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Optimization of Gas Turbine Blades Under Manufacturing Uncertainties

Student researcher: Sunkalp Gupta, Junior

Understanding the lift and drag forces of a shape in a specific flow is important because it aids in designing better machines for optimal performance in a fluid medium. Turbine blade geometries may differ from nominal designs due to manufacturing imperfections, operational uncertainties, and natural wear and tear. Designing blades that are robust to these geometries will positively impact the reliability of turbine engines.

The research objective is to quantify the effect of geometric uncertainties due to manufacturing imperfections on the drag and lift force on turbine blades without the use of the more expensive computational fluid dynamics (CFD) software. To accomplish this, the first task was quantification of geometric uncertainties. We parameterized the blade geometry using a signed distance measure. Our hypothesis is that geometric uncertainties can be characterized by random perturbations of this signed distance measure. Using point in polygon technique, the position of the center of the pixel was found in reference to the geometry. Then, using signed distance measure, the pixels were color-coded as follows: blue–inside the boundary, black–on the boundary, and transition from blue to red with increasing distance from the boundary, as shown in the figure.

The second task was propagation of geometric uncertainties through CFD to calculate drag and lift. However, since CFD calculations are too expensive for this approach to be feasible, we decided to use surrogates based on deep neural networks, which are foundations of machine learning that enable the computer to perform tasks by analyzing training data. Neural networks were utilized for this research as they are ideal for image-like inputs and can automatically discover ways to reduce the dimensionality of the problem.

At this stage, additional work is needed to establish the convoluted deep neural network that takes the color-coded data and outputs the lift and the drag forces for the geometry. Furthermore, to make the neural network accurate it is necessary to train the network by means of large amounts of data, which can be generated through the process of data augmentation.

The overarching goal of the research is to improve efficiency of gas turbines through quantification of geometric uncertainties arising from manufacturing imperfections. Neural networks provide a cheaper and alternative way to study the effects of turbine blade imperfections on lift and drag forces, which directly impact the turbine efficiency.

Research advisor Ilias Bilionis writes: "Sunkalp's research set the foundations for propagating inherently high-dimensional geometric uncertainties through expensive simulations. By modeling geometric uncertainties using probability measures on the space of signed distance measures, we will be able to define an algebra quantifying the uncertainty induced by each step of a complicated manufacturing process."

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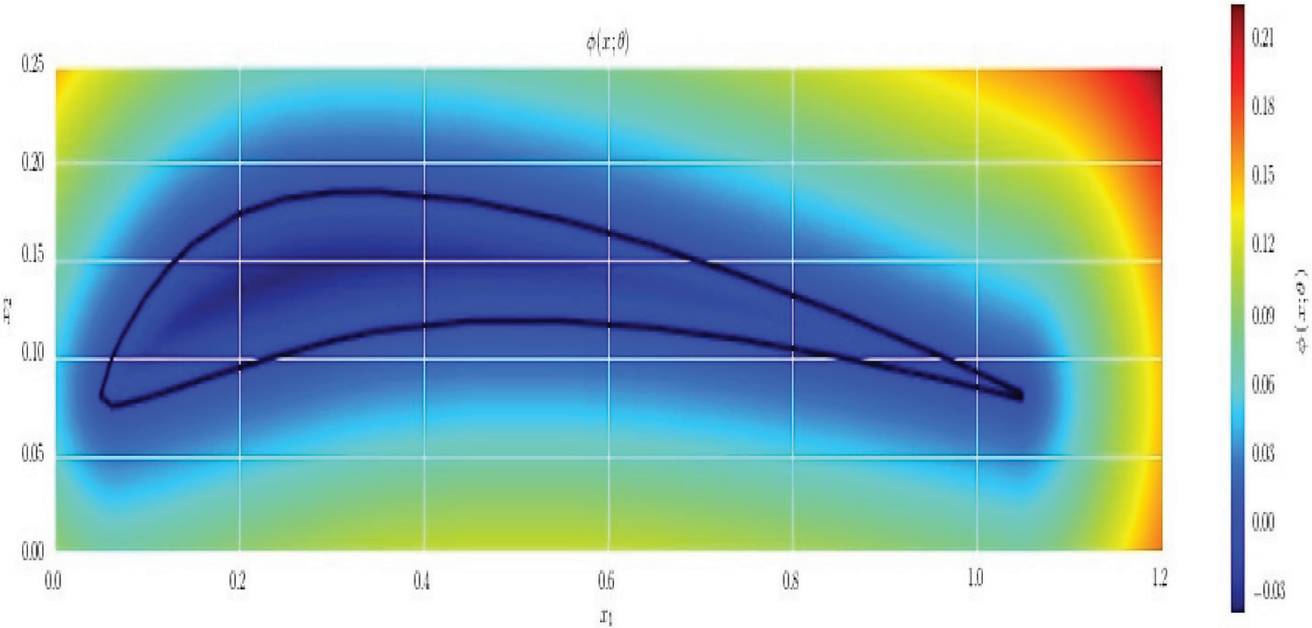

Variation in color with respect to their position relative to the foil geometry.

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