Support collaboration with AGILE paradigm enablers for MDO.
- TASK C – Perform optimization through surrogate models.

Table I: AGILE Academy Challenge numbers

AGILE Academy Challenge	
Participants	36
Organization	15
Continents	4
Topics	All aircraft aeronautics disciplines
Teams	3
Supervisors	10

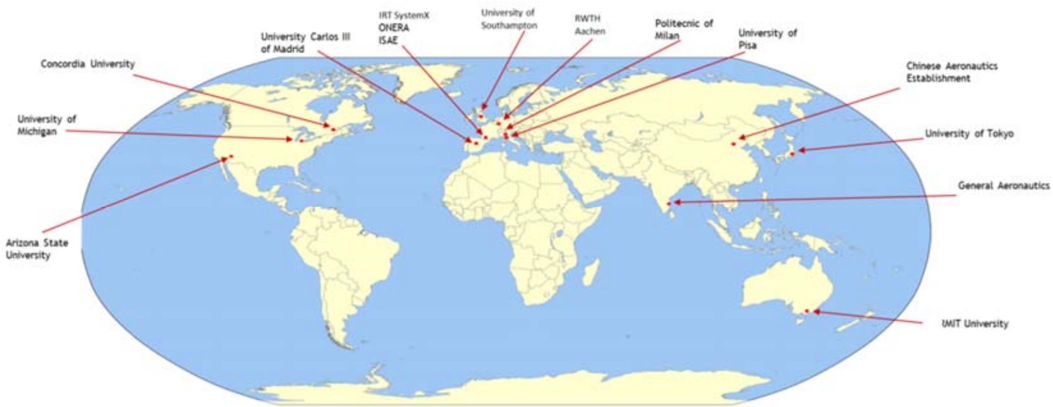


Figure 7 : The AGILE Academy Challenge "World"

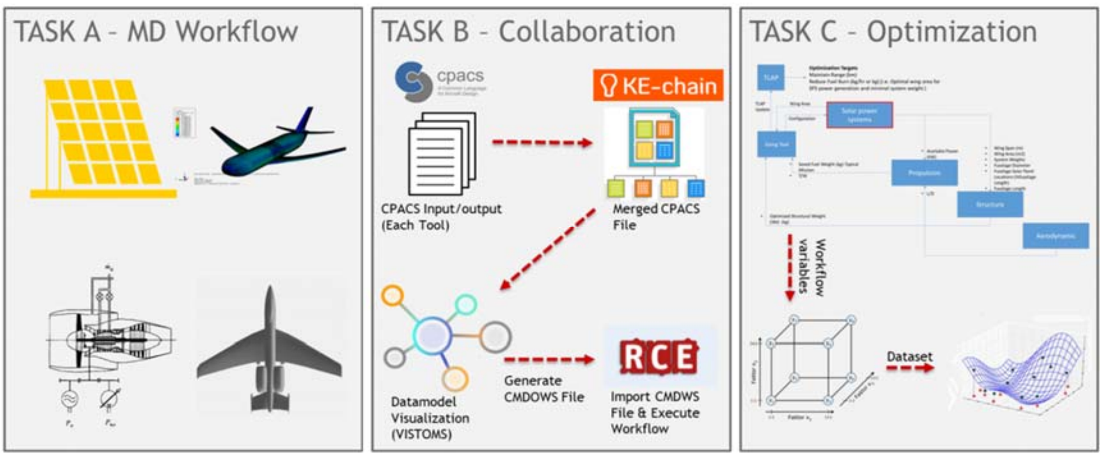


Figure 8 : AGILE Academy Challenge Tasks

1. TASK A

The main objective of task A was to introduce participants to the collaborative remote multidisciplinary aircraft design. The three teams were asked to assemble their own MDO workflow to design an aircraft, based on the same Top-Level Aircraft Requirements (TLAR). Many components of the AGILE environment have been distributed to the students to accomplish the task: *i) CPACS* as a central common data exchange format, *ii) RCE environment*, to have a collaborative design chain and *iii) BRICS* as a service to enable connecting design competence across organization.

The aircraft baseline has been initialized (based on TLAR) by the AGILE consortium and distributed to the teams in the CPACS format as a starting point for their own investigations.

The use case is a conventional (wing-tube) medium range transport jet aircraft. The TLAR are summarized in Table III. The use case has to cover a range of 3000 nautical miles with 130 passengers, at a cruise Mach number equal to 0.78 and an initial cruise altitude of 11000 meters. Take-off and landing field lengths are equal to 1900 and 1500 meters respectively.

Table II: AGILE Challenge use case TLAR

Conventional Large Regional Jet Reference Aircraft (EIS: 2020)

	Metric	**Imperial**
Range (102 kg /pax)	5556 km	3000 nm
Design payload	16329 kg	36000 lb
PAX	130 pax @ 102 kg	130 pax @ 225 lbs
MLW (% MTOW)	90%	
Cruise Mach (LRC)	0.78	0.78
Initial Cruise Altitude (ICA)	11000 m	36000 ft
TOFL (ISA, SL, MTOW)	1900 m	6233 ft
LFL (ISA, SL, MTOW)	1500 m	4921 ft
Engine	TURBOFAN high bypass	
Design objective	TO BE DEFINED by Teams	

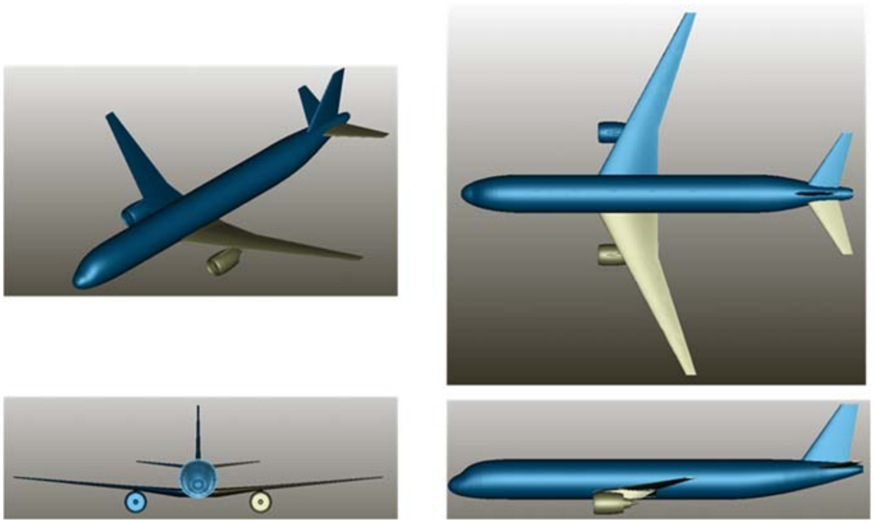


Figure 9 Three views of the CPACS file with the baseline aircraft.

The CPACS initialized use case has a wing area of about 113 m^2, a fuselage length of about 38 m and a main fuselage diameter of about 3.7 m. Nacelles and pylons have been "appended" to the wing geometry as external ".stp" files, in a specific CPACS branches. Main dimensions of the aircraft are summarized in Table III. The used engine is a high-bypass ratio turbofan and is provided as an engine performance deck by the AGILE consortium. It can be modified, substituted or used as rubber engine by the teams. All the dimensions and data are indicative and have to be changed during the AGILE Challenge.

Table III: AGILE Challenge use case main characteristics

Data are indicative and can be changed during the challenge.	
	Metric
Wing area	113 m^2
AR	~11
Fuselage length	~38 m
Fuselage diameter	~3.7m
Cabin abreast	5 (3+2)

2. TASK B

In AGILE, multiple technologies to enhance collaboration in MDO have been developed. Most of these technologies have been combined within one web-based environment: KE-chain. With KE-chain it is possible to setup and manage MDO problems following a five-step approach from definition of the design case to the optimization of the design solution (see Figure 10). This five-step approach and the different applications and data standards developed in AGILE are more elaborately discussed in reference paper Van Gent et al [4].

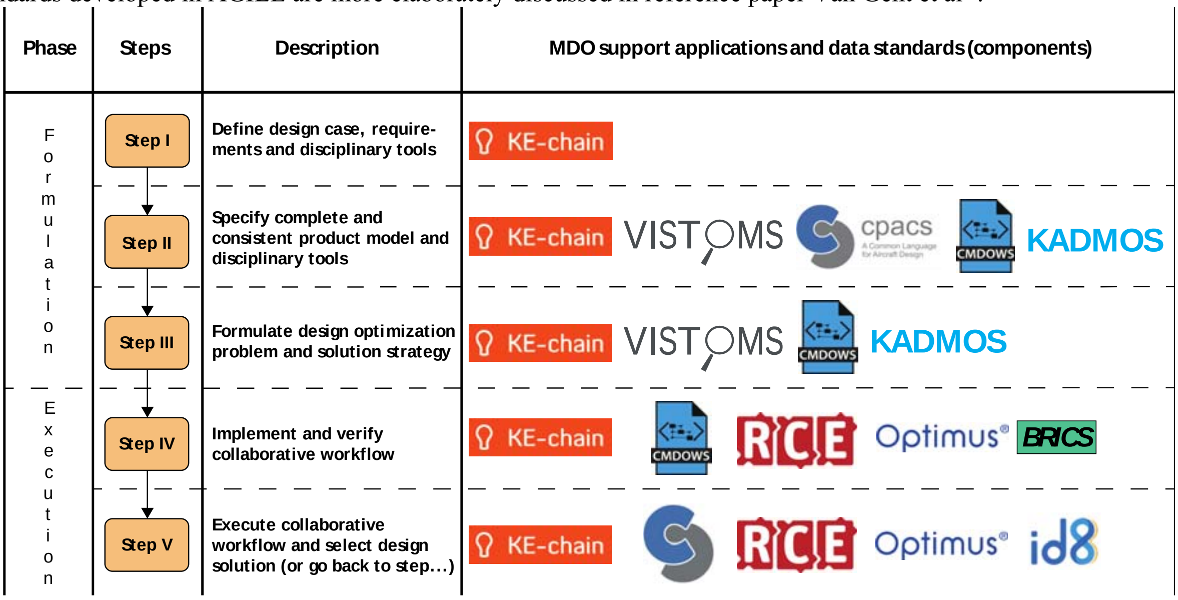


Figure 10 : KE-chain five-step approach

Within the scope of the AGILE Academy Challenge, the students were given the task to follow the approach based on their design task (see previous section) and the tools they were bringing into the project (e.g. an aerodynamic performance analysis code). Additionally, they were encouraged to independently organize their project by assigning different project roles. These roles, also called agents were introduced in the AGILE project and include:

- **Architect**: This agent is responsible for defining a suitable MDO architecture to meet the customer's requirements and therefore has to translate the customer's problem into a fully formalized computational architecture, containing the necessary design competences.
- **Integrator**: The integrator is responsible for converting the formalized neutral MDO system formulation provided by the architect, into an executable computational workflow by implementing it into a Process Integration and Design Optimization (PIDO) platform. Within the scope of the AGILE Challenge, the PIDO platform RCE, developed by the DLR, was used, as it is an open-source solution.

- **Competence specialist**: This agent is responsible for a specific design or analysis competence used within the scope of the MDO problem at hand. This can be for instance a design synthesis tool, a disciplinary analysis tool or an optimization service. Usually, multiple competence specialists are part of a single project.

Two other agents were defined in AGILE, namely the customer and collaborative engineer. In the AGILE Academy Challenge, the supervisors operate as both; customers to introduce and evaluate the tasks, and collaborative engineers to provide the students with the necessary tools and support to accomplish the tasks. For instance, during the initial phase of the Challenge, interactive support sessions on the AGILE framework were organized via webinars, in which the five-step approach was introduced and explained based on a realistic design case from the AGILE project.

The main goal of task B is for the students to implement and test different MDO architectures and problem solutions to solve a specific design task. To do so, it is important to first identify a set of parameters of interest for the MDO system (and later for the optimization), i.e. design variables, objectives and constraints. Secondly, the different tools used in the MDO system have to be connected via the KE-chain platform using the supporting systems associated with it. Finally, it is possible to apply different MDO system setups and problem solutions to solve the design task. Of course, the MDO architectures applied by the three teams can be very different, depending on the disciplinary design and analysis tools used and the focus of the design task. The teams can choose both freely, as already indicated in Table III.

3. *TASK C*

Task C is focused on the optimization through surrogate models. Surrogate models will be provided, and each team must perform its own optimization strategy in terms of objective function, variables and optimization algorithm. However, surrogate models can be also created by the team itself based on the workflows executed in task A.

4. *RESULTS*

At the time of the creation of this paper, the AGILE Challenge was still ongoing. Therefore, only preliminary results by the teams are presented hereafter with a focus on the results of team 3, that team being the furthest ahead in their task.

Team 1

Team 1 aims at performing a collaborative analysis and optimization of the baseline aircraft combining four disciplines: aerodynamics, structures, stability and control, and mission analysis. Different fidelity levels are being pursued for the aerodynamic analysis ranging from vortex lattice method and Euler methods to full CFD with SU2. Concerning optimization, the goal is to evaluate both structural (e.g. movables) and non-structural (e.g. fuel) weights and minimize the maximum take-off weight while meeting mission performance constraints. Currently, task A efforts are being concluded by testing the collection of different CPACS-compatible tools in a distributed RCE workflow, where some of the tools are executed remotely via a server. Task B was initialized by collecting the project requirements on the KE-chain platform. In addition, the formal specification of the tool collection has been started in KE-chain, but is still under development.

Team 2

The focus of team 2 lies on the aero-structural analysis and optimization of the baseline aircraft. As a post-coupled analysis, additionally the flight controls are investigated. The initial workflow for Task A consists of four different tools that are coupled via the integration platform RCE. In Task B, the focus is set on the optimization of the aero-structural sizing with the optimization goal of minimizing the MTOW by applying different MDO problem solutions within the KE-chain platform, going from problem definition to a fully automated executable workflow.

Team 3

Team 3 decided to set the focus of their design task on the integration and analysis of a solar power system for the on-board systems of the AGILE Challenge baseline aircraft. Since this is the most ambitious design task, the achieved more detail in the following this section. As already mentioned before, the team consists of five different institutions outside from AGILE consortium, with their own capabilities and expertise, as shown in Figure 11.

Institution	Tool	Capability
UNIVERSITÀ DI PISA	WAGNER	• Aero structural analysis for Prandtl plane configurations • Vortex lattice aerodynamics analysis • Aircraft systems sizing • FEM based structural sizing • Aircraft design experience
ISAE SUPAERO	SPS & Power Offtake	• Flight performance for solar powered aircraft • Engine performance analysis • Propulsion systems experience • Aircraft design expertise • CFD expertise
Concordia University	SPS & Aircraft Sizing	• Aircraft systems design • Aircraft solar power estimation • Aircraft design and sizing • Surrogate modelling experience • Solar power system weight analysis
University of Michigan	Surrogate Modelling Toolbox	• Surrogate Modelling toolbox development • Surrogate model development experience • Aircraft design experience
ONERA	SEGMOE	• Surrogate modelling toolbox development • Aircraft design experience • SEGMOE, MOE methodology

Figure 11 : AGILE Academy Challenge: team 3 composition and expertise

As shown in Fig. 9, the team competences are quite diverse and spread across the spectrum of aircraft design. A design problem incorporating the expertise of all these competences needed to be formulated. A subsequent analysis of tool capability showed that the University of Pisa and Concordia had tool capabilities that were sufficiently mature and could be used to solve a pertinent design problem. Therefore, the design task of implementing a solar powered system on the AGILE baseline aircraft was chosen as it fit well within the scope of the available tools.

The objective of the design problem was to determine the impact of implementing a solar power system (SPS) on the baseline aircraft satisfying the TLAR. To this effect the workflow was oriented in a way that the output of the various tool interactions finally flowed through an aircraft sizing tool which provided the next set of parameters to iterate. A data model was subsequently created to understand the flow of parameters between tools. This model was refined and subjected to several iterations over the course of which extraneous information was eliminated and a refined workflow was developed.

Task A for team 3 is stated as follows: assemble one multidisciplinary workflow to solve the aircraft design challenge. The design task was the implementation of a solar power system on the AGILE baseline aircraft to supplement aircraft secondary power offtake and the analysis of the subsequent fuel burn. The preliminary step for building the workflow is to determine which tools will be used and what their interactions will be. This required a comprehensive analysis of the input/outputs provided by each tool and a data model was required to that effect. Each tool owner was tasked with identifying the aircraft level parameters that their tool required and the data that it provided. This exercise allowed the formulation of tool arrangement and interaction. A preliminary workflow was defined based on the driving parameters which were associated to the SPS, mainly the wing area and subsequently available power. A schematic workflow is shown in Figure 12.

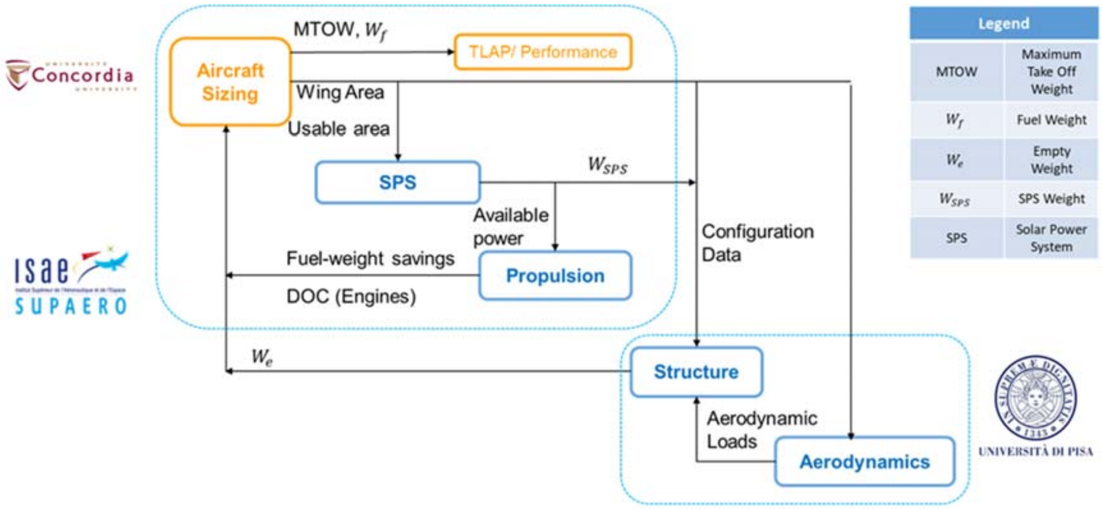


Figure 12: Formulated team 3 Workflow

The tools involved in the process are listed and connected to show the various parameters that are exchanged. The input to the workflow is the aircraft baseline written as CPACS file, which is fed into the SPS tool where the wing area is the driving parameter. The SPS tool determines the available power that can be generated using the specified wing area and passes it to the Propulsion tool. The Propulsion tool evaluates the amount of fuel that can be saved (in kg) by using SPS generated power to supplement systems power offtakes during ground and cruise segments. Aircraft parameters are also simultaneously passed to the structures and aerodynamics package hosted by the University of Pisa. Aerodynamic loads are derived for the aircraft configuration and then applied to the structure with an objective to size it for minimum empty weight. The empty weight and fuel savings are passed to the Aircraft Sizing tool that resizes the aircraft to maintain the same performance of the baseline. The tool also determines the DOC of the aircraft for a year and prepares the data used for the next iteration. Workflow execution requires CPACS file compatibility (read and write) for all tools. CPACS files are exchanged between owners after tool execution with an updated version number for each workflow iteration. The workflow consists of two modules, the first comprising of SPS and Propulsion and the second of Structures and Aerodynamics. The design problem was selected primarily based on tool availability but also because it required a truly multidisciplinary approach to investigate. Team competencies were also a driving factor in addition to the novelty of the idea in light of recent trends in sustainable aviation. Tools used reflected competences but were not formalized and directly applicable to this MDO problem. Additional tool capabilities were developed. And KE-Chain was also used to set up tool requirements and to record compliance. The workflow was executed through the exchange and processing of CPACS files by each tool owner and five workflow iterations were performed.

W_e (Kg)	L/D	W_{TO} (Kg)	W_f (Kg)	W_{area} (m^2)	SPS $_{power\ cruise}$ (kW)	Fuel mass saved cruise + APU (Kg)	SPSmass (Kg)	Δ W_f (Kg)	ΔW_e (Kg)
33497	17	67470	16865	112	80	280	55	-	-
35531	17.42	71424	17547	119	83	290	57	682	4484
36073	17.38	72582	17861	121	84	293	57	314	1193
36159	17.36	72766	17920	122	84	293	58	59	189
36204	17.28	72863	18003	122	84	294	58	83	100

Table IV: Preliminary workflow results of team 3

Table IV details the data generated by five iterations of the workflow where the overall fuel mass saved due to SPS implementation shows a consistent increase and plateaus as the empty weigh of the aircraft stabilizes. Local optimization within the Aerostructures tool causes this behavior in empty weight evolution.

In Task B, the manually assembled workflow from Task A has been formalized using AGILE's advanced instruments for MDO that are combined within the KE-chain platform. A preliminary set-up of the formalized workflow is depicted in Figure 13, showing the KE-chain tool repository including the input/output connections of the tools.

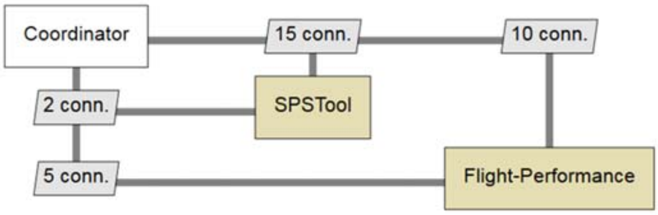


Figure 13: Visualization of the preliminary KE-chain tool repository of Team 3

Currently, only two tools, SPSTool for the design of the solar power system, and Flight-Performance for the evaluation of the impact of the solar power system on the overall aircraft, have been fully integrated in the platform. However, at a later stage of the project, the entire workflow will be formalized and visualized within the platform, thereby supporting the team with the setup of different MDO architectures and problem solution strategies to optimize the system.

Task C is concerned with the optimization strategy through surrogate models. Team 3 is creating its own surrogate model to replace the expensive in-house specific tools and perform an optimization of the workflow. First, the surrogate plan will be presented. Next**,** the optimization project will be discussed.

The aim of surrogate modeling is to create an analytical approximation of a model in order to reduce the cost to get the outputs. To train surrogate models, the user must provide some inputs and outputs, called training points or design of experiments (DOE), evaluated with the high-fidelity tool. It is clear that this DOE should be well-chosen to cover the design space and there are several ways to build one. The most common ones are regular grid, random and Latin hypercube sampling **(**LHS**)**.

Within AGILE Academy Challenge, team 3 uses LHS to cover the entire design space and their good projection properties. The surrogate modeling will only be used on the structure sizing tool because it is the only one with an important computational cost. The classical size of the DOE is ten times the number of variables. For each point of this DOE, a structural tool computation will be run, and each output will be stored. For each output, a dedicated surrogate model will be trained. Thus, the tool will be replaced by the surrogate. These approximations will ease the optimization phase of the entire workflow. DOE and surrogate model creation are still in progress. Preliminary results are encouraging.

IV. Conclusion

Feed-back coming from AGILE Academy participants are encouraging and it demonstrates the powerful and the possibility to easily disseminate AGILE Project paradigm.

Within Challenge phase, a workflow was created by each team following the identification of design competencies of all actors involved in each team. Available tools were evaluated, used a common central standard aircraft schema (CPACS), and a design problem was formulated to suit the competences of the collaborating members. Tool gaps were identified in the workflow and a requirement for tool development was initiated and tracked to completion on the KE chain platform. The platform was also used to manage the implementation of the workflow by condensing all the individual tool input-output into a single CPACS central data file. Issues with the framework and all the MDO paradigm enablers took time, as this paradigm and collaboration philosophy is still new in universities, but nonetheless the task was successfully completed. Preliminary data generated by executing the workflow is now being used to develop surrogate models to reduce execution time of the whole process. More results will be updated during AIAA conference and in https://www.agile-project.eu/.

Acknowledgments

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