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A PARALLEL AEROSTRUCTURAL SHAPE OPTIMIZATION PLATFORM FOR AIRPLANE WINGS

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Abstract. A parallel design platform is developed for aerostructural shape optimization of airplane wings. The developed tools consist of a panel method-based aerodynamic solver, a finite element-based structural solver, geometry and mesh generation modules and a parallel genetic algorithm optimizer, with emphasis given to automation and fast solutions.

1 INTRODUCTION

Aerostructural shape optimization of airplane wings is a multi-disciplinary optimization problem which requires the solution of aerodynamic and structural problems to meet an objective defined as a function of weighted sum of parameters such as drag to lift ratio and weight, subjected to constraints including structural yield stress and geometrical sizing limits to design lightweight and aerodynamically efficient wings. The problem is multi-disciplinary since it requires the design of both the aerodynamic shape (outer surface) of the wing and a structural wingbox (structural components such as spars and ribs) of the wing, which can safely carry aerodynamic loads. An aerostructural shape optimization platform can be a very useful tool for designers, if the aerodynamic and structural solvers are coupled with a parametric automated solid modeler and a mesh generator. The complexity of the problem increases with high memory and computational cost requirements associated with obtaining optimum solutions, hence searching for parallelized solutions becomes almost a must.

In this study, we present an aerostructural shape optimization solver which has been developed to address most of these issues. The key objective of the methodology presented here involves an automated and parametric solid modeler (CADeda) based on a coupled

NURBS-Class Shape Transformation (CST) method, a mesh generator (MESHeda) integrated with a 3D compressible boundary layer solver coupled with panel flow solver PANELeda for including viscous effects, a 3D parallel FEM structure solver SAPeda [1] and a parallel genetic optimization solver, which are EDA Limited's proprietary software modules of CAEeda [2].

2 METHODOLOGY

Our multidisciplinary optimization cycle starts with creation of an airfoil geometry with Kulfan parameterization method (CST)[3] coupled with NURBS (Non-Uniform Rational B-Spline) curve, followed by creation of a 3D wing geometry (Figure 1). This wing geometry can be considered as an initial shape for mesh automation system. The generated 3D wing can directly be used to generate the panel solver mesh,the initial structural wingbox is created at the same time to generate the structural solver mesh. A special 2-level offset method developed here is applied to the ribs of the airfoil geometry in order to create empty zones in the wingbox as seen in Figure 2, to reduce the weight of the wing before the meshing process. Therefore, there are two different meshes, one for the compressible aerodynamic panel solver and another for the structural solver. Data sharing between the overlapped structural and flow meshes is handled by our code-coupling interface utility SINeda [4].

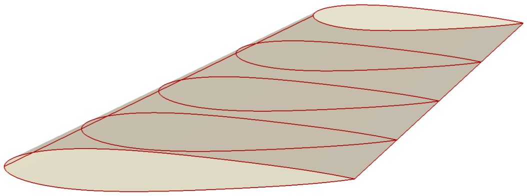

Figure 1: 3D wing geometry generated from parameters

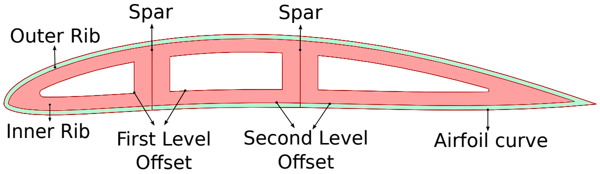

Figure 2: Generated offset rib geometry for mesh automation

For panel solver, a structured surface shell mesh is generated on the wing. In the generated 3D wing model, the upper and lower sections have four edges, which are essential for a structured shell mesh. For the structural solver, initial sizes of the spars and ribs forming the wingbox inside the wing geometry are created on a chosen topology with unstructured shell mesh. The surface and wingbox geometries and the corresponding meshes are automatically regenerated during the optimization process, which is the key novelty of the present study.

In the present study, genetic algorithms are utilized for optimization. To generate external and internal shape of wing, 13 design parameters are used, 8 of these are mathematical Kulfan parameters, which indirectly correspond to the physical airfoil shape parameters such as chord, thickness, etc. and other 5 define sizes of spars and ribs. All parameters encoded as floating point in chromosomes, which have their own upper and lower limits. Genetic algorithm evolves repeatedly generated design candidates using mutation, crossover and selection throughout the whole design process. Initial population is created from random individuals and at each generation, high fit individuals are selected for crossover and mutation operations to transfer their lineage to the next generation. The fitness value of the optimized wing is selected as minimization of (C_d/C_l) and weight of wing, where C_l is lift coefficient and C_d is drag coefficient. The wing's failure limit (material yield stress) is added as a constraint. This constraint is added as a penalty in fitness value to get only strong individuals survive through generations.

The optimization method adopted may be summarized as follows:

i) **Parametric geometry creation using CST+NURBS:**
General CST method defines an airfoil with the mathematical expressions that includes both class and shape functions as it is shown in Equation 1

$$\zeta(\psi) = C(\psi)S(\psi) \tag{1}$$

where $\psi = x/c$ as non-dimensional chord length, $C(\psi)$ is the class function and $S(\psi)$ is the shape function:

$$C(\psi) = \sqrt{\psi}(1-\psi), \quad S(\psi) = \sum_{i=0}^{n} P_i B_{i,n}(\psi) \tag{2}$$

in which $\sqrt{\psi}$ is the term for providing a round nose, $(1-\psi)$ is the term for insuring a sharp trailing edge and P_i is the i^{th} parameter. B is the Bernstein polynomial and n is the degree of the Bernstein polynomial term. Parameters size also affects to the Bernstein polynomial as,

$$B_{i,n} = \binom{n}{i}\psi^i(1-\psi)^{n-i} \tag{3}$$

where $\binom{n}{i} = \frac{n!}{i!(n-1)!}$ and $i = 0, 1, ..., n$ which is used to define $P_i|_0^n$, parameter list.

Generated points of CST airfoil are used to create NURBS (Non-Uniform Rational B-Spline) curve, since NURBS method offers great flexibility in the shape modeling. NURBS curve function is defined,

$$C(u) = \sum_{i=1}^{k} w_i H_i N_{i,n} \Big/ \sum_{i=1}^{k} w_i N_{i,n} \tag{4}$$

where k stands for the number of control points, H_i represent the homogeneous coordinates of the 3D control points, w_i are the corresponding weights and $N_{i,n}$ is the i^{th} B-Spline basis function.

In order to generate a 3D wing geometry, parametrically-created airfoil is lofted from base to tip. Then it is given as an input to the both flow and structural mesh generators.

ii) **Mesh generation:**

For flow, a structural mesh consisting of rectangular elements is constructed automatically on surface of the wings, as shown in Figure 3.

For structure, a triangular mesh constructed automatically on surface, spar and ribs of the wing, which can be seen in Figure 4.

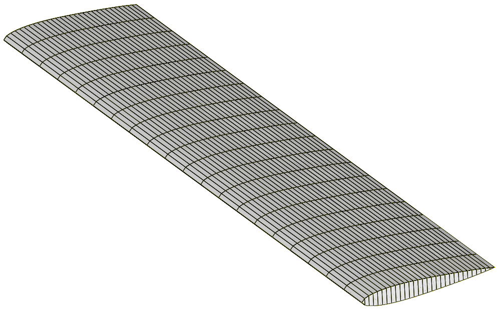

Figure 3: Flow mesh

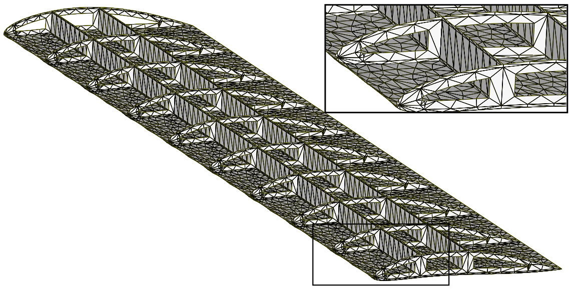

Figure 4: Structure mesh

iii) **Optimization:**

Objective function:

$$f_{\text{objective}} = w_1 \frac{D}{L} + w_2 W \tag{5}$$

Where D is drag, L is lift, W is wing weight, and w_1 and w_2 are weight factors of objectives.

Optimization is subjected to following constraints:

(a) Flow analysis around the wing: $\mathbf{AQ} = \mathbf{R}$ where $\mathbf{A}$ is the flow matrix, $\mathbf{Q}$ is the vector of flow variables, $\mathbf{R}$ is the residual vector.

(b) Transfer of aerodynamic loads to structure (Figure 5).

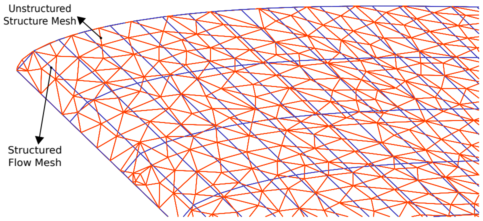

Figure 5: Interaction of flow and structure meshes

(c) Structural analysis of the wing: $\mathbf{KU} = \mathbf{F}$, where $\mathbf{U}$ is the vector displacements and $\mathbf{F}$ is the force vector.

(d) Upper and lower limit constraints for i^{th} geometrical parameter g_i:
$g_i^{min} < g_i < g_i^{max}$

(e) Upper limit for von-Mises stress σ_{vm}:
$sigma_{vm}^{max} < sigma_{vm}^{yield}$

Optimization method is a Parallel Genetic Algorithm (PGA) with steps:

(a) Population initialization with random parameters.
(b) Calculate fitness of individuals on parallel processors (See Figure 7)
(c) If stopping criteria is satisfied, then terminate genetic search process.
(d) Selection operator is applied to parents and crossover operator produces children from these parents. Then mutation operator is applied to the children.
(e) Elitist replacement is applied for taking elite parents to the next generation.
(f) Repeat with the step (b) until convergence.

More details are given in Figure 6. An earlier application is in [5].

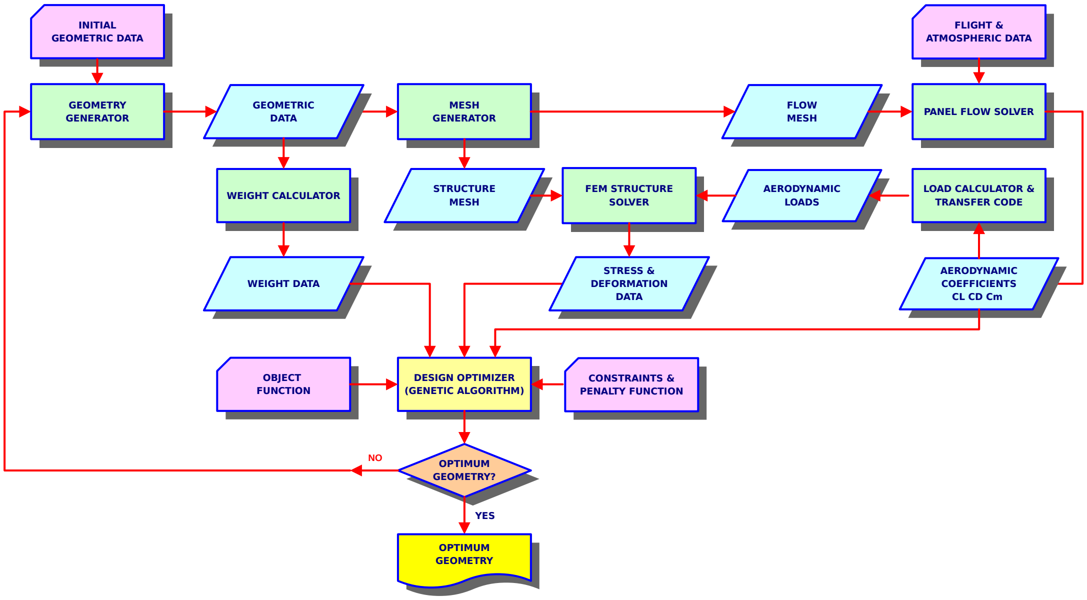

Figure 6: Modules of the developed aerostructural shape optimization solver

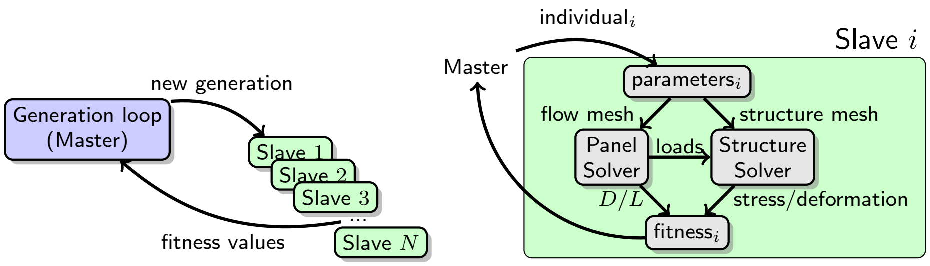

Figure 7: The master-worker paradigm for parallel genetic algorithm

3 CONCLUSIONS

In this study, an automated aerostructural shape optimization platform consisting of a parametric CAD system, a mesh generator, flow and structure solvers together with a design optimizer developed for airplane wings is presented. Automation is achieved through a CAD system that utilizes a Kulfan parametrization method with NURBS. A parallelized genetic algorithm is implemented for obtaining faster solutions. More details of the parallelization will be provided at the time of the conference.

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