STRUCTURAL SIZING FOR AN UNCONVENTIONAL, ENVIRONMENT-FRIENDLY AIRCRAFT CONFIGURATION WITHIN INTEGRATED PRELIMINARY DESIGN

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OVERVIEW

This paper discusses the application of an integrated multidisciplinary preliminary design process to an unconventional Low Noise Aircraft (LNA) configuration, with a focus on the topic of structural sizing. Through the use of higher fidelity numerical methods, structural sizing can be performed and analysed at a much higher level than in classic preliminary design processes. The effects governing structural sizing for this specific configuration are illustrated and discussed. It is shown that considerable differences exist between the LNA and a conventional reference configuration. This analysis provides a basic understanding of what can be regarded as the "cost" of reducing aircraft noise by changes in configuration.

1. INTRODUCTION

Current trends in aircraft development indicate that requirements linked to environment friendliness, such as emissions and noise limits, are strongly gaining importance. Only by considering these requirements will it be possible to handle the expected growth in worldwide air traffic. One of the goals is to enable unrestricted night-time traffic at airports in order to elevate their capacity. To achieve this and other goals, it is expected that environmental requirements may become driving parameters for a given aircraft design. This means, among other things, that unconventional aircraft configurations will have to be considered in order to fulfil all requirements.

Once environmental requirements become driving parameters, it is necessary to consider them within the preliminary design phase of aircraft development. The design process has to be adapted. If unconventional configurations are necessary to comply with all requirements, the methods used in the design process have to be able to properly consider the special features of these configurations. Statistical approaches and semi-empirical methods, on which preliminary design processes usually rely, are not likely to produce useful results, and should be replaced by methods that provide higher fidelity.

At the Institute of Aircraft Design and Lightweight Structures (IFL), the Preliminary Aircraft Design and Optimization (PrADO) tool has been under development for over 20 years [1], [2] as an automated multidisciplinary integrated preliminary design process. Currently, PrADO is able to use higher fidelity methods for key tasks such as structural sizing. The Structural Sizing Module (SSM) combines an aerodynamic panel method with finite element (FE) based Fully-Stressed-Design [3].

As part of a joint research project, a Low Noise Aircraft (LNA) design with an unconventional configuration has been developed at the Institute of Aerodynamics and Flow Technology (AS) of the German Aerospace Center (DLR). At IFL, this LNA design is subjected to preliminary design using PrADO. Special emphasis in the analysis is placed on topics pertaining to structural sizing. A conventional reference aircraft designed for the same transport mission is subjected to the same design process in order to provide a basis for comparison.

2. THE PRELIMINARY DESIGN PROCESS

2.1. PrADO

The Preliminary Aircraft Design and Optimization tool is a modular system of computer programs. Its structure is shown in **FIG. 1**. Input from the user is required in the form of an ASCII data file, which includes a basic parametric description of the configuration layout, the transport mission and data on applicable design targets and relevant constraints. From this input file, the database files are constructed. They form a set of ASCII files which contain all information relevant to the current design problem in a thematically sorted manner.

The design process itself consists of a set of basically independent programs, the design modules. Each module is responsible for a certain task (e.g. wing geometry conversion, calculation of the longitudinal control and stability margins, etc.). These modules interact with the database files through a common library, the Data Management System (DMS). Through the DMS, the design modules are able to read input data and write their results back to the database files. Different design modules communicate with each other only through the DMS and the database files.

User interaction with PrADO is enabled by a graphical user interface (GUI) which allows access to the database files, program control and result analysis, among other things. For the design process itself, the user may choose from

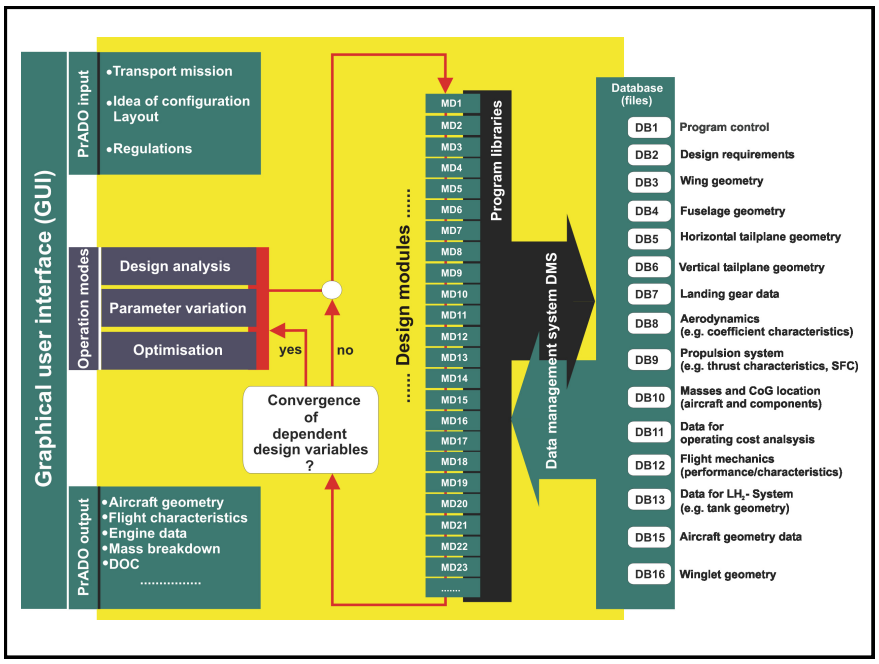

FIG. 1: PrADO overview

three modes of operation. In the Design Analysis mode, the complete set of design modules is run iteratively until convergence of main parameters is reached. In Parameter Variation mode, certain parameters (selected in the input file) are varied over a certain range (also selected). For each parameter combination, a complete Design Analysis is carried out. The Optimisation mode requires the user to specify a target function, e.g. minimum direct operating cost (DOC) or maximum range. The user also selects design variables that may be varied by the optimiser, as well as convergence criteria. PrADO then searches for the optimum combination of design variables, performing a series of Design Analyses to evaluate the target function.

The results of PrADO are available within the database files once the design process is finished. For better result analysis, the GUI provides options for formatted data output as well as various options for visualisation using the commercial tool TecPlot®.

The main advantage of using independent design modules, which communicate only through a common data interface, is that these modules can easily be exchanged. Since each module is responsible for a certain task, this exchangeability allows for different methods to be implemented for a certain task in the design process, from which the user may then select the one to be used. For example, for wing weight prediction the range of options includes statistical interpolation methods, semi-empiric handbook methods (e.g. after Torenbeek [4]), a bending beam model (after Hansen [5]) and the already mentioned FE based method: SSM.

2.2. Higher fidelity structural sizing

FE based structural sizing is available as an option for weight prediction of four aircraft components: fuselage, wing, horizontal tail plane (HTP) and vertical tail plane (VTP). Choosing it for at least one of these components causes the Structural Sizing Module to be run within module 21, which is responsible for predicting operational empty weight (OEW). SSM is in itself a system of several programs, as can be seen in **FIG. 2**.

The Multi Model Generator (MMG) creates two representations of the aircraft geometry described in the database files: The first is a panel model representing the outer contour of the aircraft. The second is a finite element model representing the major structure, including engine pylons, wing centre box and keel beam, cabin floor, HTP connecting elements, etc. In order to reduce computational effort, half models are used for both representations. In recent years, the MMG has been enhanced in order to facilitate automated geometry modelling for unconventional configurations such as the LNA (see section 3).

Aerodynamic loads on the aircraft surface are generated using the Higher Order Subsonic/ Supersonic Singularity Method (HiSSS) [6], an aerodynamic panel code provided for research by EADS. Critical load cases to be considered are provided by the SSM control program. From these, required lift and momentum coefficients can be calculated. HiSSS is used in an iterative process, changing the HTP trim angle until the required lift and momentum coefficients for a given load case are reached.

The aerodynamic loads on the surface are transferred to the FE model by the FE pre-processor FEMPRE. FEMPRE also applies loads resulting from mass inertia (accounting for payload, fuel, engines, cabin furnishings, etc.), loads resulting from cabin pressure at high altitude and ground loads resulting from landing impact, according to the selected load cases.

Structural analysis itself is performed by the in-house FE code EFEM. Structural sizing is performed using a Fully-Stressed-Design approach.

The FE postprocessor FEMPOST integrates the resulting

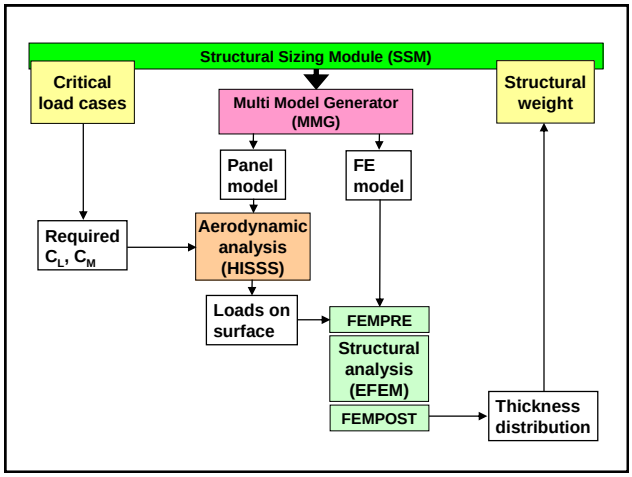

FIG. 2: SSM overview

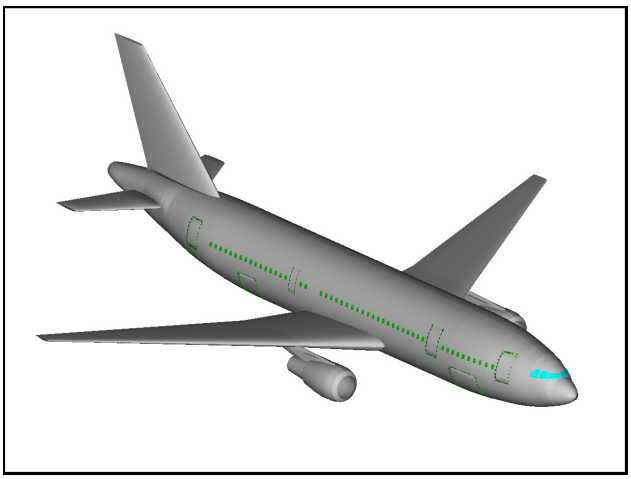

FIG. 3: Reference aircraft geometry

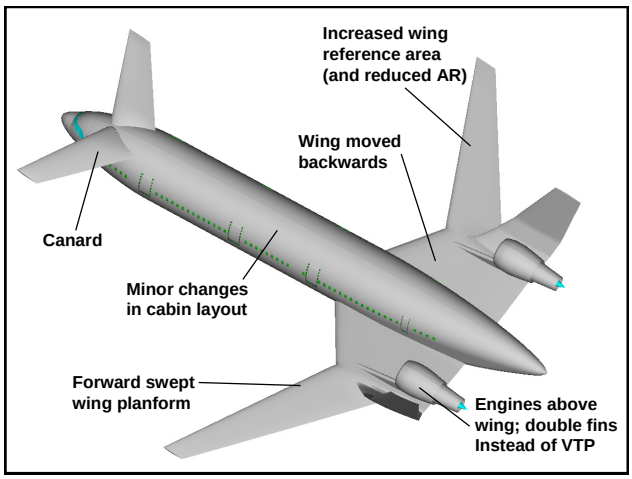

FIG. 4: LNA geometry and configuration features

element wall thickness distribution, thus obtaining the resulting structural weight for each component. Additional non-structural weight is added to account for paint, rivets, manholes, etc., leading to the component's overall weight.

3. LNA PRELIMINARY DESIGN

3.1. Configuration overview

The LNA is a 260 passenger, twin engine subsonic transport aircraft with a design range of 6500km at a cruise Mach speed of 0.8. It is studied in comparison to a conventional reference aircraft (REF) designed for the same transport mission, which is shown in **FIG. 3**. The LNA configuration results from the attempt to provide maximum possible community noise shielding. This leads to several specific configuration features:

- Wing reference area increased by 28% compared to REF; same wing span
- Modified wing plan form, including a forward swept outer wing
- HTP arranged as canard (with slight changes in front fuselage geometry, and with fuel trim tank)
- Wing moved backwards along the fuselage (with slight changes in rear fuselage geometry)
- Engines mounted above the wing
- Double fins installed on the wing instead of VTP
- Modified cabin layout

FIG. 4 shows LNA geometry with these features in an overview. Mounting the engines above the wing in the manner shown causes fan noise to be shielded by the wing, reducing noise levels below the aircraft. The wing reference area is increased for improved shielding, especially on the inboard wing section (with wing aspect ratio reduced to keep wing span constant). Forward sweep places the outer wing diagonally in front of the engine, more or less in the direction in which the main fan and compressor noise lobes can be expected (see [7]), optimising the shielding effect. Additionally, a forward swept wing can be used to provide natural laminar flow, although this possibility is not considered in this analysis. Double fins instead of a single VTP provide engine noise shielding towards the sides. The HTP is replaced by a canard to avoid engine exhaust flow impingement. The wing is moved backwards to reduce cabin noise, and to keep rotating parts out of the cabin area for safety reasons. A fuel trim tank is introduced in the canard in order to allow better centre of gravity (C.G.) management. The changes require slight modifications in rear fuselage geometry to make room for the wing, as well as slight changes in front fuselage geometry to make room for the canard. Finally, as a consequence of wing repositioning, the cabin layout is modified by moving galleys and toilets more to the front, making them more accessible for ground service. **FIG. 5** shows the cabin layout for the reference aircraft and the LNA in comparison.

For structural sizing with SSM, the two different discretisations of aircraft geometry needed are automatically generated by MMG: A panel model of the contour for aerodynamic analysis, and a structure model for FE analysis. In **FIG. 6** both models are shown for the LNA.

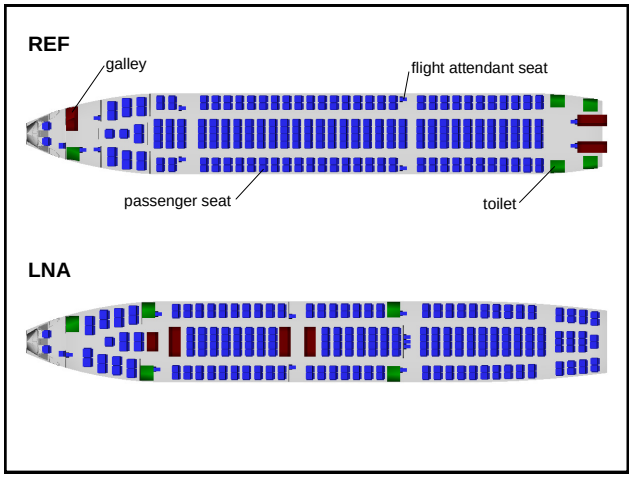

FIG. 5: Reference aircraft and LNA cabin layout

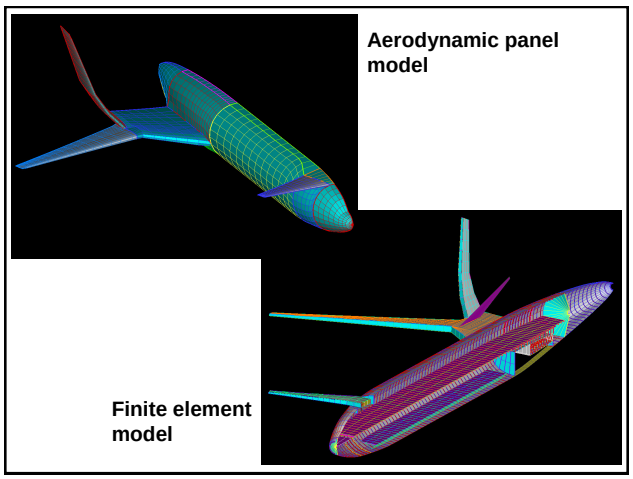

FIG. 6: MMG model geometries for the LNA

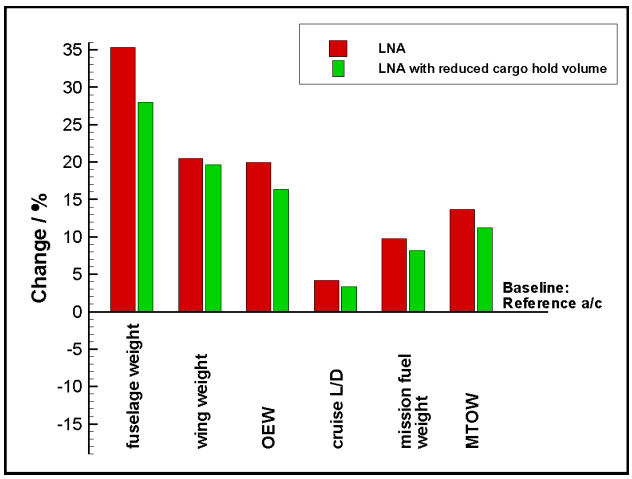

FIG. 7: Baseline Results comparison LNA vs. REF

3.2. Baseline comparison

A complete Design Analysis is performed with PrADO for both the reference aircraft and the LNA. Overall results can be seen in **FIG. 7** (together with results for an LNA variant that is discussed later), using the reference aircraft as comparison baseline. From all data available, six parameters are chosen for overall result analysis. Fuselage and wing structural weight correspond to the aircraft's most important components, and are direct results of the structural sizing process. Operational Empty Weight (OEW) includes both fuselage and wing weights, as well as the weight of other aircraft components, equipment and operational items, and can be seen predominantly as an overall expression of structural efficiency. Weights of other aircraft components are considered separately only when they are relevant for overall result interpretation. The relation of lift force to drag force at the beginning of cruise flight (cruise L/D) is an indicator of the aerodynamic quality of the aircraft. It is primarily influenced by aerodynamic design criteria such as wing position and geometry, profile shape, etc. However, since PrADO performs flight simulation for the trimmed condition (i.e. sum of moments equal to 0), cruise L/D includes aerodynamic trim losses and is thus influenced by the aircraft's C.G. range. Furthermore, cruise L/D is also indirectly influenced by the aircraft's overall weight since this determines the required lift coefficient and thereby the location of the flight point on the aerodynamic polar. Mission Fuel Weight (MFW) is the amount of fuel needed to perform the design mission (including reserves), and is basically related to cruise L/D since the design range is fixed. The better the L/D ratio, the less fuel is needed to perform the transport mission (as long as other parameters do not change too much). Mission Fuel Weight can therefore be regarded predominantly as an expression of aerodynamic efficiency in terms of weight*. In consequence, being the sum of OEW and MFW (plus payload, which is fixed), Maximum Take-Off Weight (MTOW) can be regarded as an expression of overall aircraft efficiency. MTOW is generally accepted as one of the main parameters by which an aircraft design can be judged. Other general parameters such as Direct Operating Costs (DOC) depend strongly on operational aspects and are beyond the scope of this study.

The results for the Design Analyses (see FIG. 7) show the LNA to be substantially heavier than the reference aircraft (+14% in terms of MTOW). Since both aircraft are designed for the same transport mission and carry the same payload, the weight difference must originate from the configuration layout. In terms of OEW, the LNA is 20% heavier. The increase in MFW is somewhat less (+10%) due to the increased cruise L/D (+4%), which suggests that the LNA configuration has a slightly higher aerodynamic efficiency. The main driver for MTOW seems to be structural weight. This in turn is driven mainly by wing and fuselage weight. As for the wing, the weight difference between LNA and reference aircraft (+20%) is well in proportion with the 28% increase in wing reference area, being somewhat less than linear because a larger wing has a higher thickness (since the relative thickness remains constant) and is therefore less affected by bending moments. The fuselage structure for both configurations, while almost identical in proportion and outer geometry, is 35% heavier for the LNA. The differences in cabin layout are considered to be small and therefore only of minor influence.

More information can be gathered from results of the FE analysis. **FIG. 8** and **FIG. 9** show the resulting wall thick-

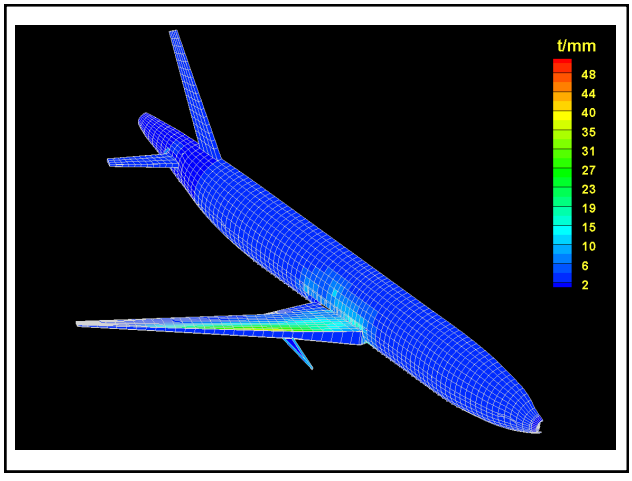

FIG. 8: Resulting FE wall thickness distribution, REF

* There is a more complicated interdependency between OEW and MFW, of course, since MFW is also basically proportional to overall weight. In the same manner, OEW is influenced by aerodynamic efficiency, e.g. through propulsion system weight, which in turn is proportional to maximum required thrust, a more or less direct function of L/D.

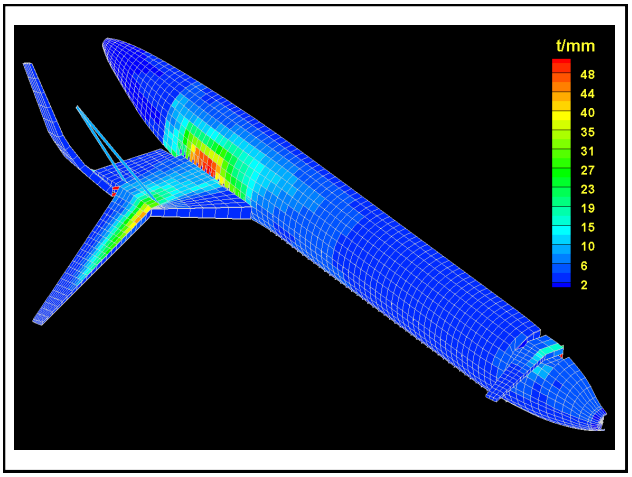

FIG. 9: Resulting FE wall thickness distribution, LNA

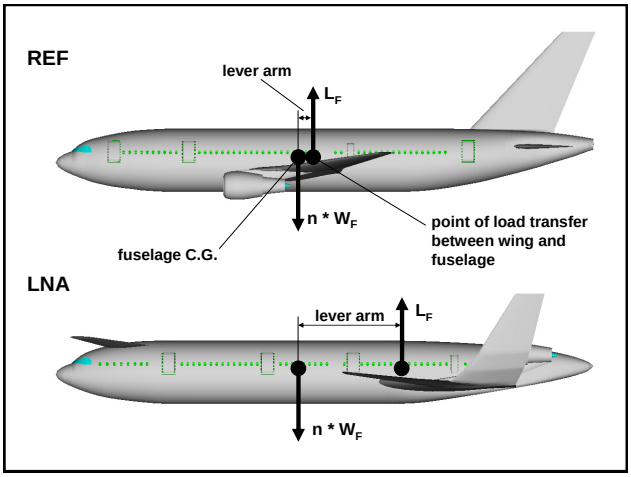

FIG. 11: Mechanical model for fuselage bending

ness distributions for the reference aircraft and the LNA, respectively. While the reference aircraft shows increased thicknesses on the wing, with the fuselage converging mostly at minimum thickness, the LNA shows maximum thicknesses on the fuselage, near the wing root. It becomes apparent that the LNA fuselage carries much higher bending loads than the fuselage of the reference aircraft. Although some of these loads result from aerodynamic forces on the canard during manoeuvre load cases, this does not account for the substantial increase in fuselage weight, as can be seen in **FIG. 10**. It shows the critical load case for each element, both for the reference aircraft and for the LNA. SSM considers nine load cases, seven of which (numbers 1, 4, 5, 6, 7, 8, 9) are flight load cases covering critical corner points of the manoeuvre flight envelope. Load case number 4, a high speed manoeuvre load case at 2.5g vertical acceleration, is critical for most of the wing and parts of the fuselage of the reference aircraft. For the LNA wing, load case number 7 (which is similar to load case number 4, but with different aircraft payload and fuel distribution) is critical. The other two load cases (numbers 2 and 3) are landing impact cases with different payload and fuel distributions. Load case number 2 implies maximum fuel and little payload, while load case number 3 implies maximum payload and little fuel. On the reference aircraft, load case number 3 is critical for a few individual elements close to the main landing gear attachment point, confirming the notion that landing impact usually plays a role only for local sizing

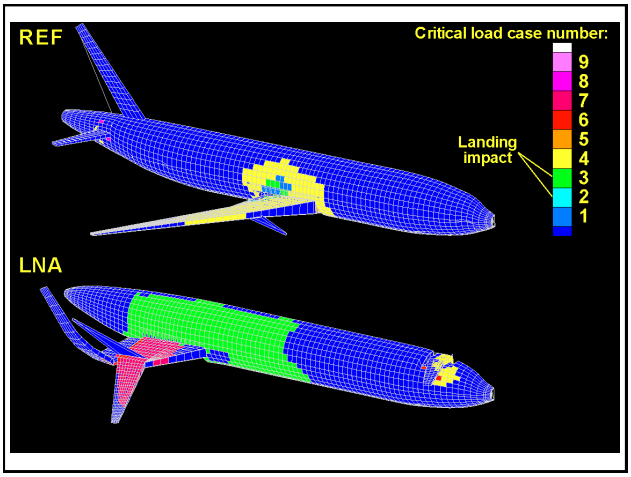

FIG. 10: Critical load cases for FE models

around the landing gear attachment structure. On the LNA, however, landing impact is the predominant condition for fuselage sizing. Load case number 4 is critical only for a small area around the canard, confirming that canard manoeuvre loads are not the main cause of fuselage weight increase.

The main characteristic of the landing impact is the high load factor (i.e. vertical acceleration) resulting from the critical sink rate of 10 feet per second required by regulations. Load factors resulting from landing impact at this sink rate can be significantly higher than the limit of 2.5g required for manoeuvre load cases. Values of approximately 3.6g are reached for the LNA. At such high load factors, forces resulting from mass inertia can easily become critical for the structure. A strongly simplified mechanical model (see **FIG. 11**) shows why the LNA is more affected. In this model, fuselage weight (W_F) is assumed to act only on the fuselage C.G. (which in this case includes equipment, furnishings and operational items). A load factor (n) is used to consider mass inertia in accelerated manoeuvres. The total effective weight of the fuselage ($n*W_F$) has to be counteracted by a corresponding force (L_F). This can be either aerodynamic lift or a landing gear reaction force, depending on the load case. The corresponding force acts on the wing (in the aerodynamic centre) or at the landing gear position (which is normally on the wing as well). Since both forces (W_F and L_F) do not act at the same point, load has to be transferred through the structure between them. Load transfer between the wing and the fuselage occurs at the wing-fuselage intersection. Fuselage bending can be considered to be proportional to the distance between the fuselage C.G. and this load transfer point. Due to the backward wing position, this lever arm is longer for the LNA, leading to higher bending loads.

The situation is aggravated by the fact that, due to the changed wing position, the LNA also has a substantially larger cargo hold than the reference aircraft (+29% in volume). While payload is fixed, meaning that this additional volume would remain unused, it does allow more options for weight distribution within the cargo hold, some of which (namely such with weight placed as far forward as possible) can become much more demanding in terms of fuselage bending moments than any load distributions for the reference aircraft. For structural sizing the most critical weight distribution has to be considered,

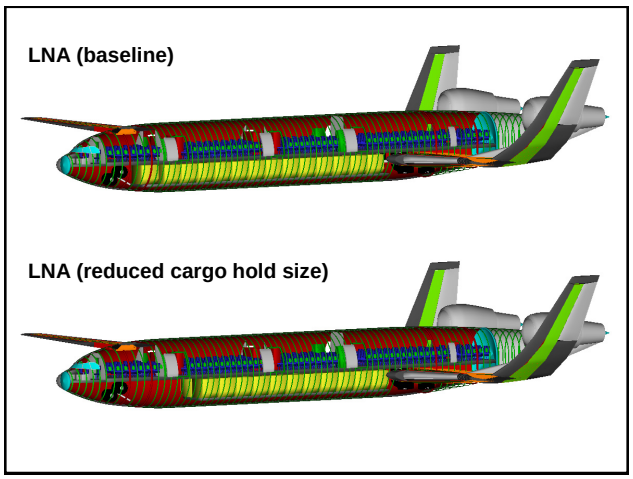

FIG. 12: Geometry model of LNA (baseline and variant)

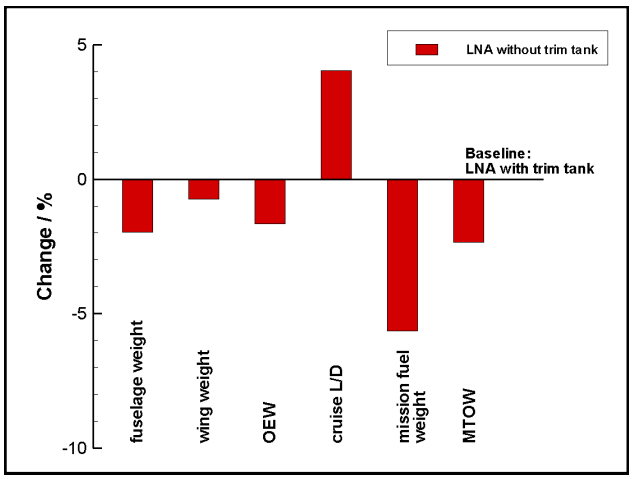

FIG. 14: Influence of the fuel trim tank in the LNA canard

so the LNA may be overly penalised. **FIG. 12** shows the LNA and a LNA model with a cargo hold reduced to the same size as the reference aircraft cargo hold, positioned as far back as possible to minimise bending loads. As can be seen in FIG. 7, where results for the LNA with reduced cargo hold volume are also provided, fuselage weight is reduced, but is still 28% higher than for the reference aircraft. Even in this case, bending loads for the LNA fuselage are higher than for the reference aircraft, leading to increased wall thicknesses and thus to increased fuselage weight, thereby causing a snowball effect which, in the integrated design process, leads to a substantial increase in weight for the overall aircraft.

Load factors experienced during landing impact are a function of landing gear dynamic behaviour. One of the main influence parameters on this behaviour is maximum combined shock absorber and tyre travel [8]. PrADO includes a module with a semi-empiric model of landing gear dynamic behaviour as a function of its geometry. Increasing maximum shock absorber and tyre deflection of the LNA main landing gear from the initial value of 0.4 metres to 0.6 metres (a value still deemed achievable for aircraft this size) reduces the maximum load factor for landing impact from 3.6g to 2.8g (-22%). Results of a Design Analysis for this LNA variant are shown in **FIG. 13**, in comparison with results for the baseline LNA. Fuselage weight is reduced significantly (-9%) and, as a result, OEW is also reduced (-5%). The decrease in landing gear

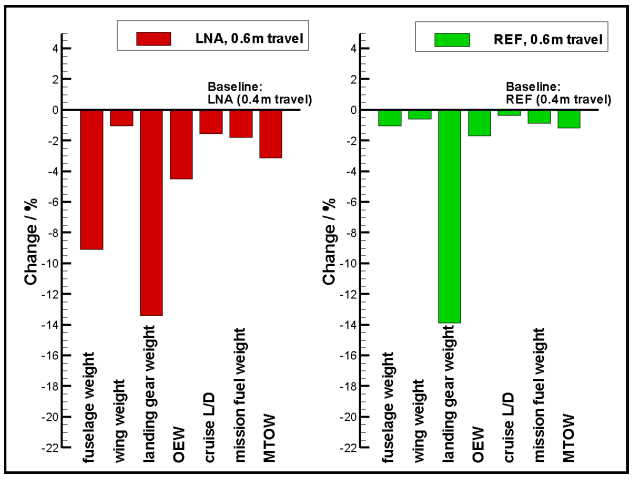

FIG. 13: Influence of landing gear travel for LNA and REF

weight (-13%) has only a minor influence (due to the low share of landing gear weight in OEW of less than 7%). Cruise L/D is slightly reduced as well, as the lighter LNA variant flies at a different point on the aerodynamic polar. The resulting increase in MFW is more than balanced by the decrease in OEW, thus reducing MTOW as well. Also shown in FIG. 13 are results for a variant of the reference aircraft with increased shock absorber and tyre deflection. These results use the original reference aircraft as baseline. For this configuration, the substantial reduction in maximum landing load factor yields a 14% reduction in landing gear weight (comparable to the LNA) , but the resulting decrease in fuselage weight is only 1%. The overall reduction of OEW is 2% (since the reduction of landing gear weight plays a more dominant role in this case). In any case, the LNA with enhanced landing gear still has a fuselage 23% heavier than that of the reference aircraft. Although landing gear dynamics might be optimised further (since the maximum load factor during landing impact is still higher than that used for manoeuvre load cases), this indicates that other factors exist which also influence the results for the LNA.

The influence of the canard trim tank is analysed by performing a Design Analysis with a LNA variant without trim tank. Results are shown in **FIG. 14** in comparison to the LNA with trim tank. As can be seen, the primary effect is a substantial change in cruise L/D (+4%) as a result of changing C.G. range. It becomes evident that the front C.G. limit is critical for LNA cruise performance. Removing the trim tank (and its fuel content) moves the C.G. range backwards, improving cruise aerodynamics. This results in lower MFW (-6%) and, since the aerodynamic loads on the canard and thus the fuselage bending loads decrease, in lower fuselage weight (-2%). As a result, MTOW decreases by 2%. However, the LNA with enhanced landing gear and without trim tank is still substantially heavier than the reference aircraft.

3.3. LNA stepwise development

A different approach to the interpretation of results for the LNA focuses on the configuration features described in section 3.1. The idea is to start with the reference aircraft and gradually develop it into the LNA, adding one or two specific features at a time. This leads to the following steps:

- Step 0: The reference aircraft
- Step 1: Step 0 + increased wing reference area
- Step 2: Step 1 + LNA wing
- Step 3: Step 2 + canard
- Step 4: Step 3 + wing moved backwards
- Step 5: Step 4 + engines above wing + double fins instead of VTP
- Step 6: Step 5 + LNA cabin layout and fuselage geometry

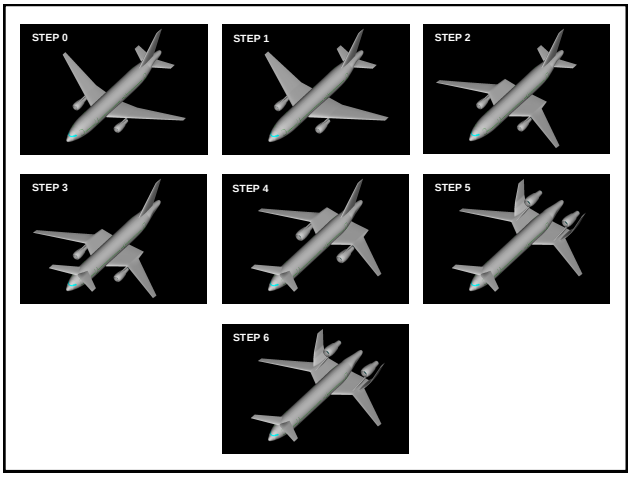

FIG. 15: Geometry models for stepwise development

Step 6 corresponds to the baseline LNA, except for the canard trim tank which is omitted, its effect being negative as shown in section 3.2. Further findings from the baseline analysis are incorporated in the form that all configurations have a maximum landing gear shock absorber and tyre deflection of 0.6 metres. Most of the steps implicitly include changes in cargo hold volume as a result of changes in wing position or centre box size. Although this influences structural sizing as shown in section 3.2, it is not discussed as a separate parameter since it is neither the dominant effect nor would its consideration provide any further insight for result interpretation.

For each of these steps, a complete Design Analysis is carried out. **FIG. 15** shows the geometry models for all configurations. While not all steps represent viable aircraft configurations and therefore some constraints of the design process can not be complied with, this approach does provide an insight into how each specific configuration feature causes the overall results to change. Results for this analysis are shown in **FIG. 16**. The parameters chosen for result interpretation are the same as those

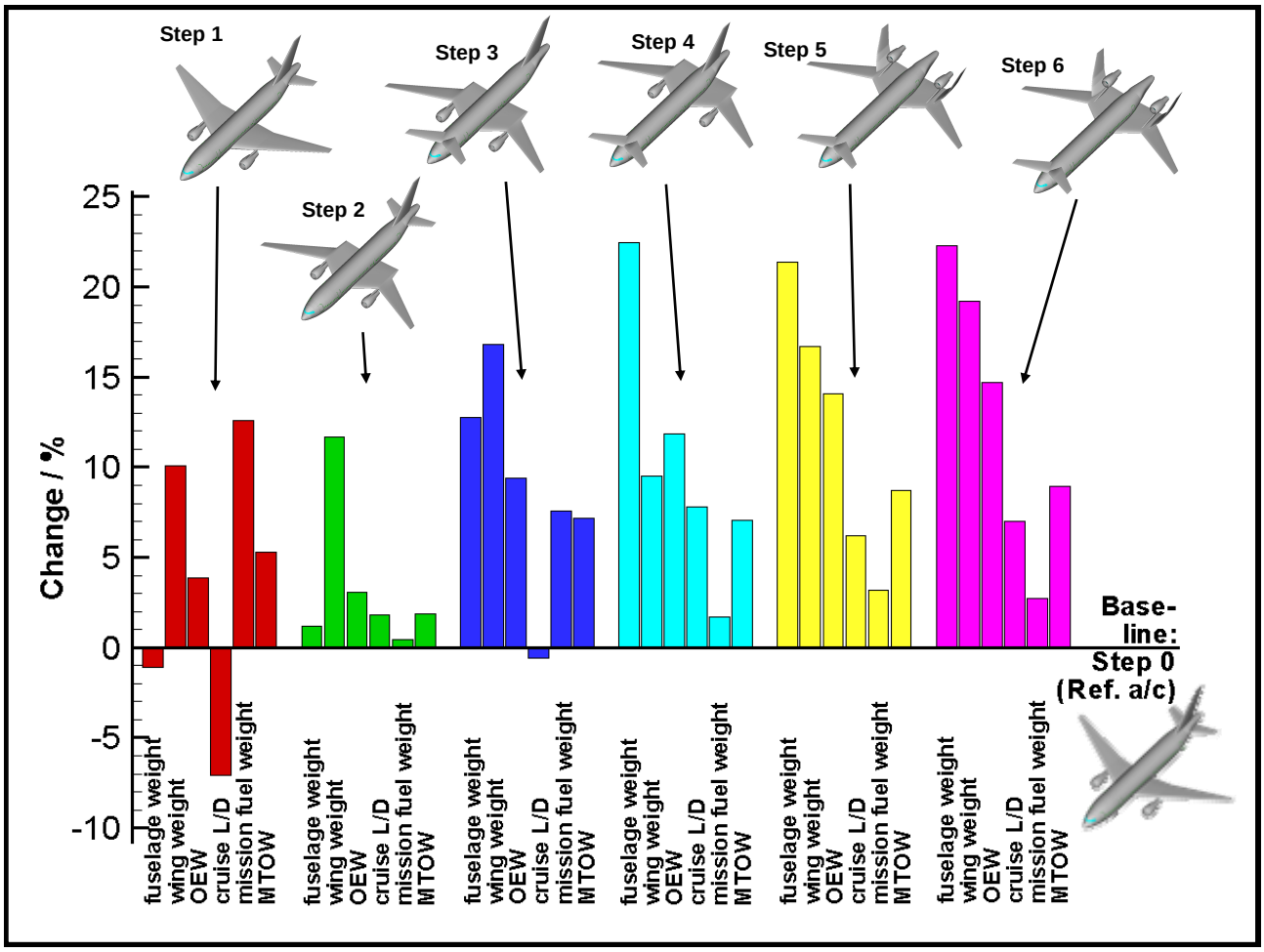

FIG. 16: Results of stepwise development

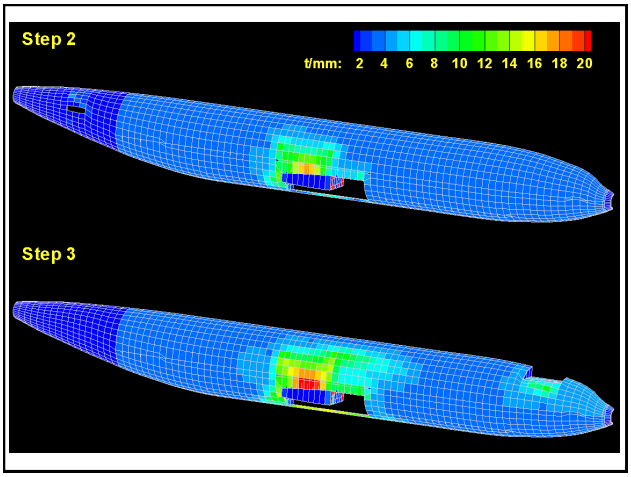

FIG. 17: Resulting FE fuselage wall thickness distributions

used in section 3.2. Again, the reference aircraft (Step 0) is used as comparison baseline.

At Step 1, wing weight increase is less than proportional to the wing reference area increase, owing to the higher thickness at the wing root as mentioned in section 3.2. Fuselage weight changes only slightly in comparison with the reference aircraft, with a tendency to decrease due to more favourable load transfer at the (thicker) wing-fuselage-intersection. The wing can now be considered as oversized for the aircraft, having a lower wing loading than that of the reference aircraft. Additionally, the wing aspect ratio has been reduced in order to keep the wing span constant. Both wing loading and wing aspect ratio influence the L/D ratio, in this case leading to a reduced cruise L/D, which in turn causes a significant increase in MFW. Wing and fuel weight are the main drivers for increasing MTOW.

At Step 2, wing weight is further increased as a result of the new plan form. Especially the slender outer wing is a contributor to the weight gain. Fuselage weight is now also slightly higher than for the reference aircraft, which can be regarded as a result of snowball effects. Cruise L/D is significantly increased with relation to Step 1, being even slightly higher than L/D for the reference aircraft. This can be attributed to the new wing, especially to its plan form and twist distribution. As a result, MFW is only slightly higher than for the reference aircraft. While the wing is considerably heavier than that of the reference aircraft, it leads to a far lower increase in OEW. Compared to Step 1, the increased aerodynamic efficiency causes the propulsion system weight to decrease by 9% (which corresponds to an absolute change in weight comparable to the absolute change in wing and fuselage weight), reducing the increase in wing and fuselage weight to a slight change in OEW. At the same time, the increased aerodynamic efficiency causes a decrease in MFW, thus leading to a decrease in MTOW.

The results obtained for Step 3 are, at first glance, surprising, since cruise L/D does not show the improvement expected for a canard configuration, but rather decreases in comparison with both Step 2 and the reference aircraft. At the same time, wing weight increases signifycantly compared to Step 2. The reason for this is the interference between the canard and the wing, which are placed relatively close to each other with the wing in the wake of the canard. This wake induces downwash on the inner wing, causing it to lose lift and shifting the resulting aerodynamic lift force outwards, thus increasing wing bending loads and making the wing heavier. At the same time, additional lift has to be generated to compensate downwash, causing more induced drag and reducing the L/D ratio, which also explains the increase in MFW. A different effect is the increase in fuselage weight. While it can partially be explained as a secondary result of the aforementioned effects, it is a substantial change and indicates that the installation of a canard in the pressurised cabin area, which requires additional bulkheads and frame reinforcements, is structurally less efficient than the installation of a HTP at the rear of the fuselage, outside the pressurised cabin area. This is substantiated by **FIG. 17**, which shows the resulting wall thicknesses for the fuselages of Steps 2 and 3. As can be seen, fuselage elements with higher wall thicknesses are found around the canard in Step 3 than around the HTP in Step 2. The overall increase in wall thickness in the area of the wing-fuselage intersection results from the higher overall load level associated with the increased overall weight of Step 3. As a result of increased OEW and MFW, this configuration also has a significantly increased MTOW.

Step 4 shows a massive increase in fuselage weight. This, as discussed in section 3.2, is caused mainly by the change in wing position and the resulting increase in bending loads on the fuselage. Apart from this, however, wing weight decreases significantly compared to Step 3. The reason for this is that the higher distance between the wing and the canard causes the effects of canard downwash on the wing to diminish. As a result, cruise L/D improves and is now distinctly higher than for the reference aircraft, as one might expect for a canard configuration. Since the increase in fuselage weight and the decrease in wing weight result in only limited OEW change, the increased aerodynamic efficiency causes MFW to decrease significantly compared to Step 3, although it still remains higher than for the reference aircraft. MTOW is driven mainly by the decrease in MFW, as it decreases slightly compared to Step 3.

At Step 5, the main change with relation to Step 4 is the increase in wing weight. This is caused by both the change in engine position and the introduction of the double fins. The change of engine chordwise position causes an increase in the torsional moment in the wing. Engines attached near the wing leading edge counteract the torsional moment resulting from aerodynamic loads, alleviating the wing, while engines attached near the wing trailing edge reinforce this moment. With the introduction of the double fins instead of a single VTP on the fuselage, the aerodynamic and inertial loads of the fins have to be carried through parts of the wing, causing an increase in structural loading and therefore a weight increase. As a result of these changes, the C.G. range is moved backwards, causing cruise L/D to decrease compared to Step 4. While fuselage weight changes only slightly, the weight of the double fins is 65% higher than that of the single VTP, thus adding to the OEW increase caused by the wing weight gain. As a result of decreasing L/D ratio and increasing OEW, MFW also increases, and therefore MTOW does, too.

Step 6 shows only minor changes compared to Step 5.

The change in cabin layout causes a slight increase in equipment and operational items weight (+2%). This increases fuselage weight slightly, but it also requires higher lift and causes higher aerodynamic loads on the wing, making it heavier. The increase in OEW resulting from this is rather small. Changes in cruise L/D, MFW and ultimately MTOW are marginal.

Several conclusions can be drawn from this stepwise development. First of all, the high weight of the LNA compared to the reference aircraft can not be traced back to one single cause. Instead, each of the configuration changes contributes to a certain extent to this result. Secondly, in the final LNA configuration, the high structural weight overrides any aerodynamic advantages that the canard configuration might inherently have. For the fuselage weight, the introduction of the canard (Step 3) and the rearward position of the wing (Step 4) are the main drivers. For the wing weight, instead, the increase in reference area (Step 1) and the relocation of the VTP and engines (Step 5) prove to have the highest influence.

4. CONCLUSION

The Preliminary Aircraft Design and Optimization tool is presented as a multidisciplinary integrated preliminary design process capable of analysing unconventional aircraft configurations. Taking advantage of PrADO's modular structure, a Structural Sizing Module is used that combines higher fidelity methods for aerodynamic and structural analysis. Effects governing structural sizing for a specific Low Noise Aircraft design are discussed.

It is shown that the LNA has a significantly higher structural weight than a conventional reference aircraft designed for the same transport mission. The reasons for this are not to be found in one single cause. A stepwise development, which begins with the reference aircraft and adds configuration features of the LNA one by one, is performed. Configuration changes with the most significant consequences for structural weight are the increase in wing size, the introduction of the canard and the backward shift in wing position. While the use of a trim tank in the canard seems to be disadvantageous, a detailed study of C.G. range influences and proper C.G. management could still show some potential for improvement by adjusting the size of the trim tank and its usage during flight.

Another result of the analysis is that for unconventional configuration layouts, the effects that drive structural sizing can dramatically differ from those relevant for conventional aircraft. In the case of the LNA, the landing impact load case (which is usually important only on a local scale) is shown to be critical for most of the fuselage structure. This is important because it shows that classic preliminary design processes relying on semi-empirical methods may not be able to analyse unconventional configurations correctly. In this case, any fuselage sizing method that does not explicitly consider fuselage bending and landing impact load factors would lead to a significant underestimation of fuselage weight. The use of higher fidelity methods for key disciplines in the preliminary design stage makes it possible to consider such influences. In the preliminary design stage, this information proves valuable as it drives the efforts for optimisation of the configuration in the right direction. The sooner in the design process such effects are discovered, the easier (and less expensive) it is to react to them in order to find the overall optimum solution (e.g. enhancing landing gear dynamic behaviour to reduce landing impact load factor).

As far as the overall evaluation of the LNA configuration is concerned, in its current state, PrADO is capable of showing the technical disadvantages of the LNA compared to the reference aircraft. The process is not yet able to show the advantages of the LNA, however, mostly since noise analysis is not fully implemented yet. Criteria for determining operating costs resulting from aircraft noise have not yet been developed, either. If one could assume, for example, that the reductions in noise would cause airport landing charges for the LNA to be significantly lower than for the reference aircraft, the LNA might become competitive even despite its higher structural weight and its increased fuel usage. Closing these gaps is the focus of ongoing work in the development of the preliminary design process.

5. REFERENCES

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