DEVELOPMENT OF AN INNOVATIVE COLLABORATIVE FRAMEWORK FOR AIRCRAFT DESIGN

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Abstract. This paper aims to provide computational modules useful to evaluate aircraft performances and aerodynamic characteristics into the AGILE European Project[20] (part of the HORIZON 2020) coordinated by DLR and participated by 19 partners. AGILE aims to the development and dissemination of knowledge and skills which are essential to exploit the potential that latest IT technologies in the field of collaborative design and MDO offer.
A common parametric .xml file, named CPACS, is used among all partners in order to describe all aircraft features and characteristics in which are stored all aircraft parameters and beyond, and through which every partners can be interconnect to each other, and it is improved during the analyses and optimization loops by the partners through specialist analysis modules. In this paper, the modules developed during the first Design Campaign concern the directional stability and control, the high lift capabilities, the take-off performances, the aircraft zero lift drag coefficient, applied on different aircraft categories. Some modules have been efficiently used and tested during the first Design Campaign, leading to success of the first MDO run.

Keywords Multidisciplinary Design Optimization (MDO), Collaborative Design, Tools development, CPACS, RCE.

1 Introduction

The main goal of the AGILE[4] project is to reduce the aircraft development time, achieve cost effective, or greener aircraft solutions. The objective is achieved by implementing the next generation MDO processes.
The design of a complex system like an aircraft involves a lot of disciplines and of course a lot of specialists distributed in several groups. The first attempt to solve this problem was to report all the features into a single chief designer or design group well versed in all disciplines in order to reduce communications and organization problems. When this way of thinking is restricted to simple problems characterized by approximate analyses the results are satisfying. This kind of design is called Monolithic Design and it has been used to face the conceptual design phase in the past. Nowadays a single group is unable to monitor a complex process[1] like an aircraft design, and new multidisciplinary design techniques appear on the international scene.
To manage all the disciplines, characterized by different decisions, analyses, methods and people, the possible way is to build a process in which the product is designed thanks to collective efforts of different area of experts; this is the way of thinking of Collaborative design. This one is typified by various participants of each team that are capable to give their contribution proposing design issues which concern their domain. The design of commercial jet aircraft involves millions of components and design issues, hundreds to thousands of participants, working on hundreds of distinct design

subspaces, all collaborating to produce a complete design[2]; in this way is possible to understand how many ideas and proposal must be evaluated.
The last evolution is the Distributed Design and optimization approach with remote participants; the main difference with respect to other approaches is that the teams can be geographically located in different parts of the world and can communicate and exchange the own tools or results through a remote server connection. In this way is possible to take advantage of the knowledge of several aerospace research centers or companies in each certain discipline.

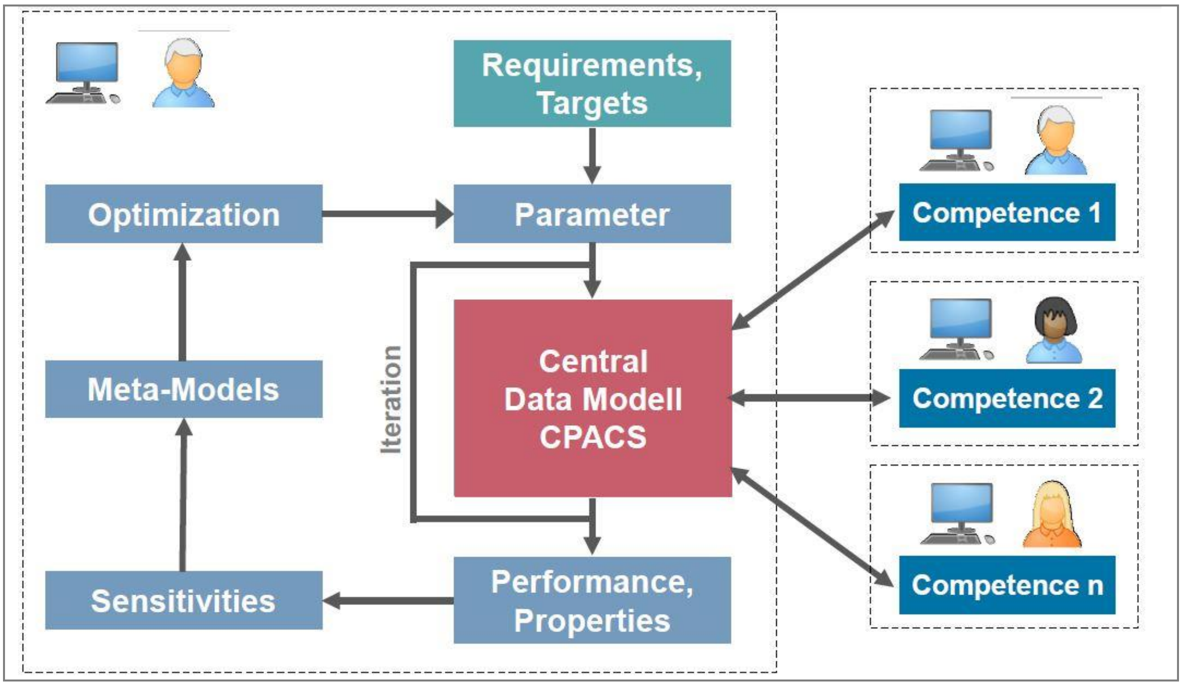

Figure 1: Third MDO generation[15]

This approach is the base for MDO[3] applications within the AGILE (Aircraft 3rd Generation MDO for Innovative Collaboration of Heterogeneous Teams of Experts) European Project coordinated by the DLR and funded by EU through the project HORIZON 2020[4].
The AGILE proposal[4] is to introduce and create a new MDO aircraft generation to promote a new approach in terms of collaborative design, knowledge dissemination among various teams of experts and MDO approaches and applications. There are some main goals such as the development of advanced multidisciplinary optimization techniques to reduce the convergence time in aircraft optimization and to face the lack of knowledge about how optimization workflows involving a lot of disciplines; the development of processes and techniques for efficient multisite collaboration in the overall design teams; furthermore, given that there are a lot of tools of specific disciplines and the results are hard to interpret without specialists, another goal is to involve companies and research centers which will share their best competencies to foster the Collaborative, Remote and Distribute design approach; to develop and publish an Open MDO Test Suite, allowing the access to the project technologies by other research activities and to provide a reference database for the future aircraft design. To judge the success of the project two important quantities will be consider:

- 20% reduction of time needed to converge the optimization of an aircraft configuration thanks to AGILE optimization techniques
- 40% reduction of time needed to solve a MDO problem in a heterogeneous team of specialists thanks to AGILE collaboration processes and AGILE optimization techniques

In particular the UniNa group wants to give his contribute developing several modules which will be used in the MDO chain loops with other partners tools to carry out the overall aircraft design; in addiction each partner will share his competences to focus on the driving design requirements.
To achieve the project goals above mentioned the DLR has provided two fundamental instruments: RCE (Remote Component Environment)[5] software and a standard file format called CPACS (Common Parametric Aircraft Configuration Schema)[6]. The first one is open source software useful to help engineers or teams of scientists to manage, run and control complex analyses and simulations and so to create some design chains. The second one is a file based on XML technology containing a parametric description of aircraft configurations in terms of geometry and beyond. The proposal of this work is to create modules usable into RCE software to build up an MDO framework in which the AGILE members, like UniNa, TUDelft, ONERA, BOMBARDIER, ALENIA, DLR, AIRBUS, TsAGI, FOKKER, NLR, CIAM and other partners can use for the Collaborative Remote Design. Each partner will have to interface only with the CPACS files to reduce time, redundance and partners interconnections. 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.
The main goals of this paper is to demonstrate the usability of the development of specialist analyses modules which can be useful into the AGILE project according to the collaborative remote aircraft design.
Section 2 describes instruments used by UniNa team for the distributed design (format file, software language and type); in section 3 the UniNa developed tools and how they conceptually work is explained. Results of the UniNa tools applications are summarized in Section 4. Finally conclusions are addressed.

2 Instruments for distributed design

The main idea of the AGILE project is to create an heterogeneous team work characterized by people with different deep knowledge about all the aeronautical disciplines, included software development and integration. UniNa followed this approach creating a team work well versed in different disciplines; in particular there are different specialists in the aerodynamic and aircraft design, in software development (with experience in Java Environment, Python, MATLab, and in the integration and testing (CPACS format and RCE framework).

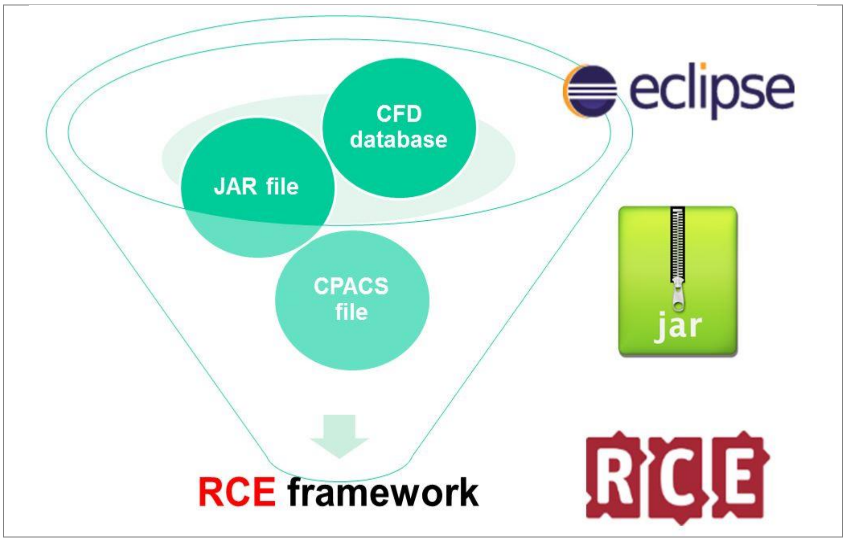

Figure 2 : Useful software packages and files for UniNa tools.

A sketch of the generic integration process is shown in Figure 2. The aircraft design specialist elaborates an analysis method which is implemented in a 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 a MDO calculations.

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 (see [16]), according to the *"AGILE"* methodology[4].
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. A '.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.

3 UniNa tools development

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[7][18]

- FusDes (Fuselage Design)
  It performs the calculation of fuselage directional stability contribution and evaluates the moment coefficients and geometry shape factors[8]

- Directional Stability
  It is a VeDSC and FusDes merging, in addiction 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[9]

- 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[7], 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[10]

- 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

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. 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).

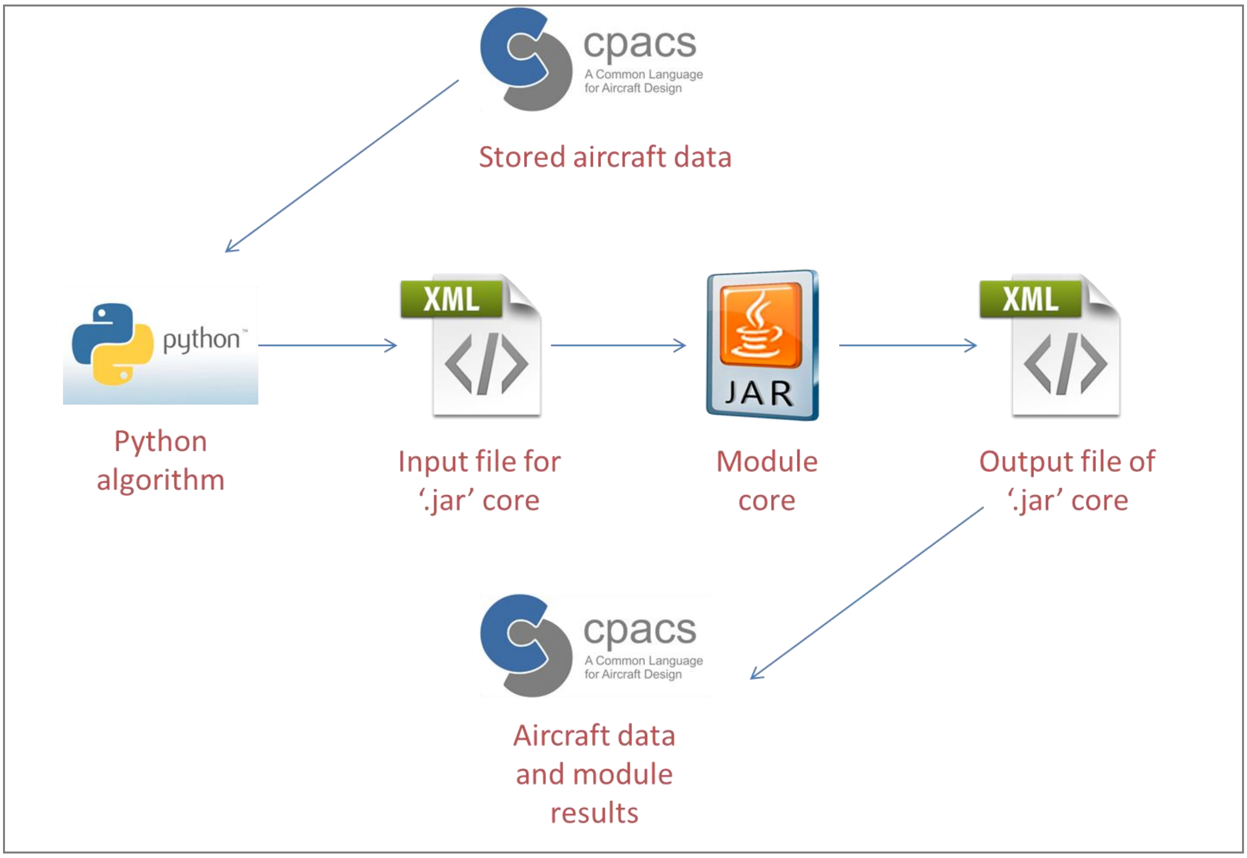

Figure 3: Conceptual module flow

These processes have been carried out thanks to various Python libraries and other two external specific libraries: TiXI[12] and TiGL[13]. The first one is an XML interface library useful for the user to create documents, to create and delete nodes and to add and remove element attributes. In addiction it is possible to extract from CPACS, thanks to specific routines, element of every type like vectors, arrays, boolean variables, integer, text or float. The second one is a Geometry Library useful to read and process the data and the information stored in a CPACS file for the main aircraft components like wings (main wing, vertical tailplane, horizontal tailplane) and fuselages and to build up the 3D airplane geometry for further processing as shown in Figure 4.

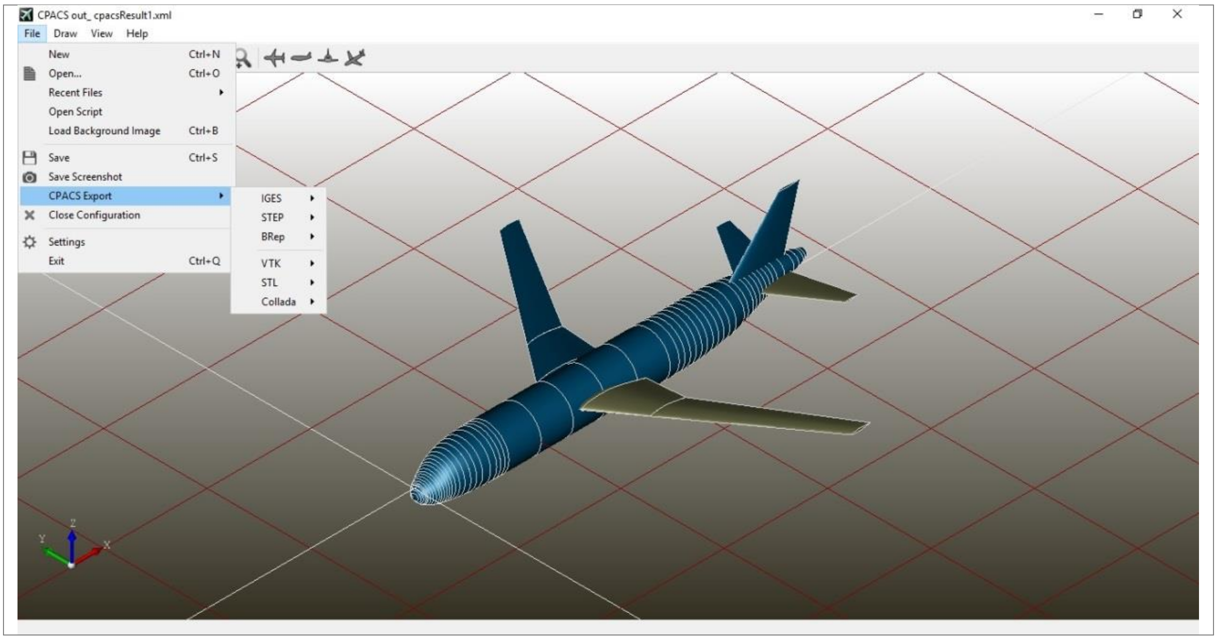

Figure 4: TiGL viewer

4 Tools application

The tools above mentioned have been tested on two different aircraft models available on the AGILE website[14], and another one (DC-1) developed in the first year of the project. The first aircraft, named D150, is similar in terms of transportation mission to Airbus A320 (D150_AGILE_Hangar.xml;, the second one is similar to the ATR72 (TP_AGILE_Hangar.xml) and the last one is that developed during the design campaign (AGILE_DC1_L0_MDA.xml) shown in Figure 5.
In the Table 1 the DC-1 CPACS model main characteristics are summarized.

Wing surface S_w	Wing span b_w	Taper ratio λ_w	Sweep angle $\Lambda_{w\_c/4}$	Fuselage length l_{fus}	Fuselage diameter d_{fus}	Maximum Take-Off Mass	No. of engines	Engine type
82.7 m^2	28.01 m	0.164	25°	34 m	3 m	45045 kg	2	Turbofan

Table 1: DC-1 main characteristics

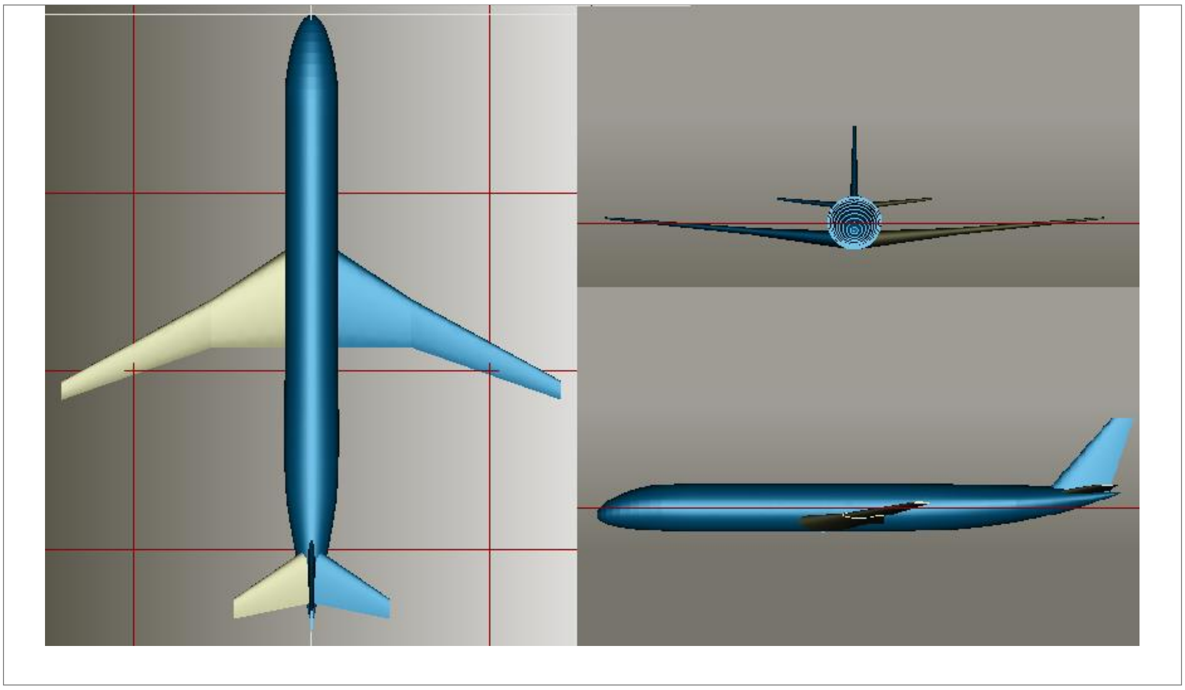

Figure 5: DC-1 views

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 2.

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

Table 2: TLAR 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 6 shows the TOFL as function of wing loading W/S varying the thrust to weight ratio T/W and fixing the weight and the $C_{Lmaxtoke\text{-}off}$. 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 7 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 6 for several C_{Lmax} values.

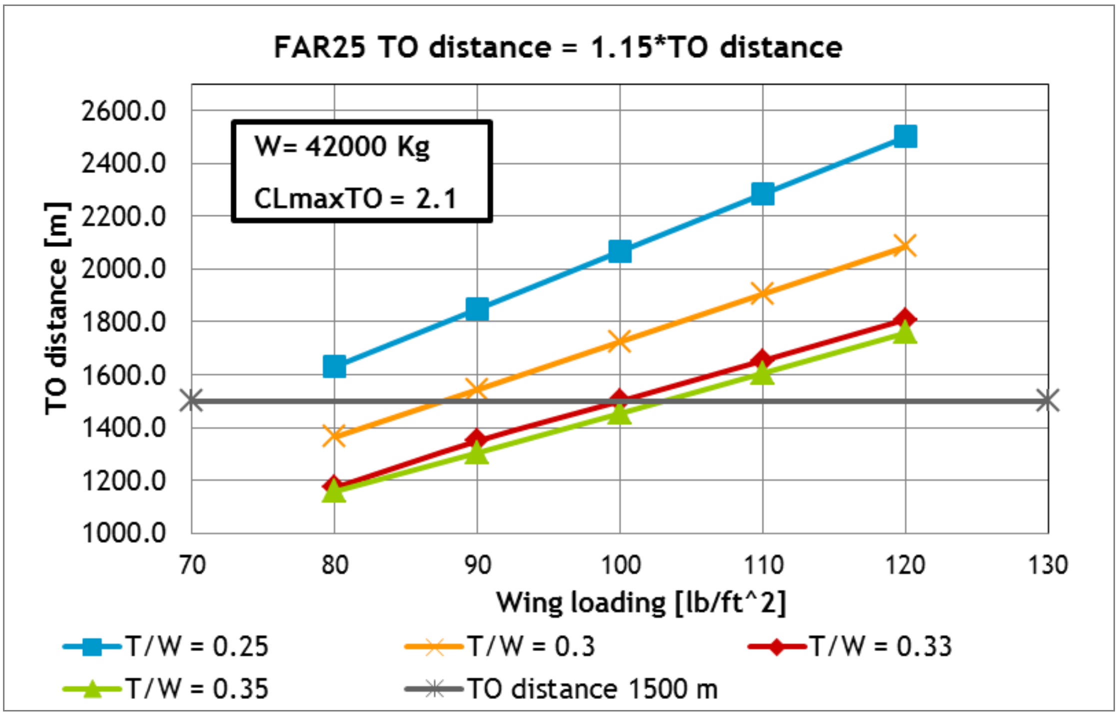

Figure 6: UniNa TOFL deterministic calculation

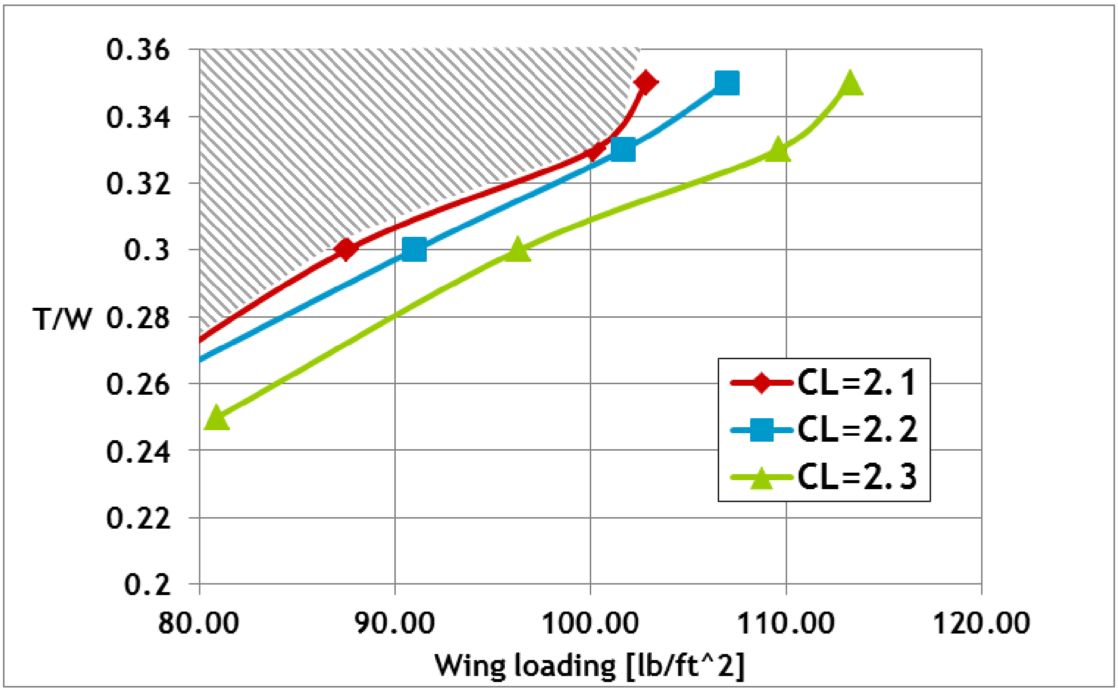

Figure 7: UniNa TOFL deterministic calculation, design space

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 1, 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[17].
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 8. 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}).

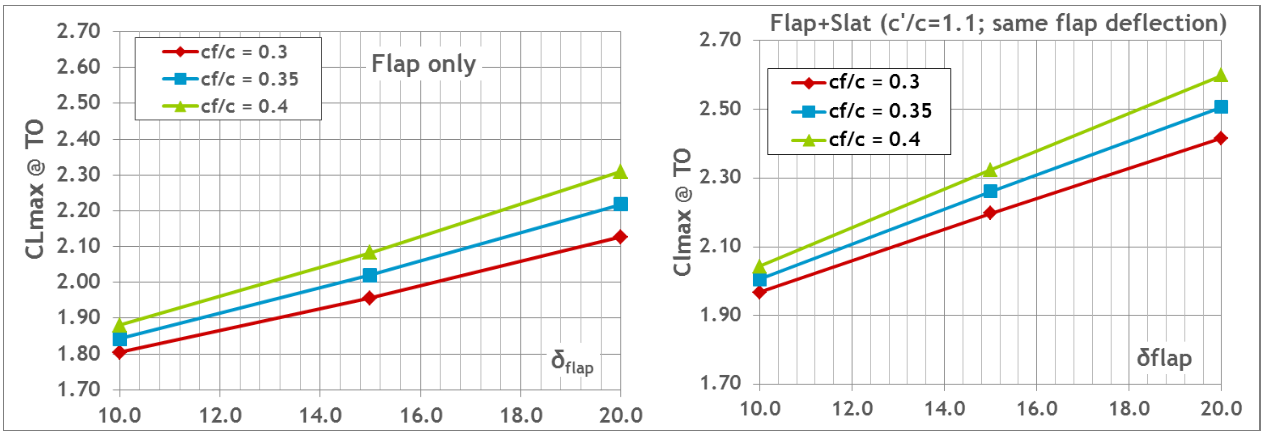

Figure 8: NO SLATS vs. 10% of SLATS chord deflected at the same trailing edge flap angle

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.

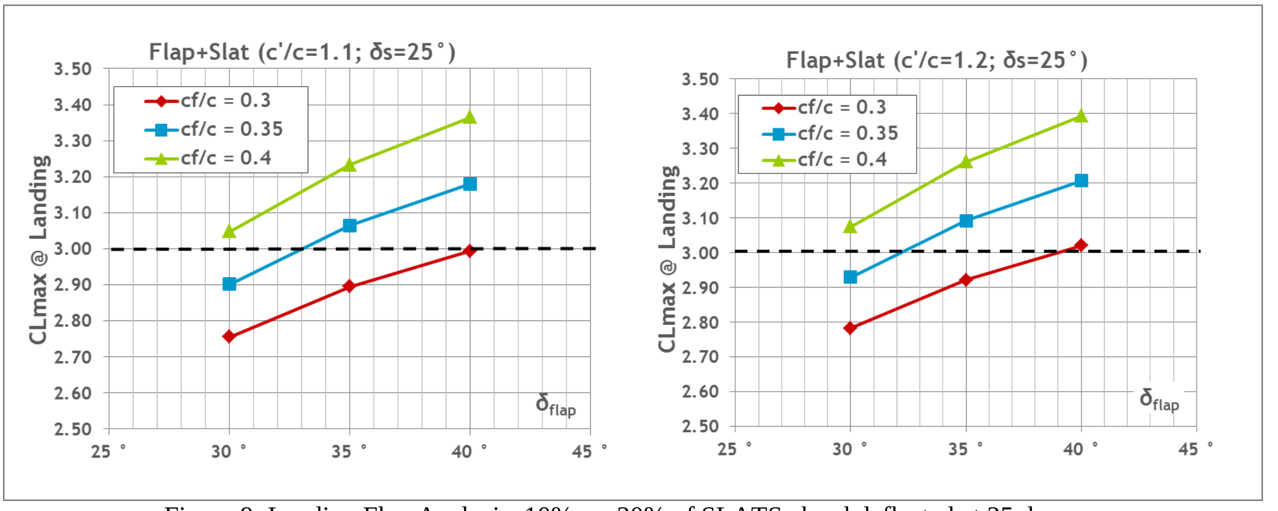

Figure 9: Landing Flap Analysis: 10% vs. 20% of SLATS chord deflected at 25 degrees

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 3.

	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 3: DC-1 vertical tail data

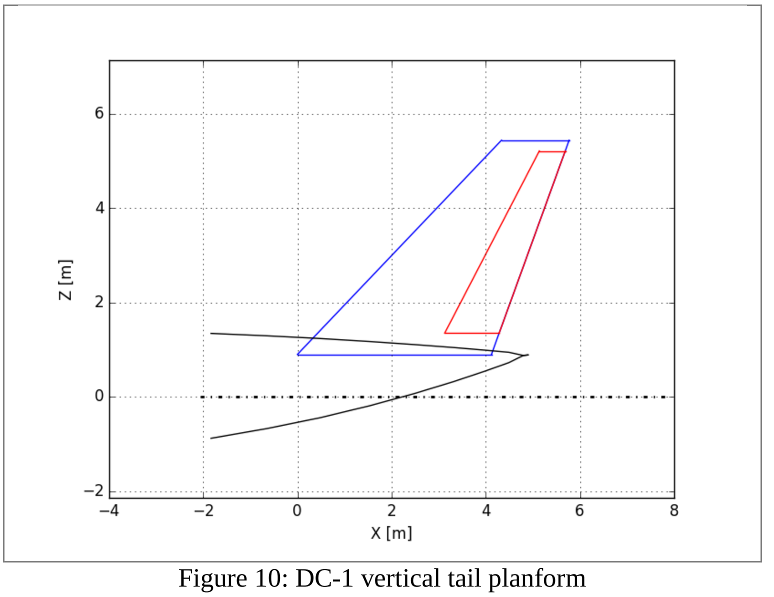

Figure 10: DC-1 vertical tail planform

In Table 4 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.

	Outputs			
	$C_{N\delta r}$	V_{eq}	$VMC_a=1.13* V_{s\_TO} \rightarrow S_v$	$VMC_a=1.13*V_{s\_FAA\_TO} \rightarrow S_v$
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 4: 'VMC' tool outputs

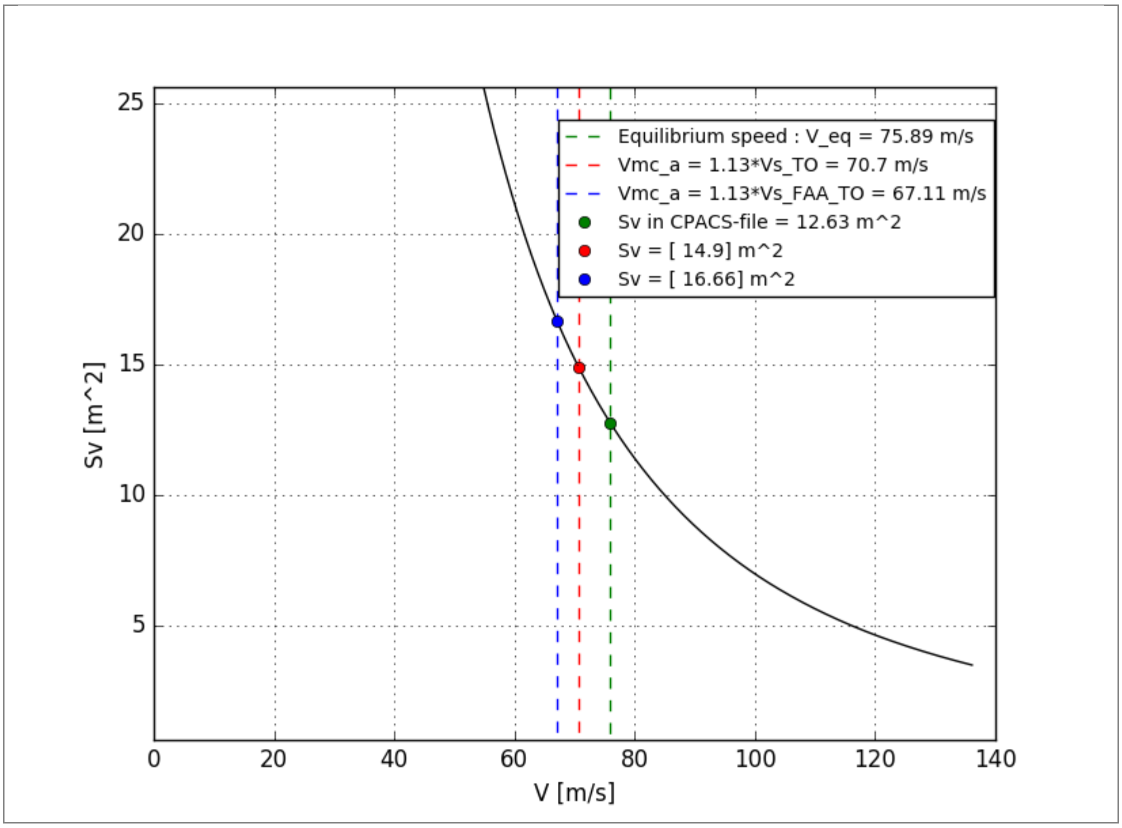

Figure 11: Necessary vertical tail area vs. speed, for equilibrium condition with one engine operative

Concerning the DC-1 model all the UniNa tools results are reported in Table 5 starting from aircraft data extracted from the correspondent CPACS file.

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 5: UniNa tools results regarding DC-1 model

Is fundamental to underline that all modules have been tested on three different aircrafts models. An example is shown from Figure 12 to Figure 14 regarding the evaluation of the total zero-lift drag coefficient[19] using the 'C_{D0}' tool.

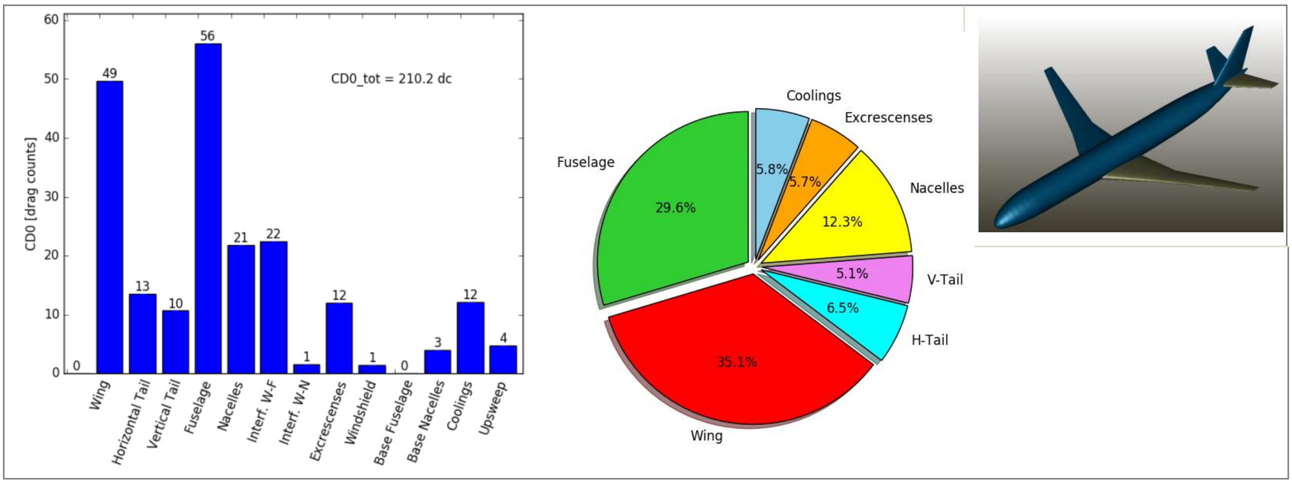

Figure 12: Zero-lift drag coefficient components breakdown (DC-1)

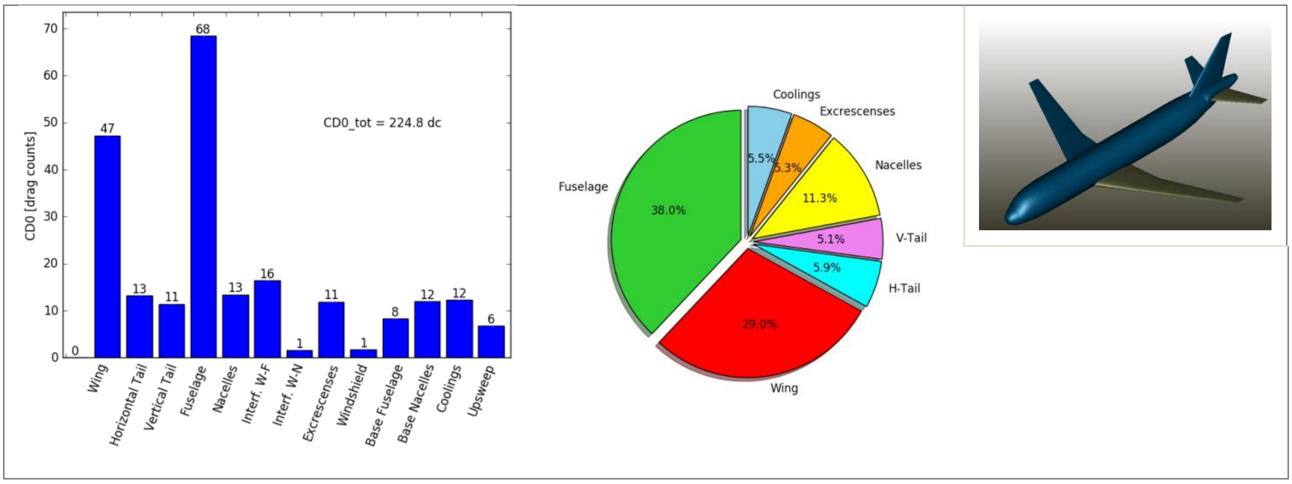

Figure 13: Zero-lift drag coefficient components breakdown (D150)

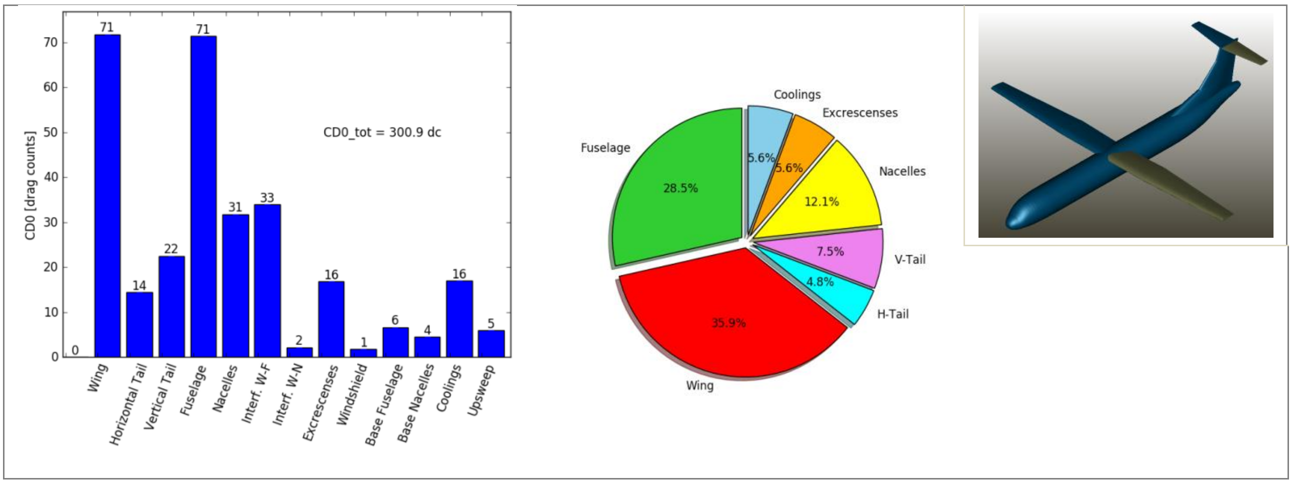

Figure 14: Zero-lift drag coefficient components breakdown (TP_AGILE_Hangar)

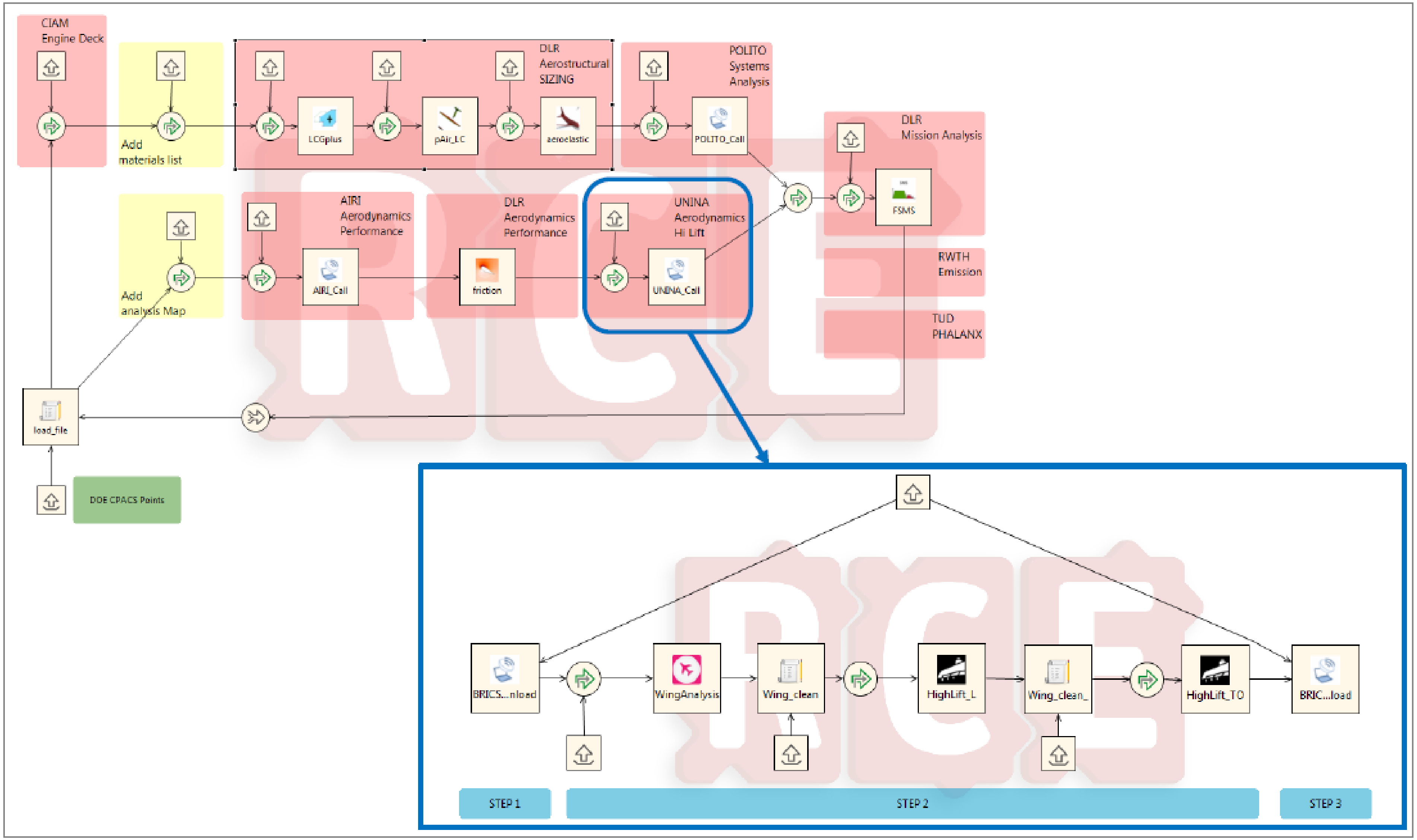

Figure 15: MDO chain: UniNa provides service through Brics

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 15), 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

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.

In Figure 16 outputs diagram of these tools, concerning the DC-1 model, are shown.

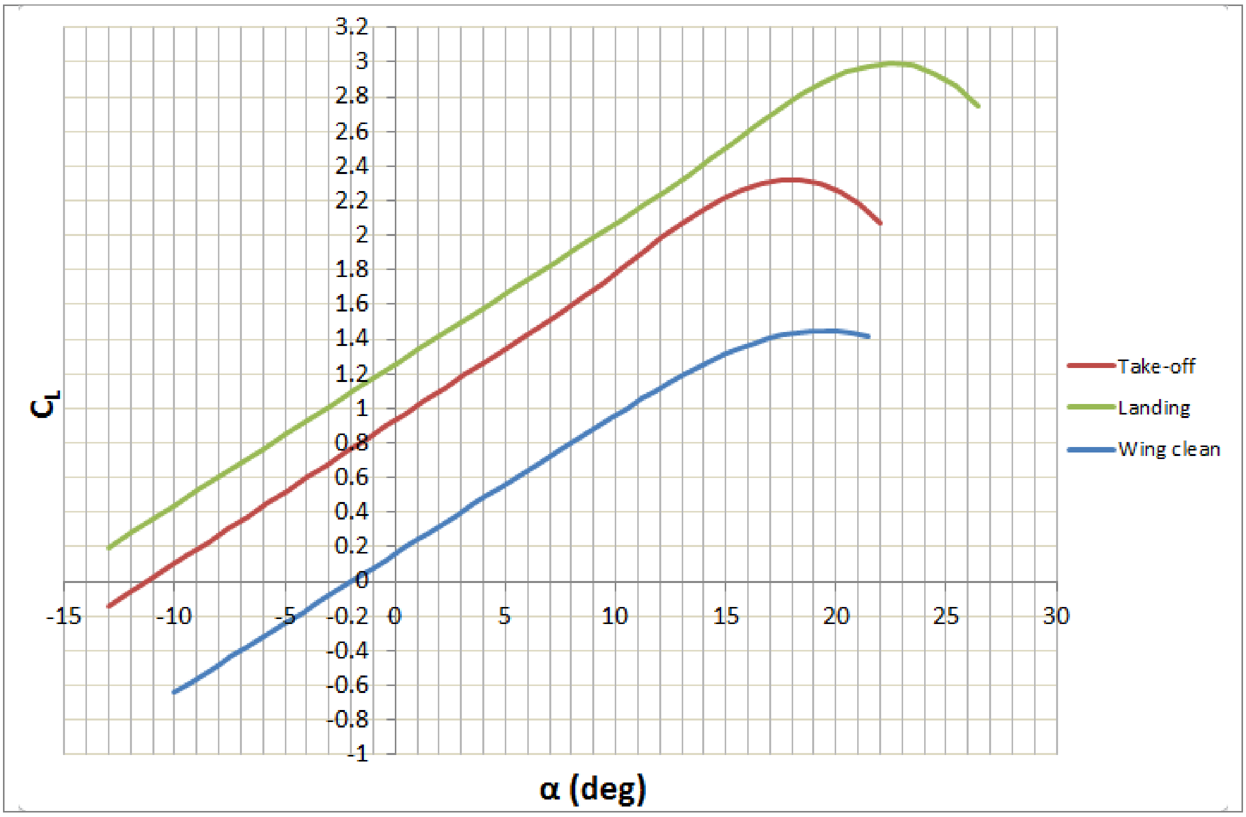

Figure 16: Wing lift curves comparison

5 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 2, 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 2 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.

Acknowledgment

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