EVOLUTIONAL DESIGN SUPPORT STRATEGY ORIENTED TO AIRCRAFT CONCEPTUAL DESIGN

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Abstract

To inspire lasting prosperity of the research in aircraft conceptual design, theories and applications of design support have been investigated. This paper firstly refers progresses of relevant disciplines, and then summarizes the multidisciplinary perspective of design support. By taking knowledge based design as example, practical issues of applying support approaches to aircraft conceptual design are also discussed. At the basis of these investigations, an evolutional design support strategy is presented and its three aspects are explained. With the implementation of this strategy, a basic interactive computer aided conceptual design tool can evolve into an intelligent, integrative and comprehensive support system. Finally, the relations between theoretic research on support strategy and design practice are depicts and emphasized.

1 Introduction

During the past decade, the outside environment and custom focus toward aircraft design have changed a lot, e.g., the primary requirements for civil aircraft are turning from 'farther, faster, higher' to 'leaner, meaner, greener' [1,2]. Moreover, new problems have arisen when designing such novel flying vehicles as micro air vehicles and unmanned combat aerial vehicles. As responses to these challenges and opportunities, the improvements on insights, methods and tools for aircraft design are quite necessary[1-5].

As the first phase of aircraft design, conceptual design plays a vital role in determining the life circle costs of a new aircraft [6]. However, comparing with efforts made to solve problems in preliminary and detail design, investigations on conceptual design, no matter theories and tools, or their applications are relatively limited and imbalanced [7,8]. Furthermore, it is not a hot topic that how to inspire lasting prosperity of investigations in this field. Considering these status, a design support strategy was proposed to supply a general guidance for exploring possible topics on supporting aircraft conceptual design. In this paper, not only the meanings of this strategy, but also the way of forming such an idea are presented.

2 Two Trends in Intelligent Design

Since the concept of 'design support' is rarely mentioned in aircraft design, it is helpful to take a brief review on relevant investigations in other fields, such as the designs of mechanical parts, ships, automobiles and buildings. In fact, in these fields, investigations on intelligent methods and techniques that aim at supporting design tasks are always hot topics [9-19], and most of them can be classified in the category of intelligent design [20]. Obviously, it is too vast to review these investigations in detail, so only two trends of intelligent design are presented here because they are instructive for developing the design support strategy oriented to aircraft conceptual design.

First, supplying intelligent support to designers instead of taking place of them has become a widely accepted perspective. Despite that the research on artificial intelligence (AI) [21] has led to a lot of fruits for comprehending the nature of intelligence, there lies in severe obstacles when developing an automatic design system that could imitate the learning capability and creativity of human designers. By contrast, theories and applications on intelligent support have achieved tremendous progresses. As pointed out in ref. [20], an intelligent design system should just emphasizes certain work of decision making according to knowledge-based reasoning, analysis and computation, as well as help designers in making crucial decisions.

Second, with the increase of design objects' complexity and progresses of relevant technologies, integrating an intelligent support design system to other systems has become more and more important. For example, symbolic reasoning can not fulfill all tasks in the design process, whereas a lot of analyses, computations, simulations and data management must be conducted, so an intelligent design support system usually needs to integrate with specific analysis tools and database management systems to support the whole design process [20]. Moreover, because necessary and available tools for a given design object must be different, integration can help the construction of flexible and synthetic support frameworks that are suitable for specific designs.

3 Multidisciplinary Perspective of Design Support

Naturally, research on intelligent design must be based on a lot of fundamental disciplines, such as artificial intelligence, science of thoughts and computer graphics. Base on this fact, the authors proposed that multidisciplinary perspective can be regarded as a distinguish feature of design support. Different from multidisciplinary analysis or optimization to a design object, the multidisciplinary perspective does not mean the different aspects involved in a design object, e.g., aerodynamic, structure and radar cross section of an aircraft. Instead, it implies that support methods, techniques and tools can be explored from a wider point of view, and more original progresses can be made by conducting interdisciplinary research.

In fact, multidisciplinary perspective can be manifested in the ways that how existed intelligent support systems apply support methods and techniques belonging to different disciplines and domains. The following three points are just summarized by the authors:

- The whole process instead of several separate stages of design should be viewed when selecting support methods and techniques. In another words, different support methods and techniques can be applied to solve specific problems in different stages, which is especially important if the design object is a complex product.
- Combined use of several basic methods and techniques is usually necessary to solve a single problem more effectively. For example, the research introduced in ref. [18] combined the basic process of evolutional computation with case-based design, so that such operations in evolutional computation as duplication, crossover and mutation can be used to revise the retrieved cases and then generate new design.
- One kind of support method or technique can function in different stages of the design process, even if this method was originally proposed for solving the problem in a certain stage. The above example about evolutional computation could also exemplify this point, because the evolutionary algorithms, such as genetic algorithm (GA) and evolutionary programming (EP) [22], were just developed and have been widely applied for global optimization.

4 Evaluations of Support Approaches for Conceptual Design

4.1 A General Illustration

Considering the multidisciplinary perspective, there will be a plenty of work that can be conducted to support aircraft conceptual design.

However, it does not imply that support methods and techniques can be tested and randomly combined to form a support approach for solving a problem in conceptual design. Naturally, applications of new methods and techniques will usually ask for some corresponding conditions when they bring benefits to quality and efficiency of design. Therefore, a support method or technique should be evaluated by taking the practical issues of aircraft conceptual design into account, and then it can be determined that whether it is applicable or should be applied at a superior level.

Fig. 1 illustrates a simplified process of aircraft conceptual design, which includes major stages in this phase. The available disciplines or domains, e.g., AI, are represented as ellipses, and the support methods, techniques and tools, e.g., GA, are represented as octagons. As explained in the figure, the arrow lines illustrate possible ways of applying them, and some of them must be abandoned after evaluations.

4.2 Evaluations for Supporting Design Synthesis

To exemplify the way of evaluating methods and techniques in a support approach, this section will discuss the knowledge based approach [23] for the task of design synthesis, i.e., how to make use of existed knowledge for 'creating an aircraft design concept, either as a modification of an existing design or as a new concept created from scratch' [24]. Design synthesis is concerned here because it is the most creativity-intensive task in aircraft conceptual design, so that it is promising to apply intelligent approaches to support it. In addition, comparing with such tasks as optimization and performance analyses, design synthesis attracts much less attention at present and therefore needs more new ideas.

To implement the knowledge based approach, the problem of knowledge acquisition should firstly be solved. As introduced in ref. [20], human experts are major resources of knowledge. However, there is only a small amount of experienced conceptual aircraft designers, and it is quite difficult if these experts would be inquired for knowledge acquisition, e. g., there is no standard way for them to express their experiences. Consequently, this kind of knowledge resource is not the best choice.

As to design knowledge in textbooks and other documents, although the values of some parameters can be determined according to them, they are not sufficient for describing an initial design concept, e.g., the sweep angle of each

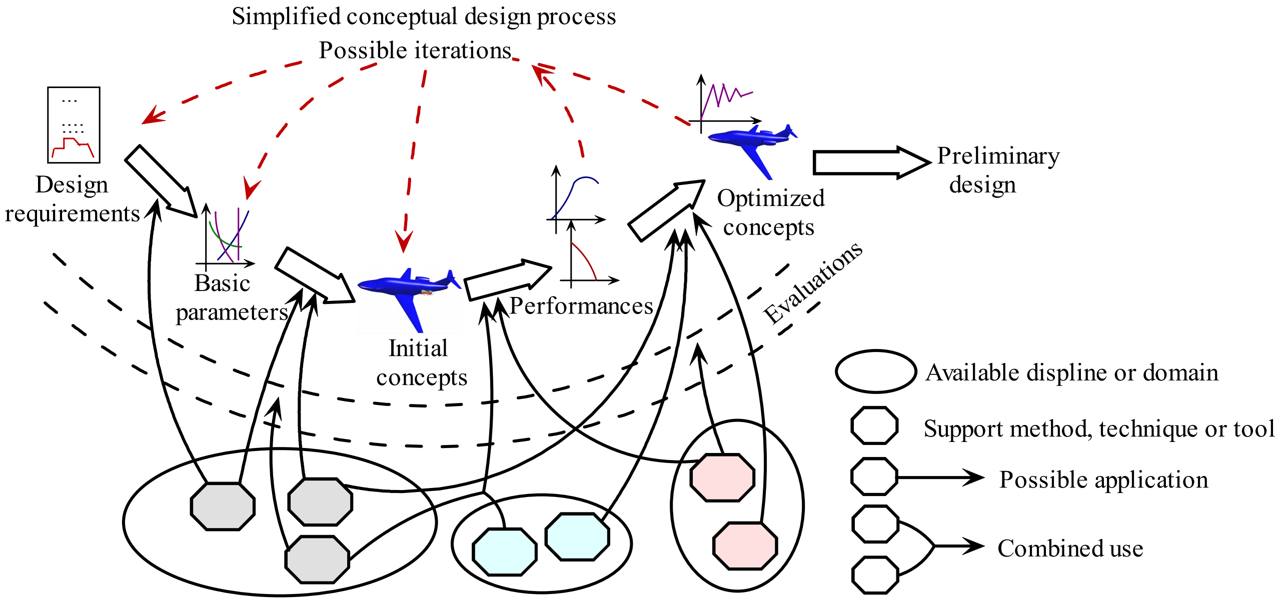

Fig.1. Supporting Aircraft Conceptual Design with Multidisciplinary Perspective

segment of a cranked wing is impossible to be directly determined. In addition, the initial concepts got from design synthesis always embody personal aesthetic insights, as well as some commonsense knowledge of a designer, but these things are hard to be expressed in formulate formats.

Case-based reasoning (CBR) is another remarkable technique in the knowledge based approach, and it has been adopted by a lot of intelligent design systems [13,14,18,25]. In fact, it is also a widely-used way to conduct baseline design according to a baseline aircraft. Nevertheless, a series of problems will be encountered when CBR is applied to aircraft design [26]. Some fundamental ones are listed below, and the relation between this technique and specific design system will be discussed.

Although collecting information of existed aircraft is more practical than getting formulated design knowledge, it is still not easy to get sufficient data of them and construct case bases. In such aircraft handbooks as ref. [27], almost all of existed aircraft are introduced, but it is impossible to list too much detailed data for each aircraft. Generally, main design parameters (such as takeoff gross weight and empty weight), major dimensions (such as fuselage length and wing span) and performances (such as range and cruise speed) are available. To such aircraft as civil transports and business jet, rough configurations and mission profiles can be determined according to these data. However, as to military fighter and bomber aircraft, these kinds of data are not enough to describe them, let alone some classified novel flying vehicles.

Furthermore, if cases would be used to support other tasks of conceptual design, more comprehend and detailed data are naturally required when constructing a case base. Taking the task of preliminary sizing that is before design synthesis as an example, using empirical equations and statistical data is the major way of conducting constraint and mission analyses, whereas practical aerodynamic and propulsion characteristics are not available because the initial concept does not exist at that time yet. Suppose detailed data of each mission segment of various concepts are available, the mission profile could be used as a criterion to retrieve and revise similar cases, and then the initial design parameters can be got more reasonably.

Representation of cases is also a vital problem in CBR. After enough data of concepts are collected, proper organization of them is directly related to the efficiency of retrieval. More importantly, since the revised case will be used as an initial concept, it is necessary to represent them in the similar way as organizing concepts' data in a design support system. In another word, it is better to develop a basic design system prior to constructing a case base. In fact, developing a set of proper data structure in a design system usually need a lot of iterations and adjustments, thus many troubles may appear when revising and reusing a case if the case base is constructed without knowing the design system that will use the cases.

The expansion of a case base can also benefit from the new concepts generated in a design system, since the base can therefore be updated more quickly than just collecting existed aircraft's data. Moreover, although design systems are always developed as general tools, a specific user, e.g., a company or an institute will obviously use them to propose different new concepts. By formatting these concepts as design cases, a case base can reflect unique design experience and practical requirements of that user.

In addition, expanding a case base at the basis of a design system enables the use of 'failed' designs. The airplanes introduced in public documents are mostly 'successful' designs that have been served for military or civil purposes, but more than one design concepts must be proposed as candidates to meet the desired requirements. Since the final concept wining a competition is always the result of deliberate tradeoffs, and it could not have superiorities over the failed ones in every aspect - the competition between YF-22 and YF-23 showed such an example [28]. Consequently, those failed designs could also be utilized in case bases if they are developed in corresponding design systems. In fact, even the concepts denied at early stages of conceptual design may embody lessons that should be avoided in future projects, so it is also necessary to reserve them in a certain part of a case base.

As a brief summary of these short evaluations, CBR is a more realistic and promising technique for supporting design synthesis, although several specific problems will arise and should be resolved. In a recent study conducted by the authors, an adopted flow for applying CBR to conceptual design, as well as new ways of case representation and retrieve, have been proposed [26], and investigations on such problems as automatically revising cases and retaining accomplished designs are just under going.

5 Meanings of the Evolutional Design Support Strategy

Taking both the multidisciplinary perspective of design support and practical issues of aircraft conceptual design into account, the evolutional design support strategy was proposed, which contains three aspects that are explained as follows.

First, at the premise that a design system can help designers fulfill basic tasks in aircraft conceptual design, intelligent support methods and techniques should be evolutionally fused into the design process, and it should be eventually realized that intelligent support approaches function in every possible task under the domination of designers. In addition to the design synthesis discussed above, the task of geometric modeling can be used as another example to illustrate this point: One possible approach of supporting it is to gradually improve the system's capability of understanding designers' intentions, so that they just need a few operations to get a satisfactory numeric model.

Second, the range of proper tools integrating with a support system for aircraft conceptual design should be eventually expanded, which is in accordance with the trend in intelligent design. Despite that a support system does not need to be constructed at the basis of commercial computer aided design/engineering (CAD/CAE) software, it is quite necessary to integrate sophisticated analysis tools to compensate for the deficiencies of empirical methods that are usually used in conceptual design. Since different companies and design institutes always have their in-house analysis codes, integrating them seamlessly with a support system can form specific support frameworks for them. Moreover, integration is also an effective approach to expanding the traditional ways of design. For instance, integrating virtual reality system can innovate in the way of human-machine interaction during conceptual design.

Third, the approaches of design support do not just confine in the applications of support methods and techniques originated in other disciplines or domains, whereas the function modules related to an aircraft should also be gradually increased, so that the design object can be described comprehensively and each of its characteristics can be supported correspondingly. As an example, the aeroelastic characteristics of an aircraft (particularly a large transport aircraft) should be analyzed in a proper level at the conceptual design phase, although such an analysis always need a lot of detail data.

Naturally, if a support system is to be constructed from scratch, it should firstly be implemented that this system can support most of the key tasks from the generation, analyses to optimization of concepts, so that it can preliminary meet practical requirements. At such a basis, the precision of a model should be improved; more characteristics should be analyzed, etc. In such an evolutional way, not only the continual expansion of support systems' capabilities can be ensured, but also a development can be more realistic.

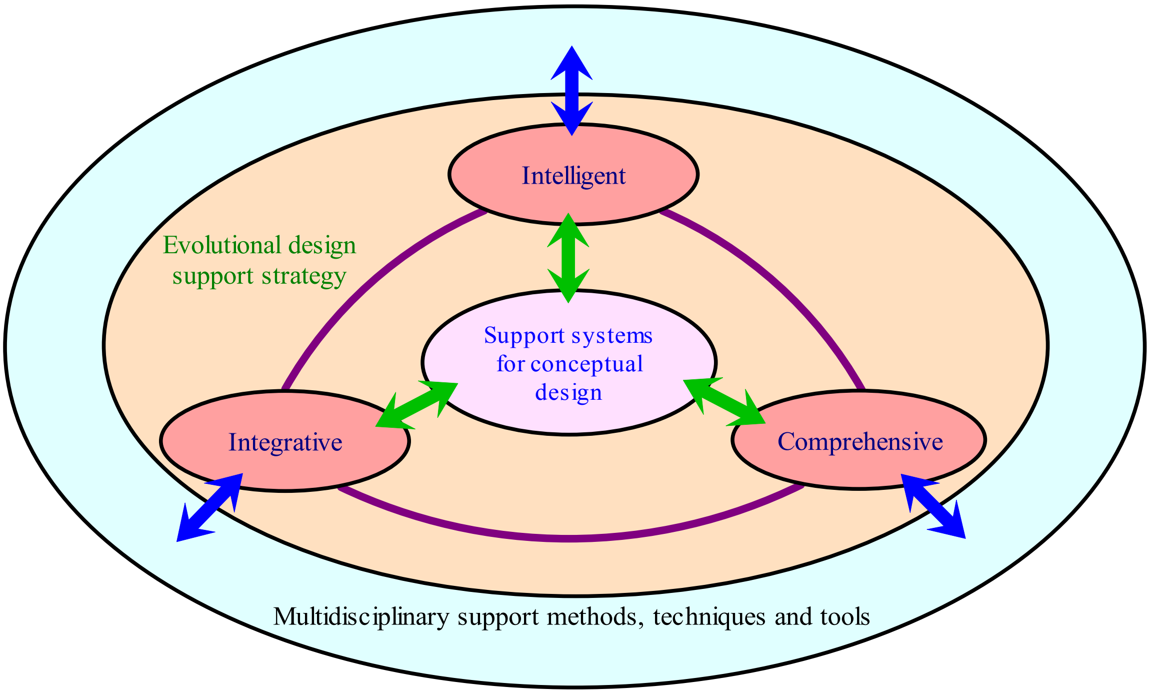

Fig. 2. Illustration of the Role of Evolutional Design Support Strategy

Fig. 2 illustrates the role of evolutional design support strategy. It can be seen that the three aspects are summarized as intelligent, integrative and comprehensive, which represent the ideal traits of support systems for aircraft conceptual design. On the other hand, these systems function as fundamental platforms for the implementation of this strategy. Moreover, possible multidisciplinary support methods, techniques and tools can be explored and applied by taking this strategy as a general guidance.

6 From Support Theory to Design Practice

Although the evolutional design support strategy was originally proposed for inspiring theoretical research, it is obvious that aircraft conceptual design should not be simply regarded as an academic discipline, i.e., design practice should benefit from progresses on support methods, techniques and tools. To get this point, much active cooperation between industry and academy should be emphasized. One way of such cooperation lies in that industry needs must be addressed when enhancing support systems. In fact, each aspect of the strategy can be related with design practice. For example, after identifying repeated operations that are frequently encountered by industry designers, intelligent approaches can be developed to make the support system fulfill them in much automatic ways.

On the other side, applications of support theories and tools enable the propositions of much more new design concepts, so that the importance of conceptual design can be accepted by more industry designers, particularly those who have to spend long time in conducting preliminary and detail design with sophisticated CAD/CAE tools. Naturally, a support system for conceptual design should also be evolutionally expanded to support the decision making when design requirements are proposed, as well as to solve more problems in subsequential preliminary design.

7 Conclusion

Despite that it is unrealistic to expect for theoretical ‘breakthrough’ in aircraft conceptual design, much active research can be conducted to advance this traditional discipline. As indicated in the evolutional design support strategy, it is promising to explore topics on support approaches and support systems, such as proper intelligent methods and techniques. It should be noted that these approaches and systems must be applied to design practice, so that not only their capabilities can be validated, but also the efficiency and quality of practical aircraft design can be improved.

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