Low Speed Wind Tunnel Testing to Measure Drag with Velocity Variation on a Cube Body

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Abstract

For centuries now, wind tunnels have been a key element in scientific research in a number of fields. Experimenting with racecars, airplanes, weather patterns, birds, and various other areas has been made much easier because of its development. In the racing field, for example, the information gathered from this testing can mean the difference between winning and losing a race. Weather simulations can also provide valuable information regarding building stability and safety. This has become very important when designing buildings today. Valuable information concerning bird flight has also been collected based on wind tunnel testing. Wind tunnels have a variety of important uses in the world today.

Wind tunnel that used here is an open loop low speed wind tunnel. The fundamental principles of this tunnel is moving the air using exhaust fan in the rear side, and placing the cube in the external balance system which used to measure the working force. This experiment is using 50mm cube of finished wood. From this experiment we can get Drag Force (FD), The Reynolds Number (Re) and The Coefficient of Drag (CD).

Keywords: Low Speed Wind Tunnel; Cube Body; External Balance; Drag; Coefficient of Drag; Reynolds Number

1. Introduction

Wind tunnel is one of basic apparatus that important to studying aerodynamics; however as the advancement of technology there is another method used to study aerodynamics, using simulation concerning aerodynamics force with computers help. This method is known by Computational Fluid Dynamics.

Experimental information is very useful to solve aerodynamic issues that can be achieved by numerous ways: from the test flight, fall test, water tunnel, rocket launch, ballistic test, and subsonic, nearsonic, transonic, supersonic, hypersonic wind tunnel and every one have their own benefits. By using wind tunnel as apparatus of an aerodynamics test can result aerodynamic characteristics information that accurate and can avoid from all accidental risks.

The purpose of this study is to search the working force on an object test consisting drag force, Reynolds number, and drag coefficient. The other purpose is to find out influence shape of an object test toward the passing air flow and flow visualization from the object test.

2. Wind Tunnel

Wind tunnel is research tool developed to assist with studying the effects of air moving over or around solid objects.

2.1. Wind Tunnel Type

There are two basic wind tunnels. First, is called open-circuit tunnel (“Eiffel” or “NPL”) it doesn’ t have reverse air flow, Fig. 1 after the air leaving diffuser, the air is release straight to free air.

The second type is called closed circuit or “Prandtl” , “G ttingen” , or “return-flow” tunnel, Fig. 2, as the last name, air that exit from diffuser is directing back to enter the entrance cone. The type of wind tunnel that will be use here is wind tunnel open-circuit type.

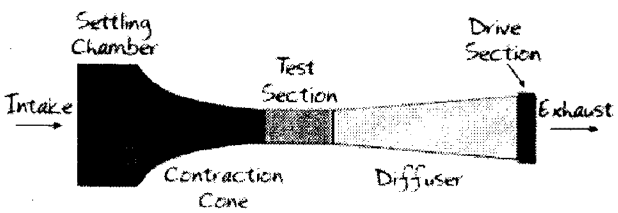

Figure 1 Open circuit wind tunnel

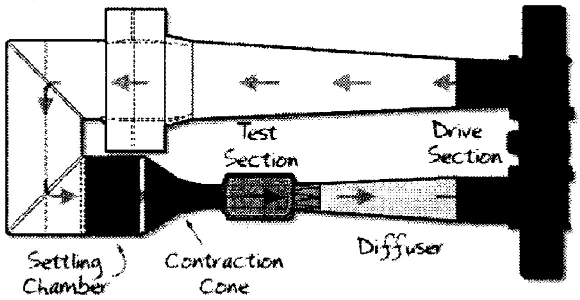

Figure 2 Closed circuit wind tunnel

2.2. Wind Tunnel Classification

Wind tunnel classified by velocity of air that is produce from the wind tunnel it self. There are four kind of wind tunnel base by the classification.

1. Subsonic wind tunnel is using at very low Mach Number operation, with the speed in test section about 400 km/h (M = 0,3). The air moved by using the axial fan that can increase the dynamic pressure to handle viscosity losses.
2. High subsonic wind tunnel ($0,4<M<0,75$) or transonic wind tunnel ($0,75<M<1,2$) is design with same principle as subsonic wind tunnel.
3. Supersonic wind tunnel is a wind tunnel that can produce supersonic speed ($1,2<M<5$). To produce the supersonic speed is use the right design of convergent divergent nozzle.
4. Hypersonic wind tunnel is design to produce hypersonic flow ($5<M<15$) in test section.

2.3. Part of Wind Tunnel

On a unit wind tunnel there are many parts, however there are five main parts;

1. Settling Chamber
   Settling chamber function is to uniform air flow. Because turbulent flow can cause the force can not be measure in the test section. Inside the settling chamber there is a honeycomb, the function is to develop or produce the smooth air flow in test section with that result the air flow is linier.
2. Contraction Cone
   Contraction cone function is to draw air that have low speed but large volume and reduce it become air that have high speed but small volume. As the size of contraction cone getting smaller more high the air speed.
3. Test Section
   Test section function is to placing the model of a wing or an airplane or an object we want to test. When the air flow base on the speed that we want. Sensor to measure the force is an external balance like drag force and lift force also placed in test section.
4. Diffuser
   Diffuser function is to slow down air flow rate that came out from test section or in closed-circuit tunnel is to recirculation. Air flow rate slow down is cause by the shape of diffuser.
5. Drive Section
   Drive section function is to provide the force can cause the air moving through tunnel. This force is usually obtained from a large fan. While the wind tunnel that need very high speed and can make air speed more than speed of sound using pressurized gases or vacuum cylinders.

3. Testing Procedure

Before testing, first of all paying attention for prepare in order that the testing is safe and secure. The step that must do in aerodynamics testing on cube body is:

1. Counting the preliminary condition on the laboratory. Consisting air temperature, air moisture, air pressure, and viscosity coefficient.
2. Placing the anemometer on center of test section.
3. Damper setting to get the speed that we want.
4. Turn on the fan.
5. Read the velocity from anemometer.
6. Turn off the fan.
7. Release the anemometer.
8. Placing the strut on the center of external balance, and tight the bolt.
9. Leveling on both side of the axis external balance refer to two water pass by arranging the load balance.
10. Descending the pressure bolt of external balance until touching the surface of digital scale.
11. Zero setting on the digital scale.
12. Turn on the dynamo motor, wait until the flow is stable.
13. Read the drag force in the digital scale. Get five sample data.
14. turn off the fan

15. Place the cube body to the strut.
16. Repeat step 11 to 15 to measure drag force on cube body.
17. Repeat step 2 to 16 for 10 different type of velocity.

4. Experimentation Result

4.1 Experimentation Data

Experimentation data is use to make a calculation and the result of calculation later will be used as reference to make analysis. From this experimentation data will have 11 velocity variations within range between 10 m/s to 20 m/s on each velocity are taken 5 data sample that reads in digital scale. Table 1 give us information that a different velocity variations can produce the different amount of force depends on the level of velocity that pass through the objects.

W_{total}	W_{strut}	W_{cube}	$F_{D\,total}$	$F_{D\,strut}$	$F_{D\,cube}$
29.2	4.0	25.2	0.286452	0.039240	0.247212
35.2	6.0	29.2	0.345312	0.058860	0.286452
42.8	8.0	34.8	0.419868	0.078480	0.341388
49.2	10.0	39.2	0.482652	0.098100	0.384552
57.2	11.2	46.0	0.561132	0.109872	0.451260
65.2	12.8	52.4	0.639612	0.125568	0.514044
73.2	14.0	59.2	0.718092	0.137340	0.580752
83.2	16.0	67.2	0.816192	0.156960	0.659232
94.8	18.0	76.8	0.929988	0.176580	0.753408
101.6	18.8	82.8	0.996696	0.184428	0.812268
108.0	20.0	88.0	1.059480	0.196200	0.863280

Table 1 Experimentation Data

4.2. Experimentation Data Processing

Experimentation data result needs further processing because the result that reads on digital scale it is not the final result. That data will converse into the forces that actually happen on cube body.

4.2.1. The Measure of Readable Force on Digital Scale

From Table 1 that is experimentation data is achieve the average velocity that accepted by digital scale in gram unit, if converse into scale of Newton with the gravity 9.8 m/s2 and we will get this result:

W_{total}	W_{strut}	W_{cube}	$F_{D\,total}$	$F_{D\,strut}$	$F_{D\,cube}$
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Table 2 Readable Data

From the external balance free body diagram under, can be measure the actual force that really happens on test object by taking reference to the center of the cube body.

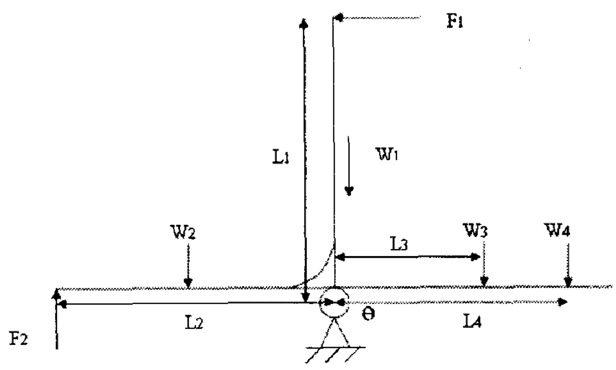


Figure 20 Free Body Diagram

F_1 = Actual force on test object
F_2 = Read force from digital scale
L_1 = Cube body center point distant with the supporting point

L_2 = Pressure bolt point distant with supporting point

L_3 = Balance shaft center point distant with supporting point

L_4 = Balance load point distant with supporting point

W_1 = Overall system weight on y axis

W_2 = Pressure shaft weight

W_3 = Balance shaft weight

W_4 = Balance load weight

Assuming the system on balance condition, the equation became like this:

Because resetting on the digital scale after leveling then the weight force because pressure shaft is not count and the equation became:

$$\Sigma M_{\Theta} = 0$$

$$F_1 L_1 + \frac{1}{2} W_2 L_2 = F2\ L_2 + W_{3\ L3} + W_4 L \quad (1)$$

Where value of L_1 = 0.320 m

L_2 = 0.211 m

Actual value of F_D will be on the Table 3

READABLE			ACTUAL		
FD total	FD strut	FD cube	FD total	FD strut	FD cube
0.286452	0.039240	0.247212	0.188879288	0.025873875	0.163005413
0.345312	0.058860	0.286452	0.227690100	0.038810813	0.188879288
0.419868	0.078480	0.341388	0.276850463	0.051747750	0.225102713
0.482652	0.098100	0.384552	0.318248663	0.064684688	0.253563975
0.561132	0.109872	0.451260	0.369996413	0.072446850	0.297549563
0.639612	0.125568	0.514044	0.421744163	0.082796400	0.338947763
0.718092	0.137340	0.580752	0.473491913	0.090558563	0.382933350
0.816192	0.156960	0.659232	0.538176600	0.103495500	0.434681100
0.929988	0.176580	0.753408	0.613210838	0.116432438	0.496778400
0.996696	0.184428	0.812268	0.657196425	0.121607213	0.535589213
1.059480	0.196200	0.863280	0.698594625	0.129369375	0.569225250

Table 3 Actual Value

1.1.1. The Calculation of Drag Coefficient and Reynolds Number

To determine the drag coefficient and Reynolds number, the first thing that we should know is amount of air density using equation:

$$\rho = \frac{P}{RT} \quad (2)$$

With value of P = 92300 kg/s^2

R = 287 kg/m º K

T = 301 K

That we can get value ρ = 1.608 kg/m^3

Then determine the air viscosity coefficient using equation:

$$= {}_0 \left(\frac{T}{To}\right)^{\frac{3}{2}} \left(\frac{To+110}{T+110}\right) \quad (3)$$

Value of = 1.1173 x 10^{-5} kg/ms

Then determine the air flow rate using equation:

$$q = \frac{\rho V^2}{2} \quad (4)$$

From the above calculation is use to calculate Re and Cd using equation:

$$Re = \frac{\rho VL}{\mu} \quad (5)$$

$$Cd = \frac{Fd}{qA} \quad (6)$$

A is cube body frontal wide, Length x Width.

The Value of Re and Cd on each velocity variations is:

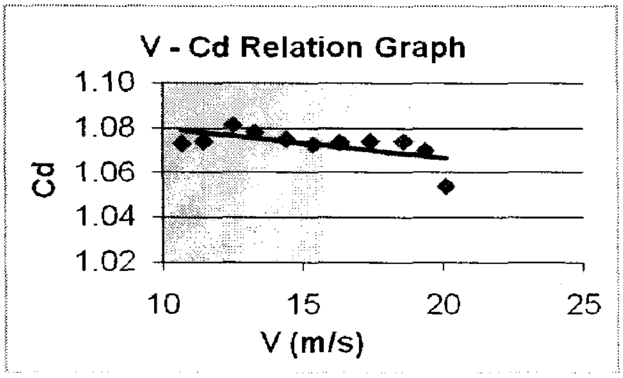
Variation	Vave.	q	Re	Fd cube	Cd cube
1	10.668	60.7725236	50986.41368	0.163005413	1.072886663
2	11.476	70.3270396	54848.15179	0.188879288	1.074291132
3	12.486	83.2507047	59675.32444	0.225102713	1.081565440
4	13.272	94.0619555	63431.91623	0.253563975	1.078284940
5	14.398	110.6994837	68813.49682	0.297549563	1.075161518
6	15.384	126.3804215	73526.96438	0.338947763	1.072785669
7	16.346	142.6803763	78123.72684	0.382933350	1.073541744
8	17.410	161.8597254	83208.98595	0.434681100	1.074216823
9	18.612	184.9810945	88953.79934	0.496776400	1.074225237
10	19.362	200.1896815	92538.33348	0.535589213	1.070163474
11	20.112	215.9990185	96122.86763	0.569225250	1.054125623

Table 4 Value Re and Cd

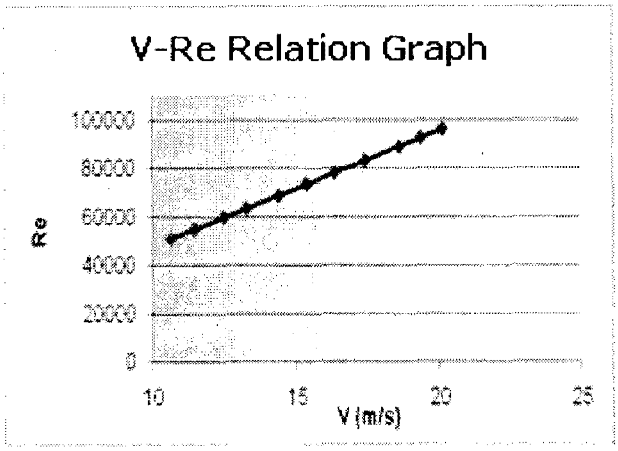
1. Analysis

From the Table 4, we can see that the influence of getting faster the velocity of an air flow can increase the drag force. On the contrary the drag coefficient is decreasing by the getting faster the velocity of an air flow. This is caused by the increasing of Reynolds number when the velocity is increase. Graphic 1 is relationship between velocity and Reynolds number, where between velocity and Reynolds number is linier.

The decreasing of drag coefficient can be see on Graphic 2, where this decreasing is cause when the Reynolds number getting higher an then the boundary layer surrounding the cube body will be reaching turbulent state, which is when the boundary layer entering the turbulent state the drag coefficient will fall.

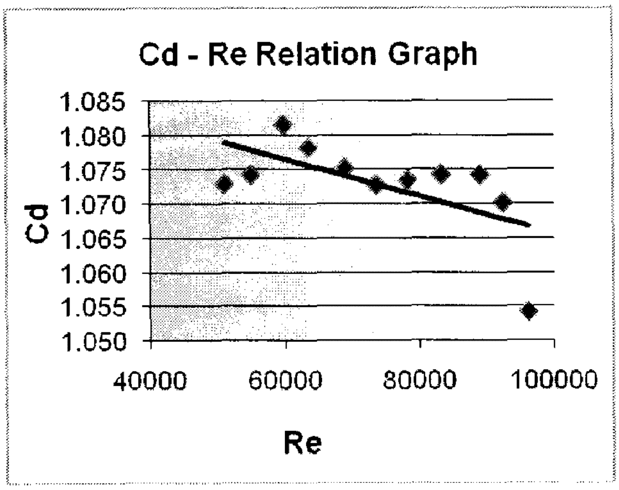


Graphic 1 Velocity and Drag Coefficient Relation



Graphic 2 Velocity and Reynolds Number Relation

From the experimentation data processing obtain relationship between Reynolds number and drag coefficient, drag coefficient have decreasing trend line tendencies as the escalation of Reynolds number and this is same like the theory of low speed wind tunnel testing.



Graphic 3 Drag coefficient and Reynolds number Relation

Drag coefficient that happen on experimentation of cube body around 5 x 10^4 to 5 x 10^4 Reynolds number is CD ≈ 1,072. This value is already approach to reference value (Table 5).

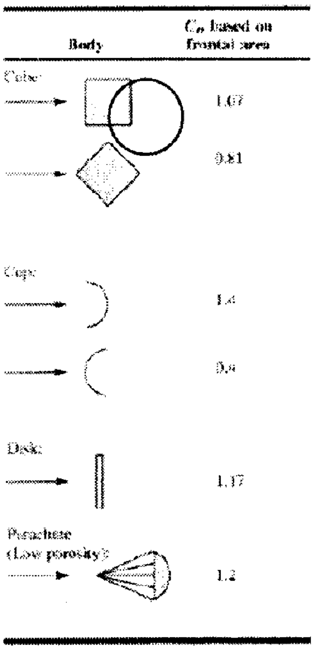


Table 5 Drag Coefficient of Three Dimensional Bodies at Re $\geq 4 \times 10^4$

1. Conclusions

(1) From the aerodynamics testing result on a cube body within length 50mm with velocity variations 10 m/s to 20 m/s is obtain value of drag coefficient in range of 1.05 to 1,08.

(2) Value of drag coefficient on the cube body the trend line tendencies is decreasing because the increase of Reynolds number.

(3) From the calculation for the velocity variations between 10 m/s to 20 m/s the Reynolds number is around 50000 to 95000.

(4) For the Reynolds number value 50000 to 95000 the value of drag coefficient is in range 1.05 to 1.08.

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