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3D Printed Models vs Conventional Models: Comparison of Aerodynamic Performance for Wind Tunnel Experiments

(Cetakan Model 3D vs Model Konvensional: Perbandingan Prestasi Aerodinamik bagi Eksperimen Terowong Angin)

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ABSTRACT

Traditionally, wind tunnel models are made of metal and the processes are very expensive. Since then, many researchers have been looking for new alternatives, hence 3D printing technology is the solution. Under right test conditions, 3D printed parts could be tested in a wind tunnel to get the aerodynamic performances. By using 3D printing technology, the cost and time can be significantly reduced to produce the wind tunnel models. This investigation was done to compare the aerodynamic performances which are drag and lift forces of the existing wind tunnel metal models with 3D printed wind tunnel models. Polylactic acid (PLA) was used as the printing materials by using two 3D printers which are Poseidon X and CR-10 S5. The wind tunnel testing covered the wind speed in the range of 0.57 m/s to 10.35 m/s at angle-of-attack of 0°. Results from experiments show that the drag and lift forces of the 3D printed models show very close similarities with the metal models. It can be concluded that the wind tunnel models produced by using 3D printing technology can be used in wind tunnels for early testing.

Keywords: 3D-printing; wind tunnel; aerodynamics

ABSTRAK

Secara tradisionalnya, model bagi wind tunnel diperbuat daripada logam dan prosesnya sangat mahal. Sejak itu, banyak penyelidik mencari alternatif baru, oleh itu teknologi 3D Printing adalah penyelesaiannya. Dalam keadaan ujian yang betul, model 3D Printing dapat diuji di wind tunnel untuk mendapatkan penambahbaikkan prestasi dalam aerodinamik. Dengan menggunakan teknologi 3D Printing, kos dan masa dapat dikurangkan dengan ketara untuk menghasilkan model wind tunnel. Penyiasatan ini dilakukan untuk membandingkan prestasi aerodinamik yang merupakan daya seret dan daya angkat dari model wind tunnel yang ada dengan model wind tunnel yang dicetak menggunakan teknologi 3D Printing. Asid polilaktik (PLA) digunakan sebagai bahan percetakan dengan menggunakan dua alat 3D Printing iaitu Poseidon X dan CR-10 S5. Ujian wind tunnel meliputi kelajuan angin dalam lingkungan 0.57 m/s hingga 10.35 m/s pada sudut serangan 0°. Hasil dari eksperimen menunjukkan bahawa daya seret dan angkat model 3D Printing menunjukkan persamaan yang hamper sama dengan model logam. Ini dapat disimpulkan bahawa model wind tunnel yang dihasilkan dengan menggunakan teknologi 3D Printing dapat digunakan dalam wind tunnel untuk pengujian awal.

Kata kunci: Wind tunnel; 3D Printer

INTRODUCTION

3D printing technology has been around for over 20 years which allows the production of a physical model directly from the CAD model layer-by-layer manner. Traditional wind tunnel models are made of aluminum or steel that are produced by CNC milling which consist of 5-axis that would take weeks, probably months to produce and cost tens to hundreds of thousands of dollars (Barlow et al. 1999). Since then, researchers have been finding a new alternative to reduce the cost and time taken to produce models for wind tunnel testing. One of such techniques that can solve these problems seems to be 3D printing technology. Several studies showed that models that are produced by 3D printing can produce good results in terms of performance of aerodynamic in wind tunnel testing.

An experiment was conducted by Landrum et al. (1999) which three 30 cm by 10 cm chord airfoil models were tested in a low-speed subsonic tunnel. Two of the models are made by stereo-lithography or SLA and the other one is made by a conventional cast polyurethane. All the models were identical except for the light sanding of one of them to produce a smoother surface finish. Olasek & Wiklak (2014) performed an experiment to compare the aero-dynamics performances of standard NACA0018 airfoil by most common 3D printing methods which are Fused Deposition Modelling (FDM), Multi-Jet Modelling (MJM), and Selective Laser Sin-tering (SLS). Materials that were used for printing the models were; ABS for FDM, UV curable acrylic plastic in MJM, and nylon and alumide (blend of nylon and aluminum) in SLS.

Although 3D model has lots of benefits, a study on emissions characteristics of hazardous material during 3D printing process has been done to evaluate the hazardous agents that could be emitted into the air. Kim et al. (2015) claimed that nanoparticle size will emit a high concentration of particulate matter or gaseous regardless of cartridge type in FDM printing method. 3D printed model and steel model as wind tunnel testing models were being compared by Widden & Gunn (2006). In this experiment, two models were evaluated where the first model is made of Steel 17-4PH H900 by CNC machining technique and the model had the same CAD section but was produced by 3D printing method, fused deposition method (FDM) by using ABS as the filament. From this research, there is an acceptable agreement of aerodynamic performances between the metal model and the 3D printed model. Widden & Gunn (2011) performed design-build-test of model airfoils for engineering education using FDM, conducted a practical project for first-year Engineering students at Lancaster University to design, build and test model airfoils that is from 3D printing by using ABS as the filament.

Moon et al. (2014) conducted an experiment to test which lattice design has the optimal elastic performance for deployable Unmanned Aerial Vehicles (UAV) for 3D printing. The proposed lattice designs were hexagonal diamond structure, 3D pyramidal structure, and 3D Kagome structure. From this experiment, 3D Kagome has the highest load capacity. More studies tested in subsonic wind tunnel by using FDM 3D printing to fabricate the model such as airfoil, wing, and fuselage (Baljit et al. 2018; Said et al. 2020; Jumahadi et al. 2017; Sidhu et al. 2016). From the previous studies, it is proven that wind tunnel models made from 3D printing technology are reliable for wind tunnel test-ing. Therefore, this investigation is intended to further compare the aerodynamic characteristics in terms of lift and drag coefficients, specifically for the subsonic wind tunnel in Universiti Pertahanan Nasional Malaysia (UPNM) together with the force-balance setup.

METHODOLOGY

All the wind tunnel models were designed by using 3D computer-aided design (CAD) software, SOLIDWORKS according to the existing models' measurements. The diameter, height, angle, and length of the streamlined model were measured by using Vernier caliper and ruler. To construct the airfoils NACA 0012-40 and NACA 0012-60, the actual coordinates of the airfoils were plotted and constructed in SOLIDWORKS. Figure 1 shows the images of the CAD of the wind tunnel drag models.

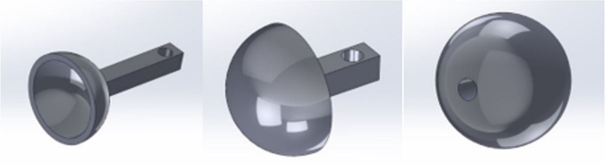

FIGURE 1. CAD model of wind tunnel drag models (from left to right; concave, convex and sphere)

Additional parts were required to be added to the models. For concave and convex models, an extension part with a hole were added to the models to make it similar to the metal model as shown in Figure 2 to enable the rods to be connected to the models. The length of these extensions is the same with the existing convex and concave models. Both extensions have the same hole diameter which is 7 mm with 2 mm of wall thickness. To connect the rod with the cylinder model, a connector is needed. This connector has an L-shape. The length of this connector is also designed based on the rod that is being mounted behind the existing cylinder model.

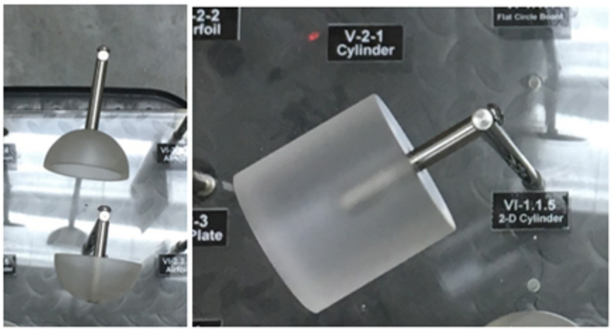

FIGURE 2. Concave and convex model (left) and cylinder model (right)

Two 3D printers were used to produce these models are shown in Figure 3. The first one is Poseidon X, which is the newest model of 3D printer by Designx3D. It uses the standard thermoplastic extrusion. Poseidon X comes with an LCD screen control panel with jog-dial that allows users to control directly the printer functionalities. It also has an SD card reader which is easier to operate than using the cable as the printer can be placed anywhere even far away than the computer. The printing material used was PLA plastic.

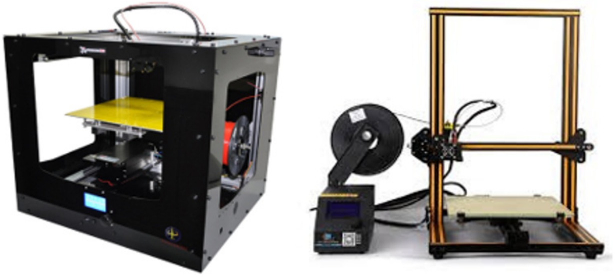

FIGURE 3. 3D printer used to print the wind tunnel models/ Poseidon X (left) and Creality CR10-S4 (right)

After all the models had been printed, some of the models need to undergo post processing finishing. This is because, the 3D printed models need to have the same smooth surface as the existing models as the 3D printed models have rough surface after being printed. This might affect the testing result as they have different surface roughness.

All the 3D printed models had been sanded to achieve smooth surface. There are three different roughness of sandpapers that were used; P150, 600CW, and P1200. Some of the models need to add filling material as they had uneven surface before being sanding to achieve smooth surface. All the 3D printed wind tunnel models were tested using a LW-9300 wind tunnel. LW-9300 is an open-loop type wind tunnel structure with a test section measuring 30cm (W) x 30cm (W) x 100cm (L) with a uniformity of wind flow more than 92% and a turbulence intensity less than 0.5%. The models were tested with the wind speed ranging from 0.57 m/s to 10.35 m/s.

RESULTS AND DISCUSSION

Testing was done over the wind of speed range of 0.57 m/s to 10.35 m/s. The wind speeds tested were 0.57 m/s, 1.07 m/s, 2.10 /s, 3.10 m/s, 4.12 m/s, 5.18 m/s, 6.22 m/s, 7.36 m/s, 8.26 m/s, 9.27 m/s, and 10.35 m/s. The drag and lift force represented by FD and FL, respectively, of both existing wind tunnel models and 3D printed wind tunnel models were compared and plotted on the same graph as shown in Figure 4.

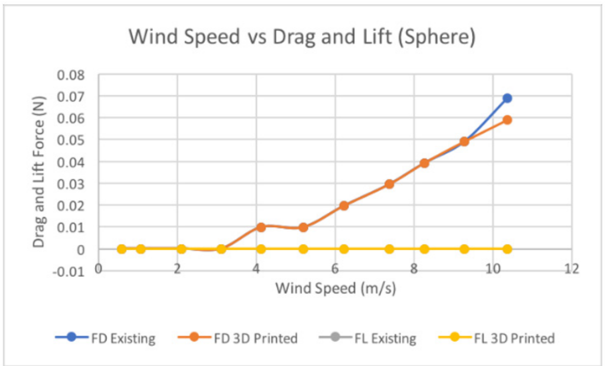

FIGURE 4. Results of lift and drag force for sphere model for existing and 3D printed models

Figure 4 shows the results for the sphere shape, after being tested in the wind tunnel. Although the drag force is more significant in this investigation, the lift force for all models will still be presented and compared to ensure the undesirable additional lift is not present. From Figure 4, the lift forces for both existing (metal) and the 3D printed (plastic) models remains at zero. Drag force for both models are similar except for the final speed tested, 10.35 m/s where a small difference was recorded. The 3D printed model recorded a slightly lower drag force of 0.01N. The difference is most probably caused by a slight vibration that occurred during the test for existing model.

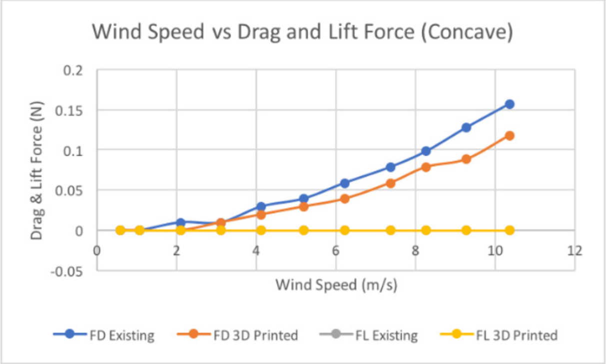

FIGURE 5. Results of lift and drag force for concave model for existing and 3D printed models

Another model tested was the concave drag model. Similar to the sphere, the readings of lift forces for both existing and 3D printed models remain at zero. In the case of drag force, both models exhibit similar uptrend readings. The 3D printed models have slightly lower drag force compared to the existing metal model. This is caused by the better surface finishing done on the model after the printing process.

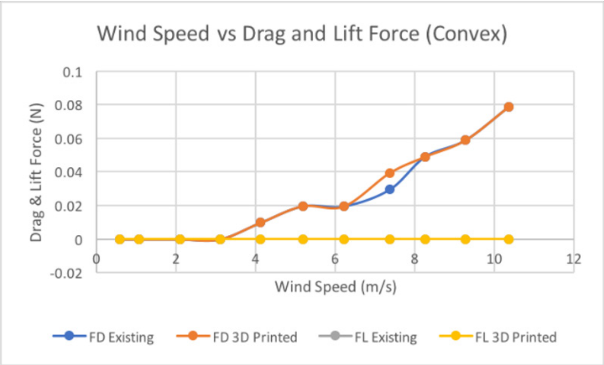

FIGURE 6. Results of lift and drag force for convex model for existing and 3D printed models

The third model tested was the convex model. Lift force for both models remains nearly zero. The drag force for both models have similar values in upward trend, except for the reading at 7.36 m/s. This might be caused by the positioning error during the model setup. Overall, the results for both types of models can be considered similar.

CONCLUSION

The wind tunnel models that are produced by using 3D printing technology and plastic printing materials are suitable for wind tunnel testing. The accuracy of the data with reference to the existing models made from metal are reliable which was proven by the three drag models tested. In some cases, the 3D printed models exhibit a better value of drag force, which was due to the better surface finishing achieved through the post-processing steps of the 3D printing. The outcome of this investigation proves that by using 3D printing technology, cost and time required to produce the wind tunnel models can be achieved with reliable accuracy.

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DECLARATION OF COMPETING INTEREST

None

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