Adjoint based design optimization of a U-bend for minimized pressure losses

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The aim of this paper is to reduce the pressure losses of a u-bend passage of a serpentine cooling channel of a turbine blade. A steady state Reynolds Average density based Navier-Stokes solver is used to predict the pressure losses at a Reynolds number of 40,000. The u-bend shape is parameterized using trivariate BSplines defining directly the volume of the internal passage. The deformations of the shape are controlled by the external control points of the BSpline volume, while the internal control points are repositioned using an elliptic smoothing algorithm to ensure a smooth and regular internal representation of the shape. The sensitivities of the control points with respect to the objective function are computed using a hand-derived adjoint solver and a backward differentiated geometry generation system.

I. Introduction

INTERNAL cooling channels of turbine blades are essential to enable high firing temperatures, and hence high efficiencies. They are characterized by multiple passages of relatively cool air through serpentine ducts. Among the salient features of these cooling passages, the U-bends that connect consecutive passages play a key role by turning the flow 180 degrees while still cooling the outer structure. The aim of this paper is to reduce the pressure loss associated to the flow turning by optimizing the shape of the bend. The U-bend under study is one which has been investigated experimentally at the von Karman Institute for Fluid Dynamics[1,2].

II. Parameterisation

A novel parametrization method has been developed to directly deform the internal volume of the U-Bend. The most classical approach in CAD to define shapes is through a boundary representation method, in which the shape is modeled by its skin using trimmed NURBS surfaces. This method is widely used in different commercial CAD packages and is the standard method adopted in industry to design and optimize shapes. When this representation of the geometry is used to perform further analyses, e.g. CFD computations, a volume grind needs to be generated based on the boundary definition of this CAD model. This process requires to generate internal grid points without a proper description from the CAD model of the volume surrounding the boundary.

In the present work, we use a volume representation of the shape by using trivariate BSplines. This has as advantage that the internal volume points are defined by a unique set *(u,v,w)* of local coordinates, which can be transformed to the Euclidian space. This simplifies significantly the mesh generation of the volume, as now a regular rectangular grid in *(u,v,w)*-space can be transformed to the *(x,y,z)*-space. Figure 1 illustrates the relationship between the *(u,v,w)*-space and the *(x,y,z)*-space, demonstrating that this relationship is controlled by the 3 dimensional net of control points. The position of the control points defining the external skin of the volume are design parameters during the optimization, while the internal control points are repositioned following a design change by an elliptic smoothing algorithm, hence guaranteeing a sufficient level of grid regularity.

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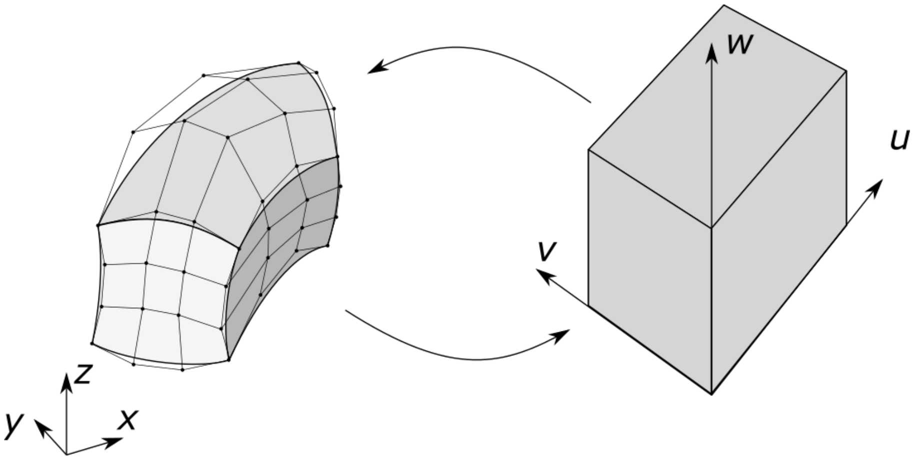

Figure 1. Relationship between the (u,v,w) space and the (x,y,z) space.

III. Results

As a first step a 2D optimization has been performed using bivariate Basis Splines. In Fig. 2 the resulting shape from the optimization is compared with the original shape. A 53% reduction in entropy increase has been achieved.

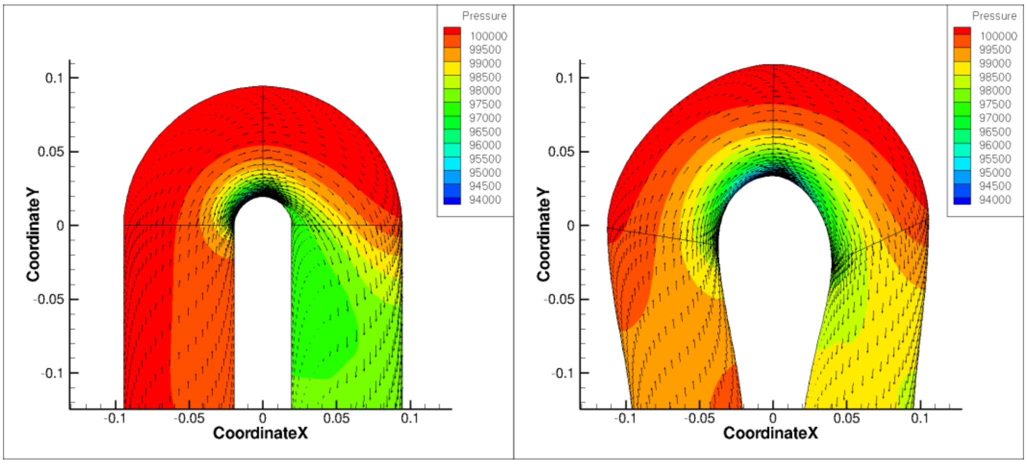

Figure 2. Comparison of original (left) and optimized (right) shape of the u-bend.

Acknowledgements

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References

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[2]F. Coletti, T. Verstraete, J. Bulle, T.V. der Wielen, N. van den Berge, and T. Arts. Optimization of a U-Bend for Minimal Pressure Loss in Internal Cooling Channels - Part II: Experimental validation. ASME Journal of engineering for Gas Turbines and Power, 135:pp 051016, 2013.