Power System Technology
ISSN:1000-3673

Received: 31-10-2024 *Revised: 14-11-2024* *Accepted: 03-12-2024*

Prediction of Flow Variables over a Serrated Double Delta Wing Aircraft using Neural Network model

A. Anand M Raikar[*], B. N Chikkanna [†], C. S K Maharana [‡]

[*†]Dept. of Aerospace Engineering, Visvesvaraya Technological University, CPGS, Muddenahalli, Chikkabalapura-562101

[‡]Dept. of Aerospace Engineering, MSRUAS, Bangalore, India

Abstract

Multidisciplinary design frameworks developed for aeronautical applications require significant computational power, which increases exponentially with the use of higher fidelity tools. The goal of this paper is to construct and apply a neural network model to predict vortices from CFD simulation data for a serrated double delta wing aircraft.

The input parameters for the neural network are the wing, airfoil geometry, and flight condition. The model is built using the sequential API which allows for a linear stack of layers to be added one after another. Neural network predicted vorticity and CFD simulated result of vorticity over absolute pressure, strain rate, turbulent kinetic energy, and turbulent dissipation rate findings corresponding within 7 to 8, 3 to 4, 1 to 2 and 0.5 to 1% of each other.

Keywords: predicted, condition, parameters

1. Introduction

Zhang et al. developed a convolutional neural network (CNN) to predict the lift coefficient of differently shaped airfoils based on variable flow conditions and an objective geometry [1]. The resulting CNN shows comparable learning capabilities to a multi-layer perceptron (MLP), while exhibiting minimal constraints in geometric representation. The use of a recurrent neural network for predicting lift coefficients at high angles of attack, with special emphasis on dynamic stall identification of rotor blades at high speeds, is described by Suresh et al. [2]. Nørgaard et al. investigate the possibility of reducing wind-tunnel test times by employing a hybrid neural network optimization method [3].

Since the dawn of flight, one of our objectives has been to enhance the aerodynamic performance of flying objects. Due to their great sweep, delta wings have a flow that is significantly more three-dimensional than wings with a high aspect ratio. A leading-edge vortex system on the lee side of the wing controls the flow pattern in subsonic flow conditions. This vortex system forms at moderate angles of attack (AoAs). A unique characteristic of delta wings in this flight domain is a nonlinear increase in lift. It is known as the vortex lift component and is produced by the vortex system, which results in an increased lift [4]. Vertical flows on these wings have been enhanced using a variety of techniques. Examples include the development of several vortices (such as for double delta wings and

Received: 31-10-2024 Revised: 14-11-2024 Accepted: 03-12-2024

tandem delta wings, often known as the canard configuration), and control surfaces, it might be difficult to manage the flow on the wings when there are several vortices present.

2. Objectives

The main objective of this paper is to predict flow variables over a serrated double delta wing aircraft using a neural network model.

Predicting the relationship between vorticity and other critical aerodynamic parameters absolute pressure, strain rate, turbulent kinetic energy (TKE), and turbulent dissipation rate (ϵ)—for a serrated double delta wing aircraft using neural network. Vorticity is a measure of the rotation of fluid particles in the flow field. In the context of aircraft aerodynamics, particularly for serrated double delta wings, vorticity plays a critical role. The unique geometry of serrated double delta wings generates strong leading-edge vortices, which enhance lift. These vortices increase the low-pressure regions above the wing, thereby increasing the lift produced. Vorticity can be manipulated to control flow separation. By generating controlled vortices, the wing can delay flow separation, which usually occurs at high angles of attack and can lead to a loss of lift and an increase in drag. Serrated edges help in stabilizing these vortices, maintaining smoother airflow over the wing surface.

3. Materials And Methodology

A simplified geometric model, shown in Fig.1(a) , of a double delta aircraft has been developed using CATIA(Computer Aided Three-Dimensional Interactive Application), a CAD modelling tool. The grid is generated using the mesh generator tool of ANSYS-workbench. The grid independence tests (3 different grid sizes considered) have verified that the numerical solution is least affected (7-10% difference exists) by the numerical discretization and meshing (average numbers of mesh nodes and elements are 47597 and 266454, respectively). The dataset used in this study has been prepared from the numerical results obtained in the CFD simulation carried out using ANSYS Fluent.

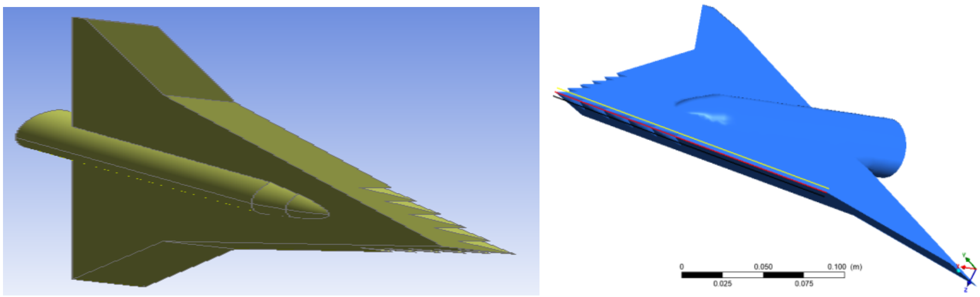


Fig.1(a) Simplified geometry of double delta aircraft

A Sequential Neural Network, used in the study shown in Fig.1(b), consists of an input layer that accepts data with a specified number of features, followed by two hidden layers with activation functions such as Rectified Linear Unit(ReLU) for non-linearity. Each hidden layer contains a set number of neurons (e.g., 64 and 32), and the final output layer produces the desired prediction, which can be a single value for regression or multiple classes for classification. The model is built sequentially, with each layer connected to the next in a straightforward, feedforward manner

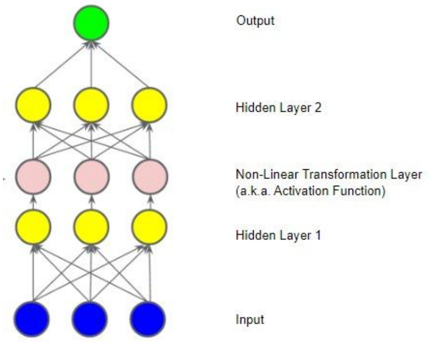


Fig. 1(b) A basic neural network model architecture

The ReLU activation function is employed across all layers. The model's performance is evaluated by computing the loss for both the training and validation datasets

4. Results And Discussion

The variables such as vorticity, absolute pressure, strain rate, turbulence kinetic energy, and turbulence dissipation rate are considered because these are fundamental parameters that govern turbulence and flow behavior, which are key to understanding complex fluid dynamics. These variables are interrelated, with vorticity and strain rate influencing turbulence and energy dissipation. Aerodynamic force and moment coefficients may not be directly predicted because they are derived quantities that depend on the complex integration of flow fields, making them harder to predict with neural networks.

Fig.2(a) shows the relation between absolute pressure and vorticity. The absolute pressure is directly related to vorticity as it affects the local rotational motion through pressure gradients.

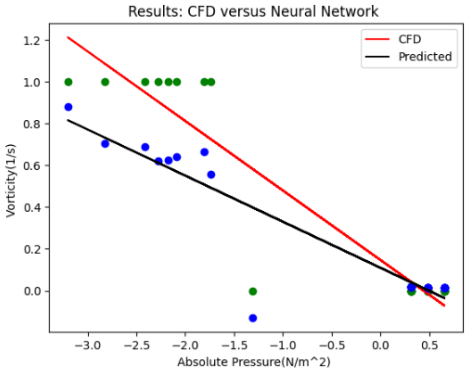


Fig.2(a) Comparison between the CFD simulated and neural network predicted data for the vorticity with respect to the absolute pressure over the serrated double delta wing, **(blue: predicted, green: actual)**

Power System Technology
ISSN:1000-3673

Received: 31-10-2024 *Revised: 14-11-2024* *Accepted: 03-12-2024*

The distribution of absolute pressure over the wing surfaces directly influences the lift and drag forces. Lower absolute pressure on the upper surface of the wing compared to the lower surface generates lift. Accurate prediction and control of this pressure distribution are essential for optimizing performance.
The model accuracy appears to be limited, as evidenced by the CFD and predicted curves in Fig. 2(a)not aligning with most data points and the presence of clear outliers. This suggests that the neural network model may need refinement to better capture the underlying flow dynamics.

Fig. 2(b) shows the relation between strain rate and vorticity. Strain rate, a measure of deformation in the fluid, influences the generation and diffusion of vortices, making it a critical input for accurate vorticity prediction.

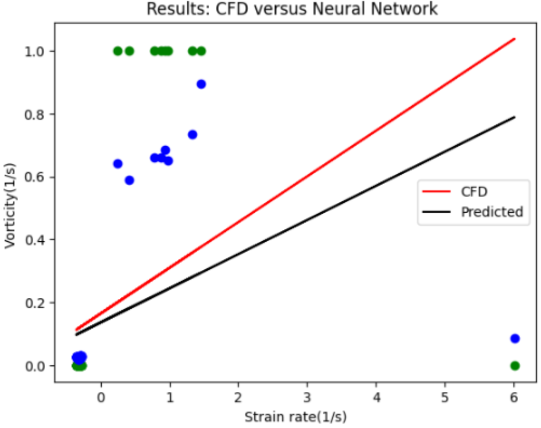
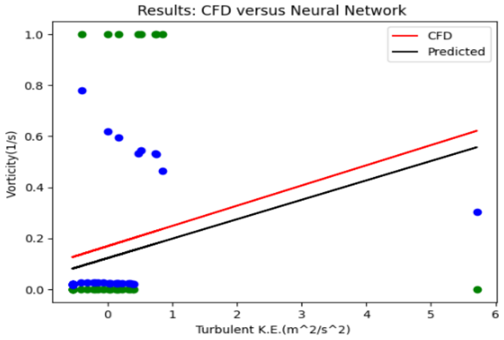


Fig. 2(b) Vorticity vs strain rate, (blue: predicted, green: actual)

For accurate vorticity prediction strain rate measurement influences the generation of diffusion of vortices. Neural network predicted vorticity and CFD simulated the result of vorticity over a strain rate range of 10 to 4000 revolutions per second findings corresponding within 1-1.5 % of each other.

Fig.3 shows the variation of vorticity and TKE.TKE is another essential parameter as it encapsulates the energy contained in turbulent eddies, directly impacting the intensity and scale of vorticity in the flow.



Power System Technology
ISSN:1000-3673

Received: 31-10-2024 *Revised: 14-11-2024* *Accepted: 03-12-2024*

Fig.3 Variation of vorticity with respect to TKE, (blue: predicted, green: actual)

In order to encapsulate the energy contained in turbulent eddies, directly impacting the intensity and scale of vorticity in the flow turbulent kinetic energy is an essential parameter. Fig.4 shows the comparison of training and validation loss computed from the code written for neural network architecture for the model.

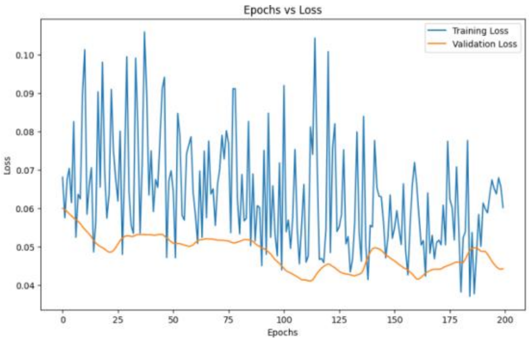


Fig.4. Comparison of training and validation loss

5. Conclusions

Using a multilayer architecture with nonlinear activation functions, the network can capture Subtle variations and correlations within the CFD-generated data. Training the model on a comprehensive dataset ensures that it generalizes well, enabling accurate predictions of vorticity under various flow conditions around the serrated double delta wing. The unique geometry of serrated double delta wings generates strong leading-edge vortices, that enhance lift. These vortices increase the low-pressure regions above the wing, thereby increasing the lift produced.

References

1. Zhang, Y., Sung, W.J., Mavris, D.N., Application of convolutional neural network to predict airfoil lift coefficient. In: 2018 AIAA/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference. American Institute of Aeronautics and Astronautics. https://doi.org/10.2514/6.2018-1903
2. Suresh, S., Omkar, S.N., Mani, V., Prakash, T.N.G.: Lift coefficient prediction at high angle of attack using recurrent neural network. Aerospace Science and Technology 7(8), 595–602 (2003). https://doi.org/10.1016/s1270- 9638(03)00053-1
3. Nørgaard, M., Jorgensen, C., Ross, J., Neural network prediction of new aircraft design coefficients." NASA TM-112197 (1997) Wind Turbine,” *ASME Journal of Fluids Engineering*, **111** (1), pp. 53-58, 1989.
4. E.C. Polhamus. 1971. Predictions of vortex-lift characteristics by a leading-edge suctionanalogy, *J. Aircraft*, 8(4), 193-199.https://doi.org/10.2514/3.44254