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# Smoke Line Geometry Impact on Airfoil Model Flow Visualization

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**ABSTRACT:** This study discusses the analysis of airflow visualization on a NACA 4412 airfoil model using a fluid mixture technique with variations in smoke line geometry. The main objectives of this study are to understand the behavior of airflow around the airfoil surface under different test conditions and methodology used involves flow simulation and experimental tests with fluid mixtures that produce flow visualization through various smoke line geometries, such as straight lines, zigzags, and curves. The test results show that variations in the shape of the smoke line produce different flow at the boundaries of the airfoil surface, which significantly affect the pressure distribution and lift coefficient. These findings provide important insights for the development of more efficient airfoil designs and the application of flow visualization techniques in aerodynamic testing.

**KEYWORDS:** Flow visualization; Liquid mixtures; Smoke line; Wind tunnel

## INTRODUCTION

Airfoil is an important component in aerodynamic design that functions to generate lift and reduce air resistance on aircraft wings, propellers, or turbine fans. One of the most studied airfoil profiles is the NACA 4412[1], which was developed by the National Advisory Committee for Aeronautics (NACA) and has stable and efficient aerodynamic performance characteristics. Understanding the airflow around this airfoil is essential to maximize efficiency and stability in aerodynamic applications.

Visualizing the airflow around an airfoil can provide deep insight into the flow patterns and aerodynamic phenomena that occur, such as flow separation, vortex rotation, and turbulence[2][3][4][5]. The flow visualization method using a mixture of fluid with smoke lines is one effective approach to showing these flow characteristics in wind tunnel tests. The use of smoke line geometry variations allows for a more in-depth analysis of the impact of different flows on the performance the NACA 4412 airfoil[6][7][8].

A flow visualization analysis was performed on a NACA 4412 airfoil model using several variations in fluid mixtures and smoke line geometry configurations. The goal is to evaluate how changes in fluid mixtures and variations in smoke line geometry affect the flow around the airfoil.

## 2. RESEARCH METHODS

### 2.1 The Test Model

The approach used to assess the airfoil involves visualizing airflow by utilizing smoke produced from a liquid mixture. The experiments were conducted on a 3D model of test. Figure 1 displays the components airfoil the NACA 4412 model[9][10].

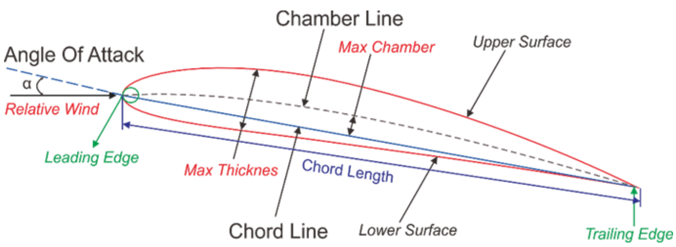



**Figure. 1. The Test Model**

The airfoil test model was built using a flexiglass structure, with its surface coated in epoxy resin. The model was created according to the geometric dimensions provided in Fig. 2. The chord length (C) is 151.52 mm, the span (S) is 300 mm, and the maximum thickness (t) is 19.18 mm.

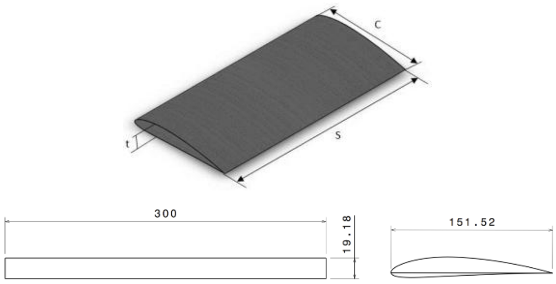
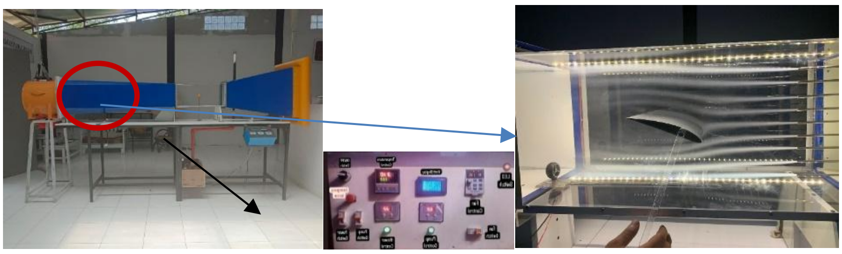



**Figure. 2. The geometry model.**

The Aerodynamics, Aeroelasticity, and Aeroacoustic Laboratory's low speed wind tunnel served as the experiment's location (see Figure. 3a). The test portion of this wind tunnel is 300 mm by 300 mm square, and its top speed is 25 m/s. The angle of attack (α) was set to 0°, 5°, 10°, 15°, and 20° during testing, while the wind speeds were set to 5 m/s, 10 m/s, 15 m/s, and 20 m/s. The fluid for the testing was a liquid mixture. The experiment was conducted again with different setups, maintaining the same ambient temperature and pressure (P = 1 atm, T = 27°C). For flow visualisation studies, a 3D model of the NACA 4412 aerofoil was placed in the test section (see Figure. 3b).[11][12]

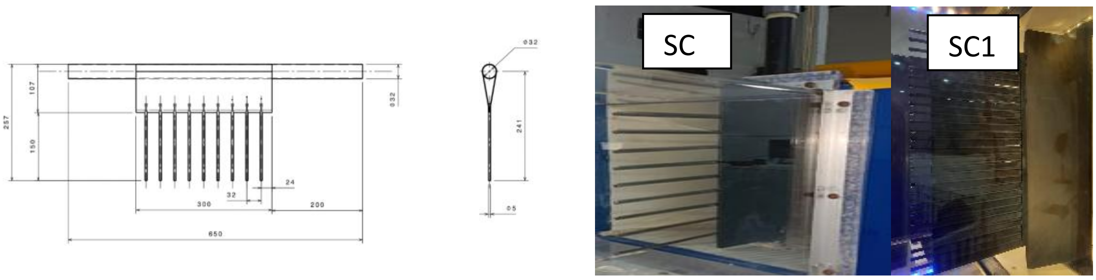


(a) Wind tunnel with smoke generator (b) Test model placement

**Figure 3. Low speed wind tunnel**

2.2 Smoke Channel

The smoke lines are illustrated in **Figure. 4**. The SC-1 system produced denser and thinner smoke lines compared to SC, with clearer visual flow patterns. SC had a 3 mm injection port, which led to a more disrupted smoke path, but the SC-1 system generated denser smoke lines and produced more consistent flow patterns (**Table 1**).




(a) Smoke channel design (b) Installed SC and SC1 smoke channel

**Figure. 4. Smoke Channel**

**Table1. Smoke channel Geometry**

| **Smoke channel** | **Smoke Line Thickness** | **Smoke Lines Number** | **The gap between smoke lines** |
|---|---|---|---|
| SC | 5.0 mm | 9 | 32 mm |
| SC1 | 3.0 mm | 28 | 10 mm |

## 3. RESEARCH RESULTS AND DISCUSSION

3.1 Research Results

The findings of the flow visualisation simulation must be verified against experimental data under the same circumstances in order to guarantee their accuracy. In this study, Gokcen Jurnal et al.'s experimental data and modelling results were compared [13][14}[15].

Additional trials were carried out at speeds of 5 m/s, 10 m/s, 15 m/s, and 20 m/s. The validation method involved comparing data at the same angle of attack and wind speed (Vo) of 10 m/s. The simulation results and experimental results using smoke-rake SC are compared in Table 2, and the comparison using smoke-rake SC-1 is shown in Table 3.

**Table 2. A comparison between the findings of Research SC and the experimental results of Gokcen Jurnal et al.**

| Gokcen J's experiment, et al. | Findings from studies conducted at 5 m/s, 10 m/s, 15 m/s, and 20 m/s with a 10° angle of attack (SC-1) |
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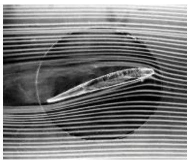
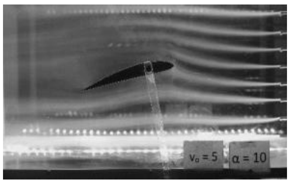
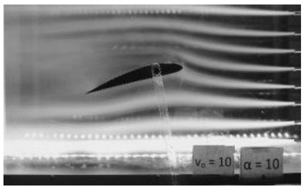
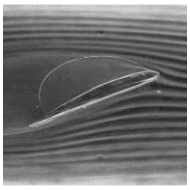
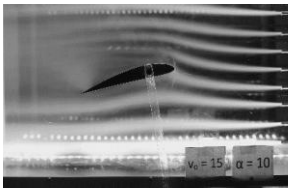
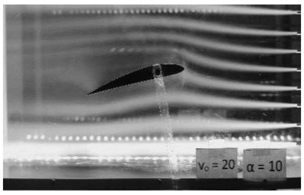
|  |     |
|  |     |

**Table 3. A comparison between the findings of Research SC-1 and the experimental results of Gokcen Jurnal et al.**

| Gokcen J's experiment, et al. | Findings from studies conducted at 5 m/s, 10 m/s, 15 m/s, and 20 m/s with a 10° angle of attack (SC-1) |
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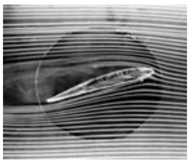
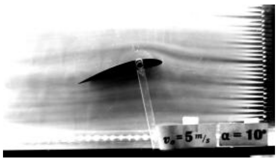
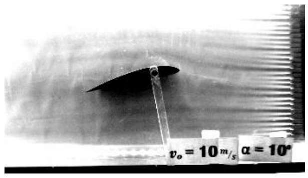
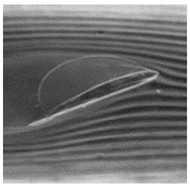
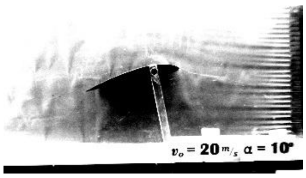
|  |     |
|  |     |

The flow from the results of flow visualization experiments on the NACA 4412 airfoil, when compared with experimental data and numerical simulations [16][17][18][19][20], is shown in Fig. 5 as follow:

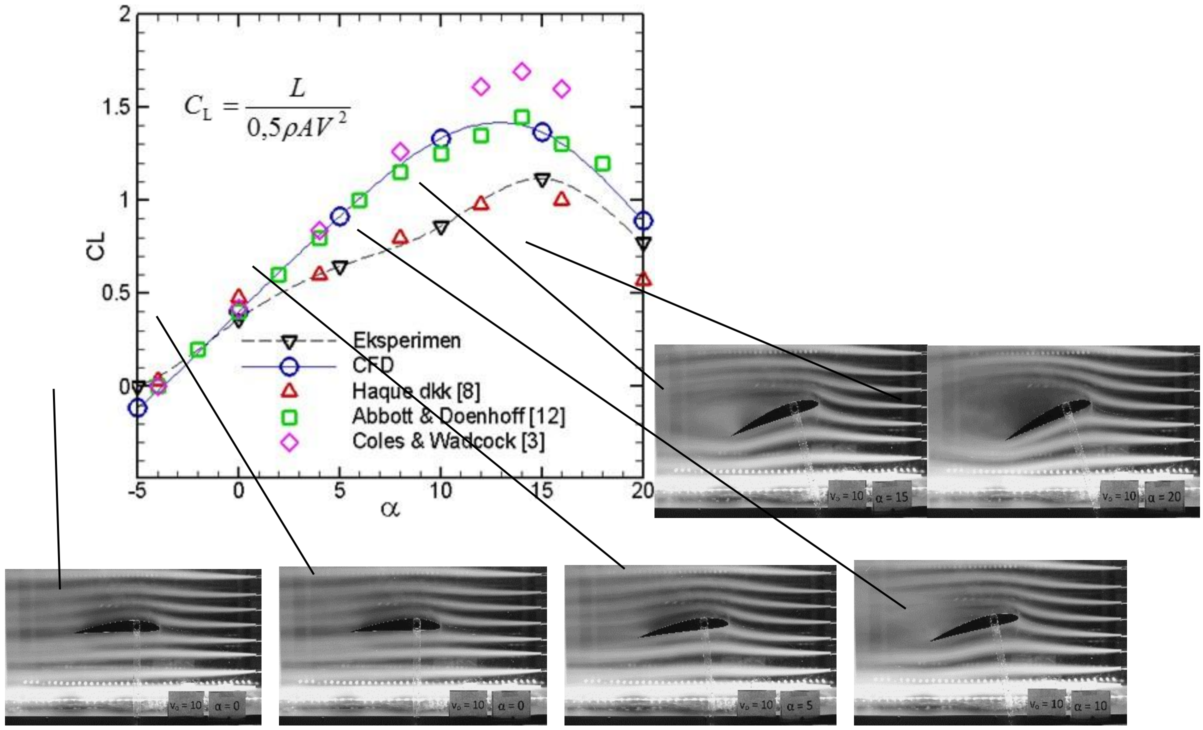



**Fig 5. Numerical experiments and Flow visualization**

## CONCLUSION AND RECOMMENDATIONS

a. Smoke Channel Design

The SC smoke rake produced thicker smoke for longer periods, while the SC-1 design generated denser smoke, making flow changes more visible.

b. Aerodynamic Flow Analysis

According to the experimental results, the NACA 4412 airfoil's aerodynamic properties at different angles of attack (α) were successfully observed at wind speeds of 5 m/s, 10 m/s, 15 m/s, and 20 m/s. The information gathered using the smoke approach is consistent with previous research. Aerodynamic characteristics, including the lift coefficient (CL) and the flow profile, were strongly impacted by changes in the angle of attack. The pressure distribution on the airfoil's upper and lower surfaces changed as the angle of attack increased.

c. Wind Speed Effects on Smoke Flow

A 75% glycerin and 25% vape fluid blend resulted in heavier smoke flows than other combinations at varying wind speeds. With wind speeds of 5 m/s, 10 m/s, 15 m/s, and 20 m/s, the smoke thickness rose.

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