MULTIDISCIPLINARY AIRFRAME DESIGN OPTIMISATION

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Abstract

Aircraft design is set to become ever more challenging in future, as development budgets shrink and time schedules of new projects are compressed. At the same time, the technical complexity of designing a new aircraft is increasing or remains at least as difficult as before. In other words, the complex technical tasks of airframe development must be accomplished with significantly reduced man-power and within shorter time frames. Traditional design methods, that iterate manually between loads calculations and sizing of structural members may no longer converge quickly enough for shortened development times or fail to meet the design and performance requirements. The answer to these challenges identified at Cassidian is to take advantage of Multidisciplinary Design Optimisation Methods in the conceptual and preliminary design phases. The loads calculation and structural sizing are tightly integrated and combined with appropriate design criteria models in order to simultaneously consider the full set of design driving requirements within the optimization process.

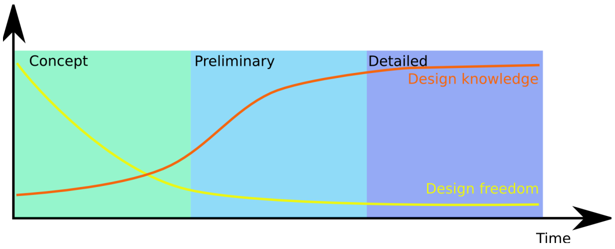
1 Introduction

The complexity of aircraft designs increases with each subsequent generation. This is often due to increased interaction between the individual disciplines determining the performance of the aircraft. The most influential from a structural point of view being aerodynamics, loads, aeroelastics, stress and flight controls. At the same time, development times are being shortened whilst the intervals between military aircraft projects increase, leading to a loss of valuable experience. Furthermore, aspects as sensor and systems integration become more and more important for future military aircraft. In order to develop sufficient knowledge about the complex multidisciplinary interactions in the system promptly enough to be of value in the early design phases, appropriate methods must be developed and provided in tools suitable for industrial use.

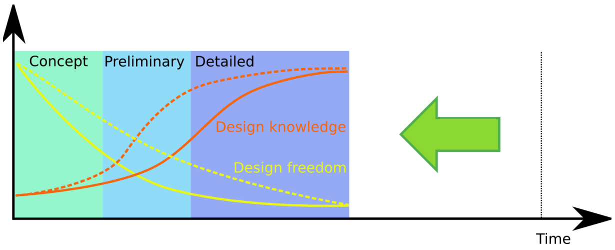
Numerical simulation tools are powerful means to analyse the complex physical phenomena influencing the behaviour of the aircraft as well as the interactions between individual disciplines at an early design stage. By coupling these with mathematical optimisation procedures, a systematic search of the parameter space for improved designs is enabled.

Multidisciplinary Design Optimisation (MDO) is based on rigorous mathematical optimisation methods that seek the minimum of a constrained objective function. The objective, in general mass and, in particular, the constraints e.g. strength and stability, flutter speed, aeroelastic control surface effectiveness etc. are usually highly nonlinear functions of the design variables – the freely variable parameters of the design. The system analysis, based on various disciplinary analysis models (usually numerical simulation models), provide the association between the design variables and the relevant responses of the system necessary to evaluate the constraints. Using the system equations as well as appropriate coupling methods between the disciplines in combination with optimisation techniques, the optimum design with respect to given criteria is determined by the optimisation algorithm. This leads not only to improvements of the design with respect to the selected design and performance criteria but also to invaluable insight into the trade-offs between various design drivers. This becomes extremely important, in particular if new design criteria with unknown influence on the design have to be considered.

By integrating MDO into the airframe design process from the very beginning, knowledge of the design in the earlier stages, where design freedom is the greatest, is thus increased leading to improved product performance (e.g. by reductions in mass) at a simultaneous drastic reduction in development time and cost as illustrated in figure 1.



(a) Traditional design process



(b) MDO assisted design process

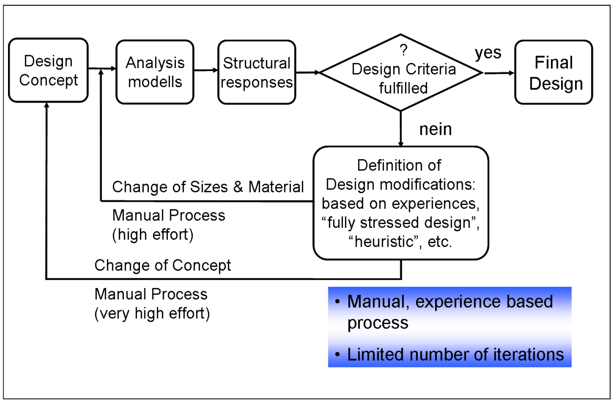
Fig. 1 Increasing knowledge at earlier design phases with greater design freedom and subsequent reduction in development times thanks to optimisation methods [2].

Of particular importance when performing optimisation of the airframe is the integration of all design driving disciplines in the optimisation process in order to ensure the completeness of the problem description. Thus, the technical relevance of the resulting designs identified by the optimiser can be ensured. The integration of the loads calculation into the optimisation process is especially important. As the design and sizing of the structure influences its elastic and inertial properties, it will influence not only its strength but also the aerodynamic and inertial loads acting on the structure. By including the loads calculation in the optimisation process, the iterative loop between the loads calculation and structural sizing, the so called load loops, can be automated. Much of the manual work involved in trimming the aircraft for an updated mass distribution and in-flight shape, determining the loads (steady and unsteady maneuvers), applying these to the structure and evaluating the relevant criteria such as stress, strain, stability and other criteria can thus be fully automated. Furthermore, the sizing to achieve a feasible design is automated by the optimisation process. This increases overall efficiency of the design process with respect to both, time and costs drastically.

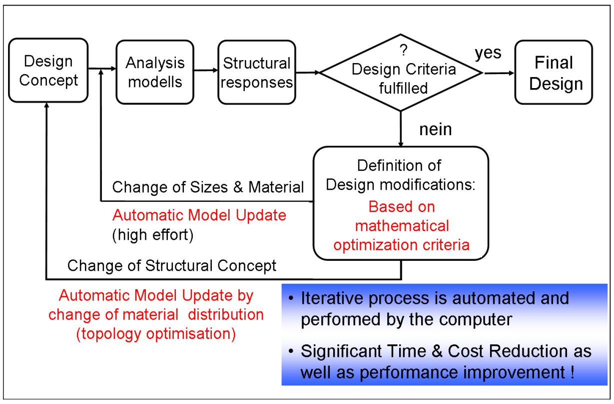
However, it also must be mentioned, that other reasons than stiffness changes will lead to changes of the design loads. Examples of these are changes to the design missions or the load envelope as well as detailing of the design driving load cases resulting from flight and landing manoeuvres, ground handling, failure cases, transport loads, fatigue etc.. These externally driven load changes (which are not resulting from stiffness changes) can of course not be updated automatically within the optimization process. They have to be considered in a subsequent optimization run with updated loads input. However, it is important to consider the major design driving load cases already in the early design phase in order to avoid the need of late concept changes.

2 Challenges of Multidisciplinary Airframe Optimisation

A very simplified aircraft design process is depicted in figure 2(a). After establishing a design concept and the necessary analysis models to determine the relevant design responses, the central activity in figure 2(a) is the determination of modifications based on experience and heuristic methods to fulfill all design criteria and improve performance. This results in a manual adjustment of the analysis models to reflect these changes. In the inner loop, changes are made to material selection or dimensioning of individual structural members. If these are not sufficient in order to meet the design criteria, possibly even changes to the design concept itself may be necessary, which can be an extremely time consuming process.



(a) Traditional design process



(b) MDO assisted design process

Fig. 2 The traditional 2(a) and MDO based 2(b) aircraft design processes.

In an MDO assisted design process shown in figure 2(b), however, the determination of design changes is based on mathematical criteria and performed automatically. This enables automation of both, the inner sizing loop and partly also the outer loop for the structural concept. However, in the following we will concentrate on the automation of the inner sizing loop rather than the automation of the outer concept loop.

Both processes, traditional and MDO assisted design process, must be supported by a wide variety of tools to evaluate the feasibility of the design, by e.g. determining the strength and stability of individual parts. These tools are often specific to the company or even the particular aircraft. In addition, there are company specific analysis methods for aeroelastic behaviour and loads calculations as well as guidelines and rules with respect to design and manufacturing.

Therefore the design of the aircraft, in particular the airframe, will be driven by a large number of multidisciplinary design criteria determined by various different tools and methodologies. These will include manoeuvre, gust and ground loads, aeroelastic control surface effectiveness, flutter speeds, strength and structural stability criteria, flight control input, dynamic responses, manufacturing requirements etc. (see figure 4 and table 3). An acceptable design must meet all of these requirements and thus the design process must take all of the design driving criteria into account *simultaneously*. This enables the determination of an optimum feasible compromise solution. This means that the integrated airframe design process must combine all disciplines and design criteria driving the airframe structural sizes and composite layup in order to determine a feasible, minimum weight design.

An important fact is that, on the one hand, the level of complexity of applied analysis methods (and models) must fit the design phase (concept, preliminary, detailed), and on the other hand, a harmonisation of applied analysis methods between optimisation and subsequent analyses for certification purposes must take place, in order to generate feasible and certifiable designs.

The comprehensive integration of tools and processes has been identified by the NATO-RTO as a major enabler increasing the affordability of air vehicles. According to the RTO technical report TR-AVT-093: “Integration of Tools and Processes for Affordable Vehicles” [1] the key elements of such a process are firstly, the integration of design information to make data available as soon as they are generated and secondly, acceleration of the design and decision process by extensive use of mathematical modelling and simulation combined with multidisciplinary design optimisation methods. The report calls for the relevant design information to be provided to all that need to know in the engineering design organisation whilst maintaining a clear distinction between proposed and approved states of the design. The methods of MDO shall be applied at the detailed level as well as on the system level in order to automate and accelerate the overall design process as well as to assist human creativity.

The major benefits to aircraft design through this integrated process identified in the report are: improved process integration and automation reducing manual effort, reduction in the number of design cycles, improvement in the performance of the product (mass, flight performance etc.) and a reduction in development time (up to 50% as stated in the report [1]).

2.1 Tools Developed at Cassidian to Meet these Challenges

Several commercial software packages are available that include physical analysis capabilities and optimisation techniques. Within these tools the disciplinary analyses are generally based on the finite element or finite volume methods for e.g. structural or fluid analyses. These tools are not tailored specifically to the needs of the aerospace industry and do therefore not include important airframe design criteria. Furthermore, it is usually a challenge to include company specific tools in commercial analysis or optimisation tools. However, if important design driving criteria are not included in the optimisation criteria model, it will most likely result in impractical designs being determined by the optimisation process.

Another approach is followed by commercial optimisation frameworks. These allow the user to link several company specific or commercially available design tools into an overall, integrated design process. However, as these optimisation frameworks have no influence on the internal analysis process of the individual tools, they are generally limited to working with numeric gradients resulting in high computational costs. This severely limits the number of design variables and constraints that can be included; this is not mitigated through high performance computing since numerical sensitivity analysis overstrains current parallel computing capabilities.

Due to the lack of suitable commercial tools, Cassidian started the development of its own inhouse multidisciplinary structural optimisation tool LAGRANGE as early as 1984. In the subsequent decades, LAGRANGE has been continuously enhanced as well as applied to the design of various military and civil aircrafts including the Eurofighter, X-31, A400M, A380, A350, Talarion and ATLANTE as well as to future aircraft projects. An overview of some previous and current designs developed with the help of this optimisation procedure can be seen in figure 3. A description of its application to the A400M rear fuselage design may be found in Schuhmacher et al. [6].

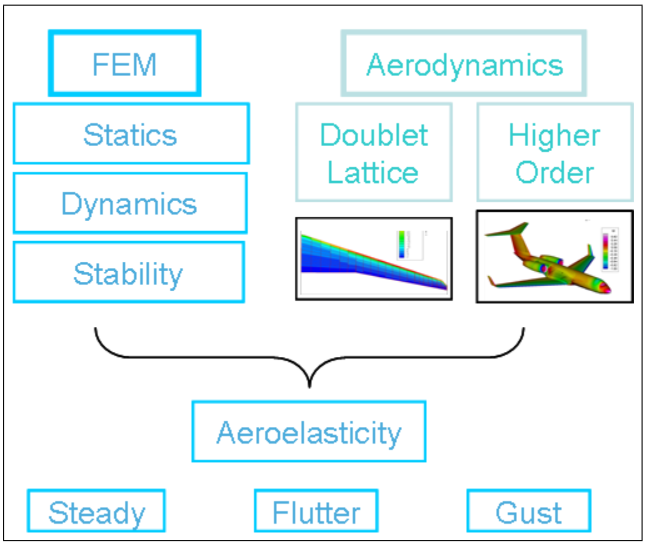


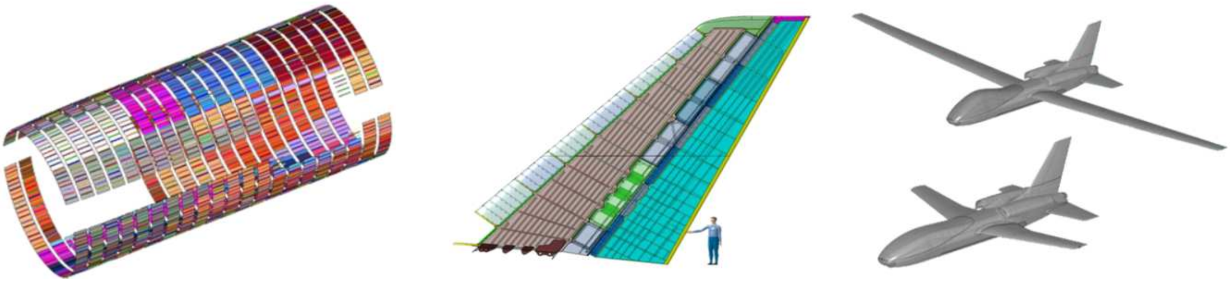
Fig. 4 Overview of system analyses types available in LAGRANGE.

LAGRANGE consists of a general purpose finite element solver well suited to the thin walled stiffened structures used in aerospace, optimisation algorithms and routines for evaluation of criteria models. Particular attention is paid to the modelling of composite structures. The unique aspects of LAGRANGE, however, when compared to commercial structural optimisation codes, are the availability of the fully analyt-

(a) Eurofighter (≈ 1985): composite wing and fin (b) X-31A (1990): composite wing (c) Stealth demonstrator (1995): full aircraft design

(d) Trainer (2000): composite wing and fin (e) A380 (2003) droop nose (f) A400M (2004 - 2006): rear fuselage skin and frames

(g) A350 XWB (2004 - 2006) tail section (h) A400M (2006) cargo door (i) A30X (2007) composite wing



(j) A350 XWB (2008) fuselage (k) A350 XWB (2008) vertical tailplane (l) Advanced UAV (2006+): composite wing and fuselage

Fig. 3 Overview of past applications of the LAGRANGE software.

ical sensitivities of each system response to a given set of design variables and the integration of diverse linear aerodynamic analysis tools for aeroelastic and loads analysis, including analytical sensitivity of aerodynamic and aeroelastic responses. This enables highly efficient gradient based search of the design space for the optimum design. Several optimisation algorithms are implemented in the program to this end, each suited to a specific type of optimisation problem. These

- Linear statics
- Linear dynamics (eigenvalues, transient response)
- Linear stability
- Steady aeroelastics (including trimming)
- Unsteady aeroelastics (flutter and gust)

Table 1 System analysis disciplines in LAGRANGE.

include both, first and second order methods supporting a large number of design variables ($\sim 10^5 - 10^6$) and many constraints ($\sim 10^6 - 10^8$). The automation of both load analysis and structural sizing process is a key capability for the cost efficient development of high-performance flying aircrafts.

2.2 Analysis, Design Variable and Criteria Models

LAGRANGE supports the following system analyses: linear statics, linear dynamics, linear stability, steady aeroelastics (including trimming for automatic generation of equilibrium flight conditions) and unsteady aeroelastics (flutter and gust), see table 1.

Each of these analyses can be coupled with an optimisation model linking physical model parameters to the mathematical design variables of the optimisation algorithm. Modifiable parameters (see table 2) include cross sectional areas of bars (e.g. stringers), geometrical sizes and composite lay up of various cross sections commonly used in aerospace, thicknesses of shell elements, ply thicknesses in composites, fibre orientations in composites, shape variables (currently being redesigned) and in the case of steady aeroelastic analyses, the trim variables, i.e. angles of attack of the aircraft and control surfaces.

To complete the picture, a range of design criteria (see table 3) are available to define the multidisciplinary requirements to be met by the airframe design, and to differentiate between feasible and infeasible designs. Most common are traditional requirements related to stress in the structure and appropriate failure criteria for isotropic or composite materials. Additionally, a wide range of stability criteria are available based on analytical buckling formulae covering skin and web buckling for isotropic, orthotropic and anisotropic structures, Euler (column) buckling of stringers and several company specific variations thereof, sometimes tuned to specific applications. Analytical postbuckling criteria are also included. Some details may be found in Daoud and Calomfirescu [3]. In addition to strength and stability requirements, constraints may be placed on displacements (requiring minimum stiffness). W.r.t. dynamics, natural frequencies may be confined to given frequency bands and furthermore, displacements, velocities or acceleration responses of FEM-nodes can be constrained. Aeroelastic criteria include requirements on aeroelastic effectiveness and flutter speeds. Finally, a range of manufacturing constraints, particularly with respect to composite structures, are supported.

In order to give an idea of the complexity of the software, it currently comprises around 3.5

- Bar cross sectional areas
- Geometric sizes of various (isotropic and composite) bar cross sections commonly used in aerospace (I, Z, T, Omega etc.) as well as the lay up of composite bars
- Shell or membrane thicknesses
- Composite ply thicknesses
- Composite fibre orientations
- Concentrated masses
- FE node coordinates (shape)
- Shape control points
- Trimming variables (angles of attack of the airframe and control surfaces)

Table 2 Physical design parameters in LAGRANGE.

- Various strength or failure criteria for metals and composite materials
- Global stability criteria based on finite element analysis
- Local stability criteria based on analytical solutions for skin and web buckling (isotropic, orthotropic, anisotropic), stringer column buckling and crippling
- Analytical postbuckling effects
- Displacements
- Natural frequencies
- Accelerations and velocities
- Aeroelastic criteria (control surface control surface effectiveness, flutter speeds)
- Manufacturing constraints (e.g. ply shares, ply drop off, stringer / skin stiffness ratios, etc.)
- Trim constraints i.e. global force and moment equilibrium

Table 3 Design criteria within LAGRANGE.

million lines of code. Input of the finite element model uses a NASTRAN compatible input deck allowing any NASTRAN supporting preprocessor, such as MSC Patran or Altair HyperMesh, to be used to generate the model. Apart from text file output, results can also be stored in binary formats compatible with Altair's HyperView post processor and in the near future in the OP2 format compatible with any post processor capable of reading NASTRAN OP2 result files. In recent years, a comprehensive modernisation of the entire code has been taking place, moving to the Fortran 2003 standard, adding parallelisation of performance critical routines and improving the robustness and flexibility of the code to integrate further analysis types in order to meet future requirements.

2.3 Integration of Loads Calculation into the Optimisation Process

In the traditional airframe design process, the loads analysis and structural sizing process are performed sequentially in an iterative loop as shown in figure 5. Because of the strong coupling between the deformed shape, mass and stiffness distribution of the structure on the one hand and the aerodynamic and inertial forces acting on it on the other, several iterations (load loops) may be required. Furthermore convergence to a feasible design is not guaranteed due to time and resource limitations. In this context, feasible refers to a design fulfilling each of the disciplinary requirements with respect to, for example, stress, stability, aeroelastic and manufacturing design criteria.

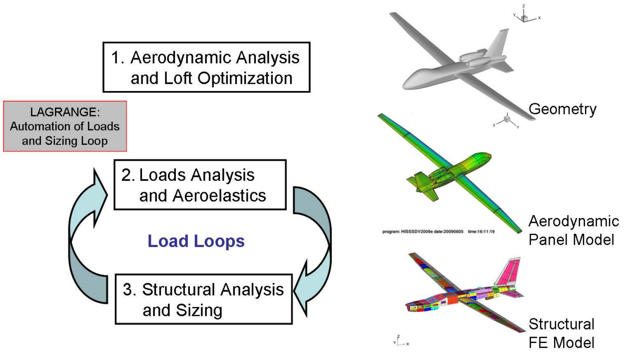


Fig. 5 Automated load loops; within LAGRANGE the trim and loads analysis (using the aerodynamic panel model and the finite element model representing structural mass and stiffness) is automatically conducted at each optimisation iteration, updating the loads and aeroelastic properties for the structural sizing.

The approach at Cassidian to speed up this process and increase its robustness with respect to delivering feasible designs is to combine the loads calculation with the classic sizing process in an overall automated cycle. The determination of the structural loads dependent on the deflections thus becomes part of the MDO procedure in the LAGRANGE programme.

In practice, this means that in addition to the structural finite element model (bottom right hand corner in figure 5) the aerodynamic influence coefficients from the evaluation of a higher order aerodynamic panel model (right hand centre in figure 5) are supplied to the program. Furthermore, the user supplies a coupling model to one of the available mesh interpolation algorithms in the programme. These create coupling matrices between the analyses meshes, transferring displacements to the aerodynamic mesh and forces to the structural mesh.

The sensitivity analysis is more involved than in a standard static loadcase as the applied loads now implicitly depend on the structural sizing variables through aeroelastic effects. The details of the coupled sensitivity analysis may be found in Daoud et al. [4].

Figure 6 shows the traditional design process leading from an external aerodynamic loft and inboard profile to the global finite element model of the structure (GFEM) used for the manual loads and sizing loops. The resulting structure is subsequently being used by the stress department for detailed checks. Furthermore, dynamic and aeroelastic criteria have to be checked. In the traditional airframe design process, usually specific simplified models have been used for the dynamic analysis (flutter, gust etc.), instead of working with the GFEM (s. Fig. 6). This results in additional effort and delays, in order to incorporate results from the manual sizing into the dynamic model. Figure 7 shows how the manual design updates can be replaced by the automated MDO process leading to an optimised GFEM, which will be subjected to detailed checks. Generally, no significant subsequent design changes are required as the relevant design criteria have already been considered during the optimisation process.

In ongoing development work LAGRANGE is being extended to also include dynamic aeroelastic loads due to turbulence (gusts), details of which may be found in Petersson [5]. Furthermore, in future, the process is to be extended beyond the realm of linear aerodynamics by enabling coupling to high fidelity CFD analyses.

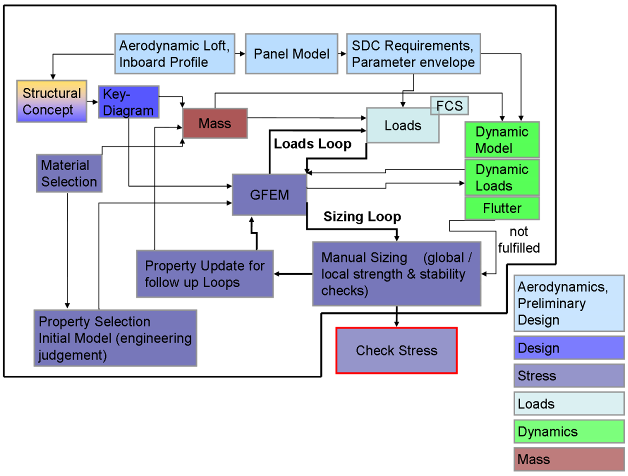


Fig. 6 The traditional sizing process from outer loft and structural concept via global finite element model (GFEM) and manual loads and sizing loops to final stress check.

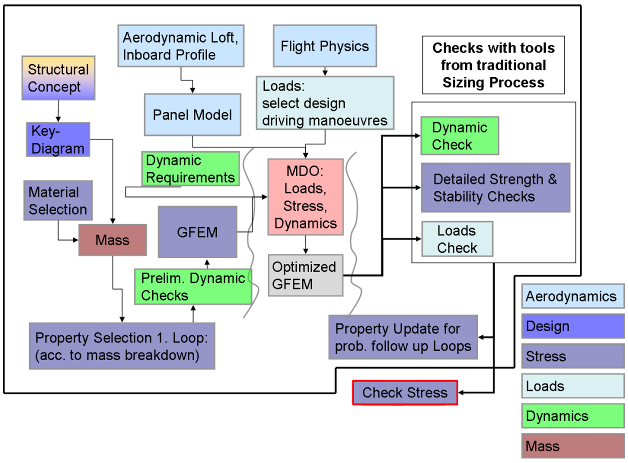


Fig. 7 MDO design process replacing the manual loads and sizing updates with an automated MDO based process leading to a fully automated load calculation and sizing process.

3 Application Examples

Figure 3 shows an overview on past applications. Below, a couple of application examples of the MDO process implemented in LAGRANGE are described in more detail.

3.1 Aeroelastic Tailoring of A350 Wingbox

Aeroelastic tailoring refers to the tuning of the elastic properties of a structure in a fluid in order to influence its deflected shape and, thus, also the fluid forces themselves. A simple example is that of a clamped plate at a positive angle of attack to the flow. The lift generated by the plate along its span will cause it to bend upward. Modification of the stiffness properties of the plate to introduce coupling between bending and torsion (e.g. by using a non-symmetric laminate) will cause the plate to twist as it deflects due to the lift, influencing the local angle of attack and subsequently the spanwise load distribution. A detailed description of the theory and application of aeroelastic tailoring is given by Shirk et al. [7].

Although aeroelastic tailoring as such is not limited to composite structures (bending-torsion coupling is influenced also by purely geometric variables such as sweep angle, for example, or the orientation of stiffeners such as ribs or stringers) the finely tunable elastic properties of composite materials make them particularly well suited to the task.

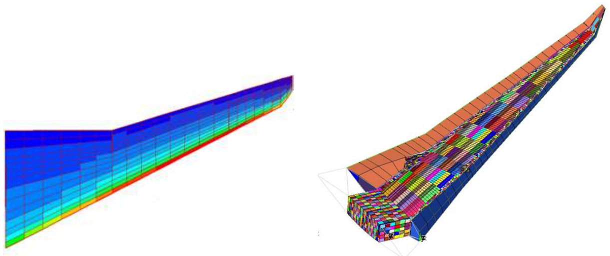
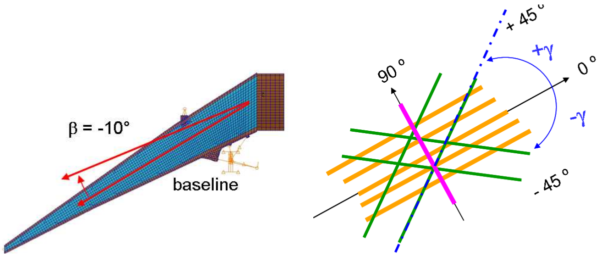

(a) Aerodynamic mesh (b) Structural FEM model

Fig. 8 Aerodynamic panel model and structural FEM model of the A350 wingbox used for aeroelastic tailoring. Differently coloured regions in the structural model indicate groups of elements with shared properties influenced by a design variable.

The A350-XWB will be the first civil aircraft from Airbus to use a wing constructed entirely of composite materials (outer skin and internal support structure). The composite wing box of the A350 was the subject of a design study performed by Cassidian jointly with Airbus to assess the potential weight savings through aeroelastic tailoring.

The study was performed using the two numerical models shown in figure 8 for evaluation of aerodynamic loads, structural displacements, stresses and buckling reserve factors. The design parameters that could be varied by the optimiser were the cross sectional area of the stringers represented by beam elements attached to the outer skins, the thickness of individual plies in the composite skin (homogeneous, non discrete ply thicknesses were assumed) and the fibre angles. These are defined in figure 9. A rotation of the entire stack orientation with respect to the baseline structure was defined as a design variable as well as the angle γ of the diagonal plies.

The parameters of clusters of 4 buckling fields (2×2 patch in chordwise and spanwise direction) were grouped together and controlled by single ply thickness design variables with a corresponding grouping of stringer cross-sections to reduce the total number of design variables. This resulted in up to 3000 design variables for the studies with the greatest design freedom. Some studies allowed the thickness of the diagonal plies to be varied individually creating unbalanced lay-ups.



(a) Orientation, β (b) Variable ply angles, γ

Fig. 9 Design variables controlling the wing skin ply angles: orientation of the of the 0° ply with respect to baseline design and global structure and diagonal ply angles.

The criteria models implemented in LAGRANGE were used to define constraints on the buckling of the anisotropic composite skin, column buckling of the stringers, stress and manufacturing aspects such as ply drop offs.

For the design studies, 19 load cases were defined including landing loads (landing gear attachment) and aeroelastic load cases for trimmed forward flight and roll manoeuvres. Trim variables included the total angle of attack and deflections of aileron and spoiler. The weight was defined as objective function to be minimised. Over 40 optimisation studies were performed with varying numbers of design variables and settings for the bounds of structural sizing parameters.

When rotating the stack orientation forward as a whole by a negative angle β as shown in figure 9 the studies show a reduction in the loads at the wing root through the wash-out effect of moving the elastic axis forward (reducing the local angle of attack at the tip, moving the lift resultant inboard). However, as the rotated stack is less resistant in terms of strength, especially for composite lay-ups with fixed minimum and maximum ply shares, there is a structural penalty to pay in the form of increased thickness to satisfy strength criteria.

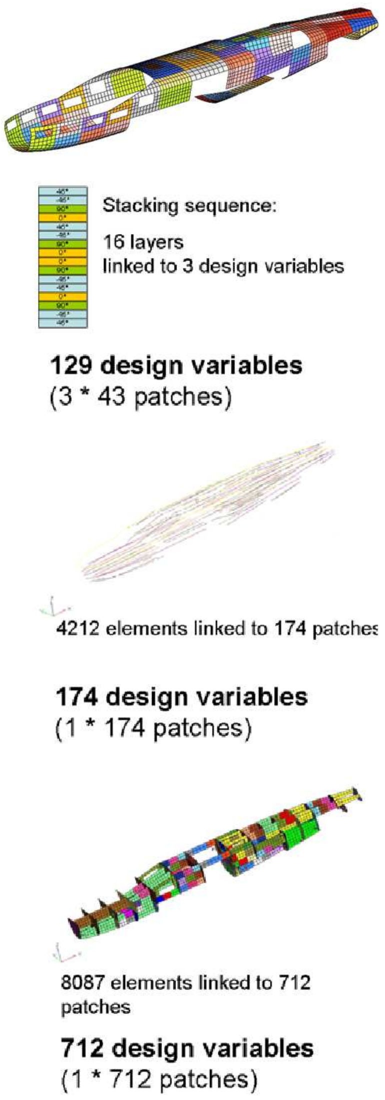
Increasing the number of variables available to the optimiser such as allowing it to vary the thickness of individual plies independently rather than of the stack as a whole or the angle between the diagonal plies, increases the size of the design space and reveals designs, where the load alleviation effect outweighs the structural penalty. This study has been performed in 2007.

3.2 Future MALE Aircraft

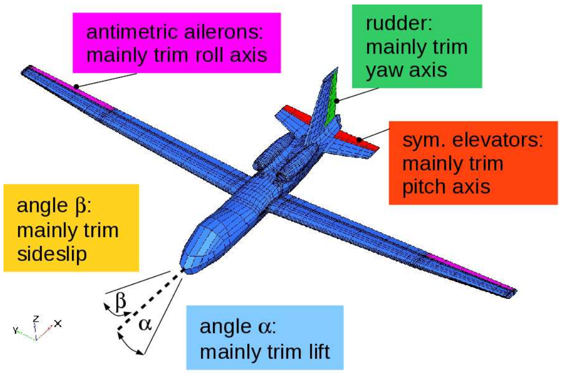
In the following, the results of a multidisciplinary optimisation of a generic MALE[1] with aeroelastic analysis, sizing and trimming variables and a multidisciplinary criteria model are presented. The aeroelastic analysis includes the simulation of trimmed flight conditions of the design driving steady manoeuvres. The study was performed in a conceptual design phase in 2010.

As the objective of the activity is to obtain a feasible, minimum mass airframe design, the whole fuselage structure is parametrised. Additionally trimming variables are defined for each manoeuvre as can be seen in Figure 10b.

The multidisciplinary criteria model can be subdivided into stressing criteria, resulting in a large number of constraints for each load case, as



(a) Sizing variables (1.015 in all)



5 design variables for each load case
~ 50 load cases

(b) Trim variables (250 in all)

Fig. 10 Parametric design variable model.

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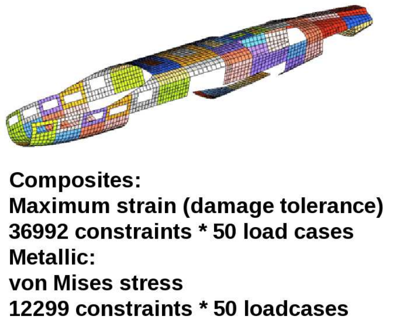
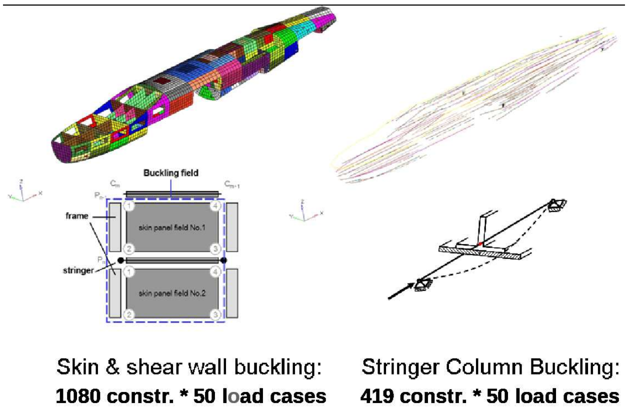
[1] Medium Altitude Long Endurance reconnaissance aircraft



(a) Strength constraints (2.464.550 in all)



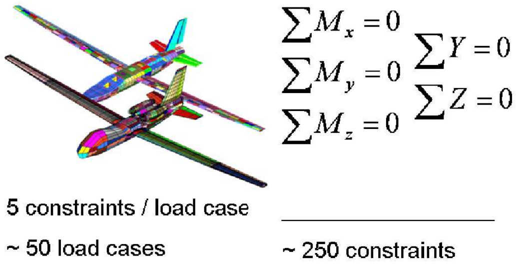
(b) Buckling constraints (74.950 in all)

Fig. 11 Stressing criteria model with a total number of 2.539.500 constraints.

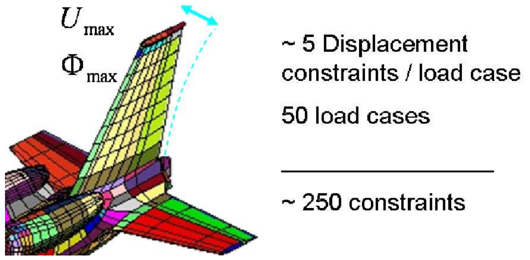
can be seen in Figure 11. Furthemore it comprises criteria such as flutter speeds, displacements and manufacturing requirements (see figure 12), which are fewer in number than the stress constraints, however, the requirements regarding modelling and mathematical complexity are usually much higher.

In Figures 13 and 14 the thickness distribution and reserve factors of the composite skin and shear walls can be seen.

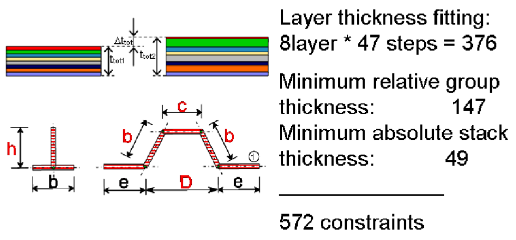
The results clearly show, that the load level in the airframe is relatively low compared to a fighter aircraft, hence, many areas run to minimum gage (waste of weight saving potential). The conclusion out of this study was that the chosen airframe design concept had to be revised. This shows that results from the MDO design process can provide valuable information already in the conceptual design phase where the structural concept may still be adjusted. The study described above was done with design variables for the fuselage only. The optimization of the wing was performed in another study. Furthermore, the optimization of the complete airframe is currently ongoing with an updated configuration.



(a) Trim constraints; an additional flutter constraint for 1 mass configuration was also included



(b) Displacement constraints



(c) Manufacturing constraints

Fig. 12 Criteria model comprising flight-physics, flutter, displacement and manufacturing.

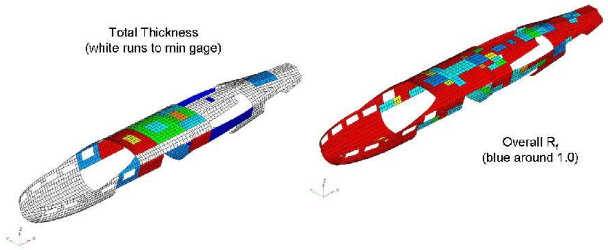


Fig. 13 Thickness distribution and reserve factors of composite skin.

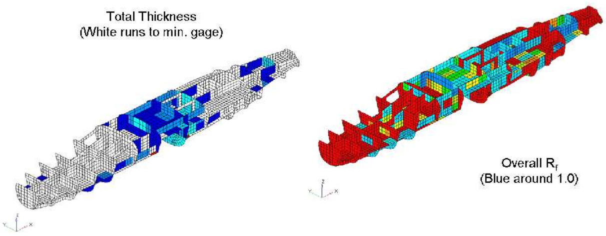


Fig. 14 Thickness distribution and reserve factors of composite shearwalls.

4 Conclusions

MDO increases the amount of information available to the engineer in early design phases regarding the behaviour of the system being studied, helps identify design driving requirements and illuminates the often complex interactions between the various disciplines affecting the performance of the system. Integration of traditionally decoupled processes such as loads calculation and structural sizing in an automated process driven by MDO methods, reduces the number of manual iterations and eases the search for a feasible optimum compromise design, fulfilling all design criteria. The major benefit, therefore, is a tremendous reduction in development time and effort and subsequently lower costs.

Commercially available analysis and optimisation tools generally suffer from either a lack of flexibility to include company internal disciplinary tools such as buckling routines or aeroelastic solvers or are very limited in the number of design variables and constraints that can be included in the optimisation due to being tied to numerical sensitivity analyses.

In the Cassidian multidisciplinary optimisation tool LAGRANGE these problems are solved by determining the *analytical* sensitivity of each design response required to evaluate a criteria model with respect to the design variables. Special disciplinary tools developed within the company to simulate the aircraft response or evaluate design criteria are either integrated into the tool directly, or, in the case of aerodynamics, deliver results in the form of linear influence coefficients from an aerodynamic panel model read by the programme. A multidisciplinary analysis of the response is thus enabled as well as optimisation of the coupled system with a large number of design variables and constraints using efficient, gradient based algorithms. In almost 30 years of development and application within the company, the code has been used for a broad range of civil and military aircraft projects, from components through large assemblies to entire aircraft. It leads to feasible designs satisfying all the relevant requirements of design driving criteria at a minimum structural weight.

The continued development of LAGRANGE is a strategic decision based on its specialisation for aerospace design tasks not available in commercial off the shelf tools, the ease with which an in-house tool can be adapted to new requirements and technology developments and the competitive advantage it offers. The fully integrated and automated multidisciplinary load analysis and sizing process results in an optimal product performance as well as a tremendous reduction in development time and costs.

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4.1 Copyright Statement