THE AGILE METHOD APPLIED TO AIRCRAFT DESIGN AT UNIVERSITY OF NAPLES

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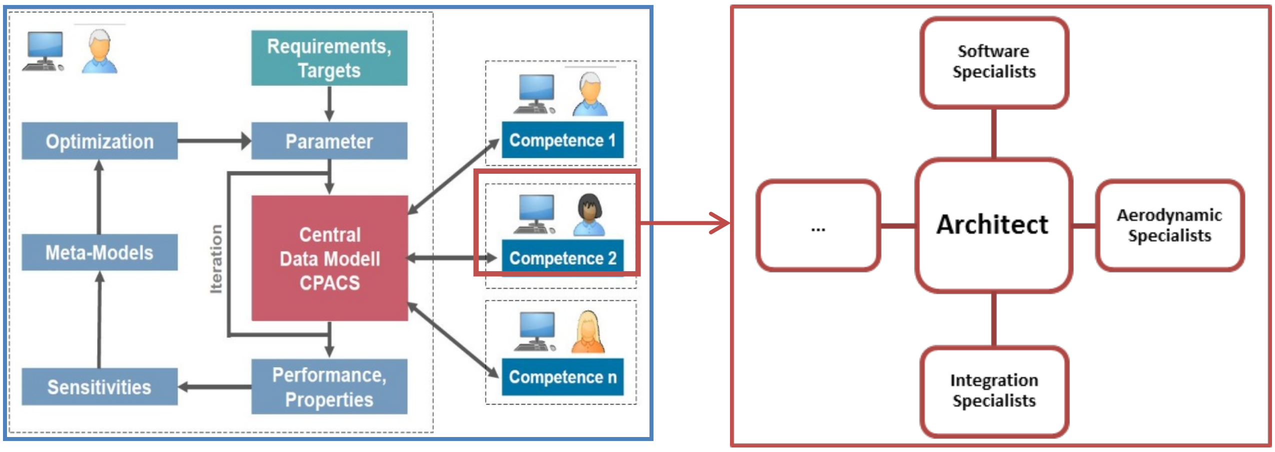
Abstract

At University of Naples Federico II (UniNa) the AGILE paradigm has been assumed as guideline to develop new methodologies, tools and software applied to the aircraft design. A heterogeneous team work cooperates to find and develop more reliable methods, updating the older, implements them into state-of-the-art framework and software language, and integrates these new procedures into a cluster of partners in order to perform MDO on innovative aircraft configurations, such as in the AGILE European project context. Methodologies have been well tested and validated for several aircraft configurations and they have been applied into the Design Challenge Level 0 (DC-L0) and Design Challenge Level 1 (DC-L1) of the AGILE project. Results have been useful to set-up the 1st stage of the 3rd MDO framework creation, which is the main goal of the AGILE European project.

Keywords AGILE project; MDO; Collaborative Design; Remote Design; Innovative Aircraft Configurations.

1. Introduction

At University of Naples Federico II (UniNa) the AGILE paradigm has been assumed as guideline to develop new methodologies, tools and software applied to the aircraft design. A heterogeneous team work cooperates to find and develop more reliable methods, updating the older, implements them into state-of-the-art framework and software language, and integrates these new procedures into a cluster of partners in order to perform MDO on innovative aircraft configurations, such as in the AGILE European project context (Nagel and Ciampa, 2015). In general, the AGILE paradigm consists in a set of principles in which both requirements and solutions evolve through the collaborative effort of self-organizing cross-functional teams (Collier, 2011). It promotes adaptive planning, evolutionary development, early delivery, and continuous improvement, and it encourages rapid and flexible response to change (Agile Alliance, 2013). At UniNa has been created a team work well versed in different disciplines. The supervision of the workflow is entrusted to the "Architect", which is an aircraft designer or an aircraft design team. The architect points out the requirements, solutions and procedures to the team specialists. Subsequently the specialists elaborate the methodologies, implement them into software algorithm and finally integrate into the design loop framework (see Figure 1). In particular, the architect aircraft design specialist elaborates an analysis method which is implemented in an executable tool (for instance .jar in Figure 2**)** by the software specialist; subsequently the integrator specialist assembles a workflow into the framework in order to perform analyses on a specific aircraft or for instance MDO calculations. All the implemented methodologies can be easily modified, improved and reviewed adopting a typical AGILE procedure.



AGILE PROJECT UNINA APPROACH

Figure 1 – The UniNa approach inside AGILE project

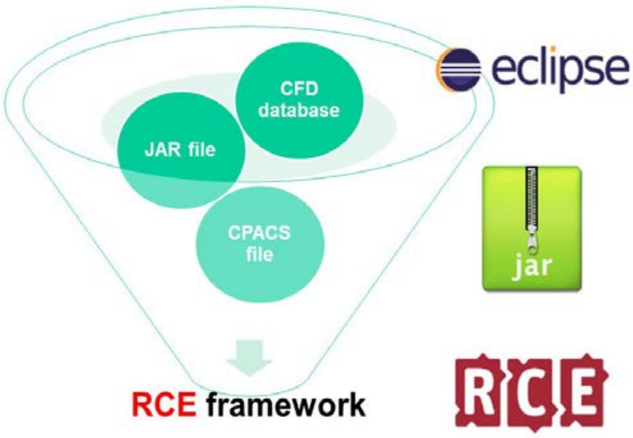


Figure 2 : Useful software packages and files for UniNa tools in the AGILE project.

The methodologies and approaches have been well tested inside the context of the AGILE European project. In the initial design campaign (DC-L0), the design space for a future transport jet aircraft has been evaluated. Then, in the design Campaign 1 (DC-L1), the developed modules have been used in first remote, collaborative MDO application. The adoption of the AGILE procedures has revealed the capability of the UniNa team to develop e release updated methods and tools in a fast and reliable manner. The AGILE approach is very suitable for aircraft design and it allows reducing time also in the conceptual and preliminary design phases. Moreover inside the UniNa team of specialists the philosophy of tools commonality and interchangeability resulted a successful way to develop and implement methods for aircraft design.

2. UniNa AGILE approach

UNINA contributions within AGILE project aim to provide several tools, using the abovementioned AGILE approach, employing several softwares and specific files.
The main idea is to create a team work, that follows the AGILE methodology characterized by people with different deep knowledge about several subjects; in particular a supervisor, one or a team of persons with experience in Java Environment, and the same about RCE software (Seider, 2012), CFD and CPACS format file (Böhnke, 2011). The CFD contribution is hidden behind Java Environment that takes advantage of CFD results and databases. This ones are '.h5' files (HDF5 website) generated by MATLAB script and it has been built from digitized scanned plots of functional data or CFD analysis carried out with the STAR-CCM+ software on lots

different geometry. The module is able to interpolate the data through a low level class ‘MyInterpolatingFunction’.
The UNINA tools concern the aerodynamic field of aircraft design and aircraft ground performances. The same type of team work can be built up for structural, propulsion, costs and other disciplines. In this way is possible to merge all advantages of these instruments and use RCE environment (Seider, 2012) to carry out various analyses and optimizations. Aircraft characteristics and data are stored in a common file format based on 'XML' technology named CPACS (Böhnke, 2011). This one and RCE software have been provided by the project coordinator (DLR).
This way of thinking allows to reduce the time to obtain the results and improves the quality of the product.
The UNINA Design/Analysis tools developed are fully embedded into RCE framework and are able to read and write a generic CPACS aircraft model. All the modules have a sublayer algorithms written in Python language useful to extract all necessary data, directly or after processing, from CPACS file, and to run the core modules '.jar'.
Starting from a generic CPACS aircraft file, the python algorithm interprets it and extracts all the useful parameters to perform the calculation; these data are then written into the '.xml' input file and passed to the '.jar' executable file which solves the analysis and writes all the results into a CPACS output file. Moreover graphs, figures and other '.xml' file are written into a dedicated output directory (see Figure 3).

2.1. *JAVA Environment*

The UniNa modules have a core software written in JAVA language. The adoption of JAVA language is mainly due to its open access behavior and its wide spread. As matter of fact UniNa group is already developing a software for aircraft preliminary design completely written in JAVA language named JPAD (Nicolosi, 2016), according to the "AGILE" methodology (Collier, 2011).
In order to use in the AGILE project the JPAD analyses functionalities, several .jar executable libraries have been opportunely created. A '.jar' archive is created in order to have a simple executable analyses method useful in every framework and environment . The '.jar' (Java Archive) file consists in a package file format typically used to aggregate many Java class files and associated metadata and resources (text, images, etc.) into one file to distribute applications software or libraries on the Java platform. The main advantages using Java language are that it strongly encourages the usage of classes to organize the code so that it should be easier to maintain and eventually modify it later (close to AGILE method), that it is widely supported, it is object oriented, it promotes the use of open source libraries and it is largely used.
The .jar archive needs of an .xml input file to start all the computations, and it creates a .xml output file plus several figures and results charts. Usually the calculations are based on semi-empirical formulation embedded into a database ('.h5' files) which is de-serialized during the execution.
In order to contribute in the MDO design chain during the first year of AGILE project the following tools have been developed and integrated into RCE environment:

- VeDSC (Vertical tail Design Stability and Control)
  It performs the calculation of vertical tail directional stability contribution and evaluates the interference factors among the main components (Nicolosi, 2013) (Nicolosi, 2015)

- FusDes (Fuselage Design)
  It performs the calculation of fuselage directional stability contribution and evaluates the moment coefficients and geometry shape factors (Nicolosi, 2016)

- Directional Stability
  It is a VeDSC and FusDes merging, in addition to these ones it performs the calculation of wing directional stability contribution and the directional stability of the whole aircraft configuration ($C_{N\beta}$)

- Zero-Lift-Drag-Coefficient
  It computes the aircraft zero lift drag coefficient according semi-empirical approach

- Payload-Range
  It computes the endurance performances and the aircraft payload-range diagram

- Wing Analysis

It evaluates the wing lift curve of a lifting surface and the c_l distribution along semi-span using the Nasa-Blackwell method (Blackwell, 1969)

- High-Lift

  It computes the aircraft aerodynamic coefficients with high lift devices (flaps and slats)

- VMC

  It computes the minimum control speed in case of inoperative engine(s), starting from engine and vertical tail characteristics (Nicolosi, 2013), and the vertical tail surface corresponding to VMC airspeed, increased of 13% with respect to the stall speed in take-off condition, and to VMC airspeed increased of 13% with respect to the stall speed in take-off condition specified by FAA documentation (Federal Aviation Regulations, 2012)

- Take-Off Performances

  It is a simulation based tool designed with the aim of evaluating the take-off distances and speeds of a generic aircraft in both AOE and OEI conditions by integrating the equations of motion that describe the aircraft state along all the maneuver

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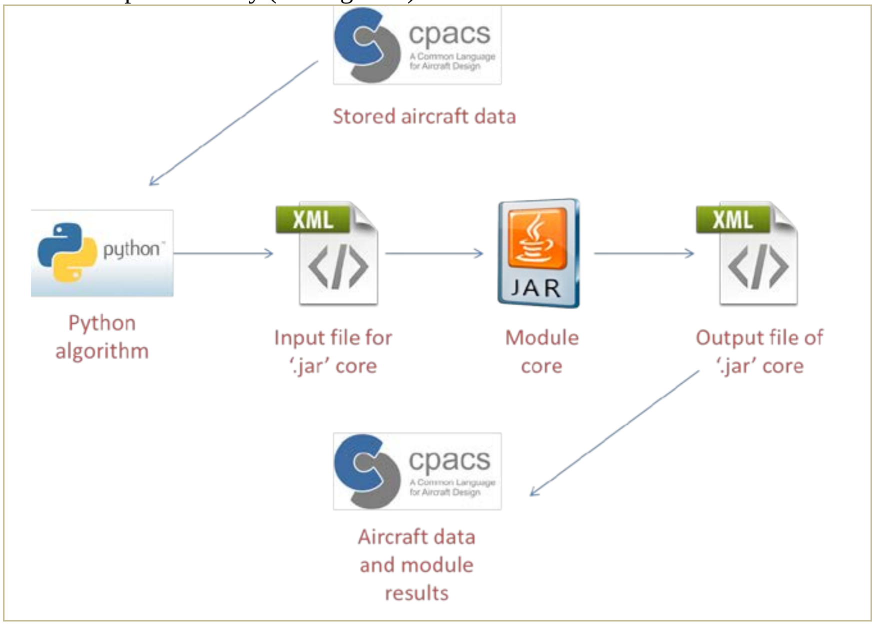

Figure 3: Conceptual module flow

3. Applications

As a partner of AGILE consortium, UniNa took part in the Design Campaign scheduled in the first year of the project and gave its contribution into the Design Challenge L0 and L1 performing some parametric analyses and tools applications.

3.1 Design Challenge L0

The Design Challenge L0 comprises 2 phases:

(1) A synchronization phase of the L0 capabilities, in which the design assumptions and the design methodologies behind the available L0 tools have been discussed among the L0 tools providers in multiple iterations. The parallel solutions generated have been iteratively updated based on a weekly review, and a consistent set of additional assumptions are defined for the reference aircraft
(2) A consolidation phase, in which assumptions have been frozen, and a L0 synthesis baseline has been selected and refined by using the different L0 tools available in the consortium . The resulting design is stored in the form of a CPACS file: “AGILE_DC1_L0_MDA.xml” (see Figure 6).

The outcome of the Level 0 is a conceptual design solution starting by a set of Top Level Aircraft Requirements (TLARs) given by Bombardier company and derived from a synthesis process consolidated among the partners that could provide the Conceptual L0 capabilities.
The design solutions have been reviewed, and compared with existing aircraft with similar transportation missions, as shown in Figure 4. A comparison of the main synthesis results is presented in Figure 5. It can be noticed that all the synthesis produces comparable aircraft designs. Most of the differences concern the estimation of the masses of the aircraft components (such as fuselage, systems, etc.) which affect the rest of the aircraft estimation components (e.g. wings masses).

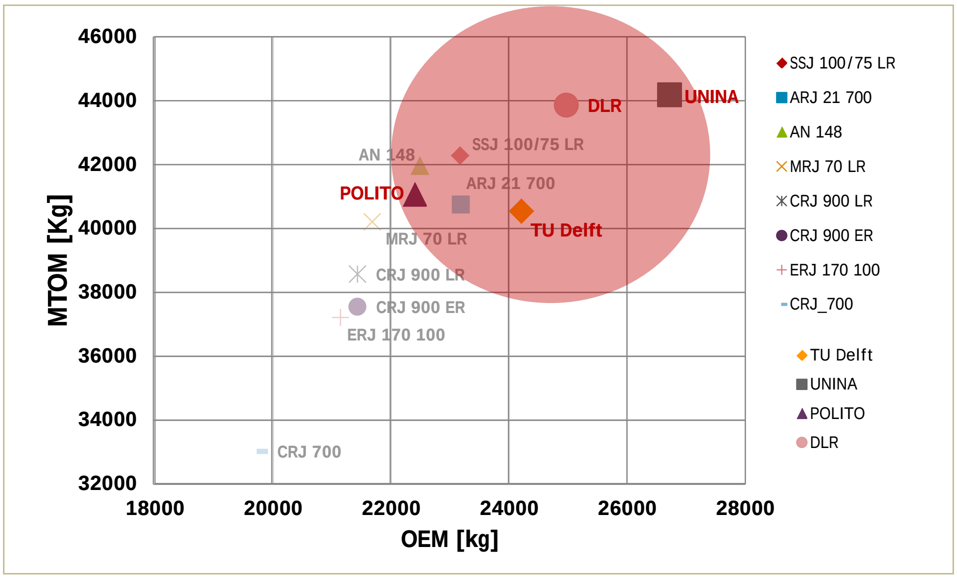

Figure 4: Design Campaign Level 0 – Results overview

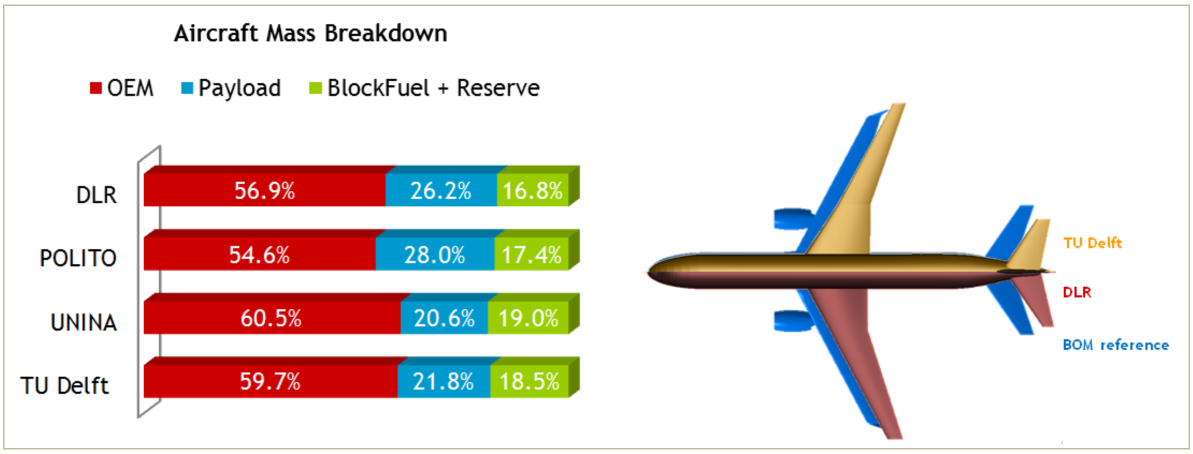

Figure 5: Design Campaign Level 0 - Synchronization phase results

The final product is presented in Figure 6.

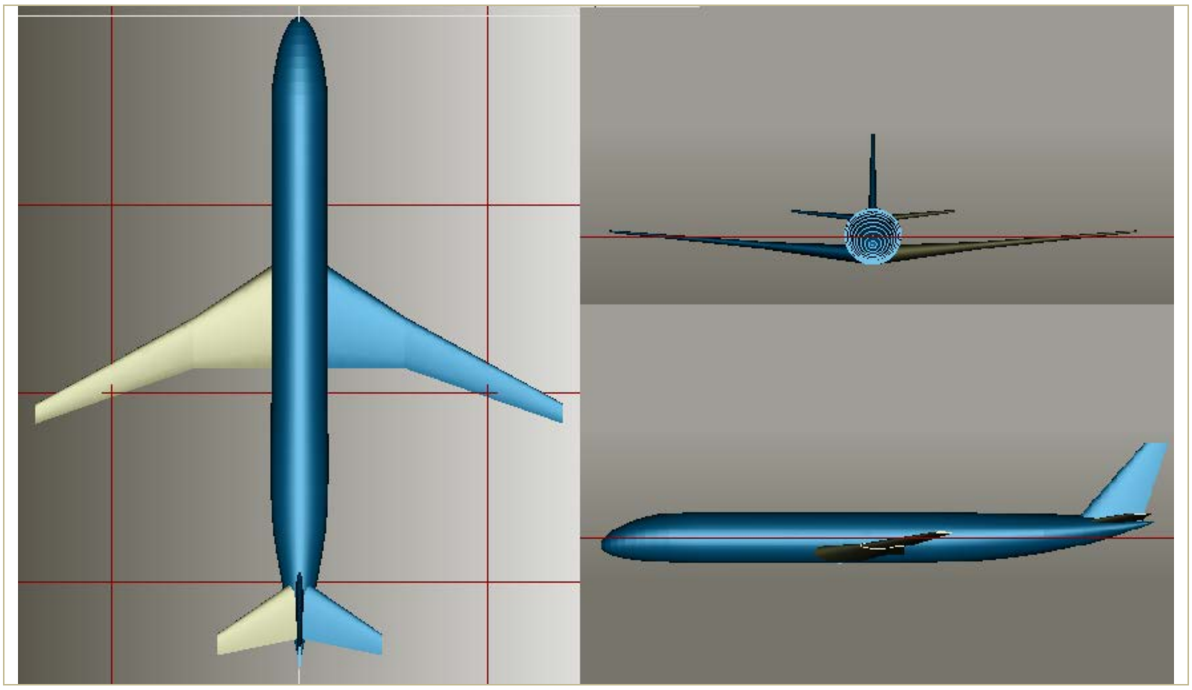

Figure 6: DC-1 views

To start with the DC-1 design, several Top Level Aircraft Requirements (TLAR) have been set; the reference aircraft represents a Use Case for the reference AGILE Design System formulated and used during the Design Campaign 1. One of the objectives during this design campaign is the capability to produce a design solution (as well as an optimum solution) for conventional aircraft configurations given a set of requirements. The reference aircraft is chosen to be representative of state-of-the-art aircraft as designed today with applied technologies suitable to be adopted by aircraft with entry into service expected in 2020.
In particular the UniNa group has dealt with the high lift and low speed performance analyses and so the driving TLAR were the maximum lift coefficient ($C_{Lmax)}$ in take-off and landing conditions and the take-off field length (TOFL). To fix the landing field length represents a challenging requirement for the synthesis solutions and a key requirement for the lifting surfaces sizing. This value is fundamental for the AGILE design system during the optimization phase too.
The specific TLAR values are listed in the Table I.

	C_{Lmax}	Field Length
Take-Off	2.2	1500 m
Landing	3.0	1400 m

Table I: TLARs concerning low speed conditions

In order to evaluate the design space in terms of thrust to weight ratio and TOFL, a deterministic analysis of take-off field length has been performed varying the maximum lift coefficient and aircraft maximum takeoff weight.
Figure 7 shows the TOFL as function of wing loading W/S varying the thrust to weight ratio T/W and fixing the weight and the $C_{Lmaxtoke-off}$. As it can be seen, to satisfy the TLAR concerning the TOFL, represented by the horizontal row, there is the need to set T/W equal to 0.3 keeping W/S close to 90 lb/ft^2. An higher or lower T/W value leads to a bigger or smaller wing surface value affecting the maximum lift coefficient.
The Figure 8 shows the thrust to weight ratio T/W as function of wing loading W/S, changing the C_{Lmax} value. The trends in this chart have been obtained representing the intersection points between the TOFL limitation and the curves depicted in Figure 7 for several C_{Lmax} values.

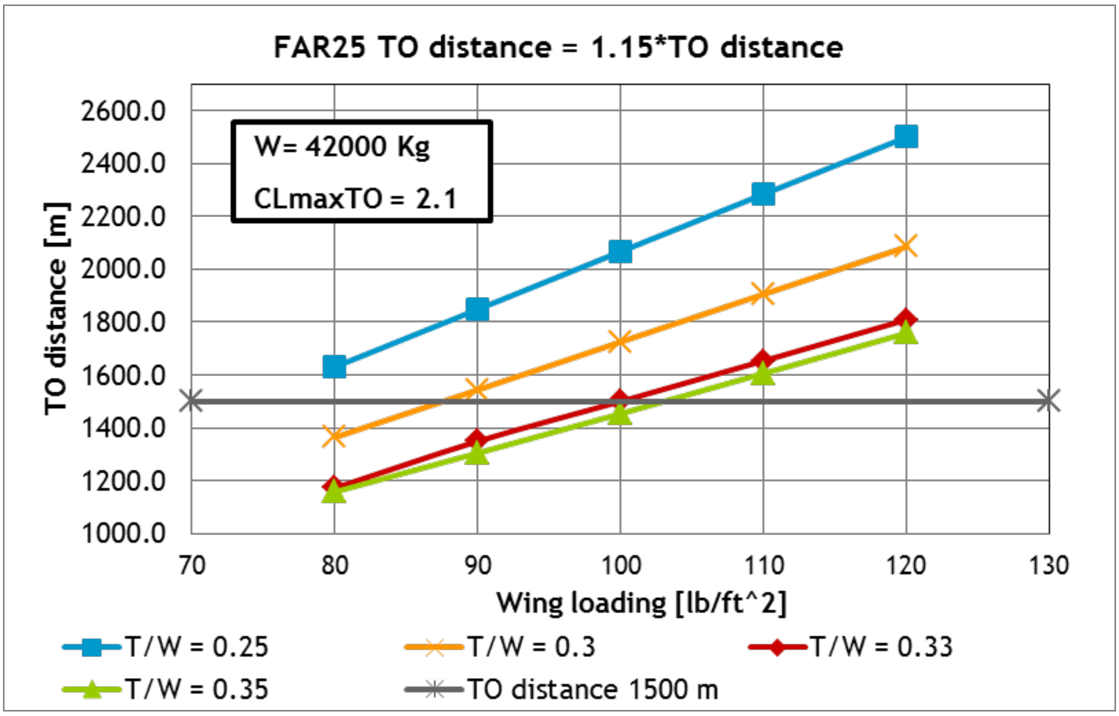

Figure 7: UniNa TOFL deterministic calculation

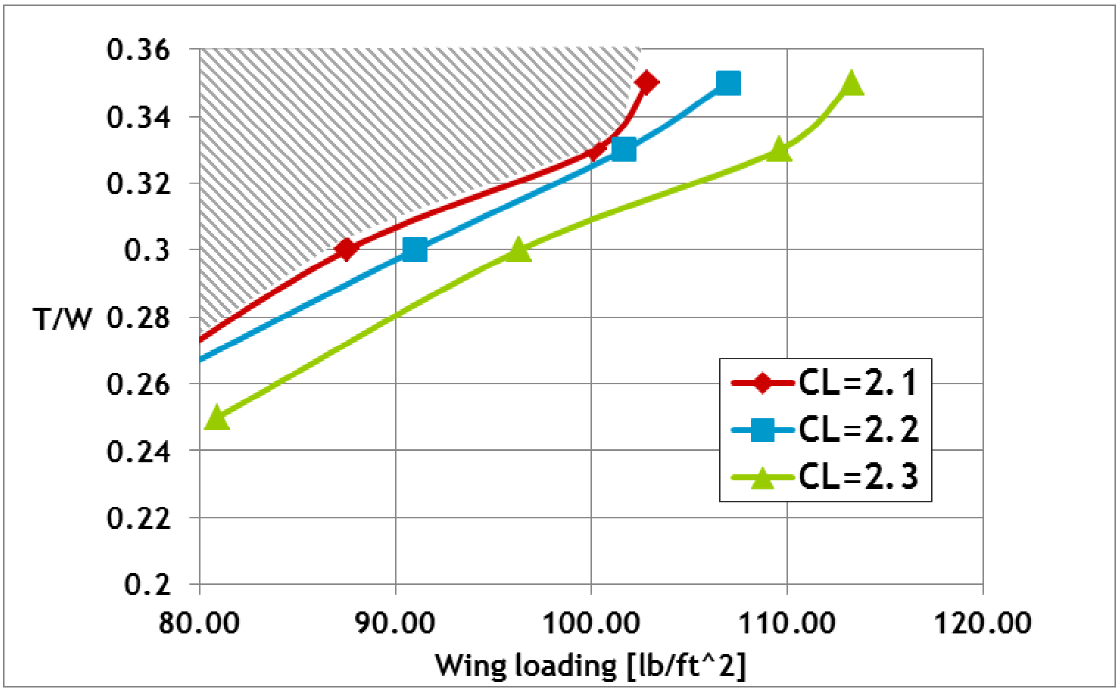

Figure 8: UniNa TOFL deterministic calculation, design space

The 'WingAnalysis' module has been used to perform analysis and design in clean configuration to evaluate the C_{Lmax} value. Thereafter flaps and slats geometrical characteristics and deflections have been set to use the 'HighLift' tool to evaluate the C_{Lmax} in take-off and landing conditions.

Starting from the reference wing data listed in the Table I, the design of high lift devices has been accomplished. The high lift devices aerodynamic characteristics, in terms of maximum lift coefficient, have been calculated by the means of the semi-empirical approach proposed by Sforza (Sforza, 2014).

The design provides a parametric investigation about the main geometric parameters for the design of the high lift devices (i.e.: flap and slat chord ratios and flap deflection angles).

The trailing edge flaps extension along the wingspan has been fixed at 75% of the wing span, and the leading edge slats have been fixed in terms of extension along the wingspan at 95% of the wing span. Results of the parametric investigation for the Take Off condition, performed through the variation of the flaps chord length, for both trailing edge flaps only and trailing edge flaps coupled with leading edge slats, are illustrated in Figure 9. The required C_{Lmax} = 2.2 for the take-off can be reached by the means of trailing edge flaps only with a flap chord ratio of c_f/c=0.35 and a 20 degrees of deflection (δ_{flap}). If a more stressed take-off performance is required, it is suggested the use of trailing edge flaps coupled with the deflection of leading edge slats. This way it is possible to reach a C_{Lmax} = 2.2 by using a flap chord ratio of 0.3 with a 15 degrees of deflection coupled with a 10% of slats chord extension (c'/c) with a deflection of 15 degrees (δ_{slat}).

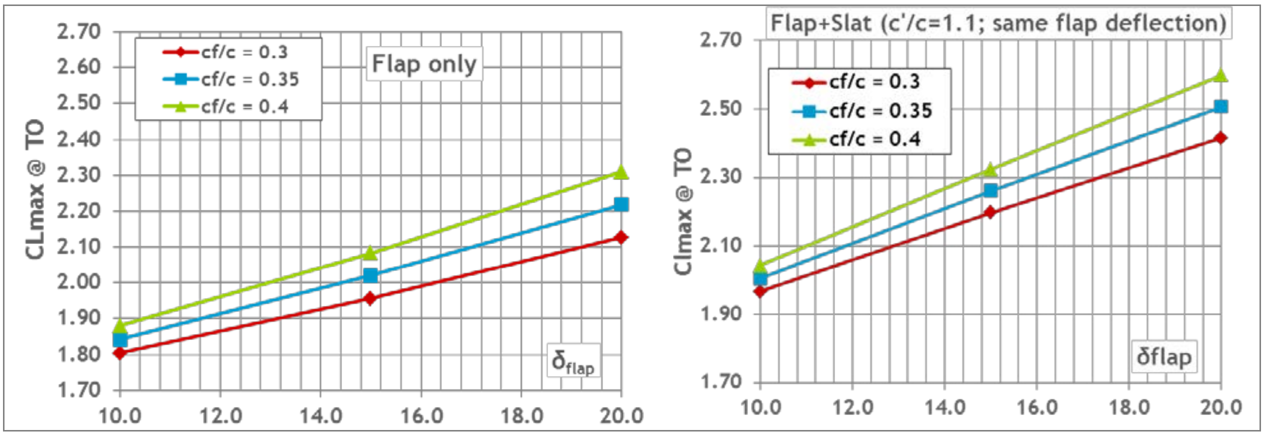

Figure 9: NO SLATS vs. 10% of SLATS chord deflected at the same trailing edge flap angle

The same parametric investigation has been conducted for the Landing Conditions. Two slats chord ratios have been investigated (10-20%). Results of this investigation are illustrated in Figure 9.
As it can been appreciated by the graphs, the required landing C_{Lmax} = 3.0 is achievable with flap chord ratio of 0.3 deflected at 40 degrees coupled with a 10% chord leading edge slats extension deflected at 25 degrees (see Figure 10).

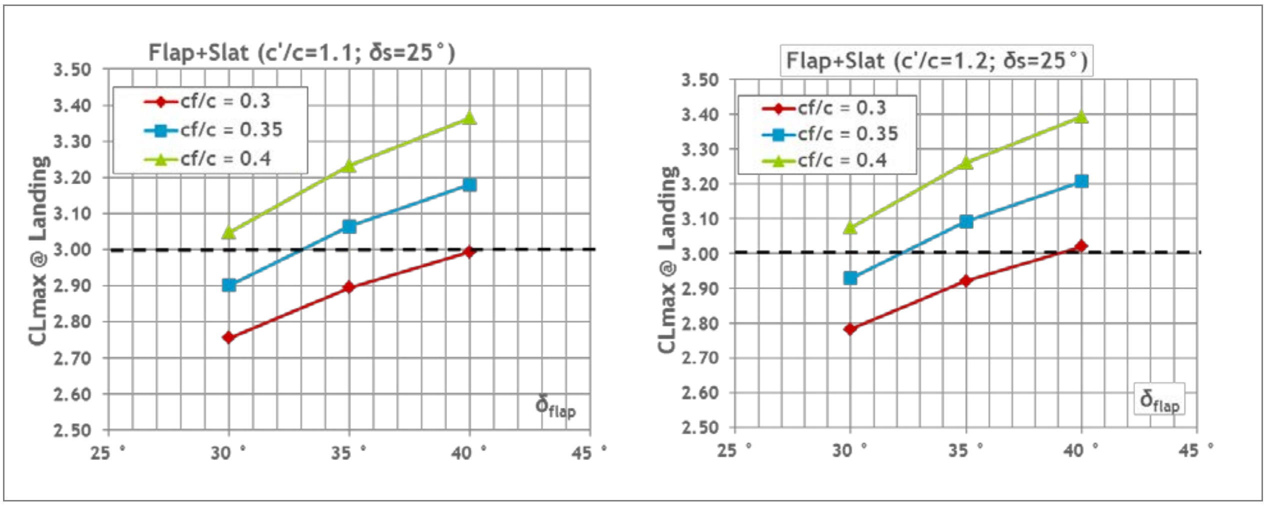

Figure 10: Landing Flap Analysis: 10% vs. 20% of SLATS chord deflected at 25 degrees

To carry out a complete analysis about the take-off condition also the minimum control speed airborne (VMC_a) have been evaluated thank to 'VMC' tool. Inputs geometrical data in terms of rudder chord ratio at inner and outer station (c_r/c), non-dimensional inner and out rudder station (η_r), maximum rudder deflection (δ_r) vertical tail surface (S_v) and span (b_v) are listed in Table II.

	Inputs				
	$(c_r/c)_i$ - $(c_r/c)_o$	$(\eta_r)_i$ - $(\eta_r)_o$	δ_r	S_v	b_v
DC-1	0.30 - 0.35	0.10 - 0.95	30°	12.63	4.54

Table II: DC-1 vertical tail data

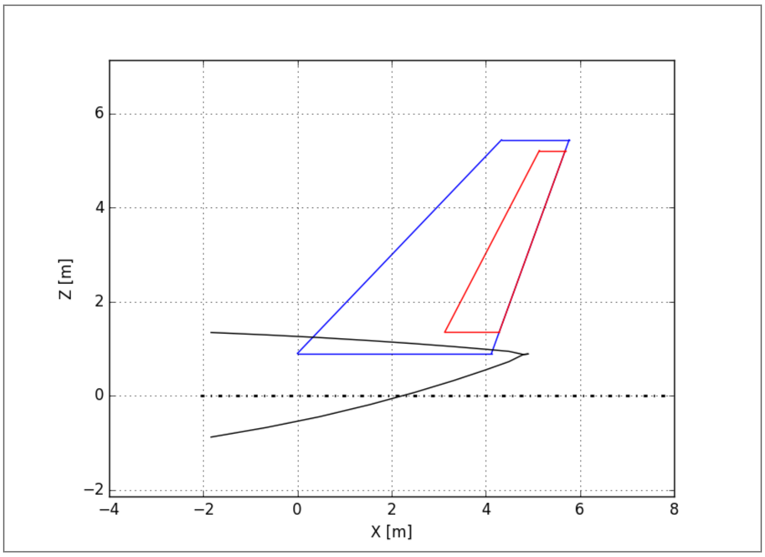

Figure 11: DC-1 vertical tail planform

In Table III numerical outputs in terms of yawing moment coefficient due to the rudder deflection ($C_{N\delta r}$), equilibrium speed (V_{eq}) and VMC starting from traditional stall speed (V_{s_TO}) and FAA stall maneuver ($V_{s\_FAA\_TO}$) are listed. The Figure 12 shows the results.

	Outputs			
	$C_{N\delta r}$	V_{eq}	VMC_a=1.13* V_{s_TO} → S_v	VMC_a=1.13*$V_{s\_FAA\_TO}$ → S_v
DC-1	0.06457 1/rad	75.89 m/s	70.70 m/s → 14.90 m^2	67.10 m/s → 16.66 m^2

Table III: 'VMC' tool outputs

Concerning the DC-1 model all the UniNa tools results are reported in Table IV starting from aircraft data extracted from the correspondent CPACS file. The results concerning the wing aerodynamic characteristics in terms of lift curve are shown in Figure 13.

UniNa Tools	Results
'$C_{D0\ total}$'	$C_{D0\ tot}$ = 210 Drag Counts
'PayloadRange'	Design Range = 1471nmi Max fuel = 10947 Kg
'WingAnalysis'	C_{Lmax} = 1.448
'HighLift'	C_{LmaxTO} = 2.32 C_{LmaxL} = 2.99
'TakeOffPerf'	Take-off field length (FAR25) = 1624 m
'DirectionalStability'	$C_{N\beta}$ = 0.1719 1/rad
'VMC'	$C_{N\delta r}$ = 0.0645 1/rad V_{eq} = 75.89 m/s

Table IV: UniNa tools results regarding DC-1 model

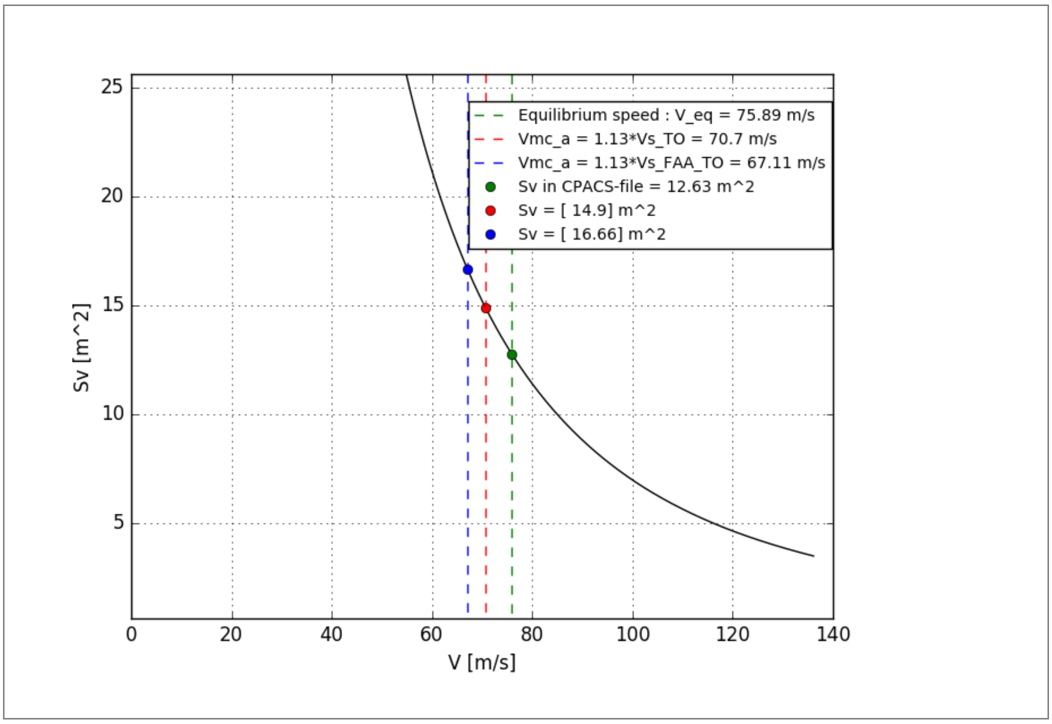

Figure 12: Necessary vertical tail area vs. speed, for equilibrium condition with one engine operative

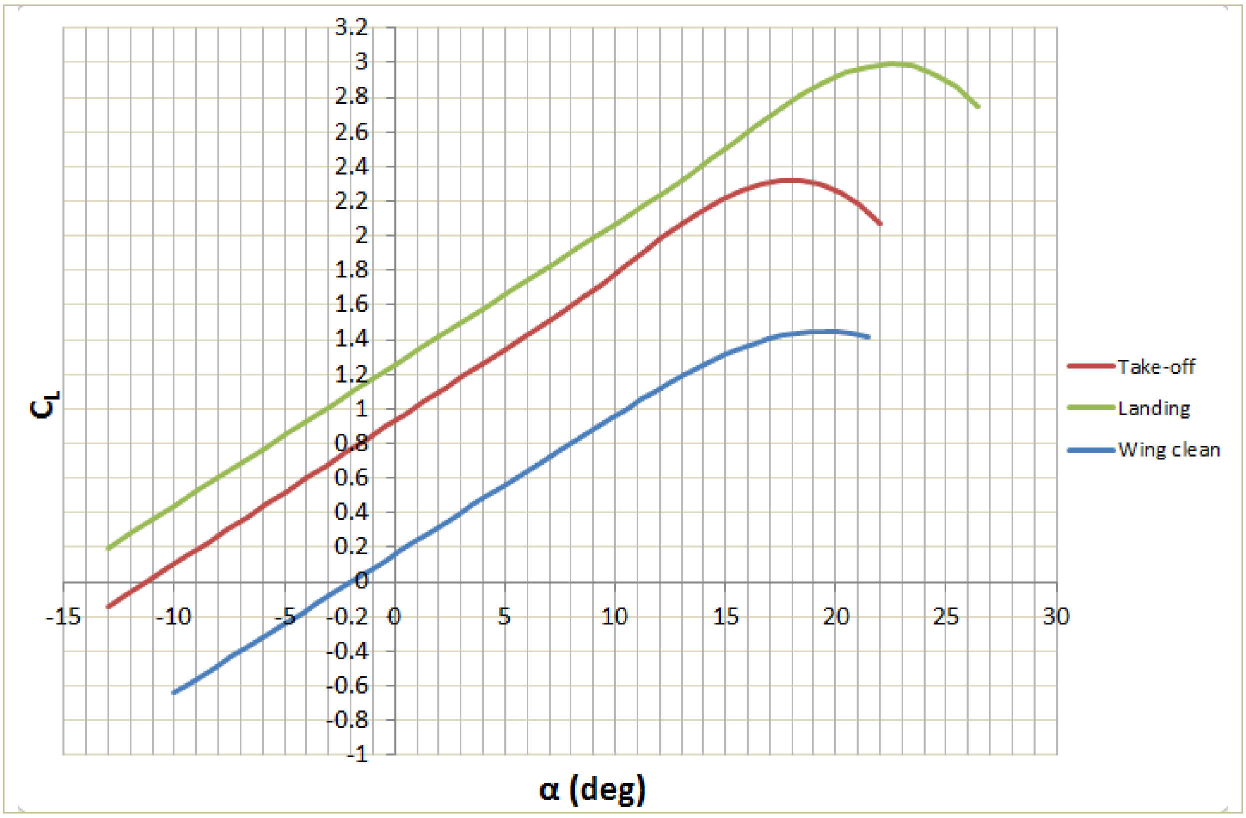

Figure 13: Wing lift curves comparison

3.2 Design Challenge L1

The next step is the Design Challenge L1 which is responsible to provide the AGILE reference system. It is planned to:

- provide a full convergent Multidisciplinary Design Analysis and Optimization (MDAO) process for the reference aircraft, coherent with the design capabilities available at this stage
- assemble the DC-1 distributed workflow including the Partners tools, which are CPACS compatible
- include design of experiments and a first optimization

Since the aim in AGILE project is to provide the capability to define the process for MDO problems that involve large teams of heterogeneous experts, the MDO process can be represented by a “ simulation chains” (Figure xxx) where several specialists tools are shown: DLR internal tools, UniNa tools, PoliTo tool and so on. In this workflow each block is a design module provided by a partners in its network and they are accessed as a “remote service”.
The deployment of the MDO problem in a single design process presents two views:

- Integrator view, which requests for a remote service
- Specialist view, which provides a service

To offer a safe connections among the partners, a reliable communications system is necessary; so a safe Collaborative Architecture has been developed to enable accessibility of the developed design modules from multiple partners, also inter companies networks.
In this case, UniNa performed a “Specialist view” to provide analyses tools. In particular aerodynamic tools have been provided: 'WingAnalysis' and 'HighLift' tools for evaluating max lift coefficient value in clean configuration and take-off/landing configuration respectively; 'VMC' tool to perform calculation concerning the minimum control speed.
In Figure 14 the Multidisciplinary Design Analysis and Optimization (MDAO) chain with different tasks assigned to each partner is depict; in Figure 15 MDAO chain into RCE environment is shown.

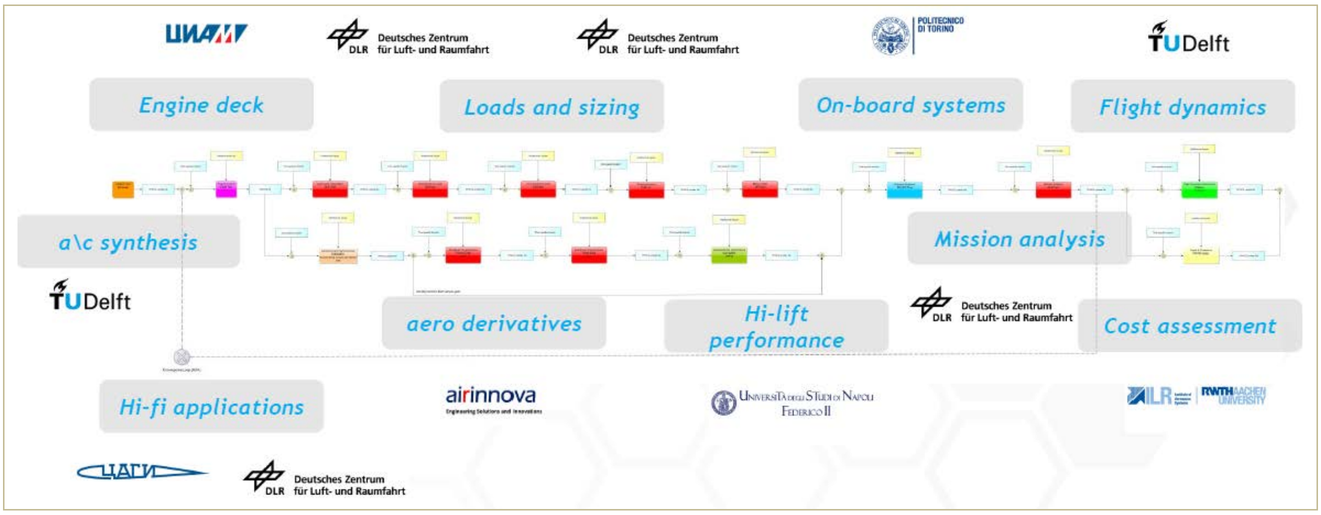

Figure 14: Structure of MDAO workflow.

In this way a Design of Experiment (DoE) has been assembled and performed choosing several variable with specific design space listed in Table V.

Parameter	Wing surface (m^2)	LE Sweep (°)	AR	$(t/c)_{root}$	$(t/c)_{kink}$	$(t/c)_{tip}$	Twist @ tip (°)
Max	95	34	9	15	12	11	1
Min	75	30	10.5	13	10	9	-5

Table V: DoE variables

Before MDA starting, multiple constraints and objective function(s) must be set to choose some results between different solutions.

Thanks to coordinator call, each partner can give a contribution using its own tools and then to update the CPACS file adding the results for the specific tool and field of competence; finally the partner have to send the file to other partners which will use the outputs of the previous partner in the chain like inputs for its own tool(s). Obviously during the chain working several outputs have to be monitored . These parameters are listed in Table VI and Table VII.

chordKink	chordRoot	chordTip	kink_y	MAC_Wing	Span	taperRatio Inboard	taperRatio Outboard

Table VI:DoE Monitored outputs

C_{LmaxTO}	C_{LmaxL}	DOC	S_{VMC}	fuelMass	mOEM	mWing	massSystems

Table VII: Metrics Outputs linked to objective and constraints

Finally a survey of preliminary results is shown in Table VIII. In particular there are three different rows concerning the results obtained reaching a minimum value of Direct Operative Cost (DOC), Maximum Operative Empty Mass (MOEM) and Maximum Fuel Mass (MFUEL) respectively (see Table VIII).

	C_{LmaxTO}	C_{LmaxL}	DOC	S_{VMC}	fuelMass	mOEM	mWing
min DOC Clmax TO > 2.2	10.5	0.11582	0.11	2.71	-0.6516	75	34
min MOEM Clmax TO > 2.2	9	0.1	0.09	-3	-0.593	75	34
min MFUEL Clmax TO > 2.2	9.98	0.1173	0.1033	2.47	0.876	77.69	33.62

Table VIII: DOE - Some preliminary results

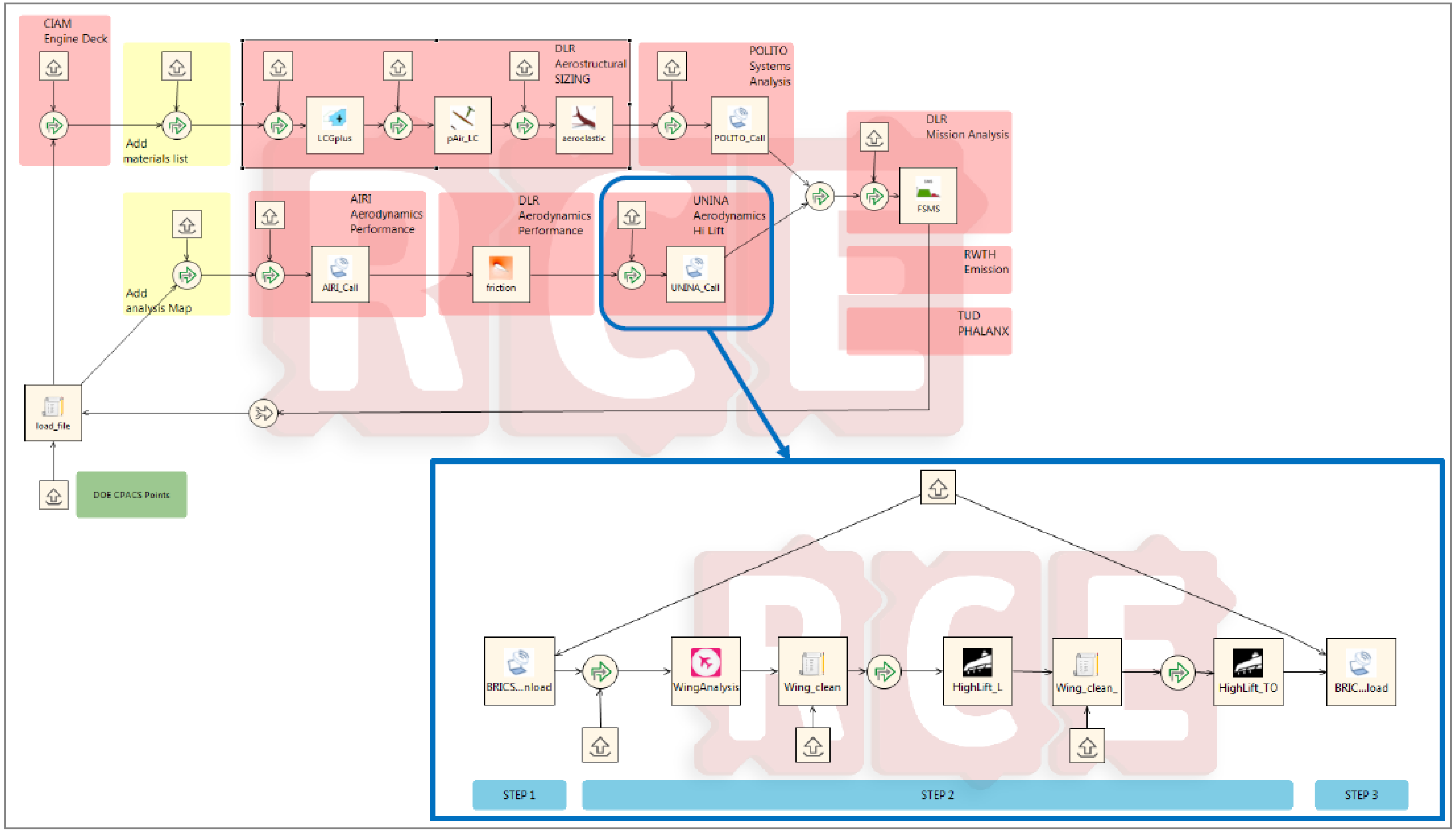

Figure 15: MDO chain: UniNa provides service through Brics

Conclusions

This work has shown that Distributed Design and optimization approach with remote participants, that is representative of the AGILE approach, allows to automate a lot of design steps and ensures the high fidelity of results because each team can work about the own specific field. In particular, at the end of the first year has been possible to run the whole Multidisciplinary Design Analysis (MDA) chain as a collaborative workflow, taking advantage of the tool(s) of each partner, and it has worked correctly. During this year the UniNa team gave its contribution providing several tools regarding the low speed performance in terms of maximum lift coefficient evaluation in take-off and landing conditions, minimum control speed calculation and take-off performance in terms field length and speeds.

To satisfy the DC-1 model TLAR for low speed conditions listed in Table 1, there is the need to choose a wing loading value close to 90 lb/ft^2 keeping a thrust to weight ratio equal to 30% to achieve a TOFL equal to 1500 m; to reach, simultaneously, C_{Lmax} values reported in Table 1 flaps and slats employment is essential. In particular, choosing a flap chord ratio of 0.3 and a slat chord extension of 1.1, there is the need to set the flap and slat deflection to 15 degrees concerning the take-off condition and a deflection of 40 and 25 degrees respectively regarding the landing condition.

About the minimum control speed, thanks to the 'VMC' tool, has been possible to reach the results listed in Table 4 setting the rudder chord ratio of 30% starting from a vertical tail area of 12.83 m^2. These analyses are ever referred to one engine operative to consider the worst case.

The first year of the project has been fundamental to test the partners' tools capability and partners interconnection and to lay the basis to perform MDO techniques on conventional configuration of a commercial transport jet.

This way of thinking could be the new way concerning aircraft, and complex systems in general, design that will allow to reduce the overall aircraft design time by the 40-50% overthrowing the production costs, to improve the quality of results and to develop new MDAO techniques and to build up and release an Open MDO Test Suite usable by companies or research centers for future design campaigns. Furthermore thanks to an hard and excellent coordinator's work, in terms of telco and meetings organization, and the availability of all the partners to share their own competencies the knowledge dissemination will be increasingly guaranteed.

Acknowledgments

The research presented in this paper has been performed in the framework of the AGILE project (Aircraft 3rd Generation MDO for Innovative Collaboration of Heterogeneous Teams of Experts) and has received funding from the European Union Horizon 2020 Programme (H2020-MG-2014-2015) under grant agreement n◦ 636202. The authors are grateful to the partners of the AGILE consortium for their contribution and feedback.

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