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Competence-based Cooperative Framework for Iterative Decisions in the Aircraft Design Process

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Abstract — The present paper proposes a new approach for developing a generic design process, taking the aircraft design as use case. Our solution extends the multi-agent approach into a competence-based human resources and agent allocation. The solution consists into an iterative design technique that considers the reality of the design process as an evolutionary process, where the new constraints are determined and take shape at each step. Alongside with the high-level aircraft requirements, each step demands the compliance and the setting up of some specific aircraft characteristics, which our solution identifies with the competences required for the involved human resources and software agents. The eventual re-definition of the current step specification involves a resources re-allocation as well.

Keywords - cooperative design; competences; iterative process; decision support; critical situations; specialized agents.

I. INTRODUCTION

The design process of an aircraft involves a multidisciplinary approach, requiring multiple disciplines like weight, range, cost estimations for aerodynamics and operating functionalities [1]. Moreover, the objectives concerning the new product are different for the manufacturers and airlines. Manufacturers are rather interested to design product families, whereas airlines are looking for personalized aircrafts satisfying their needs at best (as for example number of seats, cruise range, takeoff distance, etc.). For this reason, a lot of compromises are carried out during the design process in order to meet the both sides' interests and to acquire the best high-level design achieving expected aircraft performances [2]. This constitutes a difficult process because the constraints are numerous and inter-dependent.

There are two main strategies for developing such an aircraft design process:

- Exhaustive modeling of the aircraft's required characteristics, and of the derived ones: it is a highly difficult process, because multiple decisions should be developed dynamically, according to the current state of the design level;
- Multi-agent approach, where multiple specialized agents cooperate in order to propose solutions on the fly, while a human decision maker (project manager) choose among these.

The present paper proposes a new approach for developing a generic design process, taking the aircraft

design as use case. Our solution extends the multi-agent approach with a competence-based human resources allocation: alongside with the specialized agents, human specialists are assigned to take decisions in the case of specialized issues. In order to acquire the most suitable compromises between the manufactures and airlines, decisions should be accomplished at each design phase, and for this purpose, the most suitable agents and human resources are necessary to be involved.

Thus, the human resources are allocated to different design phases, according their competences. They are supported (helped) by specialized agents, and cooperate with the other specialists in order to take the most suitable decision at each step where their competence is required. Our approach is motivated by the importance of the human factor in taking critical decisions, while benefiting by the computer-based decision support.

The paper presents further the main existing approaches adopted in cooperative design product. Then, the proposed cooperative framework is detailed for the aircraft design process. Conclusions and further work directions are exposed in the end.

II. STATE OF THE ART

When demanding a manufacturer for a new aircraft, an airlines company is mainly led by some pragmatic objectives:

- *Minimal DOC* – Direct Operating Cost for the covered distance and accepted number of passengers;
- *Maximum speed, comfort and health conditions* for passengers (that influence the airline attractiveness)

For an aircraft manufacturer, the main objectives are:

- To be able to *respond* to airlines *demands*;
- To acquire *maximum of benefits*.

Producing *generic aircrafts*, corresponding to an established aircraft family, has multiple advantages for the manufacturer, leading to economies in terms of development efforts, material costs, training costs, etc. Some bilateral advantages concern the rapid availability of the final product and its capacity to evolve in time, according to market new requirements. Of course, a new and personalized aircraft could better respond to the airlines company particular needs, involving also higher costs and longer production cycle.

The aircraft specifications are expressed through a range of characteristics, which involve multiple disciplines to be

harmonized and a range of compromises to be accomplished in order to address the best possible the specifications [3]. This complex process is developed gradually, along the general stages that are specific to aircraft design. Figure 1 illustrates such stages as employed by the Airbus Company.

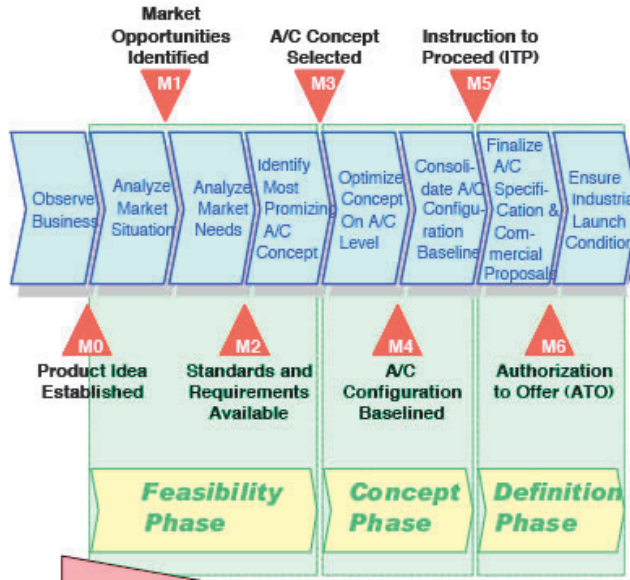


Figure 1. Aircraft Design Stages at Airbus

Currently there are multiple approaches to solve the aircraft design issues.

One approach is to consider the aircraft design as a *multi-objective optimization problem*, where the known elements are:

- TLARs – Top Level Aircraft Requirements, that represent the functional characteristics Z of the aircraft;
- Constraints over the parameters X of the aircraft design.

The approach consists in defining an optimization function F , based on which a set of design parameters X could be found that enable to reach the performances Z .

Two main solution types could be located for this approach. The first one consists in converting the problem to a mono-criterion optimization problem. For this purpose, different methods for aggregating criteria are adopted, such as balances average, goal programming or min-max [4]. The second solution type consists in simultaneously considering the assembly of all criteria [5]. No matter what solution type is adopted, the multi-criteria optimization approaches are confronted with limitations in the case of transition to a large-scale problem, mainly concerning the possibilities of solution representation and the increase of liberty degrees.

Another approach is to consider the aircraft design as a *multi-disciplinary optimization problem*, where the values of multiple parameters, which belong to different disciplines, should be integrated. The initial problem is decomposed in multiple optimization sub-problems, considering the relations between the different disciplines. The problem

resolution consists in integrating the partial results at a superior level [6]. A deficiency of this approach is the limitation of the constraint's interdependency to the pre-established problem decomposition; new dependencies are not possible to be located [7].

The further approaches adopted agents in order to solve optimization problems in the context of distributed systems. Agent-based approaches are suitable for the case of distributed optimization problems and in the case of distributed constraints satisfaction problems [8]. The existing algorithmic solutions consider backtracking procedures and a memory for the states' history [9].

The approaches based on adaptive multi-agents systems (AMAS) where further adopted in order to enable the discovery of disciplines' dependencies and to locate the inter-disciplinary compromises satisfying the entire set of constraints. The agents constitute the sub-parts in which is decomposed the global system; they are autonomous and active, thus able to employ adaptation and auto-organization mechanisms. An AMAS system is composed by multiple autonomous agents, which interact and cooperate for realizing a common activity, while negotiating and managing their individual objectives and interest conflicts [10]. A general architecture specification for an agent AMAS was proposed in [11]. Multiple systems were developed based on AMAS theory. An example is SYNAMEC, which is a project of mechanical conception, where each sub-part of the mechanism to be constructed is represented through an agent [12].

In MASCODE, an adaptive multi-agent system adopted in the preliminary aircraft design, one agent controls one discipline [2, 13]. Therefore, these agents are called Disciplinary Agents (DA). The multi-agent system is a network of DA corresponding to the model hierarchy commonly found in preliminary aircraft design. Each DA owns representation knowledge of the model and learned knowledge from experiences, which are used through a set of behaviors to communicate and to take decision according to environment perception.

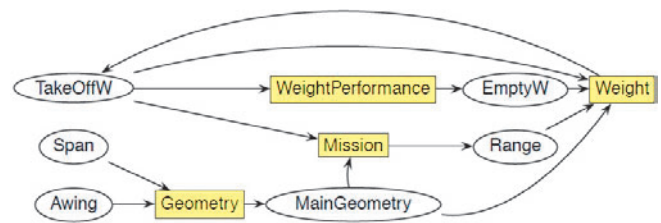


Figure 2. Example of relations between specialized agent models in MASCODE

As in general AMAS approaches, in MASCODE each software agent is characterized through a set of input and a set of output parameters, which overlap with the aircraft characteristics. The input parameters of an agent could be provided by the output parameters of other agent. For example, as illustrated in Figure 2, the agent in charge with *Weight* computation needs the parameters *Range*, *EmptyW*

and *MainGeometry*, which are provided by the *WeightPerformance, Mission and Geometry* agents.

Some collaborative approaches could be also located that are emancipated from the agent-oriented methodology while keeping the focus on the optimization. The project CSDL (Complex System Design Lab)¹ aims at developing a comprehensive collaborative environment for decision making at the earliest stage of a project by:

- exploring in a systematic manner the crucial parameters to optimize the system and enable innovation;
- estimating risks and uncertainties through an analysis in depth of robustness criteria;
- enforcing the coherence across all the levels of models;
- enabling better decisions thanks to an accurate interactive synthesis of the necessary information.

III. PROPOSED COOPERATIVE FRAMEWORK

The design of a new aircraft is initiated in the moment when the market demands for new characteristics and performances, such as X places for passengers, a price inferior to Y, a noise level inferior to Z, a pollution degree inferior to T, a fuel consumption inferior to U, a total aircraft weight inferior to V, the adoption of wireless communication for the cabin computers, the adoption of a new metal material for certain components, the aerodynamic form, motorization constraints, energy economy etc.

The sum of an aircraft characteristics is much more higher, and they are tuned progressively, during the design process.

The employees' involvement in the decision-making is a very efficient management approach [14]. Their implication should be accomplished gradually, according to the decisions' level of granularity. It is also very important a good correlation between the employees' competences and the tasks for which decisions should be taken.

Our approach is to express in terms of competences both the employees' profiles and the design tasks required at each design phase. Moreover, the computer agents will be described in terms of competences as well. More precisely, an agent is characterized by its input and output data, and these are expressed in terms of aircraft features for which the agent performs a specific calculus.

In the beginning, the aircraft high-level specifications should be established:

- First, the most important characteristics are established (by the company management team) as a compromise between the market demand and the company interests. As example, such characteristics could require for the new aircraft to have X places for passengers, the price inferior to Y, the noise level inferior to Z, the pollution level inferior to W, etc.
- The first specialists team handling all these required characteristics is selected;

- Together with the management team, they establish if the further design aircraft could be associated with a reference aircraft family (e.g. the A320 family includes A319, A320, A321) or a new family should be designed (e.g. A380).
- If the new aircraft is associated with an existing family, alongside with the above-mentioned required characteristics, all the important characteristics specific to the aircraft family should be delimited (such as aerodynamics, propulsion, structure, flight control). A supplementary specialists team is selected to cover these characteristics. The impact of all the initial required characteristics in this assembly should be evaluated, and eventually their specifications should be adapted. This re-iterated evaluation and customization constitutes a major premise for the new aircraft family to be innovator and coherent in the same time.
- If the new aircraft opens a new aircraft family, the first specialists team convoque a supplementary specialists team in order to establish the main equilibriums that are specific to it, namely the balance between aircraft's passenger capacity, fuel economy, final price, adopted manufacturing materials, engine motorization, etc.

At this stage, the high-level aircraft specifications are established. As well, the aircraft design stages are predefined (see Figure 1) together with their corresponding set of requirements and constraints. We propose further an iterative design technique that considers the reality of the design process as an evolutionary process, where the new constraints are determined and take shape at each step.

Considering the big panorama of the aircraft characteristics, each step of the aircraft design involves:

- A set of aircraft characteristics that should be set up;
- Maintaining the validity at the current step level;
- Maintaining the global aircraft specifications validity.

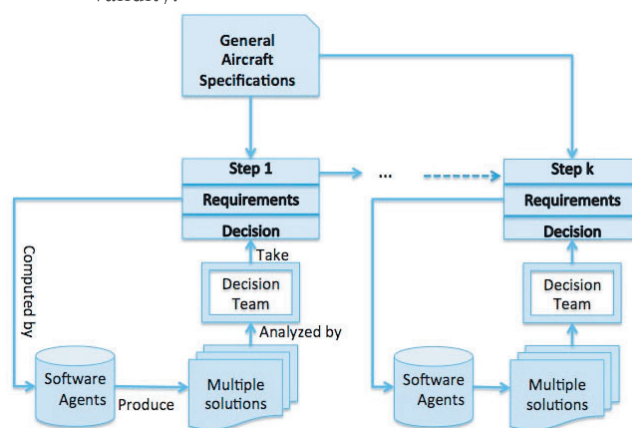


Figure 3. Agent-Oriented Aircraft Design Approach

For solving these issues, a set of specialized agents in charge with calculus are required, as well as a group of

¹ http://www.teratec.eu/activites/projetsR_D_Csdl.html

competent human resources that will cooperate for the best local decisions that suit with the global aircraft requirements. Thus, the initial specialists team increases in time.

In the classical agent-oriented approach, the calculus accomplished at each step by the software agents are checked against the aircraft specifications by the same decision team (see Figure 3). The common procedure involves at each step:

1. The *requirements* for the current design step are established using as source the general aircraft specifications;
2. Some *multiple solutions* are proposed by the available software agents in order to meet the demanded requirements;
3. A *decision* is taken by the decision team concerning the best solution for the current step.

More flexible, our solution enables a better validation of the current step decision because, beyond of the technical competences, human specialists have adaptive capabilities in critical situations that could occur:

- Two or more constraints are incompatible;
- There is a need for a new constraint;
- Certain constraints are not technically possible.

In such situations, the human specialists should re-define the current step requirements and they should eventually re-define the general aircraft specifications. Such a re-definition could lead to the necessity to eliminate some constraints or to consider some new aircraft characteristics, and thus a change could occur in the required competences for the current step. In consequence, a new selection of the software agents and human resources, as well as a re-iteration of the previous steps could be necessary.

The essential assertion of our approach is to consider the aircraft characteristics in order to express:

- The design requirements for each step;
- The competences of human specialists required as members of the decision team;
- The functionality of the software agents expressed in terms of their input and output data.

More precisely, our proposal consists in the following procedure to be accomplished at each aircraft design step (see Figure 4):

1. The *requirements* for the current design step are established and considered together with the general aircraft specifications; let us consider the electrical wiring harness as example of aircraft characteristic that should be set up at the current design step;
2. The suitable *human resources* and *software agents* are located, according their competences to solve these requirements;
3. Some *multiple solutions* are proposed by the selected software agents in order to meet the demanded requirements, as in the classical agent-oriented approach; unless the agents are filtered first according their specialization;
4. The *critical issues* are located by the human specialists team: conflicting constraints, crucial specifications that should be kept, secondary order

specifications that could be relaxed. For example, the electrical wiring harness solutions proposed by the software agents could lead to a significant increase of the aircraft total weight that could be in conflict with some high-level aircraft specification (e.g. with the requirement of a total aircraft weight inferior to V value).

5. *Redefined requirements* are established for the current step by the human specialists team. For the example of electrical wiring harness, at least two decisions are possible: to modify the high-level aircraft specification (that is the less desirable in general), or to adopt a multiplexer-based electrical wiring solution in order to significantly reduce the number of required electrical cables. In this case, some new problems occur, namely the facts that the multiplexers themselves have an important weight, and they are more vulnerable than the cables to break down. For this reason, supplementary software agents and human engineers specialized in reliability calculus are necessary.
6. A *reiteration of the local steps 2) - 4)* is accomplished;
7. If some critical issues could not be solved locally, the human specialists team *redefine* a part of general aircraft specifications;
8. A *reiteration of the aircraft design* is launched from the first step that involves the modified aircraft specifications.

The cross-validation adopted by our proposed technique, enables an effective decision process where the most suitable human specialists are involved, while they benefit of the calculus accomplished by the appropriate software agents.

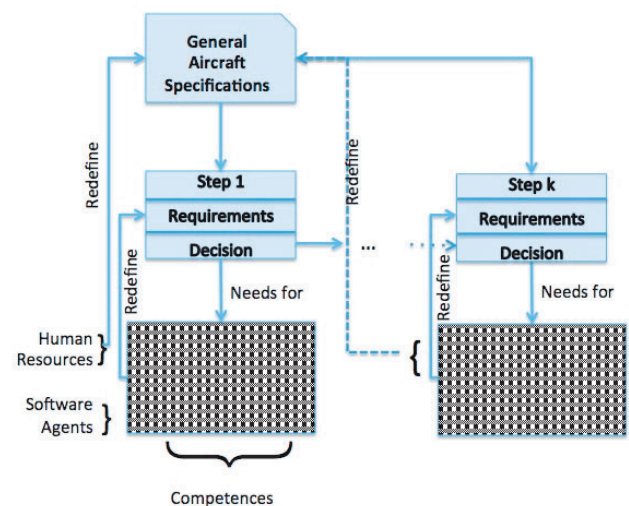


Figure 4. Proposed Competences-Oriented Aircraft Design Iterative Approach

IV. CONCLUSIONS AND FURTHER RESEARCH DIRECTIONS

The present paper proposes a new approach for developing a generic design process, taking the aircraft design as use case. Our solution extends the multi-agent approach with a competence-based human resources and agent allocation. The solution consists into an iterative design technique that considers the reality of the design process as an evolutionary process, where the new constraints are determined and take shape at each step

As further work, we intend to test this approach in multiple concrete scenarios by adopting different algorithmic solution for solving conflicts and critical situations. We also intend to adopt an ontology-based modeling of the aircraft specifications that will enable us to deeper manage the relations between different aircraft components and systems. Moreover, we will exploit this ontology in order to define the technical competences that describe users' profile and agents' capabilities. This will enable further to define rules and to make inferences in order to solve a set of critical situations that could occur during the aircraft design.

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