An Experimental Study of the Drag of Various Shape Axisymmetric Bodies Using the Mini C-2 Subsonic Wind Tunnel

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Abstract

The C-2 subsonic wind tunnel in MSU-IIT College of Engineering is a relatively small wind tunnel resulting to constricted flow of air for large specimen. This constriction resulted to deviation from an open-air environment supposed to be simulated by the wind tunnel. The study focused on this deviation. The drag forces using different sizes and shapes of axisymmetric body at different free stream velocities were measured. A correction for the supporting spindle was incorporated in the determination of the drag force. The correction was based on the whole and shortened spindle. The drag force of models was converted into a drag coefficient obtained by dimensional analysis and then compared to the published value found in the available textbooks and online documents.

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The results confirm that the drag coefficients of all models with sizes near 50-mm and 75-mm in characteristic lengths consistently fall within the vicinity of the published value with correction based on the whole and shortened spindles. The drag coefficients with sizes near to15-mm and 25-mm in characteristic lengths are close to the said value only if the correction is based on the shortened spindle. For sizes near 100 mm in characteristic lengths of sharp edged bodies, the results are consistently higher than the published values illustrating the effect of the constriction.

Keywords: C-2 subsonic wind tunnel, drag force, tunnel velocity

Introduction

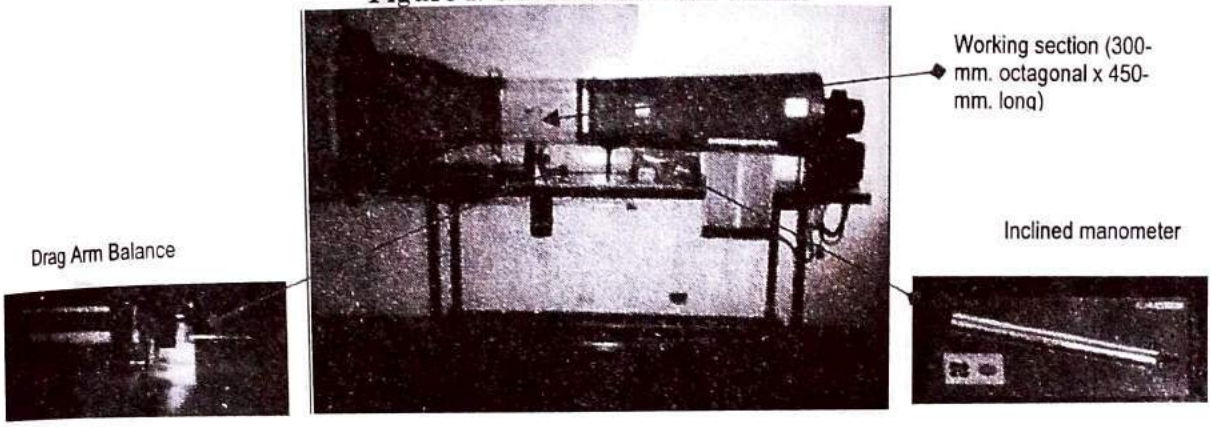
A erodynamics engineers study the way in which the air flows about the objects. One objective of aerodynamic studies is to design shapes that offer least resistance to the flow of air. Air offers a resistance to any object moving through it. It is influenced by the shape of an object. Air resistance is also referred to as drag force. If a moving object is well designed, the air will flow around it smoothly and cause less drag, hence requiring less energy to move the object. As a result, when an object produces poor airflow, more energy is needed to push it forward.

In view of economic aspect, the drag force on surface vehicles has become a very important topic in designing them. By correct design through minimizing drag of cars and trucks, it has become possible to greatly decrease the fuel consumption and improve handling characteristics of the vehicle (Munson et al, 1994).

Most of the available designs have resulted from experimental analysis through running tests on full-sized or scale model of the actual objects. Such testing includes the testing of model airplanes, cars, helicopters, trains and numerous other objects using a wind tunnel (Munson et al, 1994).

A wind tunnel is an enclosed structure that allows researchers to simulate the same condition a real object would encounter as it moves through the local environment. Thus, better performance of air or land vehicles has resulted from testing this machine. Our wind tunnel is a low speed tunnel which operates in the sub-sonic region. Its working section is limited.

Figure I. C-2 Subsonic Wind Tunnel



Models

There were seven models; figures II to VIII; considered in this study. Each set of specimens of the models was triplicated.

Figure II. Spheres

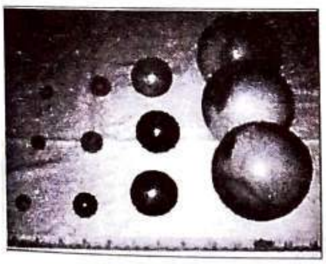


Figure III. Cones (60^0 Vertex)

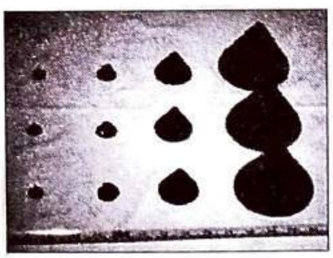


Figure IV. Disk

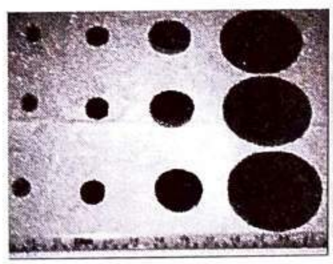


Figure V. Flat-Faced Cylinders (L/D=1)

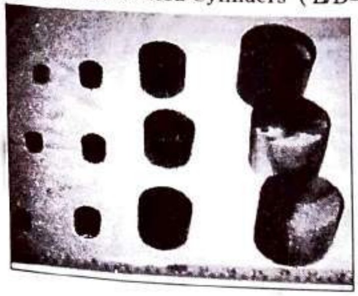


Figure VI. Rectangular Plates(B/H =1)

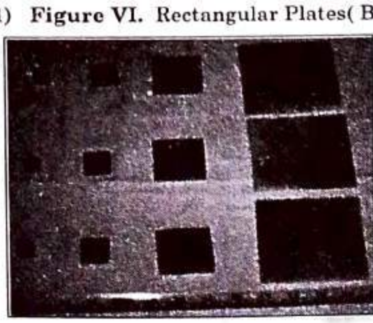


Figure VII. Cubes

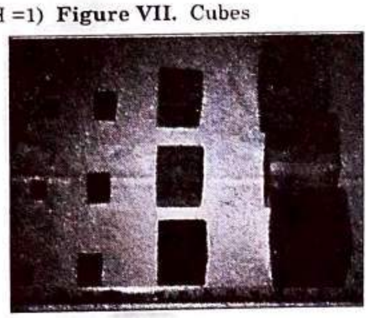
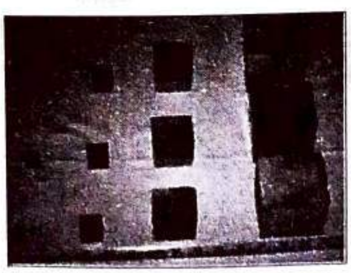


Figure VIII. Angled Cubes



Interference effects of the supporting device

The spindle supporting the model in the air stream inside the wind tunnel contributes to the total drag force of the set-up. The drag force due to the spindle must be deducted from the total force measurement in order to find the force on the model alone.

In this study, the investigation of the interference effects of drag spindle was subdivided in two groups, one dealing with whole spindles and the other with shortened spindles as shown in Figures IX and X, respectively. The design on the shortened spindle is presented in Figure XI. It can be seen that the cut-off portion of the whole spindle had no stream flow during the drag model reading. As a result, there were no pressure and fluid force in the rear region of the model. For that reason, the shortened spindle was made by deducting approximately ½ of the characteristic length of the model from the original height of the spindle.

The spindle drag was then taken, without the drag model attached, at the same settings.

Figure IX. Whole spindles spindles

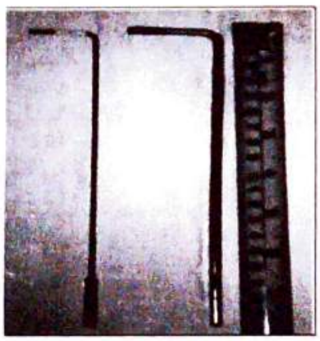


Figure X. Shorten spindles

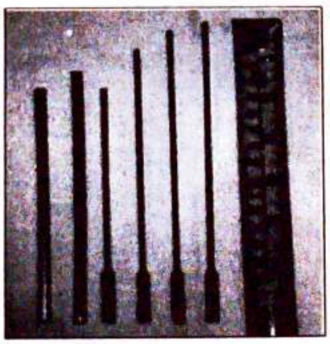
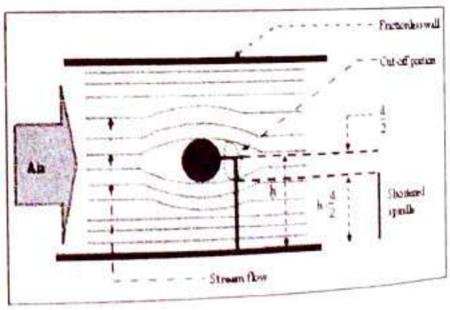


Figure XI. Design on shortened



Results and Discussions

Effect of the drag of spindles of the varying tunnel velocity

The results from the test of drag of spindles are presented in Figures XII and XIII, the whole spindles and the shortened spindles, respectively. In these graphs, the drag of spindles is plotted against the tunnel velocity. Each curve in the figures displayed the equation of drag of spindle as a function of velocity with the corresponding value of coefficient of determination. The equations on the graphs could only be used within the specified diameter and the range of tunnel velocities.

It is observed that the drag of spindle increases as tunnel velocity increases. In Figures XII and XIII, it is clearly shown that the drag of the spindle is proportional to its height and diameter.

Figure XII.
Drag of whole spindles vs. velocity

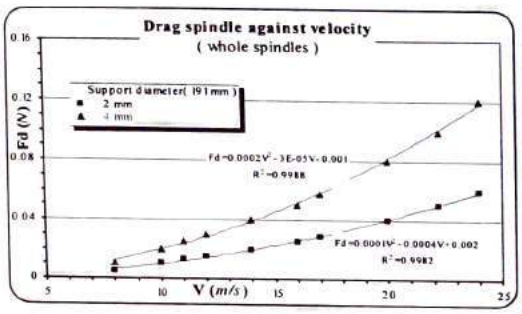
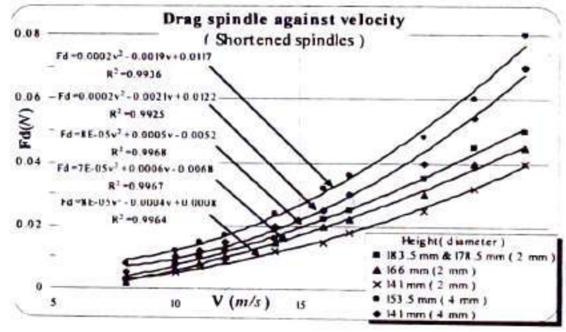


Figure XIII.
Drag of shortened spindles vs. velocity



Effect of drag coefficient of the varying tunnel velocity for disk.

Based on the statistical results, it was found out that there was a significant difference in the velocity at 5% level of significance of the tested disks.

Figure XIV The Mean Drag Coefficient vs. Tunnel Velocity for disk with correction based on

(a) Whole spindle, (b) Shortened spindle

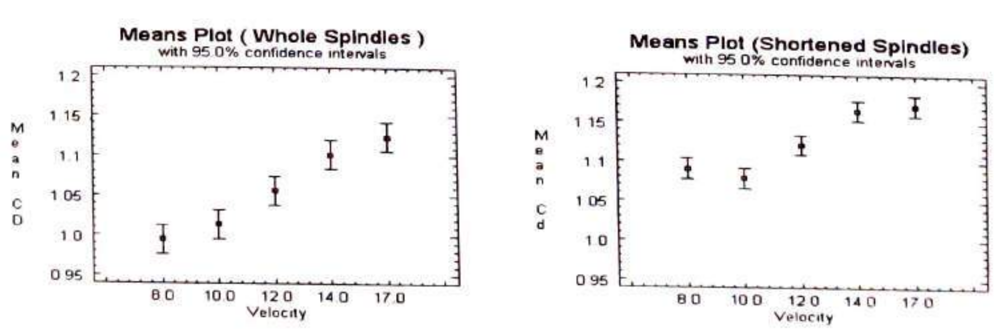


Figure XIVa shows that the mean drag coefficient of the disk increases as the velocity increases. For velocities 8 m/s, 10 m/s, 12 m/s, 14 m/s, and 17 m/s, the mean drag coefficients are 0.994378, 1.01348, 1.05604, 1.10187, and 1.124, respectively.

On the other hand, Figure XIVb shows that the mean drag coefficient increased as the velocity increases after 10m/s. For velocities 8 m/s, 10 m/s, 12 m/s, 14 m/s, and 17 m/s; the mean drag coefficients are 1.09039, 1.07819, 1.12137, 1.16506, and 1.17175, respectively. The finding reveals that the mean drag coefficient increases when the whole spindle is shortened.

Effect of drag coefficient of the varying diameter of the disk.

Based on the statistical results, it was found that there was a significant difference in the diameter at 5% level of significance of the tested disks.

Figure XV. The Mean Drag Coefficient vs. diameter for disk with correction based on

(a) Whole spindle, (b) Shortened spindle

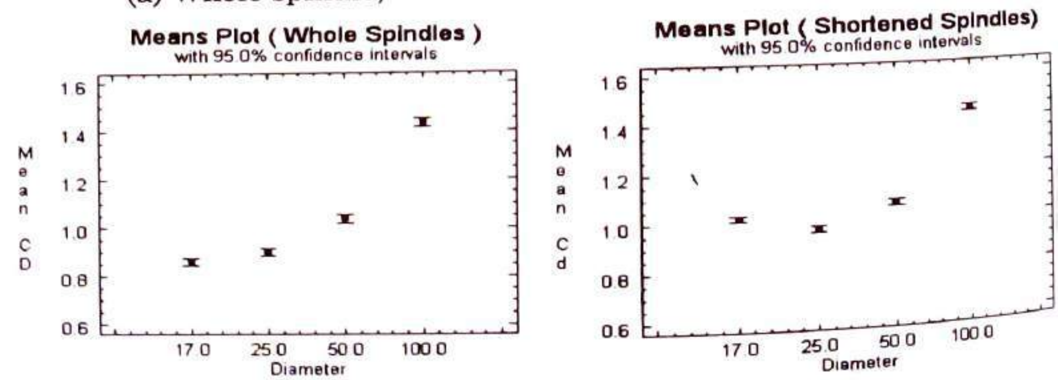


Figure XVa shows that the mean drag coefficient of the disk increases as the diameter increases. For diameters of 17 mm, 25 mm, 50 mm, and 100 mm, the mean drag coefficients are 0.860339, 0.900343, 1.03837, and 1.43276, respectively. The increase of mean drag coefficients maybe accounted largely by the corresponding increase of the constriction effect. This effect will further increase as cross-sectional area of the disk increases because the flow encounters a larger area of the disk.

Figure XVb, with correction based on the shortened spindle shows that the mean drag coefficient increases as the diameters increases. For diameters of 17 mm, 25 mm, 50 mm, and 100 mm, the mean drag coefficients are 1.01992, 0.971135, 1.06821, and 1.44215, respectively. The percentage increase of mean drag coefficients are as follows: 18.0% for 17 mm; 7.8%, 25 mm; 2.8%, 50 mm and 0.5%, 100 mm. It is observed that the percentage increase on the mean drag coefficient decreases as the size of the disk increases. At this point, one can see that the correction based on the shortened spindle is significant for the small disk, while it is insignificant for the large disk.

Comparison of the experimented results of coefficient of drag and published values as presented in the textbooks and online documents for disk

Figure XVI shows the results of the experiment conducted on the C-2 subsonic wind tunnel as compared with the published values. In Figure XVIa, the solid curves represent the characteristics of drag coefficient of the disk with correction based on the whole spindle. The broken curve, on the other hand, represents the results with correction based on the shortened spindles. Figures XVIb and 16c show percentage error of the result in Figure XVIa as compared with the published values.

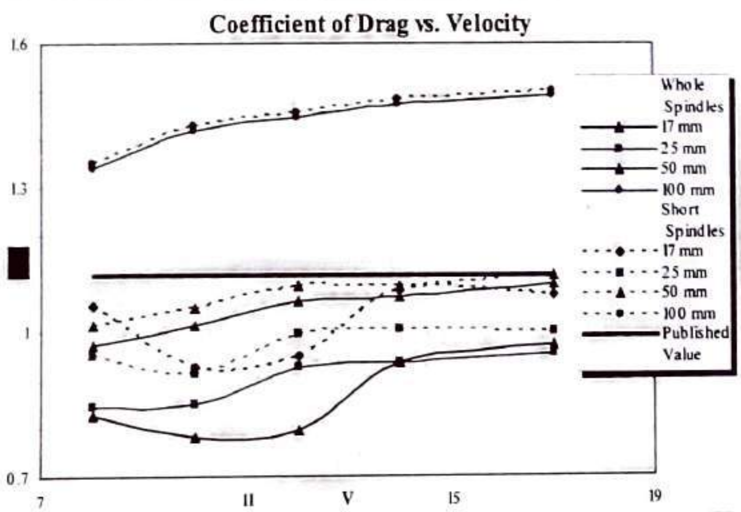
As seen in Figure XVIb, only one size of the disk, i.e., 50 mm, at a velocity of 17 m/s mark yielded results near the published value of 1.12.

In Figure XVIa, the drag coefficient increases when the correction is based on the shortened spindle. The increase of drag coefficient for the 17-mm disk is the highest among the other disks. It became clear that the contribution of the supporting spindle for the 17-mm disk was affected. On the other hand, the 50-mm disk had its drag coefficient at 17 m/s mark which fell within the published result as shown in Figure 16c while the curve for 17 mm-disk was near to the published value at 17 m/s mark.

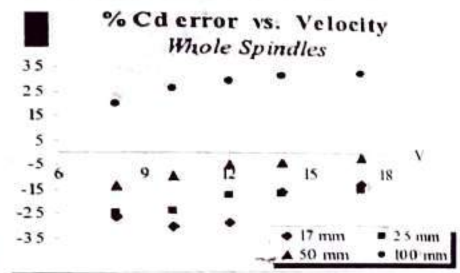
Figure XVI Disk (a) Comparison based on the whole and shortened spindles and the published value

(b) % error Cd based on the whole spindles

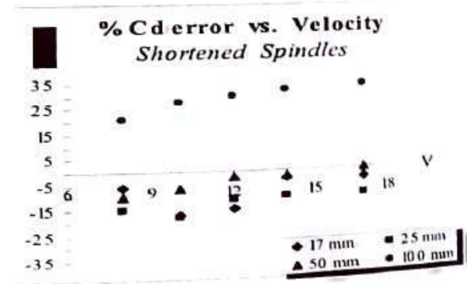
(c) % error Cd based on the shortened spindles



(a)



(b)



(c)

Over-all Observation

The curves of the drag coefficient plotted against air velocity show discrepancies compared with the published value. This can be attributed mainly to the tunnel walls which constricted the test section cross-sectional area. This effect was increased as cross-sectional area of the specimen increases, since the flow encounters a larger area of the specimen which subsequently constricted further the passage area.

The results especially for relatively small specimen were sometimes scattered. The scattering can be mainly attributed to the following:

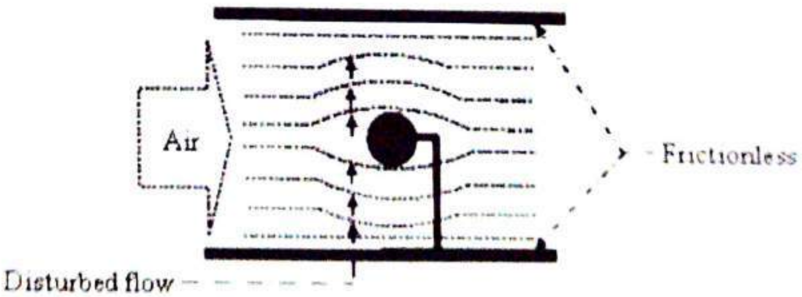
(a) The intermittent vibration was observed in the supporting spindle and specimen during experimentations. These vibrations might have affected the nature of flow over the specimen or data obtained from the drag arm balance.
(b) The misalignment of the specimen with the free stream and their position in the tunnel test section.

It can be observed that all of the results of sharp edged bodies of sizes near 100 mm in characteristic lengths were consistently and considerably higher in drag coefficients than the published values. The effect of constricted passage is quite evident in this case. However, for spheres of sizes near 100 mm in diameters can still be used because the disturbed flow (Figure XVII) is much lesser compared with sharp edged bodies.

The results of specimen of sizes near 15 mm in characteristic lengths are more scattered compared with the results of other specimen sizes. This can be mainly attributed to the significant effect of vibration in the measurement of drag force. For smaller specimen, the drag to be measured is relatively small thereby making the effect of vibration significant; however, for large specimen when the drag force to be measured is relatively higher, the effect of vibration is insignificant.

The correction based on the shortened spindle and whole spindle does not differ much for large specimen, but it does significantly differ for smaller specimen. This is because the drag force of small specimen is small, making the difference in the correction significant.

Figure XVII. Disturbed Flow



Conclusions

Based on the results of this study, the following conclusions are drawn.

1. The drag force on the whole and shortened spindles increases as the velocity of the tunnel increases.
2. For most of the tested specimens with corrected whole and shortened spindles, the mean difference of drag coefficients in the velocity at 5% level of significance is statistically significant. However, for the rectangular plate and flat-faced cylinder with corrected shortened spindles, the mean difference of drag coefficients in the velocity at 5% level of significance is statistically insignificant.
3. For all tested specimens with corrected whole and shortened spindles, the mean difference of drag coefficients in size at 5% level of significance is statistically significant.
4. The drag coefficients of all tested specimens of sizes near 50-mm and 75-mm in characteristic lengths are consistently close to the published value with correction based on the whole and shortened spindles. The drag coefficients of sizes near 15-mm and 25-mm in characteristic lengths are close to the said value only if the correction is based on the shortened spindle.
5. Specimen of sizes near 100 mm in characteristic lengths of sharp edged bodies are higher in drag coefficient values than the published values, indicating the effect of a constricted passage.

Recommendations

In using the C-2 subsonic wind tunnel the following are recommended:

1. The size of the specimen to be used in order to obtain reliable data is from 50 mm to 75 mm in characteristic lengths.
2. The correction for the drag force should be based on the shortened spindle especially for small specimen.

The following are recommended for further study.

1. The effect of surface roughness on the drag of the test specimen.
2. The effect of turbulence in the air stream upon the drag force measured on models in this wind tunnel.
3. The comparison of two methods for measuring the drag on specimens. The first method is a direct measurement of the drag force, as measured on a balance arm. The second method is an indirect method in which drag is calculated using the control volume momentum equation and the measured wake velocity profile behind the specimens.
4. The effect on the drag coefficient of higher velocity in this wind tunnel.
5. Flow visualization.

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