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Review Article

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Turbulence modeling: augmenting artificial intelligence and machine learning

Abstract

The paper presents the variables of an airfoil that has a direct impact on the movement of the airplane. The test evaluation of the impact of chaotic disturbances caused due to atmospheric or any other external conditions on the entire plane is a difficult process mainly due to the size of the airplane, so instead of testing on the entire airplane, it is divided into different parts and each part is individually calculated and the test of all the parts are put together and averaged to get the average turbulence impact on the entire plane. This paper has the results of all the different variables that directly or indirectly impact the airplane, that can cause a chaotic movement impacting the airplane movement, and its velocity based on the density and thickness.

Keywords: airplane, airfoil, atmospheric conditions, chaotic movement, artificial intelligence, machine learning, deep learning

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Introduction

Turbulence is generally defined as the motion characterized due to chaotic changes in the velocity flow and pressure, it is a sudden violent shift in the airflow. It creates the up and down current motion caused due to the atmospheric pressure which can result in the sudden jerking moment in an airplane. Turbulence modeling is an important area of performance computing and computational science.

This turbulence modeling is used in designing aircraft, turbine engine blades, automobiles, etc., to stimulate the fluid flow equations, estimating the quantities of interest like lift drag or drag on the wings of the airplane. By Direct numerical simulation, to estimate the lift and drag of each section, that section is taken individually and tested which consumes a lot of time. The RANS number, introduced by Reynolds is used to attract the velocity values for Dirichlet boundary conditions. Instead of simulating all the scales of Navier strokes equation in space and time, the turbulence modeling helps make approximations to get engineering quantities of interest more efficiently.

The turbulence can be found in several other things apart from an airplane like – Van Gough's painting, Katsushika Hokusai's painting, and Leonardo da Vinci's painting. Please see Figure 1 for multiple turbulence illustrations.

All the above paintings in Figure 1 represent different types of chaotic movements caused due to different conditions. The structure is interesting to observe mainly due to the different ways of depicting the turbulence. Turbulence is the most unpredictable phenomenon in weather. The 4 main causes of turbulence are:

i. Mechanical Turbulence – the friction between air and ground due to irregular terrain and man-made obstacles.
ii. Thermal Turbulence – Is caused due warm air rising and cold air sinking caused by surface heating.
iii. Frontal Turbulence – lifting of warm air by sloping frontal surface and friction between the two opposing air masses.
iv. Wind Shear – The change if wind direction or speed.

The Figure 2 is sourced from weather.gov[1] which depicts the type of turbulence an airplane may experience. For this dataset, the first author has used the National Aeronautics and Space Administration (NASA) Airfoil dataset from Kaggle and performed python programming to get detailed results of the turbulence modeling. The main objective of this paper is to understand the turbulence modeling and variables that contribute to the turbulence and for modeling of the date by analyzing them thoroughly, the capability and functionality of Artificial Intelligence (AI) integrated Machine Learning (ML) was augmented and results were shown below with appropriate depiction of data analytics. This data set was obtained from a series of aero dynamics and acoustic tests of 2 or 3-dimensional airfoil blade sections that were conducted in the anechoic wind tunnel using the tunnel speed and angle of attack.

Figure 1 Different types of turbulence illustration.

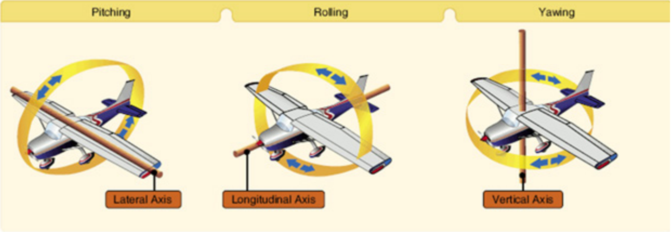


Figure 2 Research method and approach.

Literature review

The flow path generated by single-sided ventilation is driven by two main effects namely the buoyancy effect and wind effect. The effect of buoyancy alone is relatively straightforward, as it is driven by the density difference between the bottom and the top of the opening. However, the wind effect in single-sided ventilation is more difficult to analyze, as it is caused by rapid fluctuations of airspeed and direction turbulent diffusion.[2]

Three main turbulence models exist Direct Numerical Simulation (DNS), Large Eddy Simulation (LES), and Reynolds-Averaged Navier-Stokes (RANS). Only LES and RANS modeling have been selected here since DNS is still a not viable method for simulating natural ventilation with the currently available computer hardware.[2]

The turbulent stresses are linearly related to the velocity gradients found in the strain rate tensor Non-linear RANS models include non-linear terms of the strain rate for the definition of the Reynolds stresses.[3]

For the mixed convection in the fully occupied cabin, the warm thermal plumes from the heated manikins and the cool jets from the diffusers counteracted in the cabin center. The jet momentum diminished rapidly in the cabin and the flow field was rather complex. The LES had the best performance in predicting the flow, compared with the corresponding experimental data of flow and temperature fields, although the DES results were acceptable.[4]

Analysis

Figure 3 below shows the description of the data, and the type of data available in the dataset for the analysis, like frequency, angle of attack, free stream velocity, displacement thickness, and pressure level.

The Figure 4 below shows the level of frequency of the airfoil based on its density, when the density is at 0.00025 the frequency is between 0 – 5000 and the density gradually decreases with an increase in frequency.

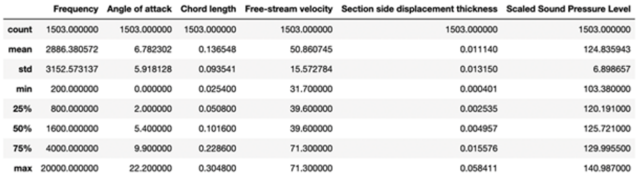
The Figure 5 below shows the angle of attack of the airfoil based on its density when the density is at 0.07 the angle of attack is low, and the angle of attack gradually increases with an increase in the density and decreases when the density decreases.

The following Figure 6 is depiction of the chord length represents the length of the airfoil,[5] as the complete length of an airplane is difficult to calculate the turbulence of the entire airplane at one time, so the testing is done in multiple intervals at different times.

As illustrated in Figure 7 below the velocity is the speed at which the airfoil is traveling in any given direction.

The Figures 8–10 are presenting the aspect of the density and frequency are indirectly proportional to each other with an increase in frequency the density increases, when the frequency is less the density is high, and when the frequency is increased the density falls and slightly fluctuates. When the density is high the angle of attack increases, when the angle of attack decreases the density gradually falls down. The chord length impacts the density, the higher the chord length the density fluctuates. The speed at which the airfoil moves in the given direction is indirectly proportional to the density.

The calculated result by this model is charted in Figure 11 as below.



	Frequency	Angle of attack	Chord length	Free-stream velocity	Section side displacement thickness	Scaled Sound Pressure Level
count	1503.000000	1503.000000	1503.000000	1503.000000	1503.000000	1503.000000
mean	2886.380572	6.782302	0.136548	50.860745	0.011140	124.835943
std	3152.573137	5.918128	0.093541	15.572784	0.013150	6.898657
min	200.000000	0.000000	0.025400	31.700000	0.000401	103.380000
25%	800.000000	2.000000	0.050800	39.600000	0.002535	120.191000
50%	1600.000000	5.400000	0.101600	39.600000	0.004957	125.721000
75%	4000.000000	9.900000	0.228600	71.300000	0.015576	129.995500
max	20000.000000	22.200000	0.304800	71.300000	0.058411	140.987000

Figure 3 Description and type of data.

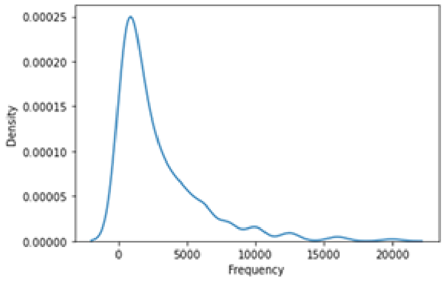


Figure 4 Frequency of the airfoil occurrence.

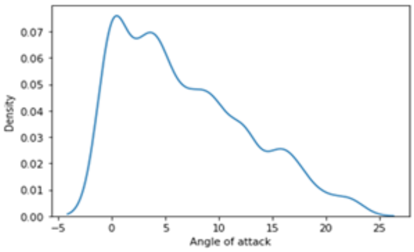


Figure 5 Angle of attack of the airfoil.

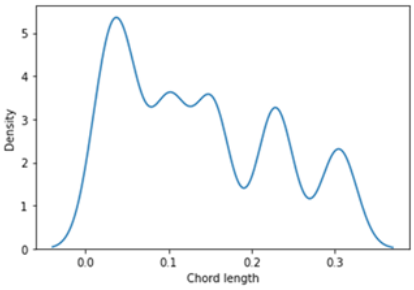


Figure 6 Chord length vs. air density.

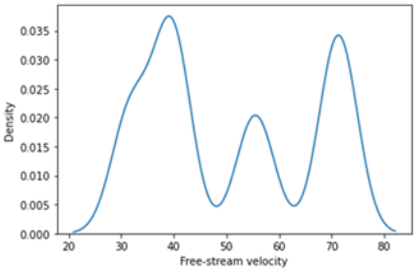


Figure 7 Free stream velocity vs. air density.

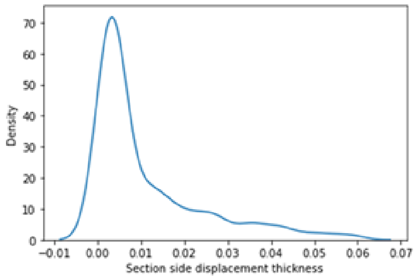


Figure 8 Density vs. section side displacement thickness.

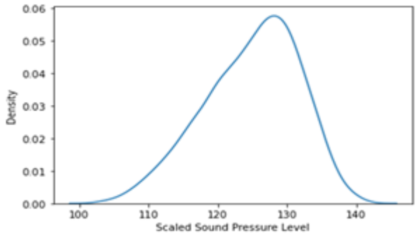


Figure 9 Density vs. scaled sound pressure level.

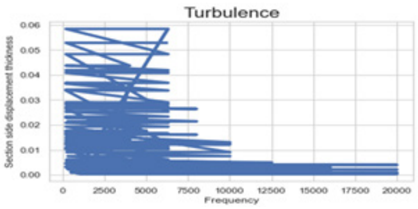


Figure 10 Section side displacement thickness vs frequency.

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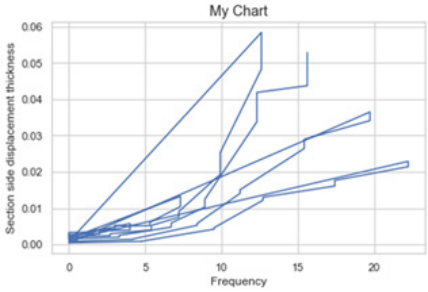

Figure 11 Section side displacement thickness vs. frequency.

The higher the velocity less is the density, the less is the velocity the higher the density. Initially, the density is higher when the thickness is low and when the thickness increases the density decreases. With the gradual increase in the pressure level, the density increases slowly at a gradual speed, and at the maximum pressure level, the density falls. The thickness of the airfoil impacts the frequency of the turbulence, resulting in chaotic movements due to external pressure.

Conclusion

As a conclusion, the higher the velocity less is the density, the less is the velocity the higher the density. Initially, the density is higher when the thickness is low and when the thickness increases the density decreases. With the gradual increase in the pressure level, the density increases slowly at a gradual speed, and at the maximum pressure level, the density falls. The thickness of the airfoil impacts the frequency of the turbulence, resulting in chaotic movements due to external pressure.

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None.

Conflicts of interest

The Authors declares that there is no Conflict of interest.

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