DOI: 10.13009/EUCASS2019-578

Assessment of aircraft conceptual design tools towards the synthesis of Remotely Piloted Aircraft platforms

Álvaro Gómez-Rodríguez, Alejandro Sanchez-Carmona**, Luis García-Hernández*** and Cristina Cuerno-Rejado*****

*Department of Aircraft and Spacecraft, Escuela Técnica Superior de Ingeniería Aeronáutica y del Espacio, Universidad Politécnica de Madrid (UPM), Plaza del Cardenal Cisneros 3, 28040 Madrid, Spain, *alvaro.gomez.rodriguez@alumnos.upm.es; ** alejandro.sanchezc@upm.es;*

**** luis.garcia.hernandez@alumnos.upm.es; **** cristina.cuerno@upm.es*

Abstract

The conceptual and preliminary design phases of aircraft projects encompass key initial tasks in configuration selection, sizing and optimisation. Relevant current trends include the use of higher fidelity tools, the study of unconventional configurations and the development of design methodologies for Remotely Piloted Aircraft Systems (RPAS). Some of these features are being incorporated in computerised design environments which are becoming increasingly widespread. The objective of this investigation is to conduct a review of current capabilities of these environments to assess the key capabilities, considering the particularities of these aircraft, towards elaborating a new design environment focused on remotely piloted platforms.

1. Introduction

Aircraft conceptual and preliminary design constitute the initial phases of the development of new airplane projects. These stages are characterised by the configuration synthesis, initial sizing and optimisation of a new aircraft in base to the Top Level Requirements (TLR) which define the task or mission that it is expected to conduct. In each of these design steps, the broad design space originally available is increasingly delimited as more detailed information about the aircraft is available and thus more accurate methodologies can be applied [1]. Different authors have investigated and classified the diverse objectives within the aircraft project and the methodologies employed to carry out the design of an aircraft into diverse phases [2] [3] [4]. These authors separate the aircraft project in mainly three different phases: conceptual design, preliminary design and detailed design. As the project progresses, the definition and accuracy of the design is expected to gradually increase.

The conceptual design phase is mainly concerned with the configuration synthesis and initial sizing of the aircraft, as well as an analysis of the viability of the project. Not only the aircraft geometric dimensions are undefined, but also its general layout has yet to be determined, which configures an extensive available design space. Since few information about the aircraft is available, and low computational times are sought, the methodologies employed are mainly based on statistical analysis of historical data. Once the basic layout of the aircraft has been selected and the main geometric and performance parameters estimated, the design advances to the following stage, which would be that of preliminary design. In this phase, the main objective is to optimise the selected configuration regarding to diverse criteria and encompassing the analysis of the different subsystems which conform the aircraft, in order to refine the initial concept [1]. The objective functions are usually composed of diverse figures of merit corresponding to the different disciplines [5]. The nature of this problem leads to many of the methodologies employed in this phase being aligned with the discipline of Multidisciplinary Design Optimisation (MDO). The use of MDO in aircraft design, particularly in the preliminary phase, has been thoroughly reviewed [6], and can be observed in recent investigations [7] [8]. Since the decisions taken during these phases shall notably restrict the design space, it is crucial that adequate estimations are conducted, especially since it has been states that the choices made during these phases of design can compromise up to 85% of the life-cycle costs of the project [3].

In the past decades, one of the main focuses in the area of conceptual design has been towards the development of computerised environments to aid in the initial phases of the aircraft project, mainly conceptual and preliminary design. The purpose of these tools is to aid the designer in the different stages of the aircraft project, providing an interface

DOI: 10.13009/EUCASS2019-578

that integrates multiple disciplines, often incorporating an optimisation process in order to obtain the most suitable design. Some examples of these design packages would be FLOPS [9], APD [9], CEASIOM [10], SUAVE [11], LEAPS [12], FAST [13] and GENUS [14], amongst others. The expansion of these tools has been motivated by the rapid development in computational capabilities, which allow for optimisation methods to be faster and to incorporate more complex formulations, and Graphical User Interfaces (GUIs), which aid in the visualization of the geometric development and the control of data flows. Moreover, since most of the information required in the different analysis procedures is related to the geometry [15], this last capability has been an essential driver in the development of these software.

However, it has been noted that many of these environments incorporate traditional methodologies such as those found in [2] [3] [4], albeit these classical sizing procedures may not be applicable to new aircraft concepts which are currently being investigated, such as unconventional configurations or Remotely Piloted Aircraft (RPA) [9], which rises the need to either adapt these methodologies or develop new computerised design tools specifically tailored for these novel concepts. Furthermore, the proprietary nature of many of these software packages leads to many of the methodologies incorporated within being unknown or not easily modified, sometimes leading to a “black-box” type of operating environment in which the design logic and models employed remain obscured, leading to significant uncertainties [5] [12].

Previous studies have analysed and compared some computerised design environments. In the case of [9], a thorough comparison between the capabilities of the Flight Optimization System (FLOPS), developed by NASA, and the Pacelab Aircraft Preliminary Design (APD), developed by PACE, was conducted. The investigation developed in [16] [17] carries out a review of some software tools combining geometric environments and conceptual design packages, and then analyses a few integration framework environments. However, an analysis which assesses particular characteristics of a larger number of these environments (such as the disciplinary modules, the layouts which they can analyse, the interaction capability with other software and the level of fidelity of the methods, amongst others) and links them with the current main areas of interest in the broader area of aircraft conceptual design so as to address their adequacy to complying with the presently open research challenges has yet to be conducted. Moreover, there is also the need to develop this analysis taking into account their capabilities in relation with the area of RPA, which is currently undergoing a noteworthy expansion in the field of aeronautics.

Within this context, the purpose of this investigation consists in highlighting, in view of the current state-of-the-art, the trends which have been considered to be amongst the most relevant in the general area of aircraft conceptual design, to then conduct an assessment of the capabilities of existing computerised design environments, evaluating the key areas towards the development of an initial design environment specifically focused on the design of RPA. The identification of these features shall be conducted by analysing the differences between these aircraft and conventional manned ones, examining the level of agreement of current tools with these requisites and evaluating future areas of interest for aiding in the development of the aforementioned initial design environment for RPA.

2. Current trends in initial aircraft design

The first step in the research process of this paper has been focused in identifying relevant research areas of interest within the broad area of aircraft conceptual design. This analysis is oriented towards verifying in section 3 the degree of adaptation of currently available computerised design environments to these fields in which new concepts and procedures are being introduced. Amongst the different areas of current research in aircraft design, the ones which have been found to be more relevant in current state-of-the-art investigations have been: software integration [17] [18], multi-fidelity methodologies [16] [7] [11], unconventional configurations (referring to such as those aircraft with atypical general layouts of their lifting surfaces) [19] [20] [21] [22] [14], and RPA design [8] [23] [24] [25].

2.1 Software integration

Seamless interoperability amongst the initial design environments and different disciplinary analysis tools has become one of the main efforts within aircraft conceptual and preliminary design research. The capacity to combine a variety of tools, even from different creators, serves as a means to incorporate capabilities not available in the core design package and to accelerate the workflow and combine data from different analyses [17]. This topic is aligned with the area of data format and flow, which has been identified as one of the current key issues for these tools [14]. In view of the current trends in aircraft computerised design environments, which will be further expounded on in section 3, many of these design packages incorporate some degree of software synergy. Most of these interfaces are established either

DOI: 10.13009/EUCASS2019-578

with geometric modelling tools [9] [13] or with high fidelity software such as those focused on Finite Element Method (FEM) or Computational Fluid Dynamics (CFD) modelling [9] [11] [10].

One of the main recent efforts in establishing a common language and data standard for tool interoperability in aircraft design has been the Common Parametric Aircraft Configuration Schema (CPACS), developed by Deutsches Zentrum für Luft-und-Raumfahrt (DLR) [18]. CPACS is an XML-based data format, which organises the information on an aircraft design in a hierarchical structure. CPACS allows not only to organise the information managed by the different design teams in an efficient manner, but establishing it as a central module to connect with the different tools involved in the corresponding stages of design enables the team to deal with a much lesser number of interfaces to guarantee the correct flow of information [18],

2.2 Multi-fidelity methodologies

The main idea behind multi-fidelity analyses appears from the need of employing tools and methodologies with a higher degree of accuracy in the conceptual and preliminary phases of design. This necessity is often driven due to the larger uncertainties associated with the modelling of unconventional configurations [10] [11], for which proven methods for conventional configurations may not be sufficient [9]. However, the simulations required by higher-fidelity tools tend to be much more expensive and time consuming. Therefore, the purpose of multi-fidelity analyses consists in employing the adequate level of design fidelity at the appropriate time [11], providing in this way with more flexible computerised design environments which can reduce the gaps between the procedures with differing levels of accuracy [7].

Since the geometric definition of the aircraft evolves as the design process advances, this line of research is also supported by the CPACS schema. Regarding the focus of research in order to improve the level of fidelity for unconventional concepts, some works emphasise integrating high fidelity tools, such as CFD analyses, in earlier steps of the design process, such as developing subrogate models to incorporate in the optimisation process [11], whereas other studies seek to improve and generalise lower fidelity tools, so as to decrease the level of uncertainty when adapting them to new concepts without the need of augmenting the computational resources needed [14].

2.3 Unconventional configurations

From the decade of the eighties onward, due to the diverse petroleum crises, as well as the rising environmental and economic pressures, there has been much research in analysing the possible benefits that can be achieved in these areas by modifying the general layout of the lifting surfaces in aircraft [26]. A myriad of possible unconventional aircraft configurations with different variations in number and position of lifting surfaces and fuselages can be checked in [1]. Statistical analyses on these type of aircraft might be unfeasible, due to the lack of data and the difficulty of generalising conclusions with low samples, therefore many authors recommend employing physics-based models [9], generalising current methodologies for a broader spectrum of configurations [14], or employing multi-fidelity analyses [11] to handle these unconventional layouts.

Many recent aircraft design investigations have focused on the possible advantages of unconventional configurations, as well as on developing or adapting methodologies for their analyses. The Blended-Wing-Body (BWB) configuration has been considered as an alternative for a commercial transport aircraft with a conventional layout [20], and the BWB layout has even been implemented in some computerised design environments [14] [12]. Regarding non-planar configurations, previous studies have proposed this concept as a way to achieve higher aerodynamic efficiencies by reducing vortex drag [27]. This line of research has also seen analyses to evaluate the advantages of this configuration as an alternative to medium commercial transport aircraft [19]. The interference effects of adding a canard lifting surface as a layout modification has also been analysed [21]. It must be noted that these unconventional configurations can also be focused in the tail surfaces, such as in the case of modifying the conventional tail of a commercial transport aircraft to a V-tail empennage [22].

2.4 Remotely Piloted Aircraft (RPA)

As it was stated beforehand, the notable expansion that Remotely Piloted Aircraft Systems (RPAS) are currently experiencing in the aeronautical industry [28] configures these type of aircraft as some of the most relevant towards the development of new design methodologies. Since the surge in their use and development, particularly in the civil market, is relatively recent when compared to their origin, the design methodologies which are currently available for them is comparatively scarce when compared to conventional manned aircraft.

DOI: 10.13009/EUCASS2019-578

Furthermore, as it has been stated by other authors, the development of design methodologies for RPA presents particular challenges, some of which are new with respect to conventional aircraft [29]. Most notably, RPAS present a notable variety in missions and operational environments. As a result, a significant variety in weights, layouts, engine types and take-off and recovery systems can be observed [30] [29]. This makes the extraction of general design procedures difficult when analysing the RPA population as a whole, due to the scatter that the parameters can present. An additional difficulty is encountered due to the relative lack of RPA data when compared to conventional aircraft, which is due to their recent expansion. In order to bypass the lack of historical information, some authors have proposed adjustments on the methodologies employed for traditional aircraft in order to perform the initial sizing of RPA with similar configurations [4]. Whereas for RPA with high values of Maximum Take-Off Weight (MTOW) their larger similarity with manned aircraft could allow to employ these adapted procedures, the differences between these two groups become more relevant in lightweight and middleweight RPA. Therefore, in these cases some authors recommend against the application of conventional manned aircraft methodologies [31] [24]. All of these considerations point towards the need of investigating new conceptual sizing methodologies specifically for RPA.

Considering the above, in the recent years there has been a significant effort in the development of RPA conceptual design procedures. These works can generally be grouped into two lines of research: those that investigate the development of general rapid sizing methodologies for RPA [30] [32] [23] [24] [25] [33], and those that develop in detail the design of a particular RPA model, detailing the different procedures which have been employed in its sizing and optimisation and covering the different adjustments to the design process due to the particularities of the project [31] [34].

Therefore, it can be seen that in recent years the investigation on design methodologies of RPA is expanding at a notable rate. Nevertheless, it must be stated that, for both of these two groups of investigations, few of these procedures have as of yet been integrated in computerised design environments. One example of a computerised design software developed specifically for RPA, focused in the preliminary design phase, can be found in [35] [8].

In order to further evaluate the applicability of conventional design methodologies or existing computerised design software tailored for manned aircraft, the differences in the design environment of RPA with respect to conventional aircraft must be analysed. To this end, a database of fixed-wing RPA was developed, which has been employed in a previous study in order to develop conceptual design methodologies focused on H-Tail RPA [23]. From this database, the following graphs have been extracted regarding aircraft weight and general layout of the lifting surfaces so as to illustrate the combinations of these characteristics which are more frequent for fixed-wing RPA. It must be stated, however, that this analysis does not include rotary wing RPA, save for those which can operate both in fixed-wing and rotary-wing modes. Within the rotary-wing RPA, two groups can be identified: those akin to manned helicopters, and multicopters, the latter being mostly employed for very low weight RPA. These two categories would fall out of the scope of the present paper.

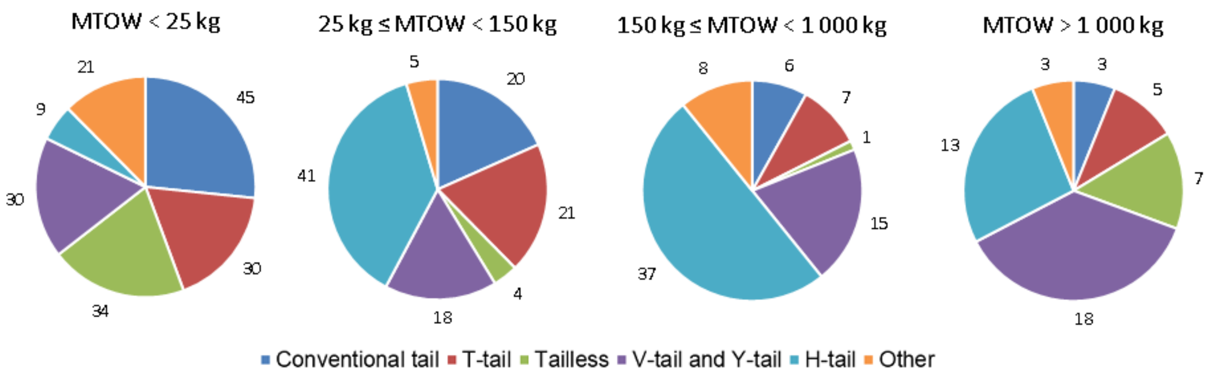


Figure 1: Graphs representing the number of Remotely Piloted Aircraft (RPA) according to general layout of the lifting surfaces in four different weight categories. The “Other” category encompasses RPA with the following layouts: canard, no Horizontal Tail-Plane (HTP), delta wing, joined wing, ring tail, cruciform tail and tandem wing.

This analysis highlights significant conclusions regarding both the applicability of current methodologies to RPA in view of this sample, and also regarding those features which must be emphasised in the development of future design

DOI: 10.13009/EUCASS2019-578

methodologies for these aircraft. Some of the configurations which were labelled as unconventional for manned transport aircraft in the previous section, such as V-Tail, H-Tail and tailless configurations, are more commonly employed in RPA. In the case of manned commercial transport aircraft, the conventional and T-tail configurations prevail, whereas the situation is quite different in the case of RPA. It has been noted that RPA tend more towards the use of unconventional configurations than manned aircraft [30]. However, some of these such as the joined wing and canard layouts are still scarcely used for these aircraft. Regarding mission types, RPAS can develop a wide variety of missions due to their characteristics [36], showing a more ample range when compared with manned aircraft. The most prevalent mission would be Intelligence, Surveillance and Reconnaissance (ISR) [37].

3. Review of computational design environments

Having analysed in the previous section four of the main areas of current research and development in aircraft design, the study will move on to the assessment of the capabilities of state-of-the-art aircraft design computerised environments. The purpose of this analysis is not only to review some of the main characteristics of these software and their current state, but also to examine their adequacy with respect to the four areas that were analysed in the previous section (software integration, multi-fidelity analyses, unconventional configurations and RPA design), with particular emphasis on the last one, which is the main purpose of the current study.

The first step towards this review consists in establishing a definition of the “computerised design tool” concept so as to fix the scope of the data gathering process. This step is required since the different software available for aircraft analysis and design is notably diverse, with different tools having a variety of objectives and procedures. Having described this concept, the next step shall consist in the data gathering process and trend analysis of the different software capabilities.

3.1 Analysis procedure and hypothesis

Prior to the data gathering process and assessment of aircraft computerised design tools, a certain definition of this concept must be adopted so as to focus the scope of the investigation. The authors have considered as such those software packages which encompass at least two aircraft design and analysis disciplines (initial sizing, aerodynamics, structure, weight estimation, mission requirements and analysis, optimisation, etc.) and in which the results of the analysis of these technical subjects have a direct influence in sizing or updating the geometric dimensions of the aircraft which is being created or optimised. Furthermore, these tools must be integrated, meaning that even if a variety of analysis software with diverse origin have been assimilated in the framework, the design process is covered either from the initial specifications to the concept design, or starting from an initial geometry to the optimised one, therefore covering the conceptual or preliminary design stages or both.

There exists a notable variety of software which focus on some of the different disciplines which intertwine in the design of an aircraft. Such tools cover one or several areas including: Computer Aided Design (CAD), aerodynamic modelling, structural analysis, flight dynamics simulation or autopilot design, amongst others. The objectives of these software consist in obtaining reliable results referred to the considered disciplines, such as the aerodynamic loads or the structural stresses. Therefore, they are mostly oriented to the analysis of a certain aircraft design, and unless paired with other tools or included in an optimisation package, the results seldom loop to the geometry sizing of the aircraft, therefore not having a direct effect on its dimensions and design variables (weights, power, range, etc.). Consequently, these tools, when considered isolate, would fall out of the scope of this investigation. Nevertheless, in the particular case of RPA design, a previous study developed a comprehensive review of currently available open-source disciplinary analysis software which could aid in the design and analysis process [38].

An additional hypothesis regarding the possible differences in capability of geometric and other disciplinary modules shall be established. There exists both specialised CAD tools and geometry modules within the computerised aircraft design environments which present a notable flexibility in the definition of diverse aircraft configurations, being able to develop 3D models for unconventional layouts such as Blended Wing Body (BWB), Joined Wing or Box Wing. However, this expanded capability regarding geometry definition may not imply that the other disciplinary analysis modules contain the specific methodologies which are necessary to accurately analyse these layouts. Therefore, in the case that the references do not explicitly express the capability of the other modules (aerodynamics, weight estimation, structure analysis, etc.) to evaluate these configurations, this shall be indicated in the trend analysis as a purely geometric capacity.

DOI: 10.13009/EUCASS2019-578

As it was stated in the introduction, a great effort has been conducted in recent times to apply and develop MDO procedures in the preliminary design phase. In the case of the current study, the optimisation procedure of an aircraft considering diverse disciplines can be considered as a computerised design environment for aircraft design focusing in the preliminary phase. However, stand-alone MDO or optimisation procedures conducted in one or few cases of study would remain out of the scope of this investigation. This is due to the current study seeking to evaluate those integrated environments which cover the whole design stage and preferably the analysis of the complete aircraft, in which the input data (either the TLRs in the conceptual phase or a baseline geometry in preliminary design) have a certain degree of flexibility so that the design package is generalizable within its category of application, staying those tailored for a specific characteristic or need within the aircraft design process out of the range of study. Nevertheless, an exhaustive review on the applications and capabilities of MDO processes in air vehicle design can be found in [6].

Having established the former definition and hypothesis, the following step prior to the computerised design software capability analysis consists in the data gathering process. The information compiled for the current study has been mainly obtained from the open academic literature and from the websites of the software creators. Therefore, no information neither from unpublished documents nor from the source code of the computerised environments when available has been incorporated.

3.2 Key features of computerised design environments

The main areas regarding software capabilities which shall be considered in this analysis have been selected not only to reflect the current state-of-the-art of these computerised design environments but also to evaluate their adequacy with respect to the previously expounded four main lines of research in aircraft design: software integration, multi-fidelity methodologies, unconventional configurations and RPA design.

Attending to the analysis of these areas which was conducted in section 2, a series of key features which enhance the capabilities of the design environment in these fields have been selected. Reviewing the number of software which take into account these considerations can provide an adequate measure on the capacity of currently available design packages to address these relevant characteristics. A list of the different areas analysed are shown below:

- **a** **General software capabilities:** this broad category includes diverse features which are common to various software or have been considered relevant with respect to the current advances in aircraft design. These include:
  - **1** <u>Software interaction:</u> referred to the use of various software in conjunction with the design environment, having adapted their interfaces for data and analysis sharing.
  - **2** <u>CPACS compatibility:</u> capacity of the software to read and write in the CPACS common language for aircraft design.
  - **3** <u>Method flexibility:</u> referring to those software which allow certain degree of freedom to the user with respect to the methods to apply, objective function definition, establishment of layout, etc.
  - **4** <u>Trade-studies:</u> specific tools to aid in the comparison of different design alternatives, so as to evaluate the advantages of some configurations with respect to others. This feature has been identified recently as a relevant characteristics in new conceptual design environments [14].
  - **5** <u>Multi or high fidelity:</u> as mentioned in section 2.2, some design software are incorporating more complex calculations methods to add more information in the initial phases of design.
- **b** **Aircraft type and mission:** this classification shall consider both the type of aircraft from a broad point of view (manned civil, manned military or RPA) and the type of mission that the software can analyse, for which four types have been considered (transport, combat, Search and Rescue (SAR), and Intelligence, Surveillance and Reconnaissance (ISR)).
- **c** **Aircraft general magnitude:** this category has been classified according to regulation weight limits. Since the following analysis encompasses both tools which design conventional manned aircraft and RPA, this category mixes different regulatory limits for both types of air vehicle, so as to cover the full range of weights. The following weight limits refer to the MTOW:
  - **1** <u>Small RPA:</u> up until 25 kg. This category has been created taking into account that, in the case of the European Union (EU), RPA up to this weight operated under certain conditions are regulated according to the “open” category of operations [39] [40]. In the case of United States (US) regulations, RPA under 25 kg operated with commercial purposes are regulated according to Part 107 of the Title 14 of the Code of Federal Regulations [41].
  - **2** <u>Medium RPA:</u> from 25 kg up to 150 kg. Historically, this weight reference served as a threshold in the European Regulations to distinguish those RPA regulated by the European Safety Aviation Agency (EASA) and the ones under the competence of the EU Member States (MSs). However, it

DOI: 10.13009/EUCASS2019-578

is still in place in certain military regulations, as well as in civil regulations in countries such as Brazil and India.

3 Very Light Aircraft and large RPA: from 150kg up to 750kg. This weight category mixes both very light manned aircraft and large RPA, albeit the former categorisation b. shall consider these aircraft separately. In the case of manned aircraft, these would be regulated with CS-VLA, up until 750 kg.

4 Normal Aircraft: from 750kg up until 8618kg, regulated according to CS-23 and FAR-23.

5 Transport Category Aircraft: regulated according to CS-25 and FAR-25.

d **Engine type:** the different types of engine compatible with the capabilities of the design package are included in this classification.

e **General configuration of lifting surfaces:** this categorisation is directly related to the capability of the software of considering unconventional layouts in the sizing or optimisation procedure.

f **Disciplinary modules:** this category analyses the availability of the various disciplines which can be covered by an aircraft design computerised environment. A distinction has been made when the module is externalised to an analysis software outside of the design environment.

In order to more clearly reflect the relation amongst the selected features to assess and the formerly analysed key areas of development within aircraft conceptual design, Table 1 shows the key areas of interested bundled in each of the current trends analysed in section 2. Those categories which have not been included in this table still serve as a means to carry out a general software classification, according, for instance, to the engine type.

Table 1: Interrelation amongst the relevant areas in aircraft conceptual design research and the key features of computerised design environments to assess

Software integration	**Multi-fidelity analyses**	**Unconventional configurations**	**RPA**
a.1 Software interaction	a.3 Method flexibility	a.4 Trade-studies	b. Aircraft type and mission
a.2 CPACS compatibility	a.5 Multi or high fidelity	b. Aircraft type and mission	c. Aircraft general magnitude
f. Disciplinary modules	f. Disciplinary modules	e. General configuration of lifting surfaces	e. General configuration of lifting surfaces
		f. Disciplinary modules	f. Disciplinary modules

As it can be seen, “c. Aircraft general magnitude” has been included in the RPA category since, as it was commented regarding Figure 1, there are relevant variations in the usage of certain layouts for the different weight intervals which were commented in section 2.4. This is also the reason for “e. General configuration of lifting surfaces” being listed under the RPA column, since the most employed configurations differ significantly from those of manned aircraft, therefore a computerised design environment which seeks to design RPA should include the capabilities to size these layouts. With respect to “f. Disciplinary modules”, it has been included in the four main categories. In the field of software integration, as it was mentioned beforehand, many disciplinary module analysis is externalised to specialised tools. Regarding multi-fidelity analyses, these disciplinary modules may have the capabilities of performing high fidelity calculations or employing a variety of methodologies, or even resort to external software to perform these calculations. In the field of unconventional configurations, the capabilities and methods implemented for the analysis of the different disciplines shall determine whether new layouts can be analysed accurately, as would also be the case for RPA, which usually display configurations different to those of conventional manned aircraft.

3.3 Trend analysis

Having expounded on the main areas of interest and capabilities to be evaluated, the trend analysis of state-of-the-art computerised design environments is conducted in this section. Below, a series of graphs are shown representing the results observed for these trends. These results shall be discussed considering the needs of the current aircraft design

DOI: 10.13009/EUCASS2019-578

research areas developed in section 2. The total number of software which has been analysed accounts to 16 computerised environments.

3.3.1 General software capabilities

The first of these graphs illustrates the number of software which comply with the different general software capabilities which have been considered as “a. General software capabilities”.

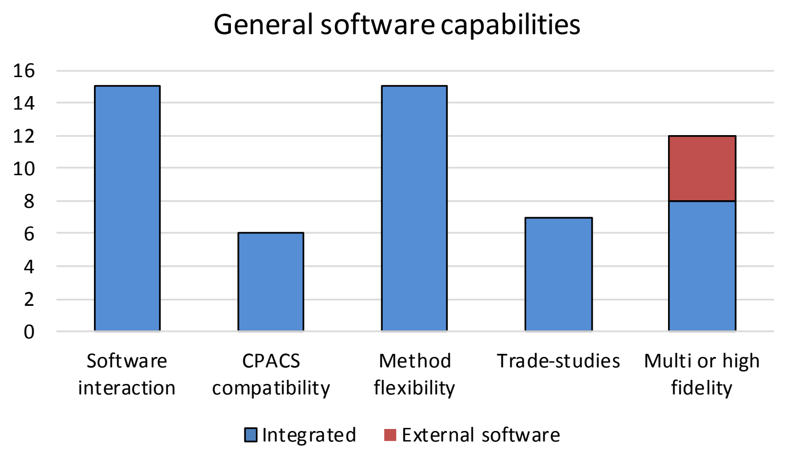


Figure 2: Number of design environments presenting each of five relevant general design software capabilities.

As it can be seen in Figure 2, there is some dissimilarity amongst the different capabilities which have been analysed. Nearly the total number of computerised design environments analysed incorporate some degree of software interaction and also certain freedom for the user to select the methodologies which shall be applied, either in the techniques employed for certain analyses, in the optimisation cycle configuration or in the mission definition. The area of software interaction has been noted by some authors [14] [16] to be of great benefit to the development of these environments. This is due, as mentioned in section 2.1, to the number of analysis software for the different disciplines which are becoming widespread. Establishing a proper interface amongst the design program and these tools, these modules do not need to be developed by the software creators, allowing them to focus in the interfaces and the influence of these analyses in aircraft sizing and optimisation.

Precisely this notion of the importance of software collaboration in aircraft design is one of the driving forces behind the CPACS initiative, which intends to create a common language for aircraft design which can serve as an efficient interface amongst different programs [18]. However, the incorporation of this common format into these design tools still has room for improvement. It appears that many of the interfaces of each of the design environments which correspond to the “software interaction” capability have been developed specifically for each software, and not using the common schema for aircraft design.

Regarding the methodology flexibility, even though most software incorporate this capability, a more detailed analysis would have to be conducted to check in which fields this design freedom is offered more frequently, and which areas have less degree of choice regarding the methodologies. Often this flexibility is achieved due to the capabilities of the different external disciplinary analysis tools, which allow the user to select which to employ depending on the design needs, being this feature related to the multi-fidelity options too.

With respect to the development of trade-studies, less than half of the analysed design environments incorporate specific tools for configuration comparison. It is supposed that this capability could also benefit the design environments, especially when analysing the viability of unconventional configurations. The design, analysis and certification processes for these layouts are expected to be much greater than employing already tested configurations. Therefore, there is need to evaluate the potential benefits that they can involve before going further with the design particularly since the decisions taken in the early phases of design compromise the majority of the life cycle costs of the aircraft [3] .

DOI: 10.13009/EUCASS2019-578

Lastly, with regard to the availability of higher fidelity methods in early design phases, which was discussed in section 2.1, it can be seen that most currently available design environments incorporate this option. Some of them do so via external high fidelity tools, such as CFD or FEM software [9] [11], therefore saving on time and costs of creating software of their own when these proven tools already exist, and focusing instead on establishing the proper interfaces to export the geometry, sometimes with the appropriate mesh, and then to incorporate the results so as to optimise the aircraft parameters.

3.3.2 Aircraft type and mission

Moving on to the analysis of "b. Aircraft type and mission", Table 2 represents the different combinations for aircraft type and mission type with the number of software presenting this capability shown in each intersection. Before developing the analysis of Table 2, it must be mentioned that not all the intersections have been able to be checked, since some references alluded to the capabilities regarding the aircraft type, and separately regarding the mission. However, it has been assumed that if the software presents a certain degree of flexibility with regard to the mission definition, the capability extends to all cited operations. Furthermore, it must be commented that adding all numbers in any row or column may exceed the number appearing as "TOTAL" for any mission or aircraft type. This is due to many software presenting capabilities to design different types of aircraft, therefore these appear duplicate in various cells of the same row or column.

Table 2: Each intersection in the table represents the number of analysed design environments which have stated having capabilities of designing aircraft of the type and mission corresponding to the row and column labels.

	Transport	**Combat**	**SAR**	**ISR**	**Unspecified**	**TOTAL**
Manned civil	15	0	1	4	0	15
Manned military	5	4	1	4	1	6
RPA	0	1	0	3	2	6
TOTAL	15	4	2	5	3	16

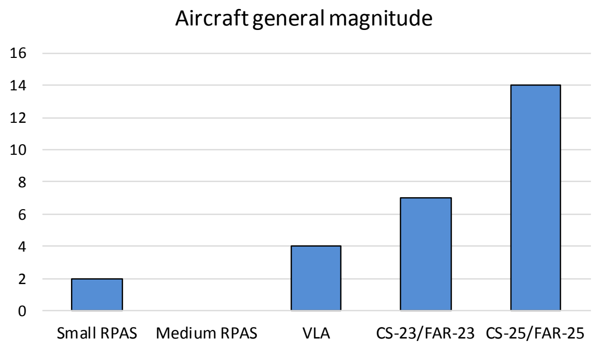
As it could be expected, most of the software include the capability of designing manned commercial aircraft which develop passenger transport missions, which is the main objective of many of these design environments [9] [10]. The other intersections usually correspond to additional features of the software, or adapted methodologies for the different aircraft types, which is also a relevant matter to highlight. The only instance, within the number of computerised design environments which have been analysed, to be developed specifically for a category different to manned commercial transport is a tool focused on the preliminary design of RPA [8].

In view of these current trends, it is clear that the area of manned commercial transport aircraft is addressed by the vast majority of software. However, there is still room for improvement in the other intersections. The aircraft types of both manned military aircraft and RPA have seldom been considered in the development of these tools. For the combat type of mission, 4 out of 6 of the total number of software that can design military aircraft consider this option, as is the case of ISR activities. Therefore, for this type of aircraft, the variety of missions that military aircraft carry out when compared to manned commercial aircraft is better represented within the, albeit small, sample of software which consider this type of aircraft. The same could be said about the RPA category. Even though the number of software is small when compared with the main aircraft type, diverse missions are considered, which is essential in the case of RPA. This is due to the diverse type of missions that these aircraft accomplish, as mentioned in section 2.4 and as it can be seen in [36], amongst other references. Therefore, it can be deduced that, albeit there is a low number of software which consider the aircraft types of manned military and RPA, the ones which do consider the diversity of missions that these air vehicles carry out.

3.3.3 Aircraft general magnitude, aerodynamic configuration and engine type

In this subsection, the sections "c. Aircraft general magnitude", "d. Engine type" and "e. Aerodynamic configuration" shall be analysed. The following graphs represent the different regulatory intervals defined beforehand and the type of engines that the software can consider while designing the air vehicle.

DOI: 10.13009/EUCASS2019-578



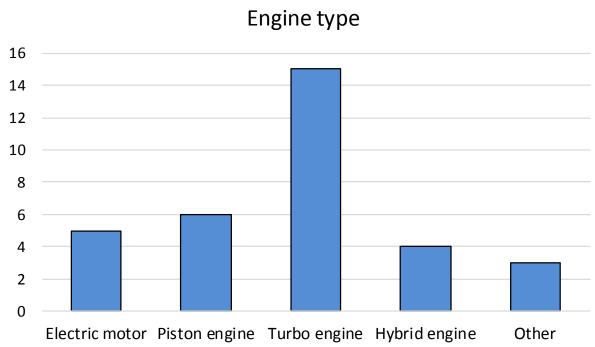


Figure 3: The left-hand-side graph represents the number of computerised environments which can design aircraft of each of the categories regarding the general magnitude of the aircraft (regulatory classification). The right-hand-side graph represents the number of environments which can consider in their analyses each of the engine types.

In view of the left-hand-side graph of Figure 3, it can be seen that the results coincide with the deductions extracted from Table 2 regarding the aircraft type and missions. The transport category aircraft (regulated by CS-25/FAR-25 codes) has achieved the most development within the current sample of computerised design environments. This is also according to the interest of investigating new configurations for commercial transport aircraft, so even though different unconventional configurations are being researched, the main field of interest remains in the larger transport aircraft. Moving to the left, a significant drop is observed when moving to the lower weight intervals of commuter type aircraft (CS-23/FAR-23). The lack of software is noteworthy regarding very light aircraft and large RPA (from 150kg up to 750kg), being there only four instances.

However, perhaps the most notable area, especially under the scope of the current investigation, is the lack of software for small and medium RPA, presenting a couple of instances in the case of the former. As it was stated in the introduction and in section 2.4, small and medium RPA require the development of new design methodologies, due to the difficulty of adapting those for existing larger aircraft and the possible errors that may come with extrapolating trends and conclusions of larger aircraft. Therefore, it is clear that there is significant room for improvement in this area.

With respect to the right-hand-side graph of Figure 3, the type of engine which is considered in the majority of software, once again coinciding with the most interest being focused in commercial transport aircraft, are turbo engines in their diverse formats (turbojet, turboprop and turbofan, mainly). However, the application in the design processes of other types of engines are still marginal, even if new technologies and more environmentally-friendly solutions such as the electric motor and hybrid engine are being investigated in a few of the computerised design environments. This trend once again clashes with the main needs of a design tool for RPA, since most of them are equipped with either electric motors or piston engines, as can be seen in previous studies [23] [24].

The following step shall consist in the evaluation of the general layouts of the aerodynamic surfaces which the design software of study can consider, which is illustrated in Figure 4. In line with the conclusions extracted from the last trends, the conventional tail configuration, being the most frequent one in commercial air transport aircraft, is considered in all the evaluated software. The results for other configurations are varied. It must be stated that, in this study, in order to consider that the software can apply certain configuration to the design aircraft, the analysed references must explicitly mention and validate this capability. It is expected that more of them can also implement T-tail configurations, since it the second most employed tail layout in commercial transport aircraft, which are the focus of nearly all of these environments. As another relevant hypothesis, if the configuration is only seen in geometric representations, the capabilities regarding other disciplinary analyses such as aerodynamic, structural or stability considerations have not been added either unless explicitly expressed. It must be emphasised that, even if these configurations affect mainly the tail surfaces, the structural, stability and aeroelastic considerations, amongst others, can greatly influence the sizing and optimisation process. In addition, many of these, such as the H-tail, may imply additional changes to the overall configuration such as engine relocation, therefore it is difficult to guarantee that accurate analyses can be conducted unless specific models are developed for their consideration. These are the reasons for the previously mentioned hypotheses to have been taken into account.

DOI: 10.13009/EUCASS2019-578

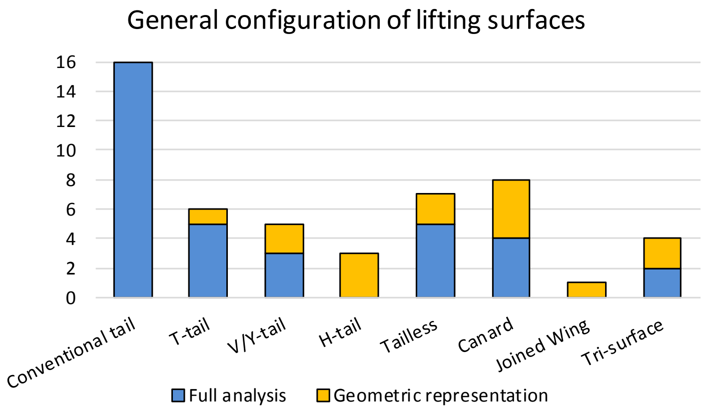


Figure 4: Number of design environments with capabilities in incorporating different general layouts of the aerodynamic surfaces, either with full demonstrated disciplinary analysis or geometric representation.

In general, the representativeness of other configurations, even when considering the software marked as “geometric representation”, is much lower. Special attention has been focused in the tailless configuration in recent conceptual design studies as a possible more efficient competitor for conventional configurations, as mentioned in section 2.2 and as can be seen in previous studies such as [20]. This could be the reason for its higher consideration as alternate configuration amongst the rest. The canard configuration also stands out, with some software offering the option of substituting the Horizontal Tail-Plane (HTP) with this type of aerodynamic surface. However, the instances of the other configurations (V/Y-tail, H-tail, joined wing and tri-surface) is comparatively low, and constitutes another area of interest for future applications of computerised design environments, especially when seeking to address more fuel-efficient alternatives for commercial air transport aircraft, amongst other applications.

3.3.4 Disciplinary modules

The following matter to be assessed shall be the number of computerised design environments which include each of the main disciplinary modules that have been considered in this investigation. Figure 5 contains the main modules which have been observed in the different design packages analysed in this investigation. The instances in which these disciplines are addressed by external software have been highlighted to also link with the “a.1 Software interaction” feature, which was seen in Figure 2 to be very frequent amongst the studied environments. Some of these even include options to either conduct the corresponding calculations or representations either within the environment or to externalise them, offering a certain degree of flexibility and perhaps multi-fidelity options, as was also studied in section 3.3.1.

The most frequent modules cover the basic disciplines in aircraft design of aerodynamics, weight estimation, stability and control, propulsion, costs, optimisation and performances. Geometry tools have become increasingly widespread due to their usefulness in allowing to visualise the whole aircraft at a glance and check how the changes in design or optimisation modify it [42]. It can be observed that, considering the proportion of externalised activities with respect to the whole number in each module, the geometric, meshing, and optimisation disciplinary activities are the ones which most often resort to external software. This may be due to the increasing specialization and level of detail of these kind of tools, and externalising these activities also allows the design package creators to focus on other modules. The ease of interfacing with geometric software has been greatly increased with the introduction of common languages such as CPACS [18].

Regarding the relative lack of structural modules, this is also one of the possible fields of improvement upon the development of new design packages. Previous studies have mentioned the advantages of integrating the structural analysis early in the design process [42], even at a conceptual level in which the number and disposition of the main structural elements (ribs, stringers, frames, etc.) are selected. However, it is clear that the need of accurate description of the aircraft geometry to carry out accurate structural analyses may postpone more in-depth studies to the preliminary design phase, at which step the interfaces with CAD systems can be highly beneficial [42]. This procedure has already been applied in some of the instances of design packages analysed [7] [16] [10].

DOI: 10.13009/EUCASS2019-578

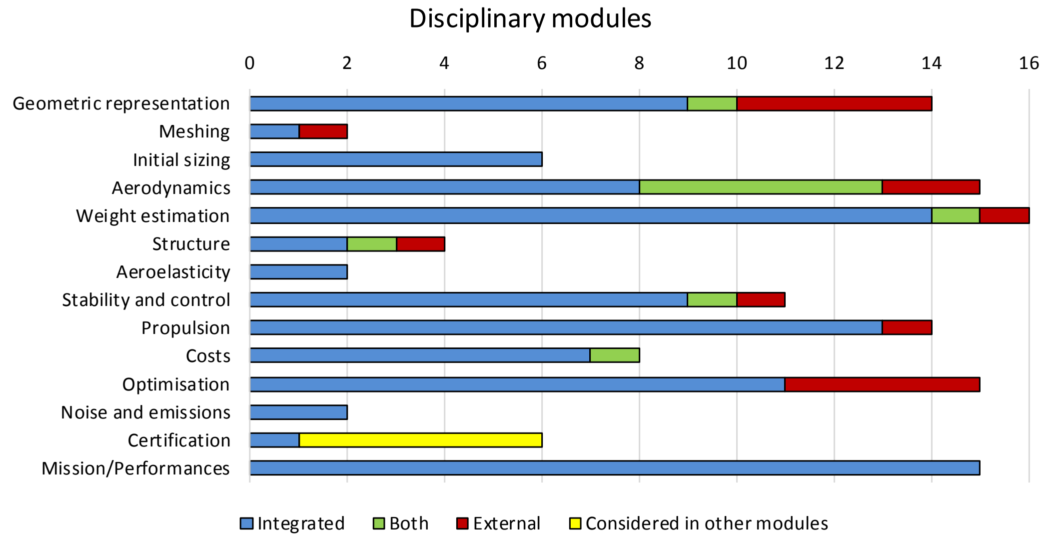


Figure 5: Number of design environments presenting each of different disciplinary modules. A more detailed explanation on the different categories can be found in the accompanying text.

The instances of aeroelasticity, noise and emissions, and certification modules are also comparatively scarce. Special attention has been given to the certification module, having differentiated between two cases: those design packages which incorporate a complete module dedicated to treating certification information, and those which incorporate some criteria relative to applicable regulations in other modules. The former case is considered to be of special interest, particularly with the high degree of current integration with optimisation tools, since this tool centralises certification requisites hierarchically in order to apply them to different stages in the design process in different ways [13]. Regarding the second way of considering these regulations, it is expected that a greater number of the design packages of study incorporate these criteria, however only those instances in which the references explicitly mentioned some certification restriction have been considered.

4. Conclusions and key features for a RPA synthesis design environment

Having conducted the review on the capabilities of current computerised design environments, two different sets of conclusions can be extracted: those regarding the general agreement of the software capabilities with the current areas of interest in aircraft design, and then the identification of the key features which would be needed for the development of a computerised environment focused on Remotely Piloted Aircraft (RPA) and the adequacy of the state-of-the-art tools.

In view of some dissimilarities found between the current research areas in aircraft design, commented in section 2, and the key features of these environments which measure their capabilities regarding current challenges, as analysed in section 3, there is still room for improvement in adapting the design methodologies and creating new procedures considering the changing needs of aircraft design.

Amongst the four different main research areas (software integration, multi-fidelity analyses, unconventional configurations and RPA), the ones which show more room for improvement in their implementation within computerised design environments, in view of the trends extracted in section 3.3, would be the capabilities relative to unconventional configurations and RPA design. It is clear that the main focus of most of the analysed design environments sample is on manned commercial transport aircraft. This can be seen through the different steps of the review, since the characteristics more common of these type of aircraft (general magnitude corresponding to CS-25/FAR-25 regulations, turbo engine, conventional tail configuration, commercial transport mission, etc.) are the most frequent instances in the assessment of the diverse categories which have been reviewed. This clashes with the needs of the aforementioned research areas, which would require adapting the different disciplinary modules to these novel configurations and to RPA, so as to broaden the scope of design space that can be considered to incorporate these concepts with an adequate level of accuracy for these stages of the aircraft project. Amongst unconventional configurations, the tailless and canard layouts have seen a greater level of development in these environments, but focused mainly in the commercial air transport type of aircraft.

DOI: 10.13009/EUCASS2019-578

Aside from the already commented possible future improvements regarding structural, aeroelastic, certification and environmental modules, a very remarkable case is the general lack of “initial sizing” modules, which would be mainly used in the early conceptual design stages. This discipline would allow to obtain an initial geometric definition of the aircraft from the TLRs, even aiding the designer in selecting the most promising configuration. It is clear that most of the analysed modules are focused in the preliminary design phase, as can be deduced from the comparatively greater number of occurrences of optimisation modules when compared to initial sizing. Indeed, many of the modules start their analyses from an already defined geometry, or this geometry is defined by the user and not obtained from initial specifications, and this layout is then optimised. This lack of initial conceptual design activities creates a gap in the design process which also reduces the flexibility of the design space, staring from an already advanced stage with a fixed configuration and nearly defined geometry.

Therefore, it can be seen that these tools are mostly designed for conventional manned aircraft, and are focused on the preliminary design phase, when the layout and general dimensions of the airplane have been already selected, and are therefore not suitable for the early conceptual steps of the project, which must include methodologies for the configuration selection and sizing. This rises the need of future developments focusing on the conceptual stage, including methodologies to aid in the configuration selection and initial sizing of both conventional and unconventional configurations and remotely piloted aircraft.

In order to identify the key needs of a computerised design environment specific for RPA and to evaluate the adequacy of current tools, the particularities of these aircraft must be identified. In view of the analysis in section 2.4, the key features for the development of such an environment are related to the main differences with respect to conventional manned aircraft and listed below. These are analysed in light of the capabilities of the tools assessed in section 3.3 to determine the suitability of these environments for RPA design:

- **Design capabilities for a broader range of configurations:** unconventional tail configurations are more frequently seen in RPA, therefore this point rises the need for more generalizable aerodynamic and structural methodologies to incorporate these concepts. Furthermore, Figure 1 illustrated that the V-tail, Y-tail and H-tail layouts are the most commonly used in RPA. However, current tools seldom consider these configurations, as could be checked in Figure 4, so the design and analysis methodologies should advisably cover these tail layouts.
- **Electric motor and piston engine analysis:** as shown in previous studies, the main engine types for RPA, especially for those in the “Small RPA” and “Medium RPA” categories considered in the current investigation, are electric motors and piston engines. Current computerised design environments are mostly focused in turbo engines, therefore these differences must also be considered for the RPA design package, which should preferably add analysis procedures for these engine types which are more prevalent
- **New initial sizing and weight estimation methodologies for parameter ranges differing from manned aircraft:** RPA can display low values of Maximum Take-Off Weight (MTOW) and of general dimensions such as the wingspan and length which would be unfeasible for manned aircraft. Since extrapolating the methods of manned aircraft further from their application range is discouraged, even when employing those for the same configurations, new weight estimation and initial sizing methodologies should be developed specifically for RPA and incorporated in the environment.
- **Flexibility in mission definition:** RPA can develop a wide array of missions, being most of their applications in Intelligence, Surveillance and Reconnaissance (ISR) activities. Even though mission and performance modules are widespread in state-of-the-art environments, these would have to implement a greater degree of flexibility in mission definition so as to encompass the multiplicity of activities for which RPA can be deployed.

These key features have been identified according to the main differences that these aircraft feature with respect to conventional manned aircraft. Since the majority of current environments are focused in the latter type of aircraft, as it was concluded in view of the analysis conducted in section 3, these key characteristics are still seldom found in currently available design packages. Therefore, in order to develop a computerised design environment specifically focused on RPA, it would be necessary to take into account these characteristics so as to assure the applicability of the different methodologies and analyses in the design process. The rapidly growing needs of the Remotely Piloted Aircraft Systems (RPAS) industry due to its intense expansion increasingly demand the development of these specialised computerised environments, which can suppose a noteworthy contribution in the design process for these versatile and promising aircraft.

DOI: 10.13009/EUCASS2019-578

References

[1] E. Torenbeek. 2013. Advanced Aircraft Design: Conceptual Design, Analysis and Optimization of Subsonic Civil Airplanes. John Wiley & sons Ltd.. Chichester, West Sussex, UK.

[2] E. Torenbeek. 1982. Synthesis of subsonic airplane design. Springer. Dordrecht, The Netherlands.

[3] J. Roskam. 1985. Airplane design, Vol. I-VIII. DAR Corporation. Lawrence, Kansas, USA.

[4] D. P. Raymer. 2012. Aircraft Design: A Conceptual Approach. AIAA Education Series. Sylmar, California, USA.

[5] E. Torenbeek. 1994. Analytical techniques for the optimum conceptual design of subsonic and supersonic transport aircraft. In: *Advances in computer-aided engineering*. 40-58. Delft University Press. Delft, The Netherlands.

[6] A. Papageorgiou, M. Tarkian, K. Amadori and J. Ölvander. 2018. Multidisciplinary Design Optimization of Aerial Vehicles: A Review of Recent Advancements. *International Journal of Aerospace* Engineering. 2018, Article ID 4258020, 21 pages.

[7] F. Daoud, S. Deinert, R. Maierl and Ö. Petersson. 2015. Integrated Multidisciplinary Aircraft Design Process Supported by a Decentral MDO Framework. In: *AIAA AVIATION Forum, 16th AIAA/ISSMO Multidisciplinary Analysis and Optimization Conference*, Dallas, Texas, USA.

[8] H. Aliaga-Aguilar. 2018. RPAS Design: An MDO Approach. PhD Thesis. Universidad Politécnica de Madrid, Escuela Técnica Superior de Ingeniería Aeronáutica y del Espacio, Madrid, Spain.

[9] D. Locatelli, B. Riggins, J. A. Schetz, R. K. Kapania, B. Robic, C. Leenaert and T. Poquet. 2014.Aircraft Conceptual Design: Tools Evaluation. In: *AIAA AVIATION Forum, 14th AIAA Aviation Technology, integration and Operations Conference*, Atlanta, Georgia, USA.

[10] CEASIOM. Computerised environment for aircraft synthesis and integrated optimisation methods. Available: https://www.ceasiom.com/wp/?page_id=32. [Accessed 9 June 2019].

[11] T. MacDonald, M. Clarke, E. Botero, J. M. Vegh and J. J. Alonso. 2017. SUAVE: An Open-Source Environment Enabling Multi-Fidelity Vehicle Optimization. In: *18th AIAA/ISSMO Multidisciplinary Analysis and Optimization Conference, AIAA AVIATION Forum*, Denver, Colorado, USA.

[12] J. R. Welstead, D. Caldwell, R. Condotta and N. Monroe. 2018. An Overview of the Layered and Extensible Aircraft Performance System (LEAPS) Development. In: *AIAA Aerospace Sciences Meeting, AIAA Scitech Forum*, Kissimmee, Florida, USA.

[13] P. Schmollgruber, J. Bedouet, A. Sgueglia, S. Defoort, R. Lafage, N. Bartoli, Y. Gourinat and E. Benard. 2017. Use of a Certification Constraints Module for Aircraft Design Activities. In: *AIAA AVIATION Forum, 17th AIAA Aviation Technology, Integration, and Operations Conference*, Denver, Colorado, USA.

[14] H. Smith, D. Sziroczák, G. E. Abbe and P. Okonkwo. 2019. The GENUS Aircraft Conceptual Design Environment. *Proceedings of the Institution of Mechanical Engineers, Part G: Journal of Aerospace Engineering*. 233(8):2932-2947.

[15] C. Bil. 1994. The Aircraft Design and Analysis System (ADAS): An overview. In: *Advances in computer-aided engineering*. 9-16. Delft University Press. Delft, The Netherlands.

[16] C. Briggs. 2015. A Survey of Integrated Tools for Air Vehicle Design, Part I. In: *AIAA SciTech Forum, 56th AIAA/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference*, Kissimmee, Florida, USA.

[17] C. Briggs. 2015. A Survey of Integrated Tools for Air Vehicle Design, Part II. In: *AIAA SciTech Forum, 56th AIAA/ASCE/AHS/ASC Structures, Structural Dynamics and Materials Conference*, Kissimmee, Florida, USA.

[18] Deutsches Zentrum für Luft-und-Raumfahrt (DLR). Official CPACS Webpage. Available: https://www.cpacs.de/. [Accessed 9 June 2019].

[19] C. Cuerno-Rejado, L. Alonso-Albir and P. Gehse. 2010. Conceptual design of a medium-sized joined-wing aircraft. *Proceedings of the Institution of Mechanical Engineers, Part G: Journal of Aerospace Engineering*. 224(6):681-696.

[20] S. Ammar, C. Legros and J.-Y. Trépanier. 2017. Conceptual design, performance and stability analysis of a 200 passengers Blended Wing Body aircraft. *Aerospace Science and Technology*. 71:325-336.

[21] M. Ghoreyshi, R. Darragh, S. Harrison, A. J. Lofthouse and P. E. Hamlington. 2017.Canard-wing interference effects on the flight characteristics of a transonic passenger aircraft. *Aerospace Science and Technology*. 69:342-356.

DOI: 10.13009/EUCASS2019-578

[22] A. Sanchez-Carmona and C. Cuerno-Rejado. 2018. Vee-tail conceptual design criteria for commercial transport aeroplanes. *Chinese Journal of Aeronautics*. 32(3):595-610.

[23] Á. Gómez-Rodríguez, A. Sánchez-Carmona, L. García-Hernández and C. Cuerno-Rejado. 2018. Preliminary correlations for remotely piloted aircraft systems sizing. *Aerospace*. 5(1):5.

[24] D. Verstraete, J. L. Palmer and M. Hornung. 2018. Preliminary sizing correlations for fixed-wing unmanned aerial vehicle characteristics. *Journal of Aircraft*. 55(2):715-726.

[25] F. Götten, D. F. Finger, C. Braun, M. Havermann, C. Bil and F. Gómez. 2018. Empirical correlations for geometry build-up of fixed wing unamnned air vehicles. In: *The Proceedings of the 2018 Asia-Pacific International Symposium on Aerospace Technology (APISAT 2018)*, Springer, 2018.

[26] J. Roskam, Lessons Learned in Aircraft Design. 2007. DAR Corporation. Lawrence, Kansas, USA.

[27] I. Kroo, J. McMasters and S. C. Smith. 1996. Highly Non-Planar Lifting Systems. NASA Technical Report. NASA. Available: https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19960023622.pdf. [Accessed 19 June 2019].

[28] Teal Group Corporation. 2018. Teal Group predicts worldwide civil drone production will soar over the next decade. Available: https://www.tealgroup.com/index.php/pages/press-releases/54-teal-group-predicts-worldwide-civil-drone-production-will-soar-over-the-next-decade. [Accessed 19 June 2019].

[29] M. Hassanalian and A. Abdelkefi. 2017. Classifications, applications, and design challenges of drones: A review. *Progress in Aerospace Sciences*. 91:99-131.

[30] R. Austin, Unmanned Aircraft Systems: UAVS Design, Development and Deployment. 2010. Wiley. Chichester, West Sussex, UK.

[31] S. G. Kontogiannis and J. A. Ekaterinaris. 2013. Design, performance evaluation and optimization of a UAV. *Aerospace Science and Technology*. 29:339-350.

[32] J. Gundlach, Designing Unmanned Aircraft Systems: A Comprehensive Approach. 2013. AIAA Educational Series. Reston, Virginia, USA.

[33] Á. Gómez-Rodríguez, A. Sanchez-Carmona, L. García-Hernández and C. Cuerno-Rejado. 2019. Remotely Piloted Aircraft Systems conceptual design methodology based on factor analysis. *Aerospace Science and Technology*. 90:368-387.

[34] M. Tyan, N. V. Nguyen, S. Kim and J.-W. Lee. 2017. Comprehensive preliminary sizing/resizing method for a fixed wing - VTOL electric UAV. *Aerospace Science and Technology*. 71:30-41.

[35] H. Aliaga-Aguilar and C. Cuerno-Rejado. 2017. Development and validation of sofware for rapid performance estimation of small RPAS. *Advances in Engineering Software*. 110:1-13.

[36] European Comission. 2016. Flying new way - RPAS - a boost for European creativity and innovation. Available: https://ec.europa.eu/docsroom/documents/19184. [Accessed 19 June 2019].

[37] P. G. Fahlstrom and T. J. Gleason. 2012. Introduction to UAV Systems. Wiley. Chichester, West Sussex, UK.

[38] T. Vogeltanz. 2016. A Survey of Free Software for the Design, Analysis, Modelling, and Simulation of an Unmanned Aerial Vehicle. *Archives of Computational Methods in Engineering*. 23(3):449-514.

[39] European Commission. 2019. Commission Implementing Regulation (EU) 2019/947 of 24 May 2019 on the Rules and Procedures for the Operation of Unmanned Aircraft.

[40] European Commission. 2019. Commission Delegated Regulation (EU) 2019/945 of 12 March 2019 on Unmanned Aircraft Systems and on Third-Country Operators of Unmanned Aircraft Systems.

[41] Federal Aviation Administration. 2016. Part 107 - Small Unmanned Aircraft Systems. Washington DC, USA.

[42] A. Rothwell. 1994. Interactive programs for aircraft structural design and optimization. In: *Advances in computer-aided engineering*. 30-39. Delft University Press. Delft, The Netherlands.