CST PARAMETRIZATION FOR UNCONVENTIONAL AIRCRAFT DESIGN OPTIMIZATION

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Abstract

This paper introduces an approach to enhance the predesign stage for unconventional aircraft configurations. When prior knowledge is not available, a novel design space has to be explored thoroughly and higher fidelity analysis codes may be employed. A promising recently introduced shape parametrization technique is implemented for the development of a model generator, which is integrated in a multidisciplinary design and optimization (MDO) environment for the predesign of the blended wing body (BWB) aircraft. The generated model is analyzed with DLR in-house disciplinary tools, coupled by means of DLR's CPACS interface. At this stage the methodology is demonstrated by considering only aerodynamics and structural design aspects. The parametrization is used to drive a combined shape and sizing optimization problem. Preliminary results are presented, showing the potentials of the approach.

1 Introduction

Preliminary aircraft design is a multidisciplinary process which requires an extensive exploration of the design space in order to gain insight into the relations between the design variables and the aircraft performance. In case of unconventional aircraft configurations, design methodologies that primarily rely on statistical data derived from existing aircraft do not represent this novel design space and thus cannot be used. Hence there is the need to introduce physics based models in order to correctly capture the behavior and the interdisciplinary dependencies of unconventional concepts. However this approach may increase the complexity of the analysis in the early design stages, when multiple design options are compared and the driving parameters are still subjected to large variations [1]. A multidisciplinary design optimization approach is necessary to make a global assessment of the preliminary designs when no previous knowledge of the system behavior is available. Fundamental for an efficient optimization process is the parametrization of the shapes defining the aircraft geometries and the choice of the governing design variables. Desirable properties of the process are a limited number of design variables, a well behaved analytical description of the geometry, and the capability to provide a consistent input model to the different analysis tools. Novel modeling techniques are based on parameterizations which allow to sweep through highly dimensional design spaces, and at the same time minimize the number of unfeasible solutions which may be generated during an optimization process. This property becomes substantial within MDO approaches, and when costly physics based analyses are needed to explore the design space. The paper presents an investigation on the applicability of the Class-Shape function Transformation (CST) method as the core of the geometrical parametrization in a multidisciplinary environment for the preliminary design of unconventional aircraft configurations, when shape and sizing optimizations are concurrent processes. CST is a powerful and versatile means to describe complex aeronautical shapes ranging from 2D airfoils to 3D geometries of aircraft using analytical functions. This methodology is applied to build a geometry generator which quickly adapts the model to the changes driven by the optimization process. As a test case the Blended Wing Body (BWB) configuration is chosen. The MDO strategy and the chain architecture are explained. At this stage the aerodynamic and the structural designs are the only disciplines considered in order to assess the potentials of the proposed methodology. Therefore the results of the integrated shape and sizing optimizations are presented.

2 Shape Parametrization Methodology

The shape parametrization represents the geometrical description of the aircraft configuration by a set of functions which makes use of a reduced set of variables. Several parametrization techniques are currently available. The choice of the most suitable technique is dependent on the level of detail in the design stage, the number of disciplinary analysis involved and the type of optimization study to be performed. Polynomial based representations, for instance, have characteristics which make them suitable in the conceptual design stage, when large changes in geometry are under investigation [2].

Recently a Class Shape Transformation technique (CST) has been presented [3], which provides an efficient geometrical description for aircraft components with the use of polynomial. The CST formulation parameterizes airfoils and wing-shaped surfaces as analytically well behaved and smooth shape functions. The mathematical formulation is given by a number of parameters consistently lower in comparison to the discrete description, which makes it suitable for the implementation in optimization problems. The CST approach is based on the definition of a physical normalized geometry as a combination of a class function "$C(\psi)$" and a shape function "$S(\psi)$", as follows in Eq.1:

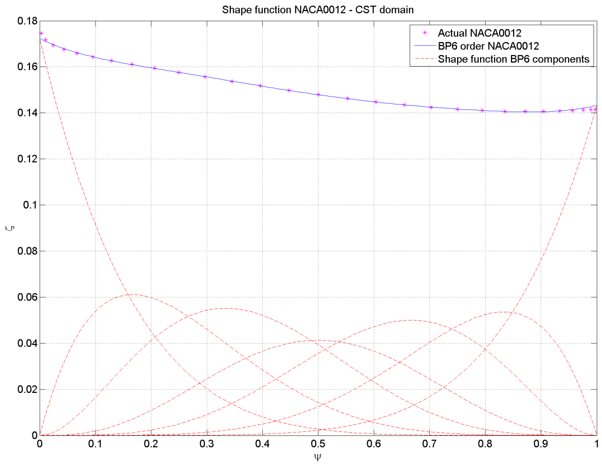
$$\zeta(\psi) = C_{N2}^{N1}(\psi) \cdot S(\psi) \qquad (1)$$

where ζ and ψ are the 2D airfoil cartesian coordinates normalized over the airfoil chord. The class function coefficients N1 and N2 determine the shape type, such as an airfoil with round leading edge and sharp trailing edge, whereas the shape function provides the relation to transform the airfoil physical domain into a well behaved analytic function. The shape function is represented by a Bernstein polynomial of arbitrary order n, which is composed by n+1 scalable components. Thus the airfoil geometry can be expressed as:

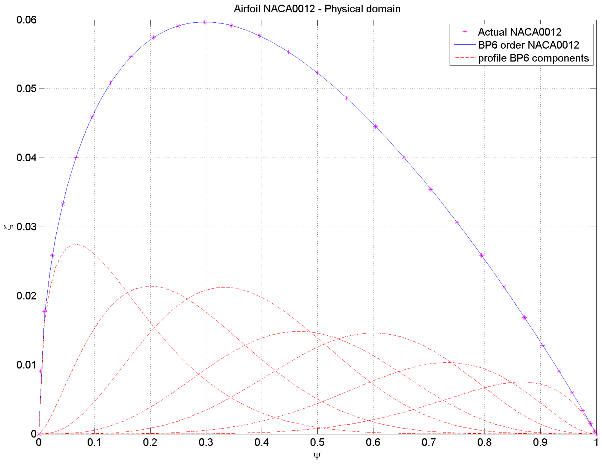
$$\zeta(\psi) = C_{N2}^{N1}(\psi) \cdot \sum_{i=0}^{n} B_i S_i(\psi) \qquad (2)$$

where B_i is the shape coefficients vector, whose components determine the shape of an associated smooth airfoil. As already shown by Kulfan, the CST parametrization allows to sweep the entire design space of smooth airfoils by making use of polynomials of relatively low order. Potentially each set of shape coefficients leads to a smooth airfoil like shape. Figure 1 shows the CST parametrization concept for the 2D airfoil case. The upper side of a NACA 0012 airfoil is represented by a 6th order shape function and it is compared with the actual airfoil coordinates. Figure 1(a) shows the associated shape function, and the decomposed basis functions of the polynomial. It is important to underline that compared to other parametrization techniques, with the shape function used here it is still possible to distinguish the physical characteristic of the original shape, for instance the nose radius, and the trailing edge angle for the airfoil case.

The accuracy of the CST model generator is investigated with the 2D NACA0012 airfoil case. The NACA0012 is chosen as it can be analytically expressed and thus its coordinated can be calculated at any chord position. The capabilities of CST for the representation of various types of airfoils have been extensively demonstrated by Kulfan [4]. It is checked whether the implemented CST geometry generator reaches the recommended accuracy for high fidelity CFD calculations [5] of a maximum residual, i.e. the abso-



(a) Shape function 6th order and scalable components



(b) CST-actual airfoil geometries comparison

Fig. 1 CST parametrization 2D airfoil NACA0012

lute difference between the actual airfoil and the CST geometry, of 8e-5 or for wind tunnel testing of 3e-4 as suggested by Kulfan. In this investigation for each order of polynomials, ranging from 1st to 10th order, the corresponding coefficients are determined and the residual of the correct NACA0012-geometry and the CST-approximation on 100 equally spaced nodes is calculated. Figure 2 depicts the maximum residual dependent on the order of the Bernstein-polynomial used for the approximation, and the suggested accuracy limits. For a maximum residual of 8e-5 the governing polynomials should be of at least 7th order, whereas a second order polynomial is already sufficient to satisfy Kulfan limit of the accuracy.

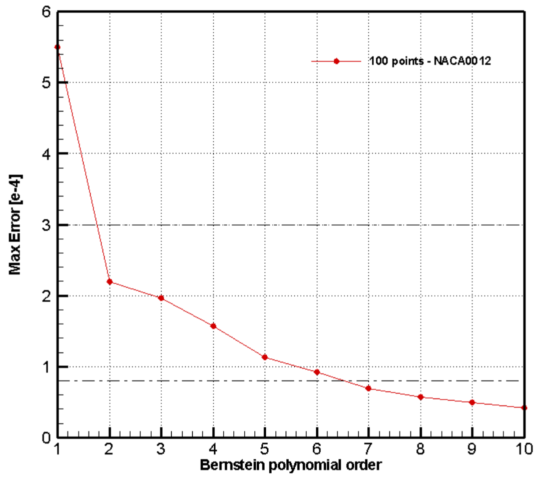


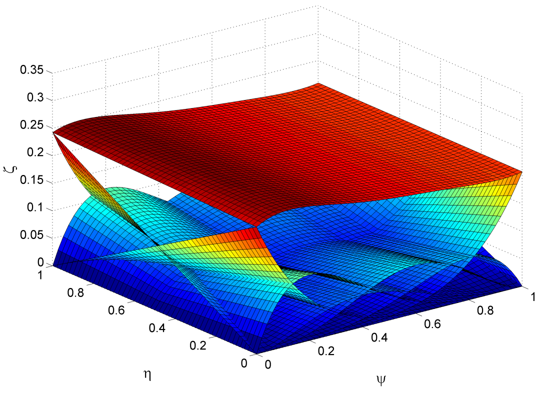
Fig. 2 Maximum residual for increasing order of the shape function polynomial

The formulation can be as well extended to the 3D case, for which a wing surface can be associated to a well behaved shape surface. The spanwise variation of the geometry is described by adding the spanwise distribution of the CST coefficients, which can be expressed as Bernstein polynomials as well. Thus the wing surface is represented in its normalized three dimensional physical domain by the Eq.3:

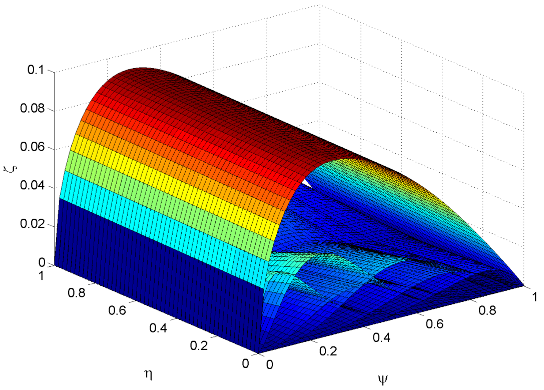
$$\begin{aligned}\zeta(\psi,\eta) &= C_{N2}^{N1}(\psi)\cdot S(\psi,\eta)\\ &= C_{N2}^{N1}(\psi)\sum_{i}^{Nx}\sum_{j}^{Ny} B_{i,j}Sy_jSx_i\end{aligned}\tag{3}$$

where η is the non dimensional spanwise coordinate. The coefficients matrix $B_{i,j}$ dimension is dependent on the polynomial order Nx chosen for the chordwise description of the surface, and Ny for the spanwise distributions. This contains the continuous surface description of the wing segment, and it allows to evaluate it in each point of the domain. The order Nx is responsible for the control of the airfoils shapes, whereas the order Ny is responsible for the spanwise control of the surface curvature. Figure 3(a) shows the shape surface $S(\psi,\eta)$ and its scalable components, whereas figure 3(b) shows the upper side of the associated wing shaped surface in the normalized domain. The normalized wing surface can be transformed in an actual wing geometry by superimposing functions describing the wing planform, such as the spanwise chord and the twist distribution for an assumed taper ratio and sweep angle. The wing geometry in the physical domain is shown in figure 3(c), and is characterized by a continuous airfoil transition in the spanwise direction, which is controlled by the coefficient matrix $B_{i,j}$.

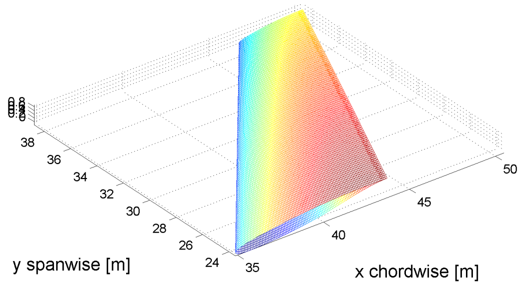
In order to model a complex planform shape, the CST techniques can be applied segment-wise along the span direction. Hence the overall configuration is defined as an assembly of segments, and parameterized by a distribution of shape surfaces which are related to the physical domain by the local segment planform properties. In the present study a parametric model generator based on the CST segment-wise concept is implemented, and integrated in a multidisciplinary environment for the preliminary design of a Blended Wing Body configuration.



(a) Shape surface function $S(\psi,\eta)$



(b) Wing upper surface normalized domain (ψ,η,ζ)



(c) Wing geometry physical domain (x,y,z)

Fig. 3 CST parametrization 3D wing surface

2.1 BWB configuration

Preliminary studies emphasized the benefits of the BWB concept in terms of improved efficiency and fuel burn reduction per seat [6]. Detailed aerodynamic optimization studies demonstrated how it could be possible to achieve the potential performances by aerodynamic tailoring [7], and underlined the need to solve the open technical questions which may require higher fidelity analysis, such as structural design. The BWB is a performance driven integrated concept, and designing it requires a MDO approach capable of efficiently sweeping the new design space. Hence the segment-wise CST parametrization approach is investigated here as a means to enhance the predesign phase of such configurations. In this paper the initial reference design is based on the geometry defined within a previous European project identified as MOB, and whose main data are available in literature [8]. As commonly considered, the BWB configuration can be regarded as the blending of a central body region and an outer wing region. For the baseline, the central body has a 48 m long root section, and a sweep angle of 64 degrees measured at the leading edge, whereas the outer wing has a sweep angle of 38 degrees and the total span length is 77.5 m. Additionally a preliminary structural layout is defined for the baseline configuration as a set of ribs, spars and body frames. The the baseline planform and the structural layout scheme are shown in figure 4 for the half model. The reference dimensions for the aerodynamic analysis and the design cruise condition are defined in table 1.

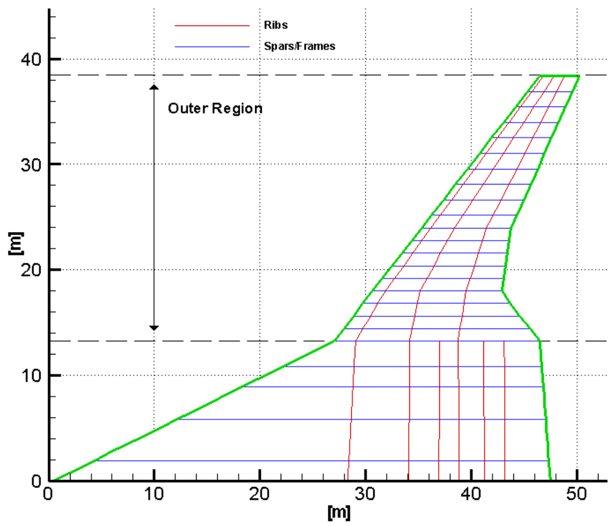
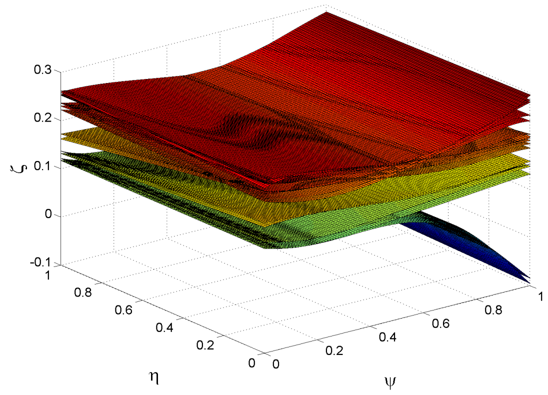


Fig. 4 BWB baseline planform and structural layout

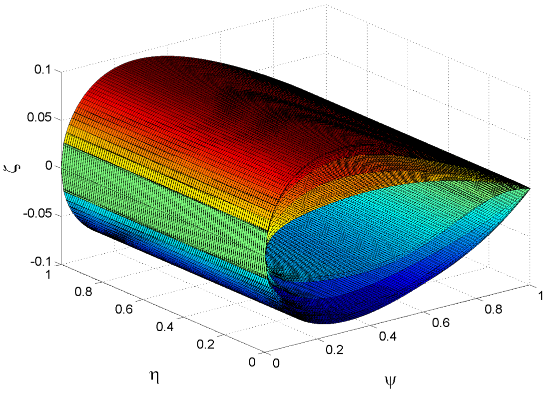
Baseline Configuration	
Central section chord	48 [m]
Reference Area	790 [m^2]
Reference Length	12.5 [m]
Ref. Wing Sweep angle	38 [deg]
Ref. Wing Aspect Ratio	7.6
Cruise Altitude	10000 [m]
Cruise Mach number	0.85
Design C_L	0.41

Table 1 Baseline reference wing dimensions and design cruise condition

In terms of parametrization the geometry is identified by 10 spanwise sections, and by 9 segments between sections. Each segment is described by a shape surface with 5th order in chordwise direction, and by a spanwise linear distribution of the coefficients between the sections. Therefore each wing surface segment is parameterized by a $B_{i,j}$ matrix. Each segment is allocated with a single value for taper ratio, sweep angle, and by a chord and a twist distribution. Adjacent segments have to satisfy contiguity constraints to guarantee a continuous shape, for instance at each of the common sections, the sharing shape surfaces have to assume identical values for the shape coefficients. Figure 5(a) shows the CST shape surfaces for the defined BWB segments, and the associated wing surfaces in the non dimensional space are shown in figure 5(b). The resulting assembly of the wing surfaces segments in the BWB physical domain with the planform parameters distributions applied is displayed in figure 6. Figure 7 shows a sweep of shapes with different sets of the planform distributions.



(a) Shape surfaces BWB segments



(b) Wing surfaces BWB segments normalized domain

Fig. 5 CST segment-wise concept application

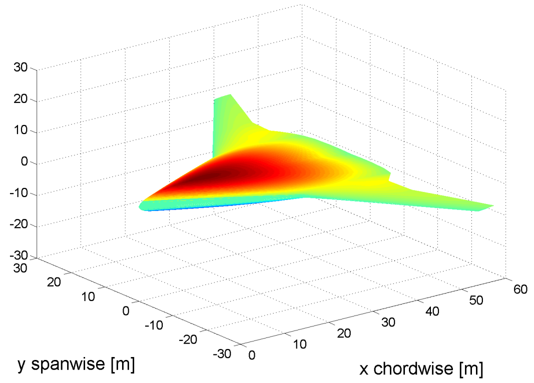


Fig. 6 Assembly wing segments geometries BWB physical domain

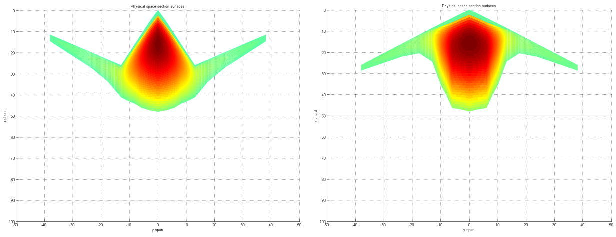
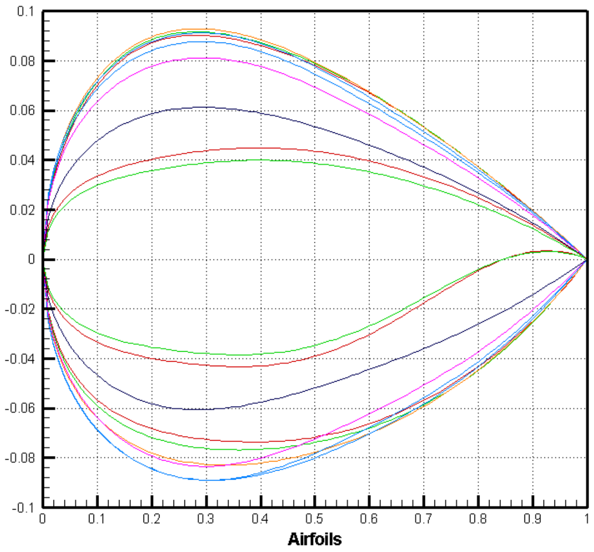


Fig. 7 Assembly with different planform distribution functions

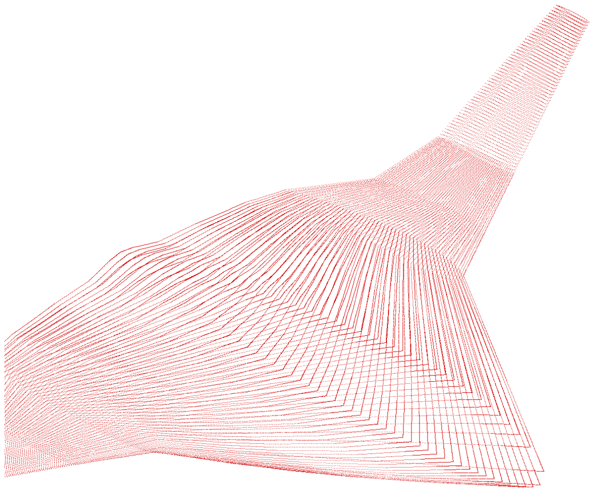
The baseline airfoils have been initially parameterized with the set of corresponding CST 5th order polynomial coefficients, sufficient to have an accurate representation of the explicit airfoil coordinates at the baseline stations. The CST representation of the airfoils along 10 stations are plotted in figure 8(a). The complete three dimensional geometry can be extracted as a grid of points with variable resolutions, as in figure 8(b).

3 Multidisciplinary analysis

The methodology described parameterizes the configuration with a finite set of parameters, which includes the CST coefficients, and the planform and twist distribution functions. The resulting model is then used to initialize and drive the analysis modules, which generate the disciplinary models starting from the common set of configuration parameters. In this first assessment of the methodology a low fidelity aerodynamic analysis is used to calculate the aerodynamic loading, and it is coupled with a high fidelity Finite Element structural solver. The shape performance and the structural sizing optimizations are performed using the parametrization variables as design drivers.



(a) BWB baseline Airfoils with 5th order CST



(b) Baseline grid extracted from the CST parametrization

Fig. 8 BWB baseline geometry

3.1 Process chain

The core of the multidisciplinary process chain is DLR's CPACS (Common Parametric Aircraft Configuration Schema), a structured XML data format, which is used as data-exchange-protocol between the different disciplinary analysis codes.

CPACS is conceived to contain all necessary data, such as the geometry description and aerodynamic parameters, required for preliminary aircraft design computations. This XML data format is continuously enhanced and extended by DLR. The process chain makes use of distributed computing approach, in which disciplinary analysis tools are run on dedicated servers located at various DLR-sites.
The coupled aerodynamic and structural optimization process chain set up for this study consists of the following components:

1. Geometry generator (CST based)
2. CPACS initializer
3. Aerodynamic analysis
4. FE Structural Modeling
5. Aero-structural grids Mapping
6. FEM analysis and structural sizing

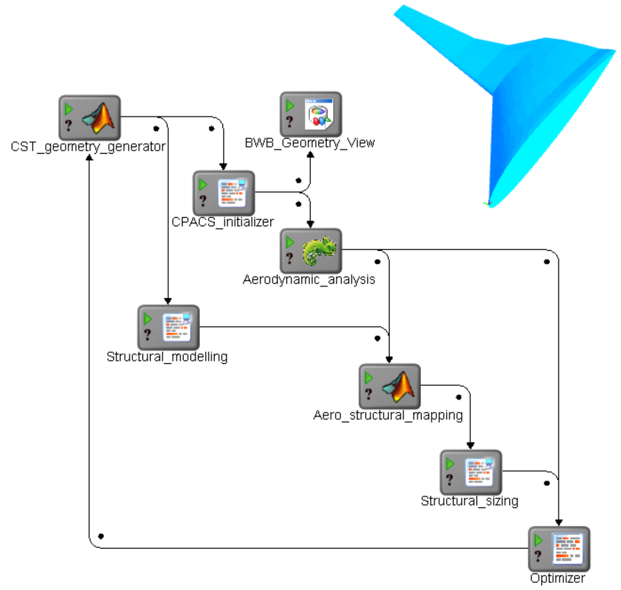


Fig. 9 Process chain

The generated geometry associated with the set of design variables is converted to CPACS format by the initializer. From a valid CPACS XML-schema an empty CPACS object is compiled with the data relative to the configuration shape (e.g., the surface geometry), and the design point conditions (e.g., the flow properties). This common data set is used to interface the disciplinary analysis tools in a fully automated process. Aerodynamic performances are monitored together with sized structural masses for each of the design points considered. The framework flowchart is shown in figure 9.

3.2 Disciplinary Analysis

The aerodynamic analysis is based on the potential multiple lifting line code for non-planar wings LIFTING_LINE [9]. The CST methodology has already been proven to be suitable to drive aerodynamic optimization problems by using full potential panel code for 3D wing geometries, either Euler solver for 2D airfoil optimizations [10]. The aim of the present study is not to derive a locally optimized shape, which would require costly high fidelity computations, but to consider the large variation of planform and airfoil parameters at the same time. Using the parametrization the optimization process considers only smooth and feasible starting geometries corresponding to a large variation of the distributions of the loads. Hence LIFTING_LINE is a viable solution to perform an overall design space exploration for unconventional designs.

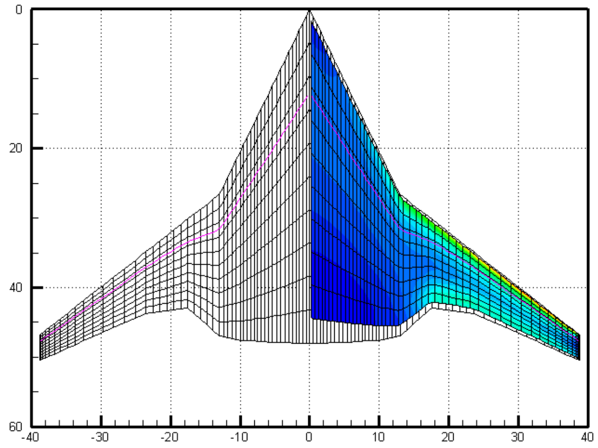
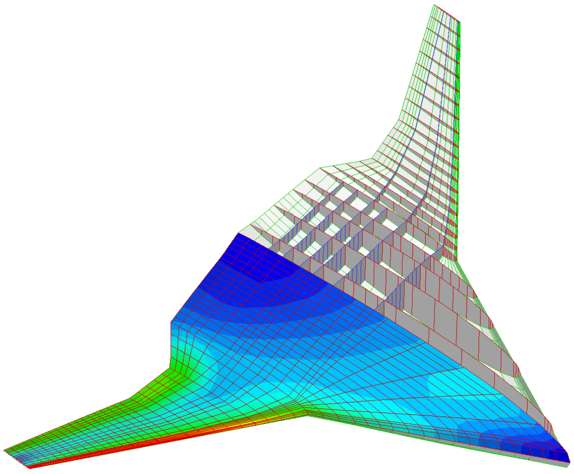
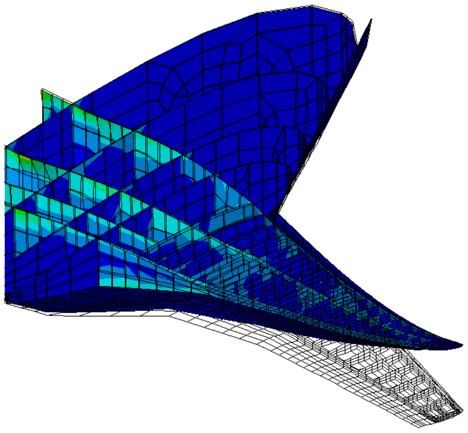


Fig. 10 BWB aerodynamics model

Figure 10 shows the aerodynamic model generated for the baseline configuration when the input is initialized by the CST module, and the corresponding distribution of the aerodynamic coefficients computed over the planform panels.
The structural model is generated with the DLR in-house prototype application PARA_MAM [11]. The tool requires a reference grid of points as input, serving as external contour surface for the finite element mesh, which in this study is provided by the CST model generator. The inner structural topology is parametrically defined in terms of number of spars, ribs and frames, and the relative positioning of the components. Thus PARA_MAM, which is realized as a set of MATLAB macros, fit the inner structures in the reference mesh, and generates a collection of matrices containing the data required to define the model within the pre-processor of the FE package. For the current approach the multilayered shell FE model generated is described by the ANSYS Parametric Design Language (APDL) format, which can be directly interpreted by the FE software package ANSYS. The structural analysis performed at this stage considers only the aerodynamic loading produced from a 2.5g pull-up manoeuvre. For this purpose a mesh mapping tool has been implemented to distribute the calculated aerodynamic loads over the three dimensional surface elements of the structural model. Thus the sizing infrastructure S_BOT (Sizing roBOT) developed by DLR is used to determine the thickness distribution of the shell elements. The tool's main input file calls the FE software, reads the FE model generated, applies the mapped aerodynamic loads, launches the analysis solver, and post-processes the loading state for each element of the structural components. Thus on the base of the sizing criterium chosen, the new elements thicknesses are calculated, and the dimensions of the skin element layers are updated for all the wing elements within the specified optimization regions. After the model updating the load path is changed, and the analysis-sizing process is iteratively repeated till convergence criteria are met. The tool explicitly model the primary structure components (i.e., ribs, spars, and skin), whereas the substructures (e.g., stiffeners) are implicitly modeled by equivalent stiffness layers [12]. Figure 11 shows the generated structural model generated for the structural analysis as output of the finite element software package. In figure 11(a) half of the PARA_MAM generated FE model is displayed without the upper skin surface elements to visualize the inner structural components, whereas the other half of the model shows the aerodynamic loads mapped on the surface elements. Figure 11(b) shows the FE analysis performed on the model during the sizing process.



(a) Baseline PARA_MAM FE Model



(b) Baseline S_BOT FE Analysis

Fig. 11 BWB Structural Model

The structural sizing involves all the FE model elements defined within an optimization zone. The bending and the torsional stiffness of the outer wing are assumed to mainly depend on the design of the wing box (i.e., the wing portion between the main front and the rear spar, including ribs and skin), and not on the leading and trailing edges areas, where movables such as high lift devices and control surfaces may be installed (e.g., flaps, slats, ailerons). For the BWB inner body the frames, the ribs and the skin elements have been considered as optimization areas. In this study a fully stressed sizing criteria is applied element-wise for the structural sizing of the shell elements. Although layered material properties can be defined, only the isotropic case is considered in this study in order to reduce the number of variables for the first assessment of the methodology. Figure 12 shows the baseline sized masses of the primary structural components at each iteration. Figure 13 displays the thickness distribution of the upper skin elements, for the region between the front spar and rear spar of the baseline configuration.

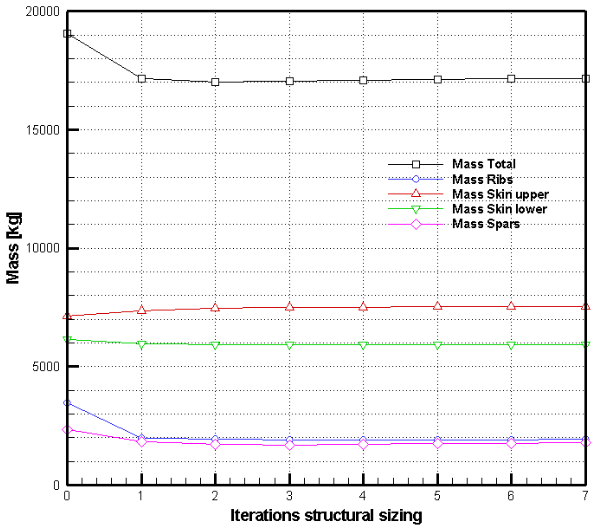
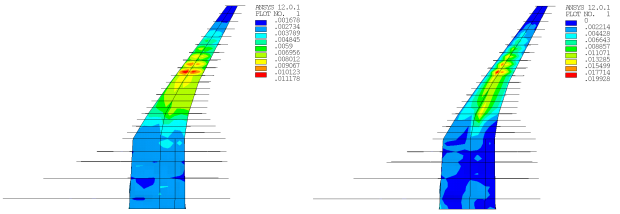


Fig. 12 Structural sizing primary structures



(a) Thickness Iteration 1 (b) Thickness Iteration 8

Fig. 13 S_BOT elements thicknesses distribution

4 Optimization Results

With the methodology potentially each set of CST coefficients will produce a smooth outer shape, and thus an initial geometrically feasible configuration. Whereas in a detailed design analysis the interest would be to perform the study on the improvement of the local shapes (e.g. wave drag reduction), for the exploration of a novel design space the interest focuses on the global assessment of the configuration with a small amount of design variables, and by avoiding the calculations of design points with an already known unfeasible associated geometry. All the parameters (i.e., CST coefficients, planform and twist distributions) defining each segment can be considered as design variables for the MDO problem. However some quantities such as the total span length, the central section chord, and the taper ratio distribution are kept constant. In this way the reference area will still be constant for different values of sweep angles, whereas twist values and the shape coefficient defining the airfoils shapes are free to change. The parametric positioning of the inner structural layout is fixed for all the shape changes, whereas the elements thicknesses are iteratively calculated during the sizing optimization for each of the MDO iterations. Thus the shape and the sizing optimizations are combined and the design points are compared in terms of aerodynamic performances and primary structural masses for equal inner topology and sizing criteria applied. Using the process chain three preliminary studies on the baseline configuration are presented.

- Aerodynamics optimization

- Structural optimization
- Aero-structural optimization

Running these optimization studies directly on the process chain is deemed to be infeasible in terms of required computational time, as higher level analysis codes are used. Thus a constrained surrogate-based approach is set up to identify the optimal solutions. For the construction of the surrogate an orthogonal-array sampling plan is created and run in the process chain. The results are used to fit a preliminary Kriging-model, whose quality is tested with a cross-validation method. For the single target optimization of L/D and sized mass a gradient-based optimizer is employed. The respective identified optimal solutions are then recalculated in the actual process chain and then used as an infill point, to improve the quality of the Kriging-model's prediction. This process is repeated until no further improvement of the solution is detected.
The multi-objective optimization problem is solved with a genetic algorithm. With the help of the Kriging-model the pareto-optimal solutions are quickly identified. These Pareto solutions are then also rerun with the actual process chain and then used to improve the Kriging-model. With the updated surrogate the optimization is restarted with the former pareto-optimal solutions incorporated in the first generation as the design seed.

4.1 Aerodynamic Optimization

An initial single objective aerodynamic optimization problem is formulated to maximize the baseline efficiency ratio L/D as target function, with the specified design cruise lift coefficient C_L as constraint. The design variables set for the problem include the CST coefficients defining the outer wing region surfaces (3 segments, 4 sections), and the twist angles of every spanwise section. The use of the CST coefficients allows to manipulate the continuous three-dimensional wing surfaces, not only the airfoils shapes at the defined stations. The results are compared with a second optimization performing only a twist tailoring of the baseline. For both cases the twist angles relative to the fuselage sections are not set as independent variables in order to avoid a heavily distorted central body, unfeasible from a payload perspective. Twist angles for all the sections are bound between ±5 degrees, and the coefficient matrix $B_{i,j}$ elements are bound to limit the change in the airfoil thickness. The list of the design variables (DV) for each segment, the lower and upper boundaries values, and their total number taking into account the contiguity constraints are given in table 2.

DV	DV/segment	DV bounds
$B_{i,j}$	12	$0.005 \div 0.02$
twist angle	2	$-5 \div 5$
Total	29	

Table 2 Design Variables (DV) for aerodynamics optimization

The full potential aerodynamic solver is not able to predict neither the friction drag component, nor the wave drag. Thus an estimation of these two components is introduced by a form factor value taking into account the flat plate turbulent boundary layer correlation and the sweep angle of the outer wing leading edge [13]. This allows to provide an aerodynamic model to the optimizer, in which all the design variables consistently affect the target function. Although the aerodynamic solver has a fast execution time, the optimizer is not directly coupled with the analysis tools, but with the refined surrogate model previously described. For the twist tailoring case the optimization on the surrogate is compared with a gradient based optimization performed of the full model. The complete aerodynamic optimization includes the CST coefficients as design variables, and the optimization is performed only on the refined surrogate model. The optima design points are re-analyzed with the actual chain to check the deviation of the performances evaluated on the surrogate from the actual values, i.e. $\Delta(L/D)$. The performances of the baseline and the optimized configurations are reported in table

3, whereas the corresponding spanwise twist and the local lift distributions are plotted in figure 14 and 15.

	C_L	C_D	L/D	$\Delta(L/D)$
Baseline^A	0.24	0.01426	16.6	-
Twist^S	0.41	0.01744	23.55	3.1%
Twist^A	0.41	0.01752	23.45	-
CST Aero^{S,*}	0.41	0.01725	24.2	3.9%

^{A} Optimization on the Actual model
^{S} Optimization on the Surrogate model
* CST coefficients + twist angles as DV

Table 3 Aerodynamics performance baseline and optimized configuration

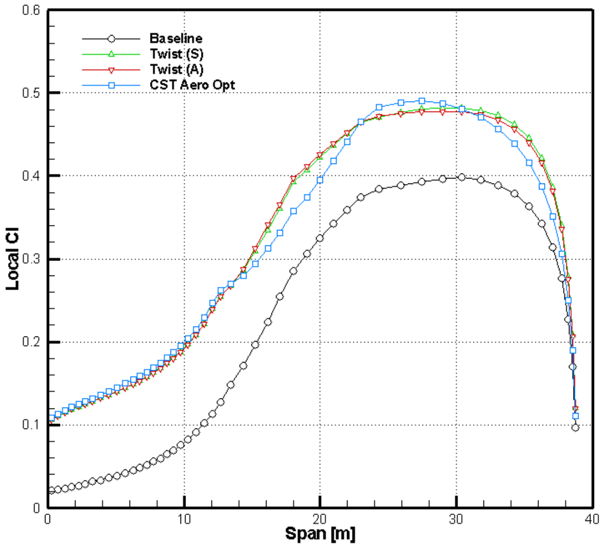


Fig. 14 Spanwise local lift coefficient baseline and aerodynamics optimized configurations

The results indicate that the performances match when comparing the optimization on the refined surrogate and on the actual model for the twist tailoring cases. The deviation is within 4% for the complete CST optimization with 29 design variables. An additional improvement of the performance is achieved when the CST coefficients are added as design variables, and thus the optimizer has more freedom to change the geometrical shape. However the L/D ratio increases for the design C_L only $\sim 3\%$ in respect to the twist tailoring case, due to the already optimized performances of the airfoils used for the baseline planform design. The improvement is expected to be higher when the optimization search is initialized with a generic starting point.

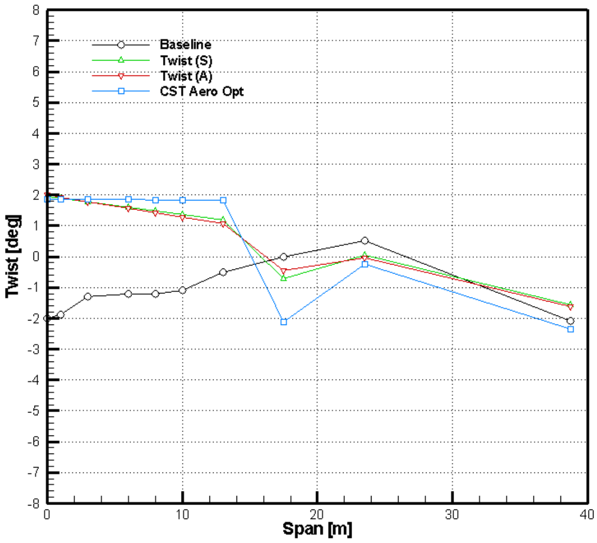


Fig. 15 Spanwise twist distribution baseline and aerodynamics optimized configurations

4.2 Structural Optimization

After the first aerodynamic model optimization, the structural component is added to the chain. Design variables and their boundaries are kept equal to the aerodynamic optimization case. This second study aims to investigate the effect of the different loading distributions driven by the CST coefficients, on the structural sizing. Compared to the previous study a larger sampling plan has been set up, and the new surrogate model is derived for both the aerodynamic and structural responses. The optimization problem is formulated as minimization of the total mass related to the sized primary structures regions, with the design C_L as constraint. The optimum configuration is compared with the baseline and with the design from the previous aerodynamic optimization, for which the structural masses have been sized as well. The results, listed in table 4, indicate the reduction of sized mass.

	L/D	Mass Opt	$\Delta(Mass)$
Baseline^A	16.6	17158	-
Twist^A	23.55	19614	-
CST Aero Opt^A	24.3	18394	-
CST Mass Opt^S	20.6	10557	4%

^{A} Mass calculated on the Actual model
^{S} Mass calculate on the Surrogate model

Table 4 Comparison aerodynamics optimized-structural optimized configurations

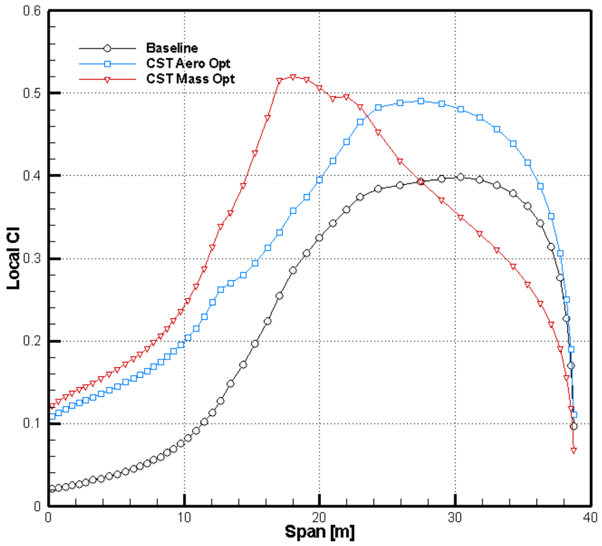


Fig. 16 Spanwise local lift coefficient aerodynamic and structural optimized configurations

Comparing the C_L spanwise distribution, an inboard shifting of the wing loading can be observed in figure 16 for the mass minimization case. The CST parametrization enables the three dimensional redesign of the complete external shape. The changes in the airfoils shapes are shown in figure 17 for the section located at the 60% of the span, and the associated CST coefficients values are compared in figure 18. An increase in the airfoil thickness for the mass minimization case, leading to the alleviation of the structural bending and resulting in a lighter structure, can be observed. At the same time the associated L/D decreases.

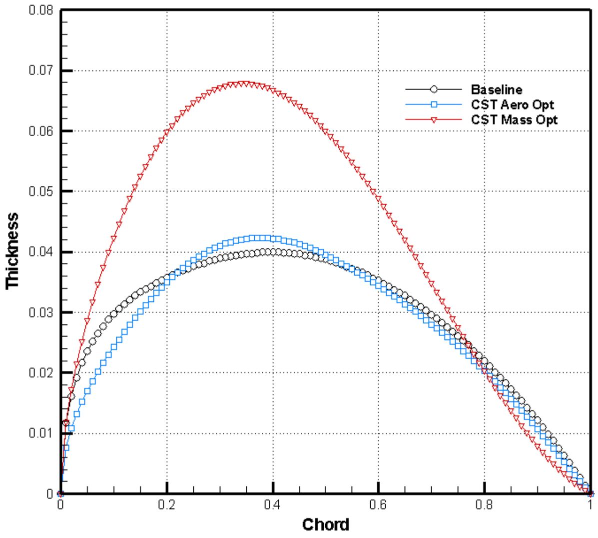


Fig. 17 Airfoils 60% span baseline optimized configurations

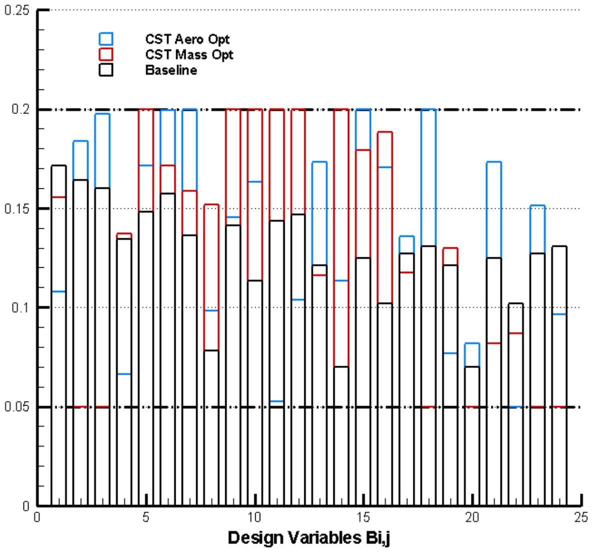


Fig. 18 Design variables comparison

4.3 Aero-structural Optimization

In order to assess the ability of the methodology to drive the MDO process, a multi-objective optimization is formulated by specifying both the minimization of the sized structural mass and the maximization of L/D as target functions. An evolutionary algorithm is used on the surrogate model. Figure 19 depicts the Pareto-optimal design solutions.

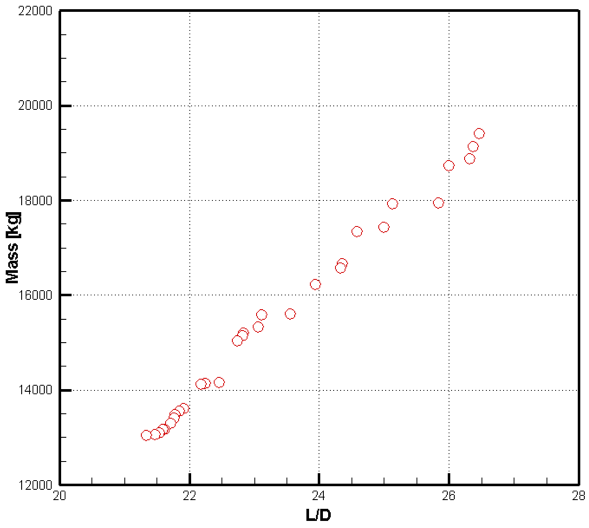


Fig. 19 Pareto front of aero-structural optimization

5 Conclusions and Outlook

The proposed approach based on the CST parametrization shows an efficient way to explore novel design spaces with a limited amount of calculated points. The ability to drive the optimization through only geometrically smooth designs represents a key feature for the aircraft predesign stages when involving higher fidelity analysis. Further the possibility to have an automated process contributes to reduce the repetitive and time consuming activities related to data transfer. The potentials of the methodology can be exploited when more disciplines are considered to the process, for instance by including stability constraints, and when the fidelity of the aerodynamic solver is increased in order to account for the drag components values with higher accuracy. Future works focus on the assessment of the optimization process, which can include smart mesh regeneration strategies, the investigation on different surrogate response techniques, and the combination with structural topology variations. Hence the complexity of model can be increased, for instance by introducing composite materials modeling or adding pressurized payloads compartments, which have a large impact on the assessment of the global BWB performances.

References

[1] Schut, E. and Van Tooren, M. J. L., “A Knowledge Based Engineering approach to automation of conceptual design option selection,” *45th AIAA Aerospace Sciences Meeting and Exhibit*, AIAA Paper 2007-968, Reno, Nevada, 2007.

[2] Samareh, J. A., “Survey of Shape Parameterization Techniques for High-Fidelity Multidisciplinary Shape Optimization,” *AIAA Journal*, Vol. 39, No. 5, May 2001.

[3] Kulfan, B. M., “Universal Parametric Geometry Representation Method,” *Journal of Aircraft*, Vol. 45, No. 1, pp. 877–884, 2001.

[4] Kulfan, B. M., “Fundamental Parametric Geometry Representation for Aircraft Component Shapes,” *Proceedings of 11th AIAA Multidisciplinary Analysis and Optimization Conference*, AIAA Paper 2007-968, Portsmouth, Virginia, 6-8 September 2006.

[5] Trépanier, J.I., Lépine, J. and Pépin, F., “An Optimized Geometric Representation for Wing Profile using NURBS,” *CASI Journal*, Vol. 46(1), pp. 12–19, 2000.

[6] Liebeck, R. H., “Design of the Blended Wing Body Sunsonic Transport,” *Journal of Aircraft*, Vol. 41, No. 1, January-February 2004.

[7] Qin, N., Vavalle, A., Le Moigne, A., Laban, M., Hackett, K. and Weinerfelt, P., “Aerodynamic considerations of blended wing body aircraft,” *Progress in Aerospace Sciences*, Vol. 40, pp. 321–343, 2004.

[8] Morris, A., “MOB: A European Distributed Multi-Disciplinary Design and Optimization Project,” *Proceedings of 9th AIAA Symposium on Multidisciplinary Analysis and Optimization*

, AIAA Paper 2002-5444, Atlanta, Georgia, 4-6 September 2002.

[9] Horstmann, K. H., "Ein Mehrfach-Traglinienverfahren und seine Verwendung für Entwurf und Nachrechnung nichtplanarer Flügelanordnungen"*PhD Thesis DFVLR FB 87-51*, 1987.

[10] Straathof, M. H. and van Tooren, M. J. L., "Development and Implementation of a Novel Parametrization Technique for Multidisciplinary Design Initialization," *Proceedings of 51st AIAA Structures, Structural Dynamics, and Material Conference*, AIAA Paper 2010-3004, Orlando, Florida, 12-15 April 2010.

[11] Nagel, B., Rode, M., and Monner, H., "An alternative procedure for FE-wing modelling," *DGLR*, , No. 048, 2006.

[12] Ciampa, P. D., Nagel, B. and van Tooren, M. J. L., "Global Local Optimization of Transportation Aircraft Wings," *Proceedings of 51st AIAA Structures, Structural Dynamics, and Material Conference*, AIAA Paper 2010-3098, Orlando, Florida, 12-15 April 2010.

[13] Cork, T., "Design of Aircraft," *Pearson Education, Inc.*, New Jersey 07458, 2003.

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