COLLABORATIVE SYSTEMS DRIVEN AIRCRAFT CONFIGURATION DESIGN OPTIMIZATION

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Abstract

A Collaborative, Inside-Out Aircraft Design approach is presented in this paper. An approach using physics based analysis to evaluate the correlations between the airframe design, as well as sub-systems integration from the early design process, and to exploit the synergies within a simultaneous optimization process. Further, the disciplinary analysis modules involved in the optimization task are located in different organization. Hence, the Airframe and Subsystem design tools are integrated within a distributed overall aircraft synthesis process. The collaborative design process is implemented by making use of DLR's engineering framework RCE. XML based central data format CPACS is the basis of communication within RCE to exchange model information between the analysis modules and between the partner organizations involved in the research activity. As a use case to evaluate the presented collaborative design method, an unmanned Medium Altitude Long Endurance (MALE) configuration is selected. More electric sub-systems combinations are considered. The deployed framework simultaneously optimizes the airframe along with the sub-systems. DLR's preliminary aircraft design environment is used for the airframe synthesis, and the Sub-systems design is performed by the ASTRID tool developed at Politecnico di Torino. The resulting aircraft and systems characteristics are used to assess the mission performance and optimization.

In order to evaluate the physics based framework and system-airframe synergies, few case studies are considered:

a) Case studies involving Subsystem Architecture's effect, Mission variation effect on overall aircraft performance with a fixed airframe.

b) Case study of optimization involving wing planform variables and subsystem architecture for a given mission

1. Introduction

There are many programs which adapt new technologies to old airframe and has shown significant benefits. In terms of Aircraft Subsystems, it has been proven that state of the art system, such as the electrically powered actuator adopted on the A380 program or Bleedless configuration in B787, has provided significant benefits. It is of high interest to integrate and evaluate impact of more/all electric sub-systems on the aircraft design in terms of weight, power consumption and maintenance. The approach of integrating new systems on conventional airframe designs, although less risky and beneficial in terms of performance, are often sub-optimal or do not allow to reap the complete benefits new systems may offer. In a traditional aircraft development process, the accurate representation of the systems properties are often not accounted at the early design stages, in which the airframe design is the dominant activity. Hence, there is a lack of synergy between the new technologies represented by several aircraft systems and configuration design within the same overall synthesis process at the early stages. Thus, the focus of the current research is to evaluate the correlations between airframe design and its systems integration from the early design process. Moreover, another factor hampering the synergy of airframe-systems design is the distribution of these activities within an aircraft development program. In fact, airframe and advanced technologies/systems are typically developed by different specialized team, often from separate organizations, and the integration of the design sub-processes cannot be closely coupled from the beginning. The present research connects specialized design capabilities from two distributed organizations within a single design and optimization process. The research is part of the EU MDO innovation project AGILE. For evaluation of framework, a notional MALE UAV is chosen as test-bed. Often the design constraints are not stringent as the case of civil aircraft, hence open up new avenues for airframe-systems integrated solutions. The objective is to consider a more electric approach for the subsystem selection for the mission requirements, and to optimize the airframe as well as systems, in an integrated design process. An innovative methodology of collaborative design and optimization is created using DLR's engineering framework Remote Component Environment RCE. Section 2 introduces the main elements of the collaborative design environments. Section 3 describes the methodology of design process and Section 4 and 5 describe case studies carried out for assessment of Airframe-subsystem synergy on overall aircraft performance in collaborative design environment.

2. Distributed Design Environment

2.1 Inter-disciplinary Tool Communication Standard : CPACS

For large scale distributed multidisciplinary optimization problem involving several partners, one fundamental requirement is to be able to efficiently communicate across organizations, exchange data between the individual disciplinary analysis tools and design modules, by making use of a common language as described by Nagel et al [1] Thus, to realize the airframe-system synergy evaluation in this study, the DLR's Common Parametric Aircraft Configuration Scheme (CPACS) is used for interdisciplinary exchange of aircraft data between heterogeneous analysis codes. The CPACS data schema contains standard structure of information on the aircraft model such as geometry description, airframe design masses, performance requirements, aerodynamic polar, structural details, engine parameters, mass properties, subsystem architecture details, and process data to control parts of a design process, which is necessary to initialize and trigger the disciplinary analysis modules. Fig 1 shows the concept of CPACS interface between various tools for this research. The following sections describe about the System Synthesis and Airframe synthesis tools compatible with CPACS.

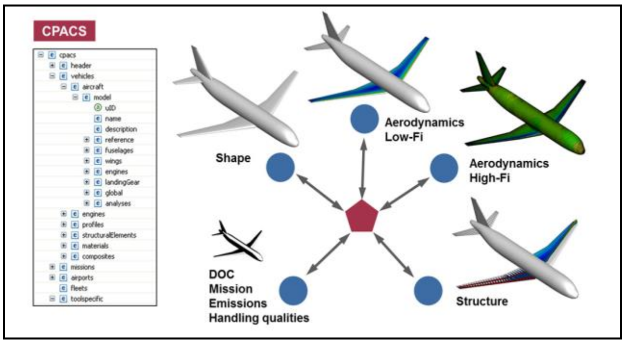


Fig 1 : Centralized CPACS data structure for Multi-Disciplinary Framework

CPACS is currently adopted within all the DLR aeronautical branches for preliminary, as well as high fidelity analysis, and also an increasing number of international partners through various European Union projects such as AGILE [2] and IDEALISM [3].

2.2 Distributed Collaborative Environment : RCE

The distributed multi-disciplinary synthesis and optimization process is deployed in the DLR's engineering framework Remote Component Environment (RCE) [4], along with the collaboration partner Politecnico di Torino. RCE [Fig 2] is an open-source integration environment for design and optimization of complex systems like aircraft, ship, spacecraft and automobile. The environment builds on a decentralized computing system, in which multi-fidelity analysis tools are hosted and run on dedicated servers located at different partner organizations. It enables collaboratively integrate external (partner) tools via server/network without sharing the tool. Therein, the disciplinary codes remain on the servers and, only inputs and outputs in CPACS standard data structure are made accessible to partners/designers. This allows each discipline stakeholder/partner to maintain its specialized domain knowledge and to keep control over the integrated analysis codes. The analysis workflow is executed automatically by RCE with secured permissions of tool stakeholders. RCE runs the workflow exchanging inputs and outputs between various tools located among partner's network. With this research activity, the capabilities of Distributed Multifidelity optimization approach [5] and Multidisciplinary optimization approach [6] previously performed within DLR is expanded to additional disciplines such as Sub-systems synthesis capability via external partner POLITO. The collaborative MDO framework is established such that more disciplinary tools can be added from new partners, broadening the optimization scope and fostering European Union's multi-institutional collaborations.

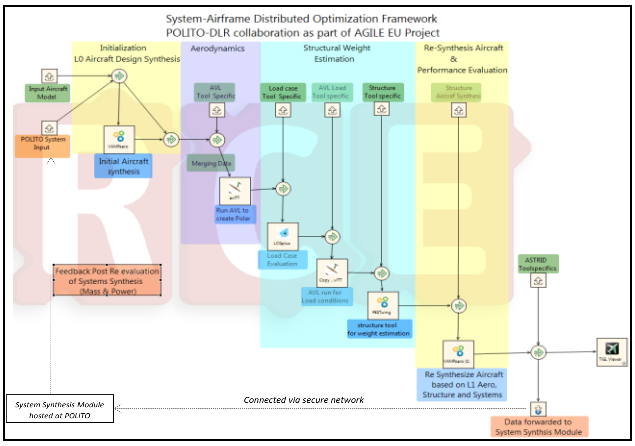


Fig 2 : DLR's Collaborative Design Environment (RCE)

3. Methodology

A collaborative design process is setup for the evaluations of methodology with UAV case studies. All the analysis tools are integrated into workflow deployed in RCE environment and connected through a secure network/server. The tools communicate with each other via CPACS standard data exchange format. The notional MALE UAV and sub-systems options considered for the evaluation are based on CONOPS (concept of operations) and TLARs. The integrated MDO process is shown in Fig 3 For the notional UAV, the DLR's Airframe synthesis module is hosted at DLR, Germany. The Airframe synthesis module uses several physics based disciplinary tools to evaluate the airframe properties such as Aerodynamics, Structures and Mission Performance (explained in detail in section 3.2). The airframe properties are transferred via secure network in CPACS data exchange file to the System synthesis module, which is hosted at Politecnico di Torino, Italy [7]. The System Synthesis Module selects subsystem architecture from the subsystem combinations [Table 1], and synthesizes the sub-systems for the fixed airframe and mission characteristics (explained in detail in section 3.1. The System synthesis module results consist of the power consumption for each mission segment and the mass breakdown of the subsystems designed. The System synthesis result is transferred back to the aircraft synthesis module. The airframe geometric properties are kept constant, but the system weights and the power required to perform the mission are updated. The Airframe synthesis module provides an updated Block fuel and Maximum Takeoff Mass (MTOM) for the given mission. Hence, the updated MTOM is used by Systems synthesis module, and the process is iterated for convergence. This iteration setup is the basis for UAV case studies (Section 5).

- Case Study 1: The iterative process is repeated for fixed airframe geometry and for multiple system architecture combinations (Section 5.1).

- Case Study 2: The iteration is repeated for fixed airframe and fixed system architecture, but for multiple mission parameters such as altitude and endurance (Section 5.2).

- Case Study 3: Sensitivity evaluation of subsystem parameters with respect to change in airframe variables (Section 5.3).

- Case Study 4: Airframe wing geometry, such as Aspect ratio and Wing Area is varied through a Design of Experiments, and for each DOE point the Airframe Synthesis and System Synthesis modules iterates until a synthesis solution is converged. The DOE results are used to formulate an optimization problem. The optimization strategy is explained in the case study section of the paper (Section 5.4).

The following section 3.1 explains POLITO's Systems Synthesis Module and section 3.2 explains Airframe Synthesis Module in detail.

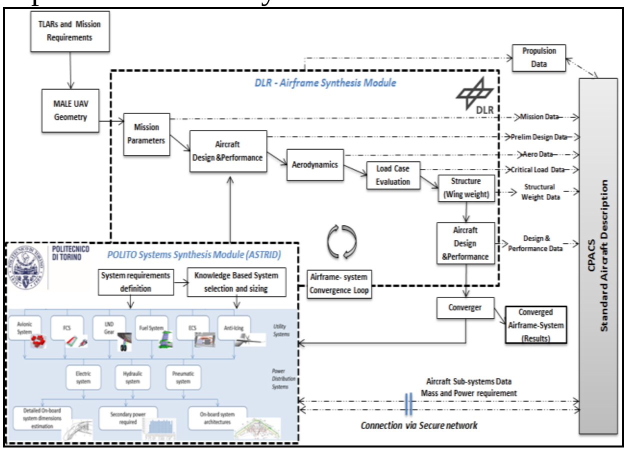


Fig 3 : Collaborative Aircraft & Systems Integrated Design Framework

3.1 System Synthesis Module

Politecnico di Torino has a great experience about the design and sizing of the aircraft on-board systems. The research team for years is focusing the attention on both conventional and innovative configurations, developing methodologies for the definition of the system architectures and for their effects on the overall airplane, in terms of weight, internal volume and fuel consumption for power supply. These methodologies are centered on the following systems:

Avionic System: definition of all the avionic equipment installed aboard the aircraft, estimation of the total weight and the required electrical power.

Flight Control System: design of the actuation systems of the primary and secondary control surfaces. The methodology considers both traditional hydraulically-powered actuators and innovative electric actuators, as Electro-Hydrostatic (EHA) and Electro-Mechanical (EMA) actuators. The estimation of system weight and required electric/hydraulic power is provided.

Landing Gear System: various architectures – e.g. bicycle, tricycle, taildragger – of landing gear systems are designed. The methodology assesses the electric or hydraulic power, according to the type of supplied power, required by the system during the phases of retraction/extraction, steering and braking. The global weight of the system is evaluated, too.

Anti-ice/De-ice System: the methodology allows the design of conventional and new typologies of ice protection systems. The electric power required by zones cyclically/continuously heated by electrical current is evaluated, as the airflow necessary for the traditional aerothermal system or for the pneumatic de-icing boots. In addition, the mass of each type of architecture is assessed.

Environmental Control System (ECS): the airflow required for the preservation of a suitable environment – in terms of air temperature, air pressure, air quality – for passengers, crew and payload, depending on the various thermal loads inside the cabin, is estimated. The system weight is then evaluated, taking into account various types of conditioning equipment, as subfreezing/not-subfreezing Cold Air Units (CAUs), Air/Vapor Cycle Machines.

Fuel System: the methodology allows the sizing of the main equipment of the system, such as the fuel flow supplied by the fuel pumps or the internal volume of the tanks. The secondary power required by the Fuel System and the total weight are evaluated.

Pneumatic System: the system is sized according to the quantity of airflow eventually required by the Anti-ice System – if conventional (i.e. aerothermal or pneumatic boots) – and by the ECS. The methodology supports the design of both conventional system architectures, where pressurized air bled from the jet engines is employed for the pressurization and the conditioning of the cabin, and innovative systems, with a "bleedless" configuration.

Hydraulic System: the global amount of hydraulic power is estimated. The methodology considers conventional engine-driven hydraulic pumps as well innovative electric pumps. The differences in terms of supplied power – and hence in fuel consumption – and of system weight are assessed. The system weight is also evaluated according to the hydraulic oil pressure level, such as 3000 psi (~20700 kPa) for traditional configurations up to 5000 psi (~34500 kPa) used on newer system architectures.

Electric System: the total electric power required by all the users, the dimensions of each electrical machine (i.e. generators and power converters) and the total weight of the system are evaluated. Again, both conventional and innovative configurations are evaluated considering the new trend of higher electric voltages, as the 270 V DC and the 235 V AC wf.

These methodologies have been implemented within an in-house tool developed at Politecnico di Torino, with the aim of automating the design processes, hence allowing trade-off studies considering various types of configurations, conventional and innovative. The present tool is named ASTRID [7] (Aircraft on board Systems sizing and Trade-off analysis in Initial Design). The software is composed by two modules, as schematically shown in Fig 4; the first one is the “Aircraft Conceptual design module”, in which an initial sizing of the entire aircraft is carried out, in accordance with the given Top Level Aircraft Requirements (TLARs). However, in the present study the Aircraft Preliminary Synthesis is provided by the DLR. The latter module is focused on the design of the on-board systems. Starting from the TLAR, sub-system level requirements are derived, as instance typology of power supply, level of technology. Moreover, detailed mission profiles are defined, in order to assess the required power levels in every mission segment during the design of each system. Consequently, all the utility and power distribution systems previously introduced are designed. At the end of the study, the results of system dimensions, secondary power estimations and architecture definitions are obtained.

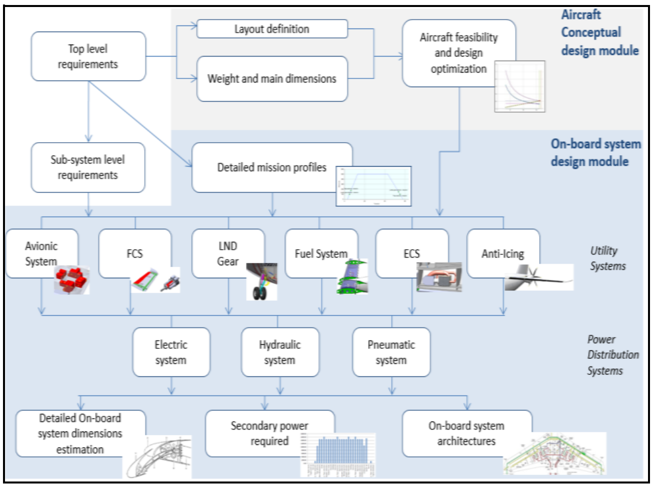


Fig 4 : ASTRID architecture

The design of each aircraft system in ASTRID follows a standard process. In a first phase, the architecture of the system is outlined, as demanded by the TLARs and by the sub-system level requirements. As instance, concerning the Landing Gear System, the designer defines the configuration of the system on the base of the number and the position of the struts and the number of wheels. Furthermore, the functionalities – i.e. retraction/extension, steering and braking – of each strut are stated. Then, the main equipment are sized and defined (e.g. weights, dimensions), according to the requirements. Finally, the analysis of employment of the components in all the mission segments leads to the power budget, i.e. the evaluation of power required by the users in each mission phase. The design ends with the estimation of the total mass of the system and power consumption for individual flight mission segments.

3.2 Airframe Synthesis Module

The Airframe Synthesis Module consists of a multi-disciplinary, multi-fidelity overall aircraft design system under development at DLR, Germany. The design system is deployed as a decentralized design process, comprising multiple disciplinary analysis and design modules suitable for the pre-design stages. DLR’s VAMPzero is an object oriented tool for the conceptual synthesis of aircraft. VAMPzero uses empirical and publicly available aircraft design data and the classical methods available in aircraft design or developed in-house. Main features of the code are:

- Based on **conceptual** design methods and require minimum # of inputs for synthesis
- Object oriented structure (Fig 5)
- Provide **sensitivities** for each Parameter
- Developed for **multi-fidelity** applications
- CPACS exporting capabilities for hi-fi (Fig 6)

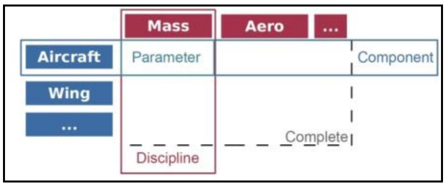


Fig 5 : VAMPzero Structure

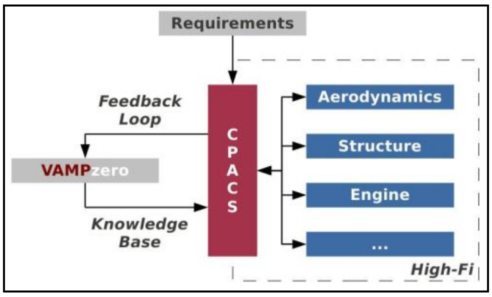


Fig 6 : Multi-fidelity architecture

Disciplinary modules: The distributed process relies on multiple disciplinary analysis and design modules accessible via distributed framework (RCE). For the current study, a VLM aerodynamics module, based on the well-known AVL solver, is chosen to calculate the aerodynamics characteristics. An in-house aeroelastic engine is selected for the loads calculation and a FEM based structural sizing of the main structural components. All the modules are integrated within a multi-fidelity synthesis process, deployed in RCE.

Example of disciplinary models generated by the design modules for the UAV configuration (geometry, VLM, FEM) are shown in Fig 8. Each of the module is extracted from the same CPACS description of the configuration.

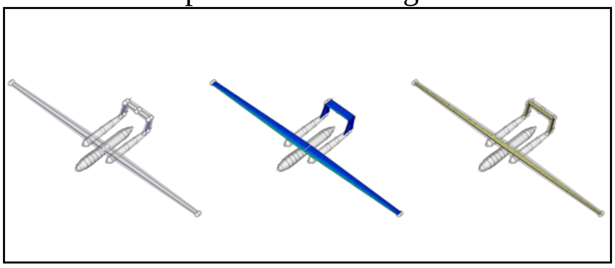


Fig 8 : Geometric, VLM and FEM modeling of Airframe Synthesis Module

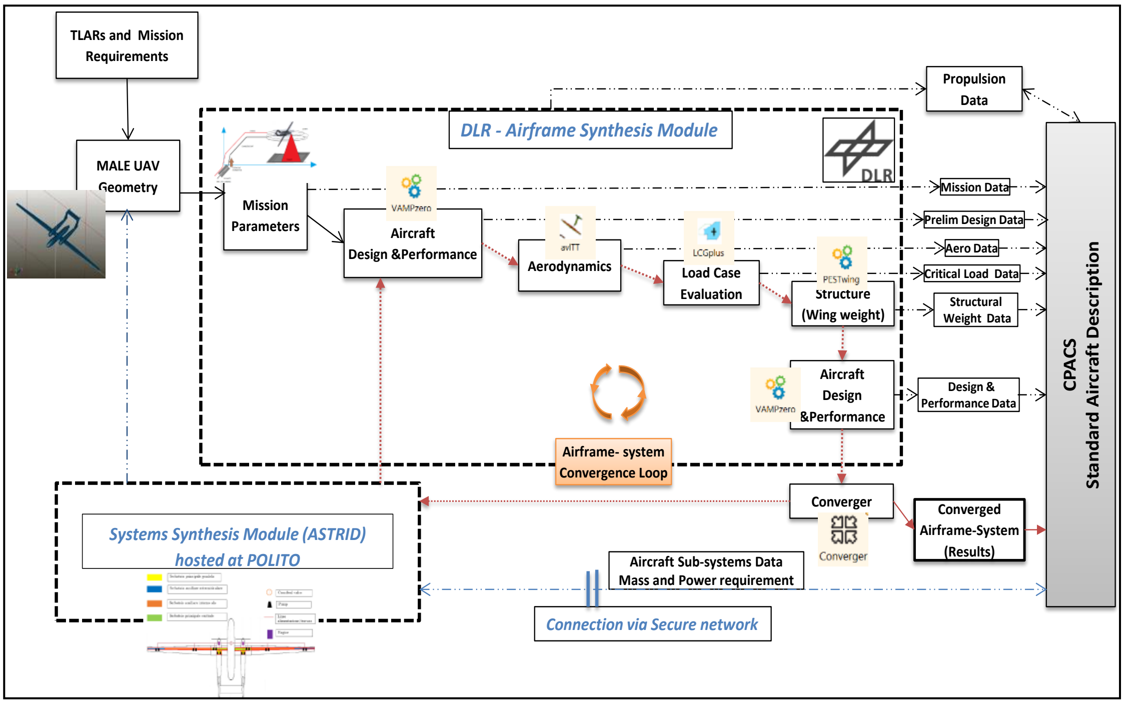


Fig 7 : Airframe Synthesis Methodology

Table 1 : Different system architectures

Architecture	Hydraulic System	Electric System	Actuators	Anti-ice	Payload
Arc 1	Innov	Tradi	Hyd	boots	SAR+EO/IR+Hyperspectral
Arc 2	absent	Tradi	Elec	boots	SAR+EO/IR+Hyperspectral
Arc 3	absent	Innov	Elec	boots	SAR+EO/IR+Hyperspectral
Arc 4	absent	Innov	Elec	Elec	SAR+EO/IR+Hyperspectral
Arc 5	Innov	Tradi	Hyd	boots	SAR+EO/IR
Arc 6	absent	Tradi	Elec	boots	SAR+EO/IR
Arc 7	absent	Innov	Elec	boots	SAR+EO/IR
Arc 8	absent	Innov	Elec	Elec	SAR+EO/IR

The Airframe-Systems Synthesis convergence loop is shown in Fig 7 through solid arrow head with dotted tails. The Airframe synthesis is performed with combination of tools, and the analysis information is shared via CPACS data standard as shown in figure. The requirements are derived and a baseline geometric model of the MALE UAV configuration is created using DLR's Simple Geometric Generator [8]. The geometry is evaluated for aerodynamic characteristics by the aerodynamics modules. Based on Geometry and calculated Aerodynamics, VAMPzero is used for the initial synthesis and performance evaluation with low fidelity/empirics based system weight and structural weights. The First Iteration of VAMPzero Synthesis results contain the aircraft mass properties, geometry and performance parameters, These are forwarded to the System synthesis module in CPACS standard to provide System weights and system power consumption. The ASTRID program performs system synthesis for the specific combination of System architecture. This result from System synthesis progresses further to DLR, and the second iteration of VAMPzero (aircraft synthesis tool) updates with new system weights and power requirements to re-synthesize aircraft. Therefore, the conceptual design is forwarded to the physics based analysis modules, in order to calculate airframe structural weight, flight loads. At this stage the VAMPzero re-synthesize the airframe considering system masses, wing mass and aerodynamics estimated with higher fidelity tools. The new synthesis results are again used by ASTRID for system synthesis for convergence. This process is repeated based on the case studies.

Based on the methodology described in the above sections, the process is validated with a case study presented in next section.

4. Collaborative Airframe-System Synthesis Case Study

In the current study, an aircraft capable of a medium altitude long endurance mission is selected to be designed by the described environment. A MALE UAV developed within the research project SAvE [9,10] is selected, a twin engine propeller aircraft, aimed at Intelligence, Surveillance and Reconnaissance missions. Therefore, the airplane is equipped with sensors necessary for monitoring tasks and an high Aspect Ratio wing. For the same reason, diesel piston propulsion is selected due to the lower specific fuel consumption.

Table 2 : UAV Design Parameters

Parameter	Value	Units
Length	10.9	m
Wingspan	28.4	m
Wing area	29,4	m^2
MTOM	3770	kg
Power plant	2x 300	hp
Fuel capacity	903	kg
Cruise speed	450	km/h
Loiter speed	300	km/h
Endurance	33	FH
Operative altitude	14000	m
Payload	650	kg

5. Case study for collaborative Design Process Validation

5.1 Subsystem Architecture Variation

First case study evaluates the effect of different system architectures [Table 1], involving all/more electric systems for a fixed aircraft geometry, and fixed mission requirements. The sensitivity of system selection, its impacts on power consumption and overall aircraft performance is assessed. In the first part of the study, different on-board system configurations are designed, accounting the effects – e.g. weight variations, fuel consumption modifications – on the entire aircraft.

The eight architectures are reported in [Table 1]. These architectures are characterized by the following features:

Presence or absence of the hydraulic system. If the hydraulic system is absent, the actuators of control surfaces and landing gear are supplied by electric power. Therefore, EMA and EHA are considered. Otherwise, if the hydraulic system is installed, the actuators are hydraulically supplied. In this case, the hydraulic oil is pressurized by electrically driven pumps, entailing a fuel reduction differently from the traditional engine-driven pumps.

Generation of traditional low voltage (i.e. 28 V DC and 115 V AC 400 Hz) electrical current or innovative high voltage (i.e. 270 V DC and 235 V AC wf) electric power. The selection of higher voltages involves a considerable weight reduction, due to the thinner electric wires and the smaller electrical machines.

The Wing Ice Protection System (WIPS) could consist of bladder boots inflated by air gathered from the external environment and then pressurized. Otherwise, in case of a "more-electric" configuration, the anti-ice system is electric, hence heating the leading edges through electrical power (Joule effect).

Two configurations of payload are considered. In both the configurations the payload mass is fixed to 650 kg, but in the first case the payload is composed by only electrically-powered sensors (i.e. a Synthetic Aperture Radar SAR, an Electro-Optical/Infrared EO/IR System and an Hyperspectral radar), while in the second case the SAR, the EO/IR and other cargo – which doesn't require electric power supply – are installed.

The architectures 1 and 5 are traditional, except for the installation of electrically-driven hydraulic pumps. The 28 V DC and 115 V AC electric system supplies electric power to avionics, fuel pumps, lights, conditioning system and other electric users. The flight controls and landing gear actuators are powered by hydraulic oil. The pneumatic anti-ice requires hot and pressurized airflow bled from the engines.

In the architectures 3 and 6 the hydraulic system is removed, entailing the installation of electric actuators.
The architectures 3 and 7 are similar to the 2 and 6, with the difference of the shift to higher electric voltages. Finally, the architectures 4 and 8 are the most innovative, as both the hydraulic and the pneumatic systems are removed. As a consequence, actuators and ice protection are electrically supplied by the high voltage electric system.

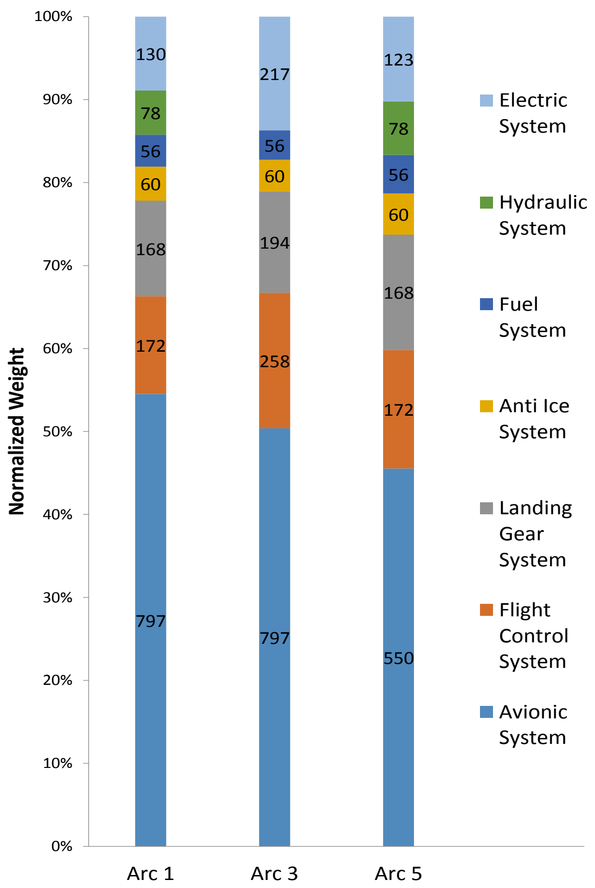


Fig 9 : Subsystem Weight Breakdown

Fig 9 provides normalized weight breakdown comparison of different subsystem architecture.

The weights are categorized into Avionics, Fuels, Flight control systems etc. The weight of surveillance mission equipment is embedded into avionics system category.

For each subsystem architecture, the airframe synthesis module and system synthesis module iterates for convergence. The subsystem synthesis results of different architectures and the impact on aircraft MTOM and Fuel consumption can be observed in **Table 3**.From these results, it appears that the lightest solution is the most conventional architecture (Architecture 5), the heaviest one is the most innovative (Architecture 3), and the weight of Architecture 1 is included among the two. These results can be explained as following:

- Despite of the removal of the hydraulic system (Architecture 3), the systems weight grows because of the higher mass of the current electric actuators, heavier than the hydraulic ones.
- Since the majority of electric users requires the 28 V DC voltage (e.g. sensors and avionics), the introduction of innovative higher electric voltages entails the installation of electric transformers, hence increasing the weight of the electric system. However, this increment is partially limited by the mass reduction of electrical machines and cables, because of the high voltage.
- Even if the electric actuators are more efficient than the hydraulic ones, the fuel reduction in not enough to balance the weight increment of the innovative architecture. The benefits of a more electric architecture would be clearer if the electrification involves all the on-board systems (e.g. electric anti-ice instead of pneumatic boots).
- Architectures 1 and 5 employ state of the art hydraulic power generation (i.e. electric driven pumps) that optimizes the weight and the power consumption of the system, hence improving the traditional hydraulic system with engine driven pumps.

The inclusion of Hyperspectral camera in some architecture adds about 250 Kg of weight penalty, an higher electrical power demand and hence an increased fuel consumption. The most innovative subsystem architecture (Architecture 3) consumes least amount of power.

The power consumed for individual architecture for given mission segment is presented in Fig 11. It is possible to infer the higher electrical power demand of Architectures 1. The reason for this is the worst efficiency of the hydraulic actuators in comparison with the electric ones. Moreover, the Architecture 5 requires less secondary power than the Architecture 1 because of the removal of the power consuming Hyperspectral camera.

Table 3 : Sub-System Architecture and Airframe Synthesis Comparison

Parameters	**Baseline**	**Arc 1**	**Arc 3**	**Arc 5**
Wing Area (sq m)	Constant @ 29.4			
Aspect ratio	Constant @ 27.4			
Loiter Endurance (hr)	Constant @ 33			
OEM (kg)		1379	1379	1379
Payload/Equipment Mass (kg) Including Landing gear	2867	1460	1560	1177
Total Subsystem Peak Power consumption (W)	-	9314.4	8753.3	8809.33
Converged MTOM (Kg)	3612	3750	3884	3382
Max Fuel Mass	745	911	945	825

The Payload-Endurance diagram comparison for different Subsystem architecture combinations [Table 1]. The max payload design point contains all equipment. The weight data of each subsystem is presented in Fig 9 if the UAV user desires to improve the range. Certain mission equipment (ex: Hyperspectral cameras) can be removed to improve the endurance but might compromise surveillance mission objective.

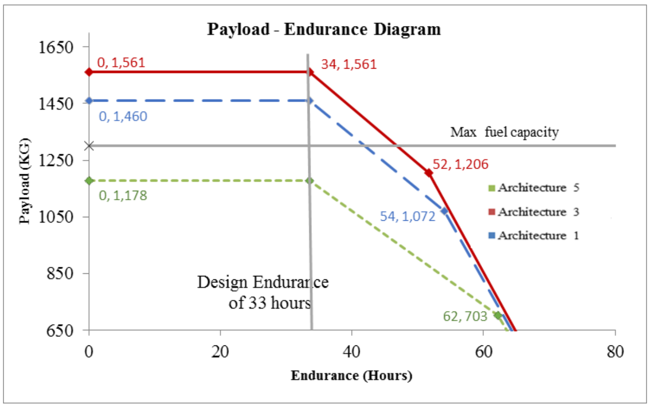


Fig 10 : Subsystem Arch Payload Endurance Comparison

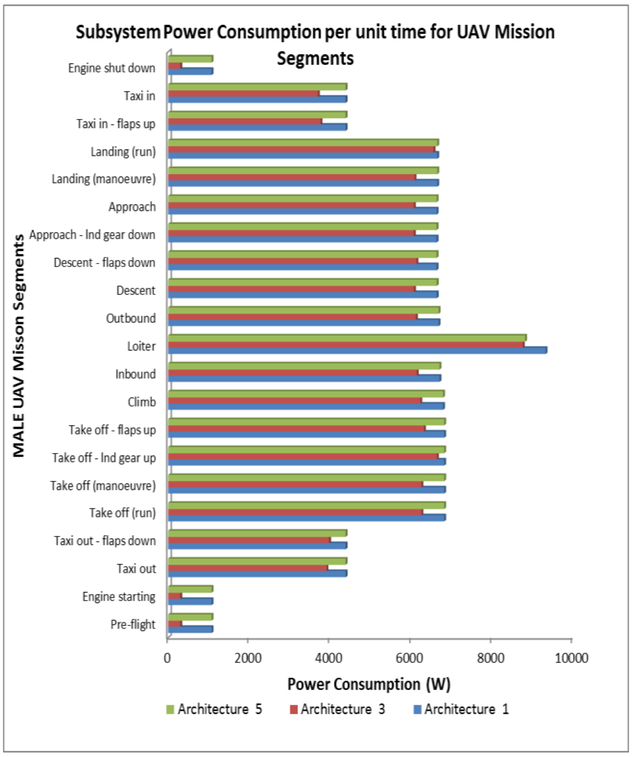


Fig 11 : Subsystem Architecture Power Required Data for Mission Segments

5.2 Effect of Mission Changes

Effect of Mission changes on Aircraft Performance for a fixed System Architecture: In the second case, both airframe and System Architecture are fixed. A study where the mission scenario is changed, and the impact on sub system power consumption and aircraft overall performance is evaluated. For the current study, subsystem architecture 3 is considered for all the mission scenario changes.

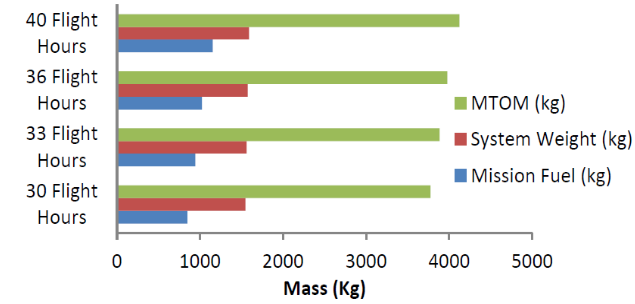


Fig 12 : Endurance Effect on Aircraft Performance

The airframe-systems synthesis was performed to assess the effect of endurance [Fig 12]. Although very minor effects, but this validates that there is correlation between systems and mission parameter. Also, as presented in Table 4, the electrical energy increases by about 10 kWh for every hour of increased mission endurance.

Table 4 : Mission Effects on Sub-systems Architecture

Parameters	30 Flight Hours	33 Flight Hours	36 Flight Hours	40 Flight Hours
Loiter Endurance (hr)	30	33	36	40
Loiter Speed (km/hr)	300	300	300	300
OEM (kg)	1379	1379	1379	1379
Subsystem Mass (kg) (Including Landing gear)	1546	1560	1572	1589
Take off field length	1343	1374	1400	1441
Converged MTOM (Kg)	3774	3884 (+2.9%)	3976 (+5.3%)	4121 (+9.2%)
Max Fuel Mass	848	945	1025	1152
Total System Electrical Energy Consumption (KWh)	246	273 (+10.9%)	300 (+21.9%)	308 (+25.2%)

A detailed design space exploration of the various mission parameters and different subsystem architecture would provide sensitive mission parameters. For the present research scope the objective was limited to validate the design process to observe airframe subsystem correlation.

5.3 Sensitivity of System Weight with respect to Aircraft Parameters

Some of the airframe and subsystem parameters are highly correlated. It is possible to use the framework to evaluate the sensitivity of Subsystem weight for change in airframe parameters. In the following graphs (from Fig. 13 to Fig 17) it is depicted the impact of some aircraft parameters, namely MTOW, cruise speed, wing span and Fuel weight, on aircraft systems. The relations reported in the graphs are applicable only in the present test case, with small deviation (i.e. up to ± 20%) of aircraft parameters from the nominal values. Certainly, many more aircraft parameters affect the on-board systems masses, but these here considered have more influence. As instance, the MTOW deeply affects the FCS mass and Landing gear system weight. The anti-ice system mass is function of the wing leading edge extension and hence of the wing span. Finally, the fuel quantity has effect on the size of the fuel systems and on the dimension of all the main equipment (tanks, tubing, pumps, valves, ..).

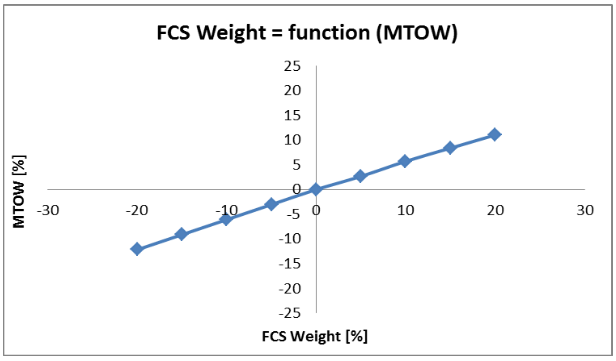


Fig 13 : Sensitivity of FCS weight wrt Maximum Takeoff Weight

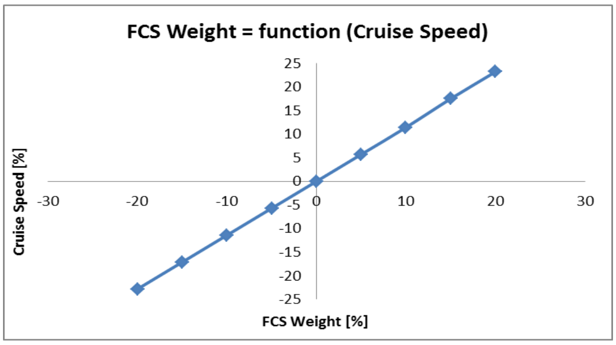


Fig 14 : Sensitivity of FCS weight wrt Cruise Speed

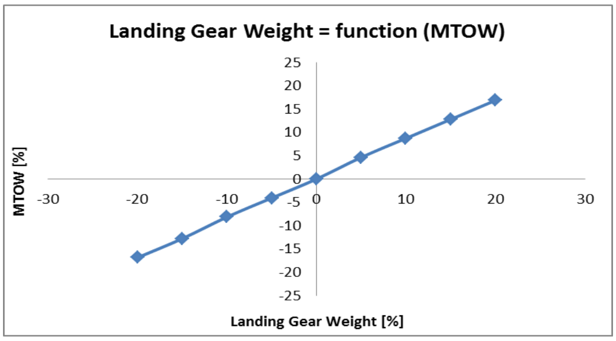


Fig 15 : Sensitivity of Landing Gear Weight wrt Maximum Takeoff Weight

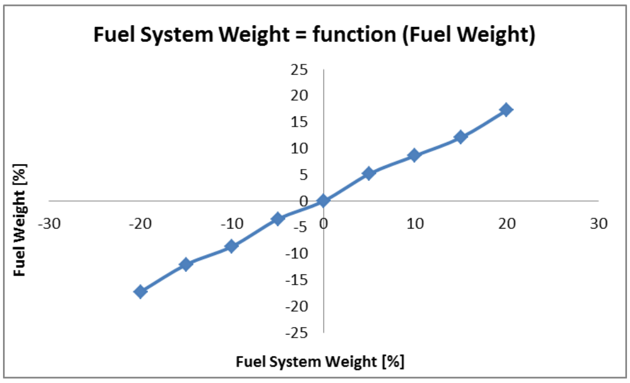


Fig 16 : Sensitivity of Fuel System Weight wrt Fuel Weight

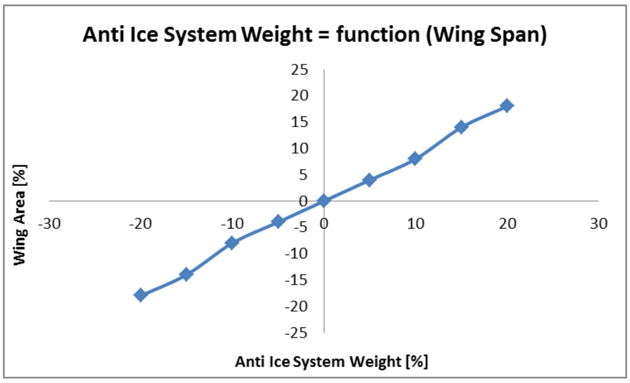


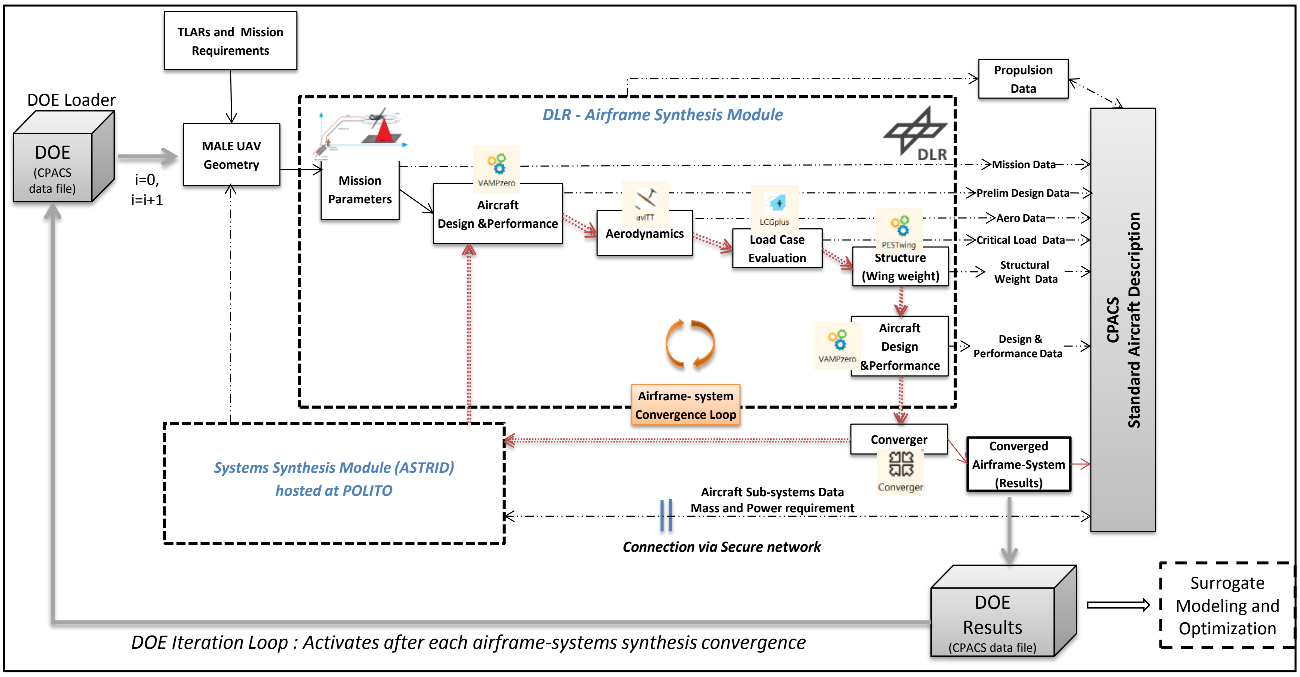
Fig 17 : Sensitivity of Anti-Ice System Weight wrt Wing Span

5.4 Redesign of airframe for a given Mission and System Architecture

From case study 1; the effect of subsystem architecture selection on the Aircraft performance, and Case 2; mission variation effects for a fixed subsystem and fixed airframe can be observed. Case 3 provides sensitivity of systems parameter which are influenced by airframe variables. Now we proceed to simultaneously change and optimize both the airframe and the subsystem. For airframe optimization, only wing planform is redesigned. The tools used in the design framework are capable of physics based evaluations of aerodynamics, wing structural weight estimations and subsystem synthesis.

Fig 18 : Airframe System Optimization Framework

A combination of Latin Hyper Cube and Full Factorial Design of Experiment (DOE) sampling plan was setup for the following independent wing design variables: i) Wing Area and ii) Aspect Ratio. The upper and lower bounds of the variables were set to ± 20% of design variables. Independent configurations were generated based on wing planform parameters from the DOE. As shown in the Fig 18, the individual airframe configurations in CPACS data format are held in DOE loader of the framework, each design of DOE is iteratively evaluated by Aircraft Synthesis Module and System Synthesis Module in the Airframe-System convergence Loop (Shown in dotted arrow loop). Upon convergence a new DOE design configuration is loaded and evaluated. Thus, the process repeats until all the configurations are evaluated. Then the DOE results are used for optimization. It should be noted that each configuration were evaluated with full airframe and system synthesis process exchanging analysis module data in CPACS data exchange format. Each DOE point represents a fully redesigned synthesis solution.



The objective function for the current research is the minimization of the Mission Fuel and Maximum Take-off Mass (MTOM). A gradient based optimization using SciPy library was performed to find optimum Wing Area and Aspect Ratio for the chosen subsystem architecture. The optimization was repeated with several starting points to make sure the minima is global minimum. For the given mission and available choices of subsystem architectures, the optimum minimum mission fuel was found to be 822 Kg of Mission fuel, Maximum takeoff mass of 3758 kg and aspect ratio 27.2 and wing area of 33 sq m. Although the difference in weight is minimum, the newer technologies of subsystem will provide additional capabilities of surveillance with least maintenance costs. Also additional constrains like Take off and landing constraints will affect the optimum points significantly which is not covered here. The result validates the distributed and collaborative Airframe – Systems synthesis process.

Post optimization of airframe and systems; Compared to Baseline and Non-Optimum configurations, the redesigned wing or increased aspect ratio of optimum configuration compensates for high systems weight, thereby reducing overall MTOM.

Table 5 : Summary of Optimization Results

Parameter	Baseline (conventional subsystem)	Non Optimum (With innovative subsystem)	Optimum (With innovative subsystem)
Wing Area (sq m)	29.4	29.4	27.2
Aspect Ratio	27.4	27.4	33
OEM	2867 (Includes systems and Equipment)	1379	1316
Fuel Mass	-	945	882
Equipment Mass (kg)	(included in OEM)	1560	1560
MTOM (kg)	**3770**	**3884**	**3758**

6. Conclusion and Future Works

The collaborative design process involving multiple partners, with multi-disciplinary tools hosted at different location was validated with a notional MALE UAV .The test cases provide insight into the Airframe subsystems synergy. The following future works are planned to evaluate sensitive parameters of the Airframe-subsystem synergies:

- The design process can be further extended by adding higher fidelity propulsion modeling
- More subsystem architecture and combinations to be considered, with an option of hybrid secondary power source and also involving more partners adding capabilities
- The mission parameters such as Take-off field length requirements and loiter speed and altitude can have significant effect on system power ,which needs to be considered
- For optimization process, more variables for DOE are to be considered. The objective function for the current research is the minimization of the Mission Fuel and hence Maximum Take-off Mass (MTOM), which can be extended to further local optimization loops of system weights, power consumption, takeoff field length and optimum loiter speed in future studies with no changes to framework.

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