MULTI AGENT SYSTEM FOR THE SIMULATION OF AN AIRCRAFT STRUCTURE DESIGN PROCESS

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ABSTRACT

This paper investigates an approach based on a Multi Agents System (MAS) for aircraft structure design such as fuselage frame part. More precisely, we propose a simulation of an engineering process through the design of a local and distributed decision model. To design the system, first we use the MESSAGE (Caire et al. 2001) methodology to formalize the problem through a description of the role organisation. Then we describe the identified agent and the chosen resolution strategy. An application using fuzzy logic and the Multi-Agent framework (JADE) was successfully developed. We are now considering the possibility to extend the results to other structural parts of the aircraft and also to investigate other areas, where the key issue is to define/simulate appropriate technical or human organisations.

INTRODUCTION

The design process of aeronautical structures implies that a consensus between various actors and disciplinary (design, manufacturing, costing, stress analysis…) is reached. To help the conception, the concurrent engineering proposes to achieve a maximum of tasks in parallel, and to discuss the opinions and the expectations between actors as soon as possible (Bernard and Taillandler 1998). This discussion allows to anticipate the problems and to earlier investigate some alternative solutions. On the whole we can say that it favours the collective decision-takings. However, in order to reach these requirements, it is necessary to provide solution for facilitating information sharing and coordination/cooperation between actors. Today, it seems that Multi-Agent Systems (MAS) offer new simulation and management capabilities to address these issues. In this context, we studied how to use physical agents to simulate the design of an aircraft structure such as a fuselage frame part. As in concurrent engineering, our physical agents will have to take collective decision and to exchange information.

Through this study, we expected to evaluate the capacities of MAS

- to propose a local representation of the part to design,
- to use interaction / negotiation to simulate a design phase and thus to propose a global configuration of the part.

MAS AND ENGINEERING

A number of MAS applications that provide assistance to engineers are already proposed with various types of architectures (Shen et al. 2001). These architectures mainly differ by the level of autonomy given to the agents. In particular, differences rest on agents capabilities to communicate straightforwardly with each other (with/without mediator), on their autonomy to take decisions… (Choi et al. 2003)

For example, the DIDE system (Shen and Barthès, 1996) showed that architectures privileging the autonomy of the agents provide dynamic and flexible systems. However, this study also showed the limits of this type of architecture when agents are too heterogeneous and numerous. In that case, it becomes necessary to structure the system through hierarchical organisations as in the Metamorph system (Shen et al. 2001). Later works such as MetaMorph II showed the advantages of combining the two approaches of autonomous agents and hierarchical organisation of agents.

We consider that the results sensitivity to the chosen agent organisation is a very interesting property of the agent technology. This property enables to simulate different organisations and to conclude about their relative efficiency.

USE CASE DESCRIPTION

The frame function is to stiffen the aircraft fuselage. The main objective of the frame design process is to minimise its mass while supporting the applied stresses.

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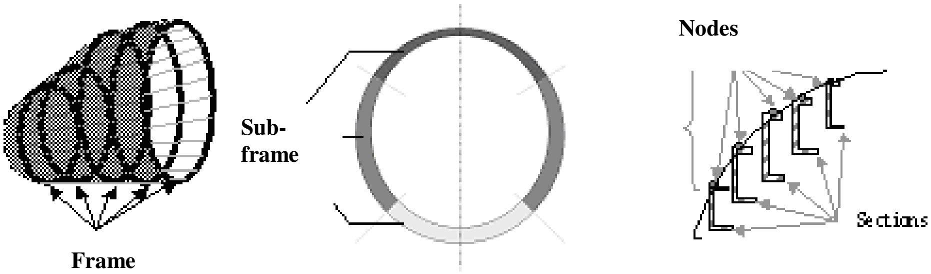

Figure 1: Frame description

A frame is not a single manufactured part, it is composed of several sub components that we will call sub-frame. The current process for designing sub-frames is to determine the frame section characteristics (shape and dimensions), at given points, (nodes) where the stress values are computed using finite element analysis methods. Although the process implies to design locally the sub-frame (section by section), the designers should also take into account global constraints. For example, he/she has to choose compatible shapes and dimensions all along the sub-frame. To resume, the challenge for designing a sub-frame is to find an effective configuration for all the sub-frame sections.
For the purpose of our study we start off with some simplified hypothesis. First, we consider only one representative dimension for the section – the height - and only four different shapes (E,C,I,J). Then, we formulated a simplified relation for each shape giving the height that supports a given stress. We call these 4 laws "height-stress laws" (figure 2).
Finally, in order to reflect the global constraints, we define a rule of shape compatibility and a rule of margin size:

- The shape compatibility rule specifies that a frame part can contain a mix of either E and C shapes or I and J shapes.
- The margin size rule defines an acceptable difference of 30 mm between two consecutives section heights.

In this article we propose to use a MAS to define an effective configuration of the sub-frame. The idea is to give some autonomy to the nodes in order to enable them to determine locally their best section characteristics. Then they use their coordination /negotiation capabilities to iteratively form coalitions (groups of nodes with common interest) until an effective configuration for the entire sub-frame is found.

SYSTEM DESIGN

To design the system, we used the GAIA (Wooldridge et al. 2000) and MESSAGE (Caire et al. 2001) methodologies to formalize the problem and to define an adapted resolution strategy.

Analyse

During this phase, we identified a lot of potential roles to play in the system and several possible organizations. For each role, we associated objectives (constraints to be satisfied), advantages to play it, and responsibilities like in (Ferber et al. 2003). Each agent can play one or several roles, which defines its individual capabilities. The MESSAGE methodology enticed us to use different points of view resulting in different diagrams (roles, organisation, workflow, collaboration…). By this way, we obtained a good global view of the study case, and identified several feasible organisations.
For our implementation, we choose to adopt a hybrid architecture, where the autonomy of the agents is partially controlled by a hierarchical manager, and to limit the implementation to the configuration of one sub-frame. However as we will see chapter 6, we foresee testing the other identified organisations.
The next paragraph explains the implemented strategy. It consists in creating coalitions between sections/nodes, which have similar configurations (shape, size). During this process, we make the agents negotiate and degrade their local optimal configurations to merge in the direction of a more global configuration acceptable for several other agents. The final objective is to find a single compatible configuration for the sub-frame.

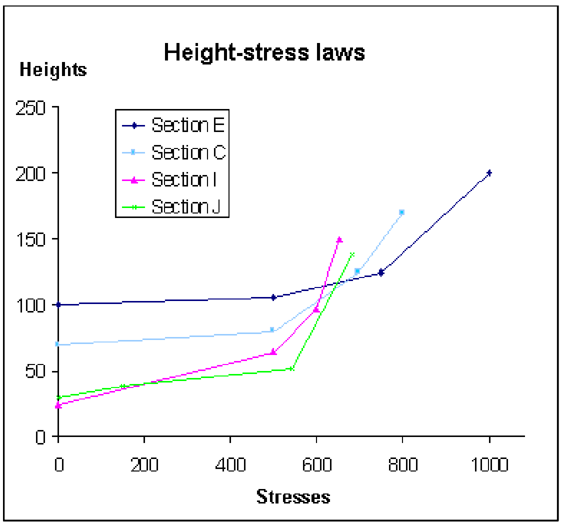

Figure 2: Height-stress laws

Agent description

Three different types of agents are implemented to solve the problem: "the configurationService agent", "the sub-frame agent' and "the node agent".

The "configurationService agent" is a service agent that answers the demands of the "node agents". Taking the applied stresses into account, the configurationService agent uses the height-stress laws to compute the minimal required height for each section shape. This capability is implemented through a service agent in order to enable the future use of external software and to manage the complexity by reusing simulation models, as in a Web-based modelling (Reed et al. 2000).

The "sub-frame agent" plays the role of a team manager for the "node agents". Its objective is to find a set of compatible shapes for the entire sub-frame that it represents. To achieve this objective, it actually plays several roles: it attributes roles to the "node agents"; it analyses their returns of experience; it informs the user of the configuration evolution of the sub-frame… But most important, it leads and organises the negotiation between the "node agents" in order to proceed with the chosen resolution strategy, which will be described later in this article.

The "node agents" are the core agents of the system. Each of them has personal objectives (section shape, sizes), local knowledge (applied stresses…) communication capacities and decision capacities, based on a fuzzy logic model. Thanks to these capacities node agents are able to negotiate one with another, to evaluate the different configurations, to compare their shapes and to take decision in order to form coalitions.

The negotiation strategy

The agents solve the problem by interacting and negotiating. Consequently, a lack of coordination may entail endless and voluminous processes, and it is essential that the communication activities are coordinated to ensure the coherence and convergence of the system. Several solutions exist and must be generally used in parallel. According to (Mathieu and Wedge 1999), negotiations are performed at two levels: a macroscopic level (the society of agents) and a microscopic level (the resolution of conflicts). With respect to these principles, the negotiation strategy is organised as described in the figure 3.

The macroscopic level allows organizing the negotiation process by defining rules and exchange protocols, which define the social model and structure the dialogues. This level corresponds to the step 2 of the figure 3, when the "sub-frame agent" allocates the roles.

The microscopic level deals with the conflict situations and allows taking local decisions. In our model, it corresponds to the step 3. When an agent is confronted to a conflict, it uses his local decision model to find a solution.

The coalition formation

As previously described, the system negotiates and converges by forming coalition of "node agents". As represented in figure 3, the negotiation is an iterative process, because coalitions are formed progressively at the initiative of the "sub-frame agent" (step 1) until a single coalition is found. During the negotiation process, each "node agent" plays its attributed role (step 2). Thus when an agent has to form a coalition (former role), it proposes to the others adopting its shape. Consequently when an agent has to join (joiner role), it chooses the coalition that offers the most interesting proposition (step 3). To compare the propositions, the "node agents" use a set of fuzzy spaces (figure 4) to calculate an adequacy for each proposed configuration. (This process will be detailed bellow, see "the negotiation spaces").

When a joiner agent finally joins a coalition, it starts playing the new role of coalition member. When a former agent obtains member(s), it plays both roles of coalition member and coalition manager, which consists in managing the coalition for the future negotiation. For

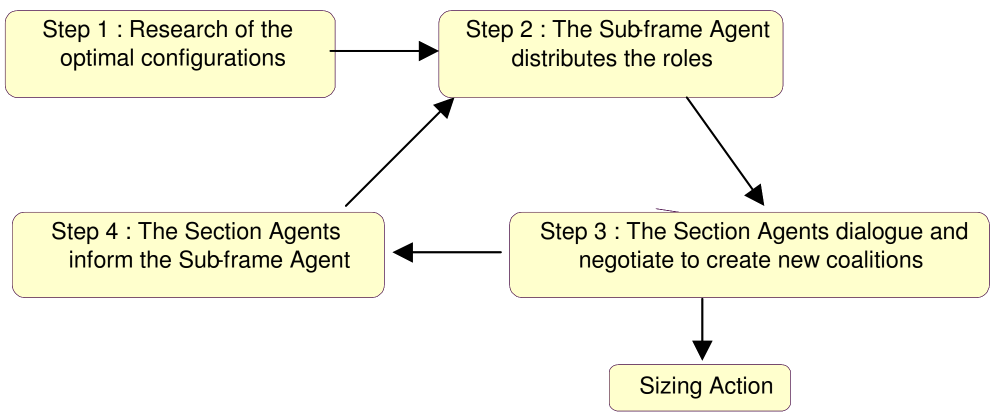

Figure 3: Negotiation Strategy

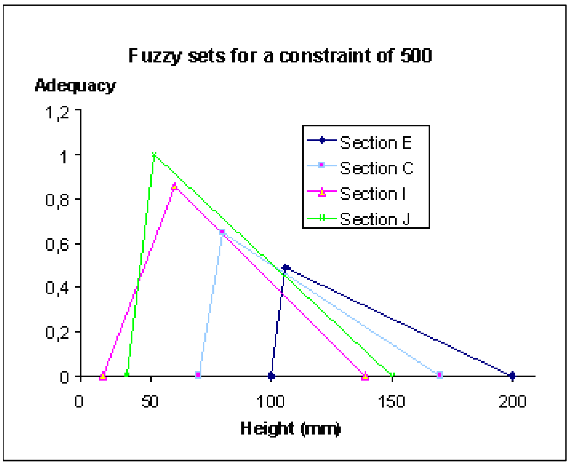

Figure 4: Fuzzy sets of a « node agent »

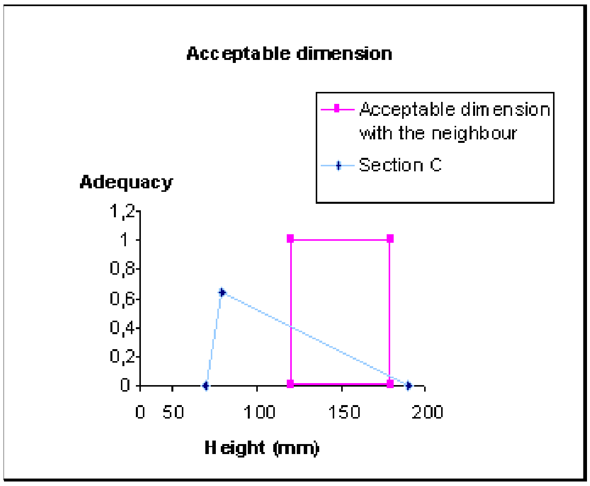

Figure 5: Adequacy determination

example, while two coalitions negotiate, the coalition manager receives/sends the propositions and takes the best decisions for all its members. Particularly, it can demand the members to compute their adequacy, to change shape for joining a coalition, to change size with respect to the margins…

In this way, the "sub-frame agent" controls a part of the strategy; attributing the roles (former, joiner) and enabling the system to converge (macroscopic level). But another part of the strategy (microscopic level) is achieved through the negotiation and the decision of the "node agent" as in the sizing action (figure 3 step 3)

Sizing action

As described, when a new coalition is created, a compatible shape is chosen by the set of agents. When the margin size between two consecutive sections is not respected a sizing phase is required. This phase allows each agent to choose a size, which respects the margin. The sizing step is an emergent process, because each "node agent" is going to adjust its dimensions with its neighbours without any central process or control. If its size is too small, the agent increases it and informs again its neighbours, who verify their compatibility with their new environment. So, the modifications are made locally and propagated across the sub-frame part only if necessary.

The negotiation spaces and adequacy computation

To proceed with the negotiation between agents we measure a node local adequacy, which is computed using fuzzy logic models. This adequacy is equal to 1 when the node characteristics are locally optimal. Then for a given shape, the adequacy decreases linearly according to the height. Each "node agent" builds its 4 fuzzy logic models (I, J, C and E) as follow:

1. The "configurationService agent" provides the best heights for each shape.
2. Each node agent constructs triangular spaces according to the configurationService heights (tops of the triangle) and to the absolute maximum/minimum height for each section (bases of the triangle) (figure4)

Finally, the fuzzy sets are constructed with respect to the global objective of weight minimisation (a penalty function is applied to heavier sections), and are used to estimate the adequacy with a proposition of a neighbour node. For example, if an agent receives a proposition in a C shape with a dimension of 150 mm (figure 5), it determines that it can take a height between 120 and 180 mm (if the margin size between neighbours is 30mm). With an intersection between its fuzzy set (C shape) and a second fuzzy set that represents the compatible sizes with the proposition, it can determine the best configuration to take and calculate its adequacy (figure 5).

To sum up, the fuzzy sets enable:

- To determine the satisfaction of the agents, by calculating the adequacy of a configuration
- To have a simple and local decision process and to compare the propositions.
- To have a simple model that can be easily customised in order to better fit with the reality

IMPLEMENTATION AND RESULTS

An application was developed according to the previously described concepts. This application uses the Multi-Agent framework (JADE) and the fuzzy logic (FuzzyJ) to define the negotiation spaces.

During the simulation, the 18 agents find an acceptable configuration after 5 processes of negotiation. Every line of the figure 6 corresponds to a negotiation cycle. The histograms in the left part give the configurations chosen by the agents (height, shape, adequacy). The right part of the figure represents the formed coalitions. For each coalition, we also give the chosen shape and the coalition adequacy, which is computed as the average of the coalition member adequacies. With these two representations, we can observe the evolution of each "node agent" during the negotiations (shape, height, adequacy), as well as the formation of coalitions. To summarize:

- At first according to the constraints, the agents choose the local optimal configuration (shape and height). This configuration corresponds to the local optimal solution.
- After a first negotiation cycle, the agents are gathered together around very similar configurations (local configurations are a little degraded).
- But during the following negotiations, the agents make more important concessions and finally find a global and acceptable configuration for the entire sub-frame.
- In our example, the agents that made the most of concessions are situated at the extremities of the sub-frame.
- Within each formed coalition, sections sizes are adapted in order to respect the margin. Consequently, the histograms progressively adopt a smoothed evolution.

FUTURE WORK

The results obtained are interesting, because they show that the MAS enable to find a solution to the problem with a local and distributed decision process. Nevertheless, several improvements are to be brought that can be ordered according to three directions:

1. Improve the Multi-Agent System and test further organisations of agents, because we would like to evaluate the influence of the organisation on the final results;
   - A first experimentation will consist in increasing the competences of the "sub-frame agent". Having a more complex strategy of role distribution, could influence the final results, and explore a more delimited solution space. The construction of this strategy could be automatic and based on the experience of the "sub-frame agent".
   - A second experimentation will consist in reviewing the negotiation process and giving more local degree of freedom to the "node agents". In such a case, the "sub-frame agent" would just choose the initiator of the negotiation, but wouldn't define directly the agent roles.
   - A last alternative will be to use a completely local logic. In that case, we get closer with a purely emergent solution. This approach is also interesting and allows to investigate the Distributed Constraint Satisfaction Problems (DisCSP) (Modi et al. 2003; Mesh and Lesser 2004). However this type of approach was presented for simple problems and it is not sure that it is well adapted to the configuration of an entire frame, which remains the final goal of our study.
2. Extend the use case and take into account more complex hypothesis.
   - First of all, it is necessary to get closer to the reality. For example, we would like to take into account several constraint situations (take off, landing…) and several sizing dimensions for the

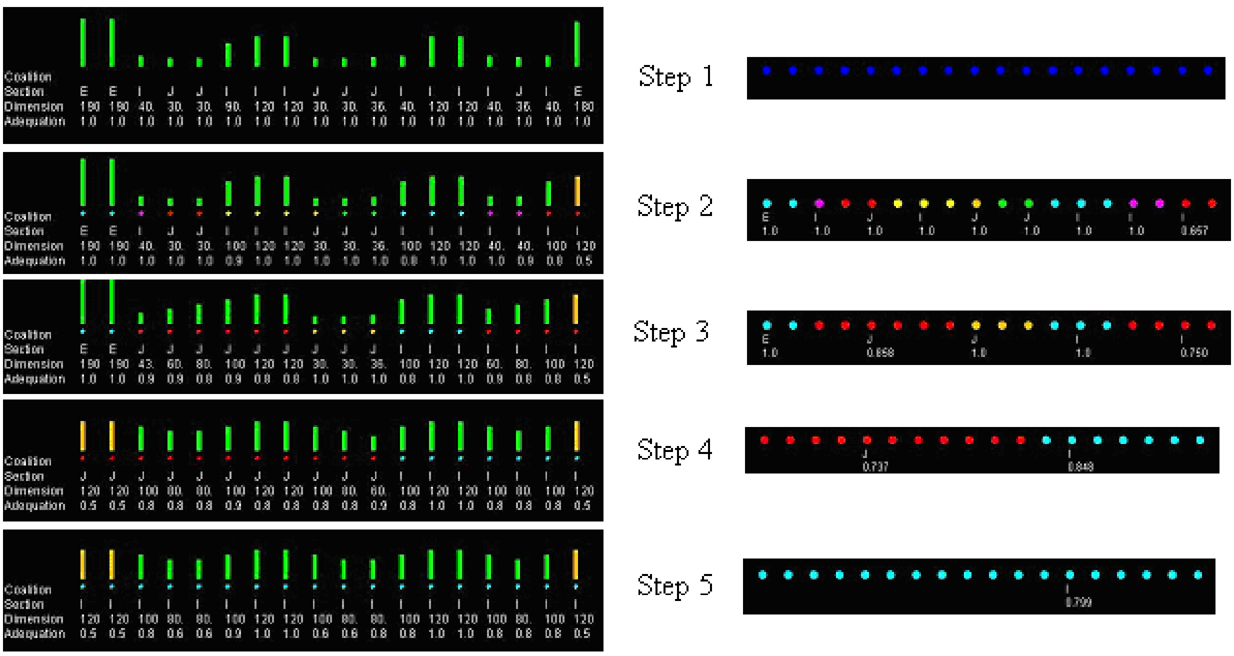

Figure 6: Results of a simulation

node (height, width, length).
- To complete the use case, we would have first to consider the sizing of the entire frame. Then in a second step, it could be very interesting to consider the sizing issues of several frames.

3. Introduce the possibility of human interactions with the system. This last point is very important to investigate, because a real system must be understandable and verifiable by the user.

CONCLUSION

In this article, we presented a MAS for the simulation of an aircraft structure design process. The design of the system showed that methods such as MESSAGE (Cairo et al. 2001) enable the efficient identification of the roles and agents. The implementation phase achieved with the framework (JADE), allowed us to validate the design choices and demonstrated that MAS are well adapted to the simulation of complex systems. This study participated in the evaluation of MAS for EADS, and allowed investigating agents negotiation processes using local knowledge and distributed decisions.
To conclude, in our view the simulation with MAS offers very good perspectives, and first results encourage us to consider the possibility to simulate/aid the design of other technical parts of the aircraft. More generally, we think the agent-based simulations could be applied for EADS in many other areas, especially, when it is justified, in simulating/testing organisation (technical/human).

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