Preliminary Design Process for a New Generation Fighter Aircraft

Philippe de Saint Martin
Head of Future Products Department

Mourad Sefrioui
Michel Ravachol
Dassault Aviation
78 quai Marcel Dassault, 92214 Saint Cloud,
FRANCE
Philippe.de-saint-martin@dassault-aviation.com

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ABSTRACT

An efficient preliminary design process relies heavily on Multi Disciplinary / Multi Level Design Optimization. The introduction of an MDO strategy must integrate the existing organizations and processes, particularly for a project done in cooperation. MDO has been used at Dassault Aviation in recent studies and program development such as the European Neuron UCAV demonstration program. The process also benefits from experience and data from the full design and test cycles of manned military and civil (Falcon bizjets) aircraft. This process also makes it possible to provide assistance to decision makers. It enables them to better manage multiple and often conflicting criteria, as well as the uncertainties always associated with decision making in complex systems design.

1.0 INTRODUCTION:

The next generation military system is a manned / optionally manned fighter aircraft, or a mix of manned and unmanned aircraft. These questions will be addressed during the development of the main future European system. In any case, the corner stone of this system will be a highly flexible multirole fighter, with high survivability, able to network with other systems and to provide superior situational awareness by intelligence and sensor data fusion.

One of the hurdles is finding a way to address the potentially conflicting technical requirements and priorities. The impact of those various requirements and priorities on the aircraft have to be thoroughly investigated regarding system performance such as range, manoeuvrability, weapons load, survivability, sensor suite, carrier version, etc.…

To manage this complexity during the early stage of development, a balanced mix of preliminary design multidisciplinary tools using optimization methods and of state-of-the-art advanced design tools must be used. In parallel, uncertainty management techniques are also employed to assess the risks linked to the innovative designs considered.

Figure 1: Example of next gen fighter design

Some of the most impactful requirements are low observability constraints, i.e. electromagnetic and infrared signatures, and the possibility to have uninhabited vehicle. These design drivers lead t features of the aircraft like aerodynamics, flight qualities, structure, flush apertures location as well as weapon and engine integration.

2.0 BACKGROUND:

From the Mirage family, to the Rafale and the unmanned Neuron aerial vehicle, Dassault Aviation has always designed complex and innovative systems using tools and methods at the vanguard of the digital-industrial revolution. Dassault Aviation dual knowhow (civil and military) makes it possible to mix the best expertise and technologies from both sides.

The European Neuron program is the most recent example of a non classical military aircraft design which benefited during the early first stages of its development from multidisciplinary design optimization (MDO). The MDO approach was based on a host of different models dedicated to the fulfilment of LO requirements : shape optimization, radar absorbing materials integration, weapon bay design, propulsion integration, apertures, as well as steps and gaps management.

Figure 2: Neuron

3.0 MULTIDISCIPLINARY DESIGN TOOLS:

Today the design of a complex systems follows a capability based approach. The problem at hand is : given a set of requirements (e.g. performances, cost,…), what is the system that fulfils them best? When this inverse problem is solved one can select the system and its architecture in terms of overall capabilities. In this approach it is necessary to establish a link between the requirements representing the expected performance of the system and the design parameters. This parametric approach allows the simultaneous convergence of both the requirements and the design of the system.

Decisions taken at the beginning of a project play an important role towards the success of the project. There is a real challenge to provide assistance to decision makers enabling them to better manage multiple and often conflicting criteria, as well as the uncertainties always associated with decision making in complex systems design. It is necessary during the very early stages of the project, to understand how requirements interact, what are their impact on the design, what are the design options to meet those requirements and their associated probability of success.

The numerical simulation can support decisions by enabling the decision makers to explore the behaviour of the system for different scenarii of the project. Up to now, MDO processes were viewed under the "simulate to optimize" aspect, the current effort is positioned in the “synthesize to decide" aspect.

The preliminary design activities at Dassault Aviation rely on a two-level MDO approach. Low to medium fidelity tools, at preliminary design level (level 1), handle global optimizations, trade-off studies and uncertainty management analyses. In addition, level 1 tools are enriched by high fidelity methods and tools (level 2), that allows calibrating and validating. This 2-level approach is depicted Figure 3 below:

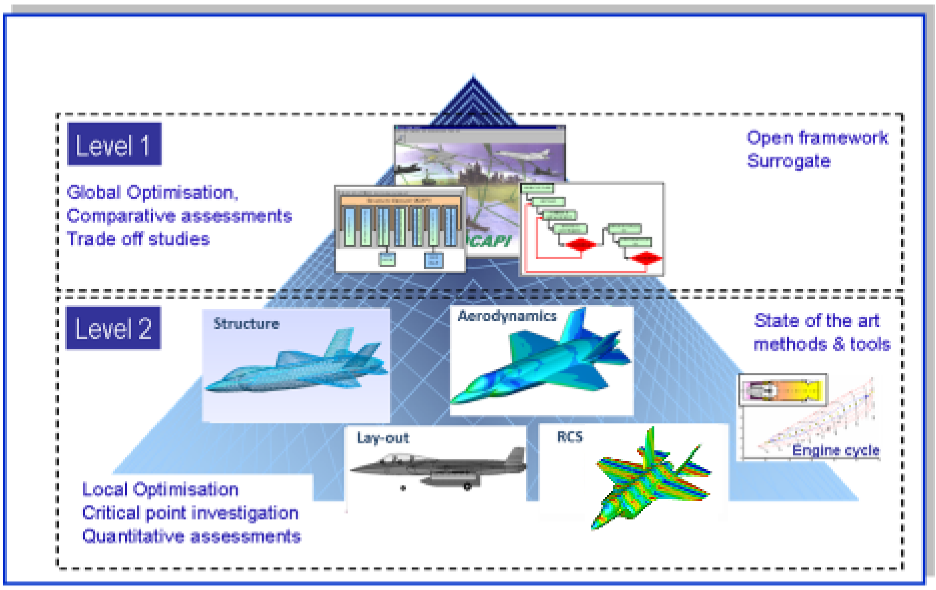

Figure 3: MDO 2-level approach.

Moreover, in our approach, level 2 models are validated through a range of demonstrations or tests (ground tests like wind tunnel tests, anechoic chamber, elementary tests…, or flight tests like flying test beds, full demonstrators like Neuron,…).

Level 1 tools are supported by a common structure that operates as a computer plug-in structure, which allows any user to incorporate a "module" linked to an aeronautical discipline.

Each individual module is composed of:

- A list of design variables
- A set of rules and models connecting the previous variables
- A user graphic interface to manage the calculations and variables

The modules are then integrated in the plug-in structure in order to benefit from fast computation times for interactive design processes and global optimizations. All the modules can be organized to create a design process adapted to the aircraft configuration to be designed.

Dassault Aviation MDO process, at level 1, is designed as a way to gain insight on the design space, quantify potential compromises and find or evaluate innovative design. It can also propose directions for level 2 activities and design refinement.

4.0 UNCERTAINTIES MANAGEMENT AND MDO AT PRELIMINARY DESIGN LEVEL

The level 1 tools achieve two things [1], [2], [3], [4]:

- Exploration of the design space through an MDO approach
- Assessment and management of the uncertainties, including sensitivity studies and impact on the

robustness of the design

The first step consists in determining the adequate design process, and isolating the proper design variables (variables of interest) that carry the stakes of the design. These variables of interests are subject to uncertainties. Proper design variables have to be identified: these design variables can be segregated into fixed design variables and uncertain design variables. Finally, the probabilistic criteria rely on the value on which the success (or the failure) of the design is measured.

The second step is significantly more complex and has a large impact on the final assessment. It consists in defining the uncertainty sources related to uncertain design variables, and in quantifying the associated distributions.

The third task consists in submitting the "uncertain design process" to the chosen propagation methods (namely Monte Carlo Methods, Quadratic moments methods or FORM/SORM methods). This provides the designer with an evaluation of the uncertainty with respect to decision criteria. It then provides enough information to the feedback loop to modify the design accordingly in order to respect the design criteria. In order to improve the uncertainty analysis process (mainly a gain of CPU time), a hybrid multi-level uncertainty analysis method is being used, with the combined use of detailed models and reduced-order models (calibrated and validated on higher level methods during the uncertainty analysis) or Radial Based Functions built on the fly [5], [6], [7]. The complete hybrid uncertainty analysis process is provided Figure 4 below:

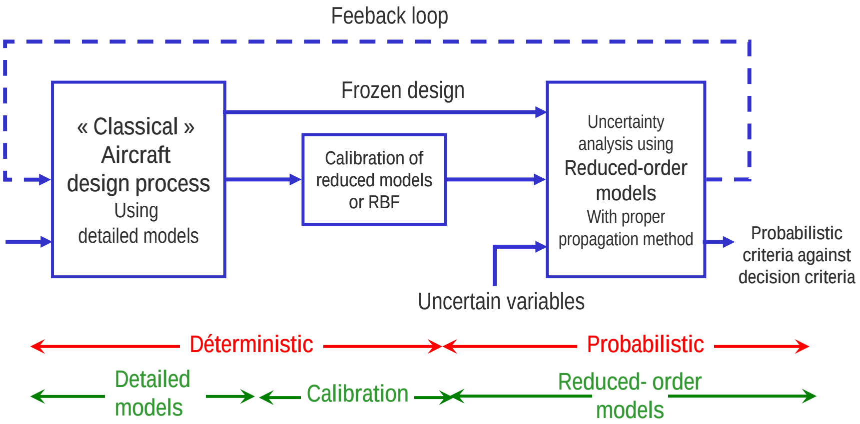

Figure 4: Uncertainties analysis process.

Sizing a new combat aircraft is essentially a smart game of compromises, as requirements tend to go in conflicting directions: speed requirement vs. range requirement and low speed / aircraft carrier requirement, LO requirement vs. manoeuvrability requirement, etc…

In addition, uncertainties related to aerodynamics evaluation, engine performance assessment or weight prediction may play a dramatic role in the aircraft sizing [8], [9], [10], [11]. To mitigate this issue, a parallel hybrid approach, based on the same set of common requirements is being used at Dassault Aviation (at the preliminary design level) to find the best compromise solution while maintaining a good level of confidence in the final design. This parallel approach aims at optimizing a technological solution, that "minimizes" the risk of non compliance with the operational requirements. The approach is depicted in Figure 5 below. Exchanges are necessary between the two branches to ensure a coherent overall design.

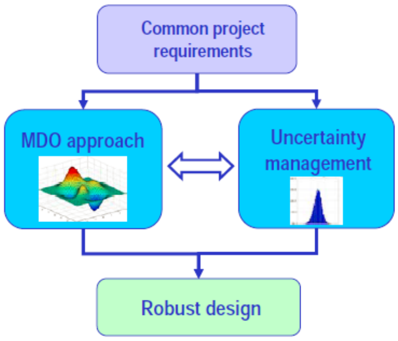

Figure 5: Hybrid MDO and uncertainties approach.

5.0 DESIGN SPACE EXPLORATION OF A NEW GENERATION FIGHTER AIRCRAFT:

The general process consists in identifying the most promising architectures and in evaluating each of them based on initial requirements. This is done with:

- Simplified geometry and models
- Wide exploration of the design space and assessment of the exchange rates between design variables, requirements and performances
- Identification of the core design variables
- Uncertainties management
- Back and forth between design and requirements to calibrate and adjust some of the most constraining requirements

The different steps of the process are depicted in the following figures 6 to 9 below:

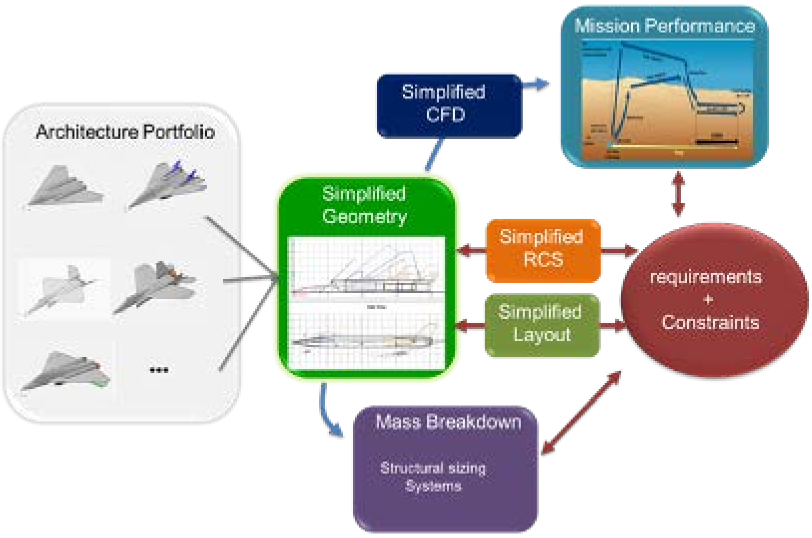

Figure 6: Classical preliminary design

The figure 6 above illustrates the design loop used to rank the various architectures from a portfolio. Each architecture in the portfolio is a set of topological choices, such as the number of engines, the presence of vertical and/or horizontal tail, the geometry of the wing… The purpose of this exercise is not to change on the fly the topology of a given aircraft, but rather to explore in parallel the best solution within each topological family.

Since we want to be able to discriminate across a large number of candidates, the screening is performed using low level models and space exploration visualization techniques [4]:

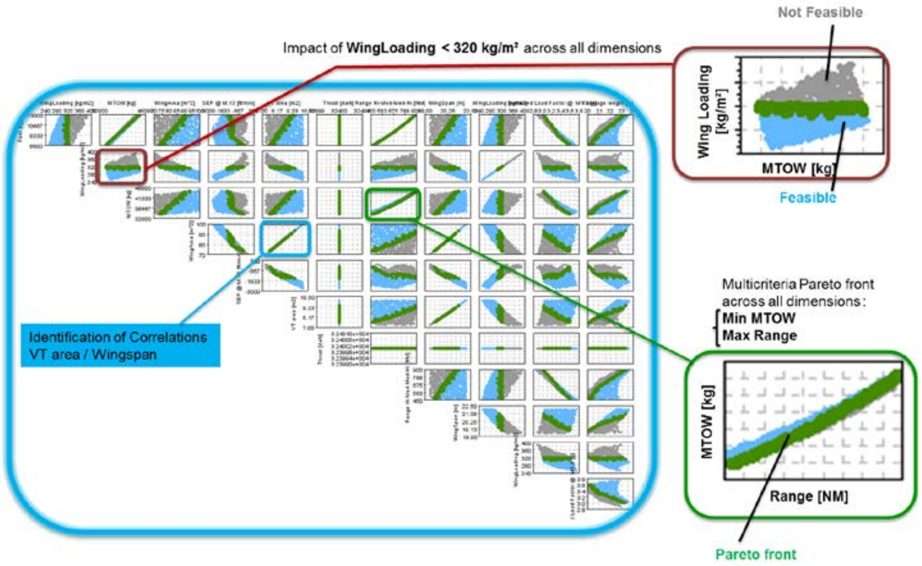

Figure 7: Visualization of functions and correlations

Figure 7 illustrate that scatter plots are very useful to visualize the distribution of functions and their correlation. In this type of representation the Pareto frontiers are clearly seen and here again filters can be used to select preferred area of the design space.

Surrogate models are automatically constructed in the visualization tool and are used to interactively explore the design space. For instance, it is possible to visualize the evolution of the feasible domain when the value of the design parameters or the requirements are changed.

The optimal solution of the MDO problem typically lies in a "corner" of the active constraints, at the crossing of two or more constraints as depicted figure 8.

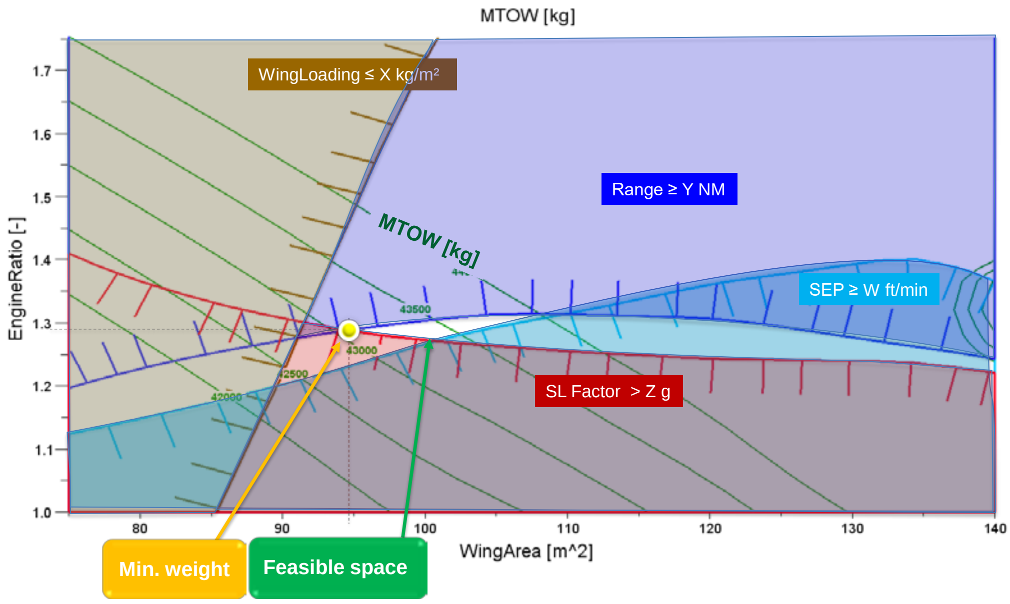

Figure 8: Feasible domain visualization

However, since we want to take into account uncertainties, we need to compute the probability of success of such a solution. To do so, we use the uncertainty distribution of each variable that has been identified as uncertain. All those uncertainty distributions are then run simultaneously through a large Monte Carlo simulation using Reduced Order Models. This gives a probability of success for the optimal point previously identified.

If the probability of success does not meet the requirements it is necessary to harden the constraints. For instance, if the required probability of success is “the optimal point should fulfil the requirements 50% of the time” but the computation yield only 39% of success rate as is shown in figure 9, the following steps are taken :

- identify the impact of hardening each individual constraint on the final probability of success

- find the minimal subset of constraints that needs the least hardening but still lead to the required probability of success

The hardening of the active constraint is illustrated below:

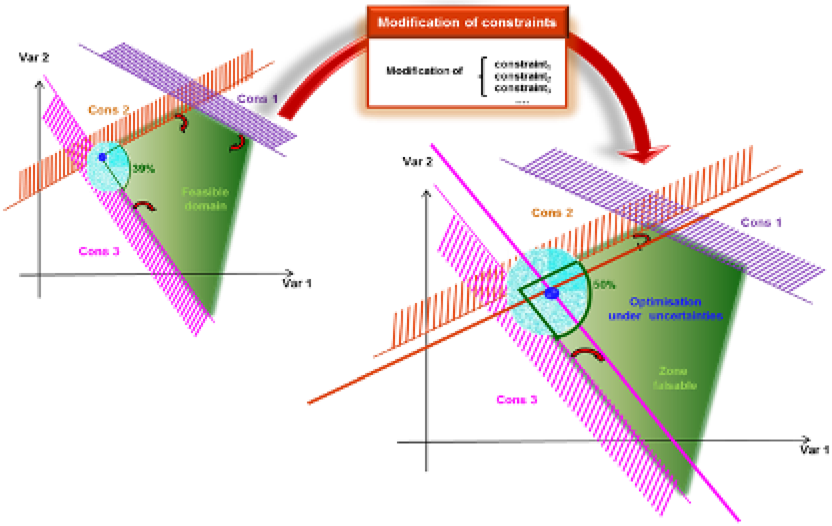

Figure 9: Uncertainties management

After the new values of the constraints are set, another MDO optimization is performed, and the procedure is repeated until convergence of the probability criteria.

Each architecture is evaluated in terms of robustness w.r.t. the requirements. During this step, the requirements are also assessed with respect to their feasibility. If none of the candidate topologies leads to a candidate aircraft in terms of size, weight, complexity or cost, another loop concerning the requirements is done with the help of operational analysis tools. At the end of the process, we have a set of consolidated requirements and architectures that meet them.

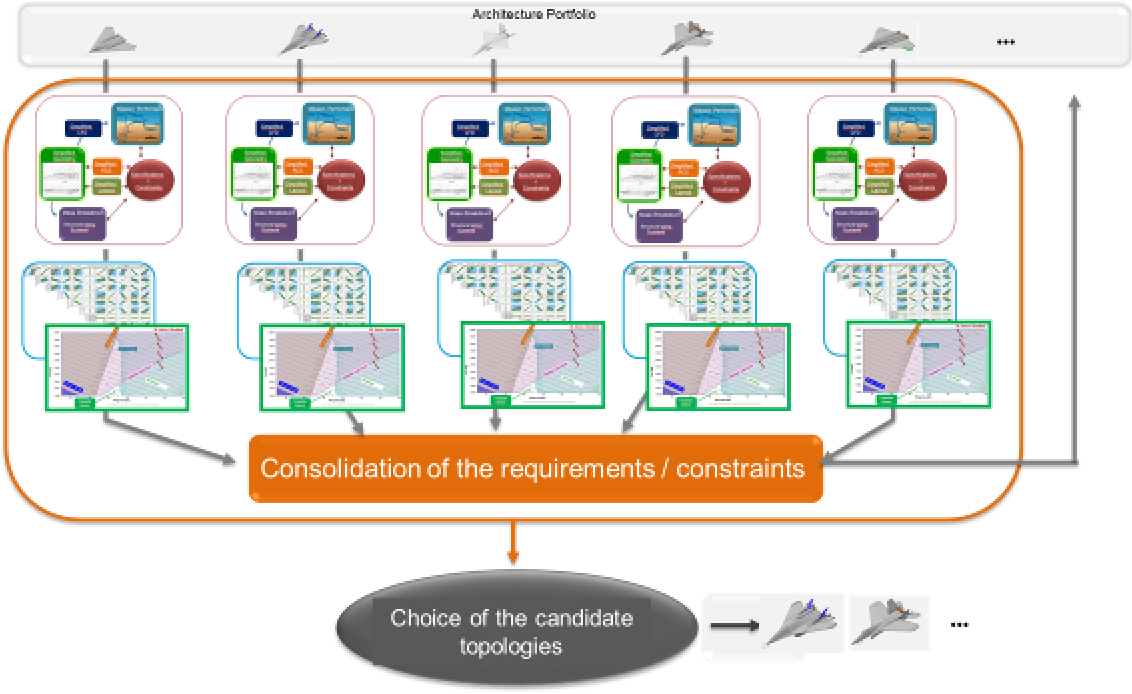

Figure 10: candidate topologies selection

6.0 CONCLUSION

The MDO approach developed at Dassault Aviation allows to evaluate in a friendly and interactive environment, multiple non classical design driven by a highly constrained set of requirements. It provides the designer with opportunities to increase its knowledge of the design space, via the use of visualization techniques or Pareto front construction. It also offers additional means to the designer to reach a "better" design, to increase its level of knowledge on a given design and potentially to keep open degrees of freedom later in the project.

Classical uncertainty management techniques and robust design approach have been developed and are used in Dassault Aviation for the design of civil or military aircraft. These two techniques provide a design that is robust to aerodynamic, weight, or thrust for instance uncertainties, and that is compliant with operational requirements. This reveals to be fundamental to give the decision makers enough confidence in the results of the design process. This approach is however complementary to the classical design approach using MDO, which remains the backbone of the preliminary design activities.

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