Topology Optimization of the Interior Structure of Blades with Optimized

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Abstract

For any given geometry of blade-type structure with desired outer-surface shape that may be determined by a CFD software for desired performance for thermal and fluid flows, a three-dimensional solid of the blade is converted into a CAD file. An optimization process is then designed to produce optimal interior structure of the blade that follows the proposed step-by-step procedure, considering both the pressure on the outer surface and centrifugal forces produced by the rotational movements of the blade. The optimized blade will be hollow with minimum materials needed to take the pressure loading on the outer skin of the blade and the centrifugal force. 3D printers were used to produce the optimized blades.

Keywords: Optimization procedure, FEM, engine blade, topology optimization, hollow blade, centrifugal force

Optimization procedure

The proposed optimization process to produce optimal interior structure of the blade follows the following step-by-step procedure.

Step 1: Read in the CAD file of the solid blade into a finite element method (FEM) software package with standard meshing and topology design capability (such as ABAQUS® that is commercially available). A typical blade generated in this step is shown in Figure 1.

Step 2: Designate a non-design space for the blade, which is a very thin skin of the surface of the solid blade. The blade tip may not have a skin, if so desired.

Step 3: Designate the interior part (solid blade excluded the thin skin) as the design space for the topology optimization.

Step 4: Create FEM elements for both the non-design and design spaces of the blade solid (see, Figure 2)

Step 5: Assign material properties to all FEM elements for this blade.

Step 6: Specify the boundary conditions on the blade base.

Step 7: Apply loads on the blade surface, including the pressure from the CFD solution when determining the outer surface of the blade.

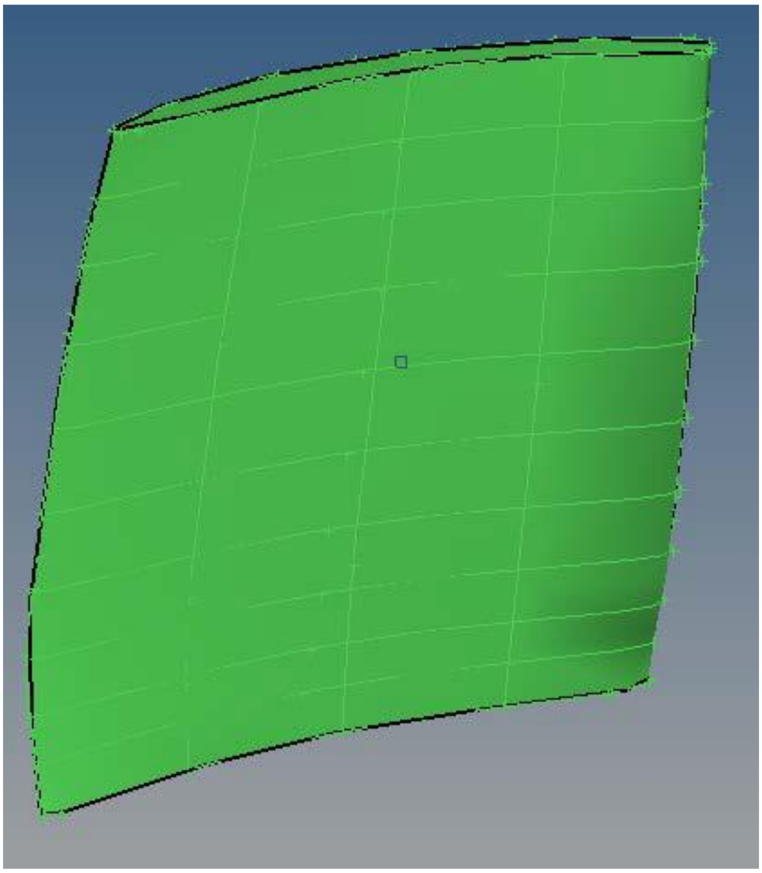

Figure 1 Geometry of a typical solid blade with outer surface determined by a CFD solver for desired performance for thermal and fluid flows under cruise conditions.

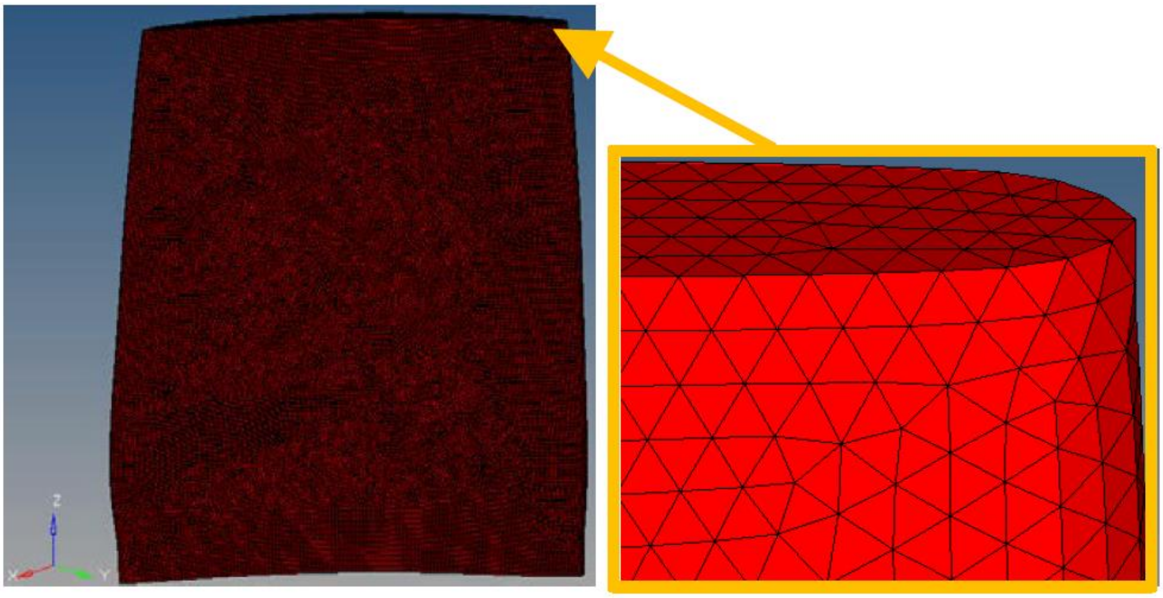

Figure 2 A typical finite element mesh for the solid blade. Left: fine mesh with dense tetrahedral elements; right: a zoomed in view

Step 8: Apply centrifugal loading for any given rotation of speed that the blade experiences at a steady state operational cruise condition.

Step 9: Set topology constraints, including limiting the stress below the material yield stress with a proper safety factor, frequency constraints, and life cycle constraints.

Step 10: Set topology optimization goal, such as aiming to create the stiffest possible structure.

Step 11: Run optimization using the standard FEM package to generate the optimized topological structure that is partially hollow, and satisfy all the design condition imposed. Figure 3 shows such a topologically optimized hollow blade

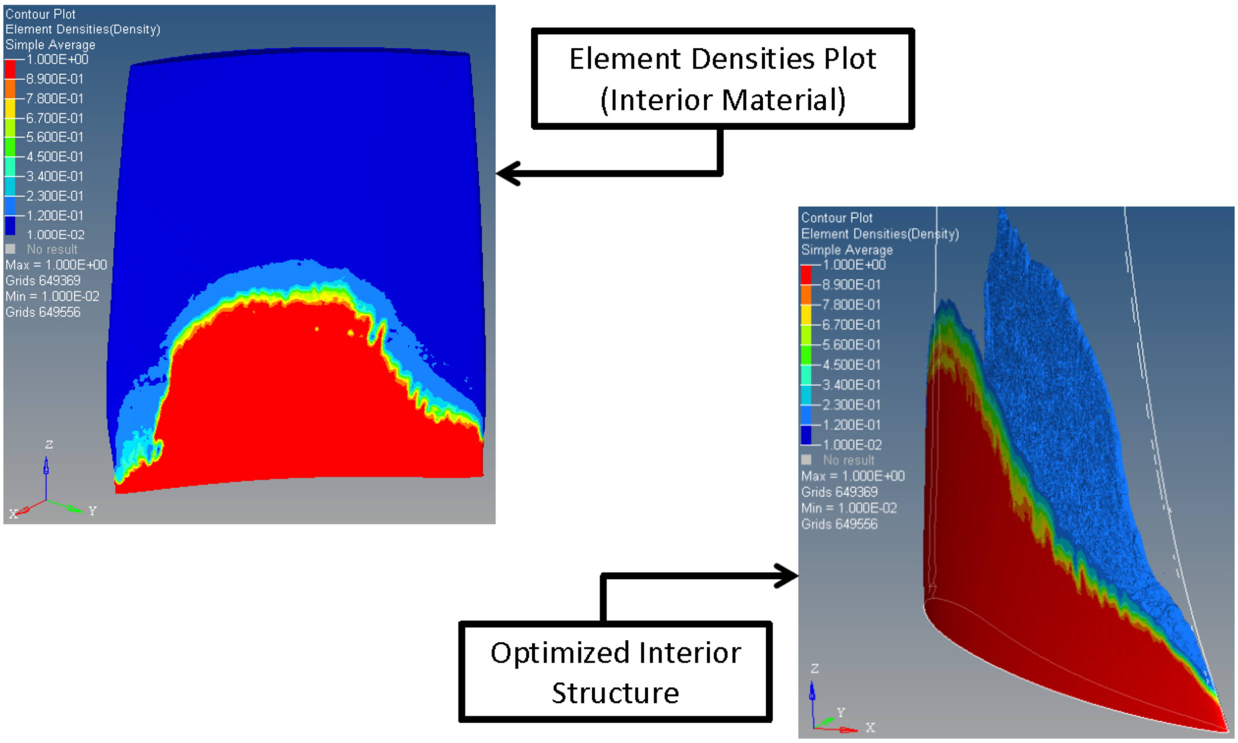

Figure 3 Topologically optimized hollow blade. The non-design space of the thin skin remains to achieve the desired performance of the blade considering thermal and fluid flow conditions. The design space of the interior solids is partially removed with materials only on the front and back surfaces of the blade near the base.

Step 12: Produce the topologically optimized blade using 3D printers.

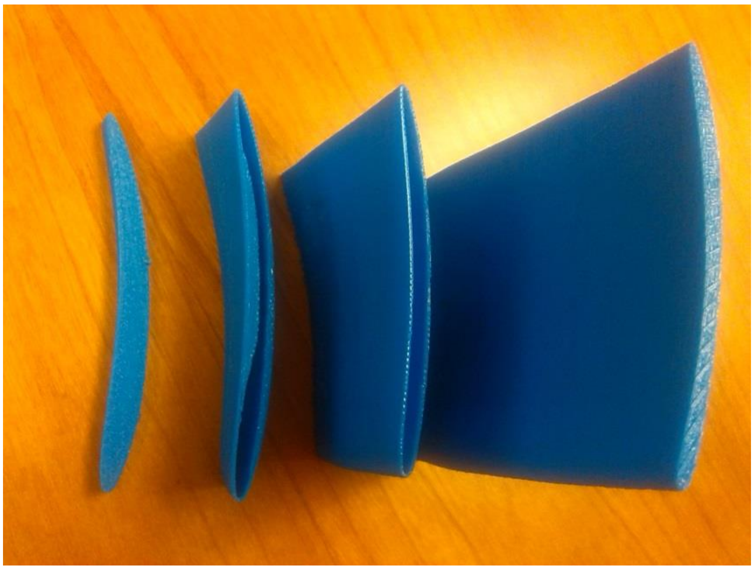

Figure 3 Topologically optimized hollow blade printed using 3D printer.

Conclusions

A topology optimization procedure has been developed using a commercially available FEM software package such ABAQUS® or any other FEM codes. For one particular example of an engine blade, the outcome of the weight reduction was 60-65%, and the max stress reduced by as much as 70%. The blade design was printed using 3D printers, and proven practical for topology optimal design for rotating structures for optimal performance with minimum weight.

References

[1] Liu GR & Quek SS, ***Finite element method****–a practical course*, Elsevier, UK, 2nd Edition, 2013.

[2] Liu GR, ***Meshfree Methods****: Moving Beyond the Finite Element Method*. CRC Press: Boca Raton, USA, 2nd Edition, 2009. (CRC bestseller).

[3] Jiang, C, Han, X, Liu, GR, et al. (2008). A nonlinear interval number programming method for uncertain **optimization** problems. *Eur J Oper Res*, *188*(1), 1-13.

[4] Tong, W. H., Jiang, J. S., & Liu, G. R. (2000). Solution existence of the **optimization** problem of truss structures with frequency constraints. *Int J Solids Struct*, *37*(30), 4043.

[5] Tong, WH, & Liu, GR (2001), An **optimization** procedure for truss structures with discrete design variables and dynamic constraints. *Comput Struct*, *79*(2), 155-162.

[6] Zheng, H, Cai, C, Pau, GSH., & Liu, GR (2005). Minimizing vibration response of cylindrical shells through layout **optimization** of passive constrained layer damping treatments. *Journal of Sound and Vibration*, *279*(3-5), 739-756.

[7] Jiang, C, Han, X, & Liu, GR (2007). **Optimization** of structures with uncertain constraints based on convex model and satisfaction degree of interval. *Comput Method Appl Mech Eng*, *196*(49-52), 4791-4800.

[8] J Yao, GR Liu, et. al. (2012), Immersed smoothed finite element method for fluid–structure interaction (**FSI**) simulation of aortic valves. *Comput Mech*, 50(6), 789-804.

[9] ABAQUS® user manuals.