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Aircraft design cycle time reduction using artificial intelligence

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ABSTRACT

In this work we show how Artificial Intelligence (AI) could effectively be used to expedite the decision making process in the early stages of the aircraft design process. We employ both Fuzzy Logic (FL) and Neural Network (NN) as two different schemes of the AI. The developed tools are intended to help to select the proper combination of engine thrust, wing area and the aircraft weight without going through elaborate details of other direct approaches. We further show how the AI could be applied to the specific class of light business jets which serves to validate these schemes. The results indicate the effectiveness of the AI approach in the preliminary aircraft design process. The actual and approximated values for the take-off wing loading and the take-off thrust loading are in agreement within ten percent. The developed design tools, therefore, prove to be effective to decrease aircraft design cycle time.

1. Introduction

"Aircraft Design Cycle" could be characterized as a set of traceable coherent decision makings which need to be managed during a limited period of time leading to a new product. The process brings into account any applicable constraints that are imposed by the aircrafts stakeholders. Stakeholders are referred to all parties involved directly or indirectly during the life of the aircraft and its fleet. Obviously, such decision making process requires proper engagement of wide variety of disciplines in different stages of the design cycle. Such an approach, on the other hand, leads to an active conflict among various disciplines; which needs to be resolved to converge to a viable design. For more details in this field one may confer with [2,41,42] which are some of the major sources in the aircraft design. These sources in the preliminary aircraft design, consider various design disciplines like: aerodynamics, structure, propulsion, performance, stability, control, systems and standards. They also mention that various disciplines are quite related to each other, and emphasize that simultaneous considerations of the different aircraft design features are necessary to the integration of a new design.

Moreover, one may find other basic aircraft design references which address classic methods for design and development of different aircraft categories in the mentioned sources.

It should be noted that the importance of the multidisciplinary methods has been shown in the design cycle tasks analyzing and also the optimization processes of aircrafts. In this way, simultaneous satisfying various disciplines in dealing with the problem at hand causes to take more efficient steps at design processes. Samples for application of these methods in the aircraft design tasks are presented in [1,16,27,29,48,49,55]. Using advanced and state of the art computational techniques, digital systems and computer aided design have a great contribution in the evolution of aircraft design cycle processes. Applying these methods in the aircraft design cause increase in flexibility, accuracy and convergence speed of the processes and on the other hand, reduction of time and cost as well [3,4,17]. Nowadays new generation unmanned autonomous aircrafts, as some important aircraft classes are applied in various operational fields. These aircrafts affect many factors such as reduction of the time and the cost, decrease in human operational rick, eliminating the necessary human vital systems and abate the environmental pollution [6,10,21,24,33,51,56]. Variable configuration and morphing abilities are also other configuration modes of the aircrafts which cause better performance in various conditions of flight environments [46,57].

However, during the preliminary stages of the design process any expected mission-leg leads to some possible combinations for Take-off Wing Loading $(W/S)_{TO}$ and Take-off Thrust Loading $(T/W)_{TO}$ (or Take-off Power Loading $(W/P)_{TO}$). Where W_{TO} represents aircraft take-off weight, S is wing area, T_{TO} shows sea level (SL) engine thrust and P_{TO} indicates SL engine power. Having found any pair of $[(W/S)_{TO}$ and $(T/W)_{TO}]$ that satisfies all

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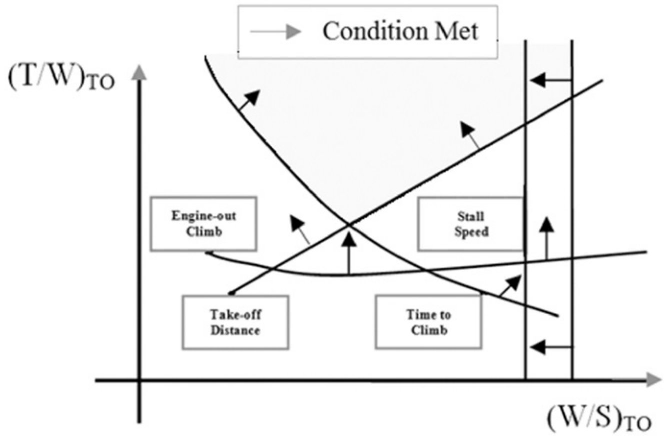

Fig. 1. Sample of the design target area for a jet aircraft.

the requirements imposed by all mission-legs; one could claim that a candidate "Design Point" or a proper combination of W_{To}, T_{To} and S (WTS) exist [2,41,42]. Nevertheless, such a WTS might not be available without proper adjustment to the design variables or users requirements. However, we expect during pass through the design cycle and proper recycling of computations, number of acceptable WTSs become available that are more or less able to satisfy all design requirements. On the other hand, we expect such a process to converge as fast as possible. Discussions regarding the source of aircraft design conflicting scenarios and how one might resolve them during the preliminary design process are extensively reviewed in various references such as [2,41,42]. As a simple example, extending the wing span leads to a bigger aspect-ratio and a better gradient for the lift curve slope versus the angle of attack; which in-turn leads to an easier take-off with relatively shorter ground-run. On the other hand, this approach results in a relatively more flexible wing, which in turn can cause an undesirable elastic behavior during high speed cruise. Here, one could see that a requirement for having a short ground-run is in direct conflict with requesting for a high speed cruise. There is no rigorous mathematical approach that helps designers to do meaningful compromises to expedite the process. All that appears is the fact that WTS of an aircraft is affected by various effects from any design decisions and all trade-off studies with their pros and cons. It is also noted that, disciplines involved in aircraft design, cover a wide variety of engineering fields from mission specification up to manufacturing process as well as technologies involved. To find convergence in such a multidisciplinary area, quite intensive managerial techniques are usually employed. Techniques, such as "Systems Engineering" (SE) [39], "Design Structural Matrix" (DSM), together with "Brainstorming" and "Critical Design Reviews" (CDR) are typical tools [54].

In the classical approach to design a new aircraft, one starts with extensive study of the existing, immediate as well as future markets, while considering the performance of any existing aircraft and their derivatives as a potential competitor which could eliminate the need for a new design. Such analysis normally leads to consider a set of tentative missions and operational requirements for the aircraft to be built. Representation of such missions in a two-dimensional space of $(T/W)_{TO}$ or $(W/P)_{TO}$ versus $(W/S)_{TO}$, is shown in Fig. 1.

The part of the space where all requirements are satisfied is referred to as "Target Area". The target area contains all possible WTSs, and its considerations indicate how a design team could select the proper WTS in their approach to meet all mission requirements [2,41,42]. Such approach, although straightforward, requires many embedded decision makings that in-turn need to observe more detailed requirements. A more serious problem regarding the current approach is the point that the 2D space represented by $(T/W)_{TO}$ versus $(W/S)_{TO}$ is not in fact continuous. This simply means that we are not able to arbitrary move a design point; or in other words, there is not necessarily a valid design point in the vicinity of an existing one in the target area. This is especially true when it comes to selecting proper engines for new aircrafts. Moreover, depending on the design team strategies and other concerns, such as cost and available technologies, the target area boundaries may vary in time as new missions or technologies emerge.

Considering various constraints and assuming that we could have a proper estimate for W_{To} from the so-called "Weight Sizing Techniques" [42], one could come up with different WTSs. It is well noted the technique known as "Weight Sizing" is directly linked to the aircraft mission profiles and its associated design constraints, such as rate of climb, range, endurance and level of technology involved [2,41,42]. Therefore, a good estimate of W_{To} inherits very important factors from expected mission. The technique known as "Performance Sizing", on the other hand, gives the space (target area) that a combination of W_{To}, T_{To} and S somehow guarantees mission legs requirements. Therefore, it is fair to say that a proper WTS is the cornerstone of the classical design process, as its parameters (W_{To}, T_{To} and S) have dominating effects on all aspects of aircraft from structural strength up to the stability and control and flying qualities [2,41,42]. Considering the high coupling among various aircraft design tasks and the WTS, the significance of initial design point selection becomes apparent in the aircraft design cycle.

It is noted that, for example, conducting traditional trade-studies with based on multidisciplinary algorithms will eventually lead to some meaningful and accurate results about the design. However, these approaches will dramatically increase required design cycle time and cost. Some serious undesirable consequences of such approaches are presented in [22].

In this regard, this work aims to develop an efficient method to approach viable WTSs in the shortest possible time; without having undesirable drawbacks. As an attempt to reduce the design cycle time, the authors desire to investigate the possibility of using AI in preliminary aircraft design as a "Time Reduction Technique". As a general term, AI refers to the intelligence of machines and the branch of computer science that aims to create it. The special characteristics of the AI are reviewed in various references such as [20,43,53]. In general, the process is usually straightforward and normally starts by developing efficient rules and/or using from available information and existing data for the subject at hand. The process does not require any complex set of calculations and so helps find quick vigilant answers in a short period of time. To prepare the ground for further details of the methodologies used in the current research, we briefly introduce the applied FL and NN techniques. More details of the models are presented in Sections 2.1 and 2.2. Also we mention some of the previous works which are relevant to different aerospace applications in these fields.

- FL is a technique which simulates the ability of the human mind to make rational decisions. It presents a systematic process to deal with uncertain and complex problems on the base of a mathematical nonlinear mapping. Application of this method is based on a set of "If-Then" rules. The rules are obtained from the human knowledge and experiences [20,43, 53]. By applying only verbal explanation, FL has the unique ability to deal with multidisciplinary problems without using any mathematical modeling and formulation. Simplicity and speed are other advantages of this method. [53] presents a wide range of detailed literature review, the main topics and evolutionary processes of FL. It also introduces many seminal sources in this field. Samples of different applications of FL in various aerospace fields are presented in [5,8,12,19,23,