# Drag Forces on Bluff and Streamlined Bodies

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## I. Objective and Requirement

Understand the types of drag

Compare the drag for different shapes of equal equatorial diameter

Measure the wake profile behind different shapes

## II. Principle

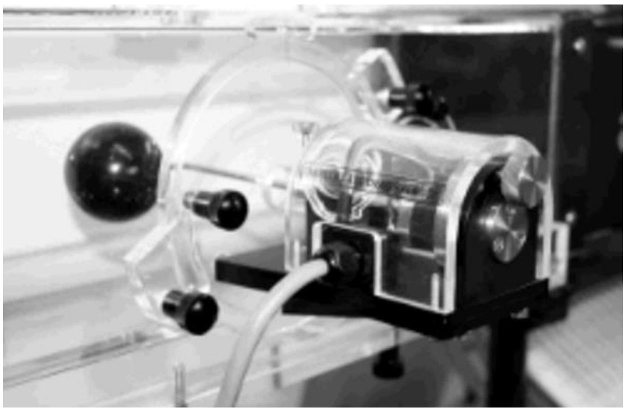
### Drag Models

A dimpled golf ball and plain sphere with 43 mm diameter.

Sphere, Concave Hemisphere, Convex Hemisphere, Circular disk and Streamlined shape with a common equatorial diameter of 50mm.

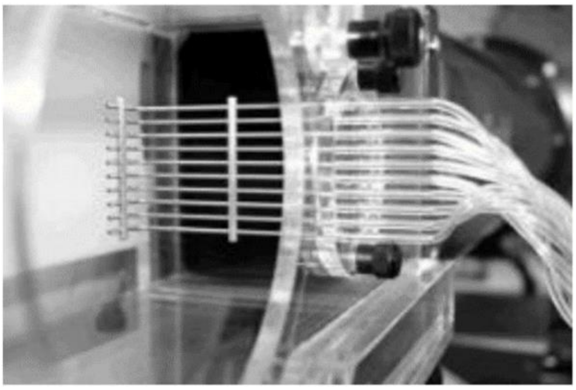
### Drag measurement

A 2-component, electronic balance is used to measure the drag. Electronic sensors are used to measure the drag force, and the drag being measured directly by the method of force moment balance.



**Wake survey rake**

The wave survey rake is designed to be installed in a small hatch on the front wall of the tunnel behind any model installed through a large hatch. The rake shall be designed to ensure that the center of the rake is aligned with the center point or zero-angle centerline of the model installed through the large hatch when installed. Therefore, it will cross the wake downstream of the model, allowing the pressure changes across the wake and the changes in velocity to be measured.



**Drag types**

Pressure drag: due to the change in motion of the air particles and the creation of eddies and wake

Friction drag: due to the shear forces between the body and the layer of air moving around the body

The total drag is formed by the combination of pressure drag and friction drag.If friction drag is the dominant part in the total drag, the body is described as streamlined, otherwise, the body is described as bluff (or blunt).

**Flow type**

Laminar flow: flow around a body may travel in smooth layers with little or no mixing between layers.

Turbulent flow: flow may travel with a significant lateral component to its velocity, with eddies, mixing, and even some flow in a reverse direction to the average.

**Boundary layer**

The region near the body where the viscous effect is significant is called the boundary layer. It is usually assumed to be the region in which the flow velocity is less than 99% of the free stream velocity.

**Boundary layer transition:** flow type changing from one type to the other within the boundary layer.

**Boundary layer manipulation**

The drag experienced by the body is significantly affected by the Boundary layer type and separation. The factors that can be controlled are the shape of a body and its surface. It is also possible to 'trip' the boundary layer into turbulent conditions by placing a deliberate obstruction on an otherwise smooth surface.

**Drag coefficient**

$$C_D = \frac{D}{\frac{1}{2}\rho V^2 S}$$

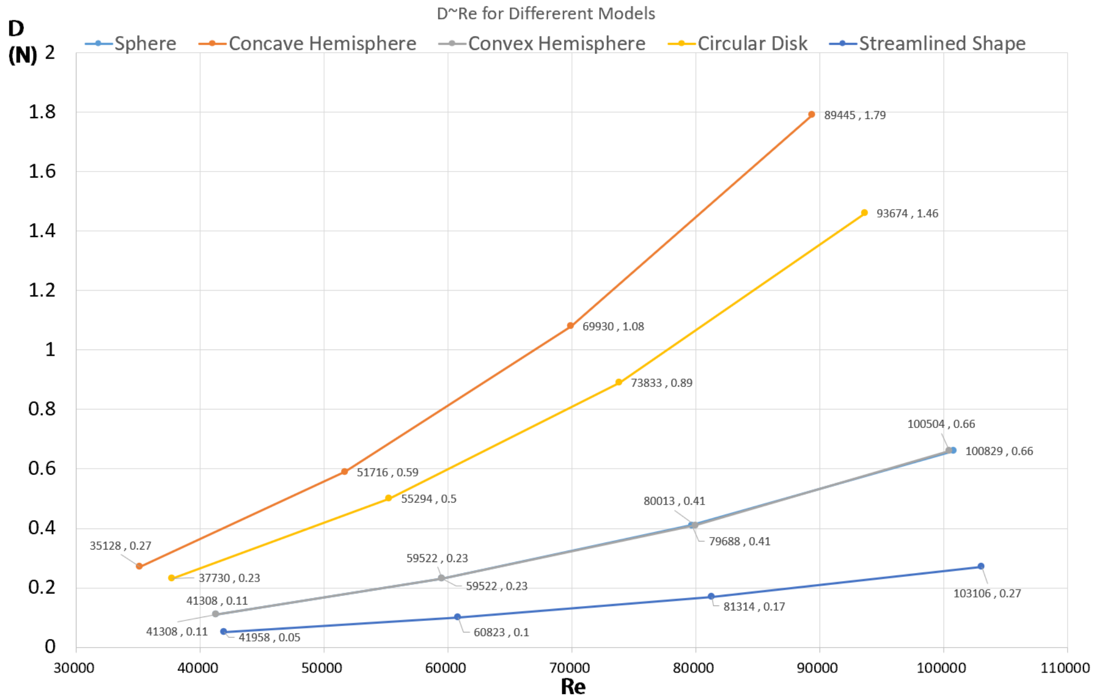
$C_D$ is the drag coefficient D is the drag force S is the frontal area

$\rho$ is the air density $V$ is the air velocity

## III. Data processing and analyzing

1. Plot D~Re for the Sphere, Concave Hemisphere, Convex Hemisphere, Circular disk and Streamlined shape models on the same graph. Plot $C_D$~Re these models

on the same graph (the diameter is 50mm). Discuss and analyze the results.




**Discuss and analyze**

Streamlined shape model:

When the streamlined shape model moves in the fluid, the fluid flows along its contour, and there is little or no separation and wake, so the drag is the minimum as demonstrated. As the Reynolds number increases, the friction drag increases, resulting in the increase of the measured drag.

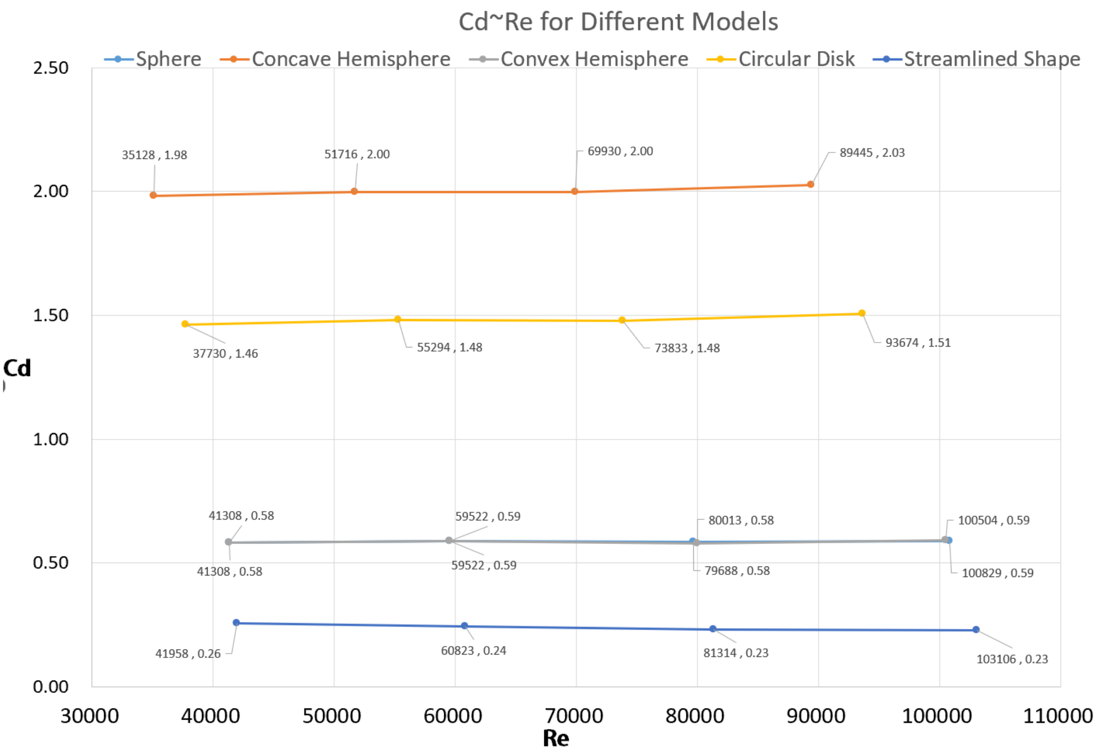
Sphere and convex hemisphere model:

Compared with the streamlined shape model, the sphere and convex hemisphere are blunt bodies whose total drag is dominated by pressure drag, so the measured drag is larger.

The convex hemisphere and sphere models have the same shape and surface condition when facing the incoming flow, so they generate almost the same pressure drag, which leads to the same measured drag.

Circular disk and concave hemisphere model:

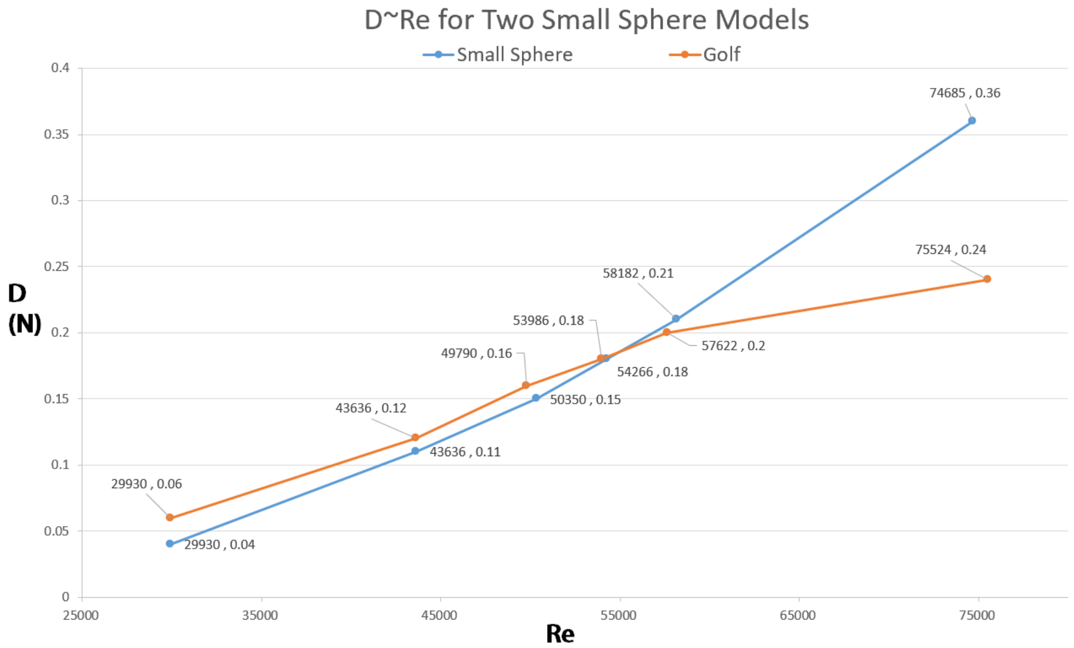
Different from the sphere and convex hemispheres, the circular disk has a plane shape in the direction directly facing the incoming flow, while the concave cavity has a concave shape. The pressure drag is the largest on the concave surface and smallest on the convex surface, so the concave hemisphere receives the greatest drag, followed by the circular disk and the convex hemisphere.

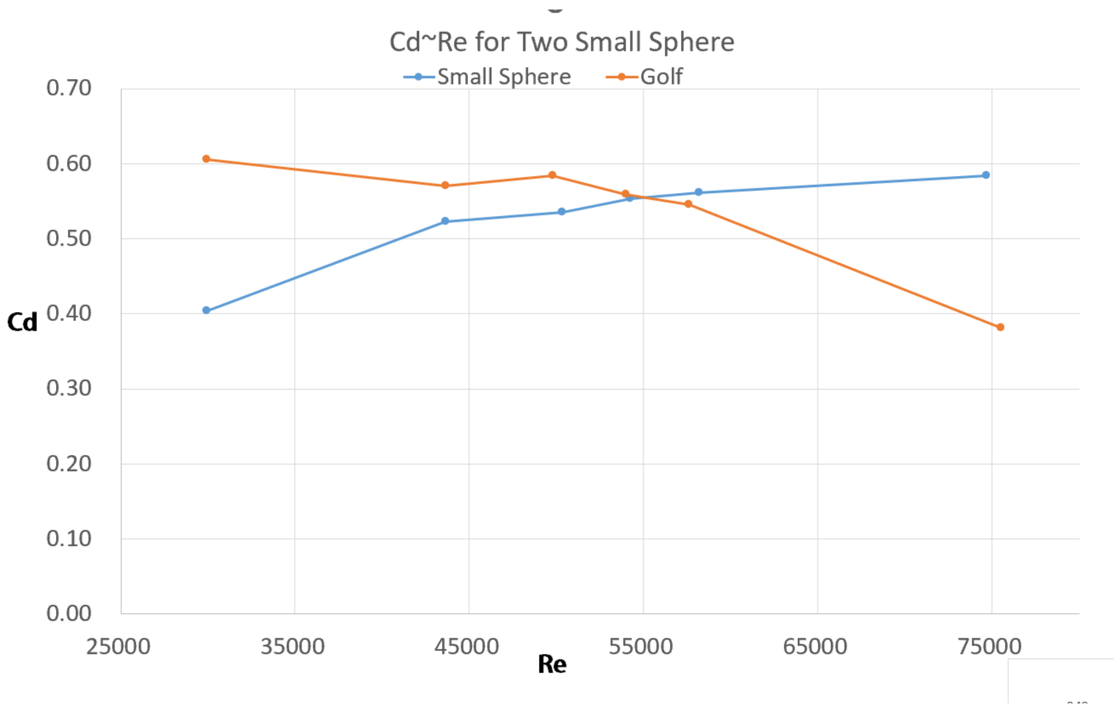



### Discuss and analyze

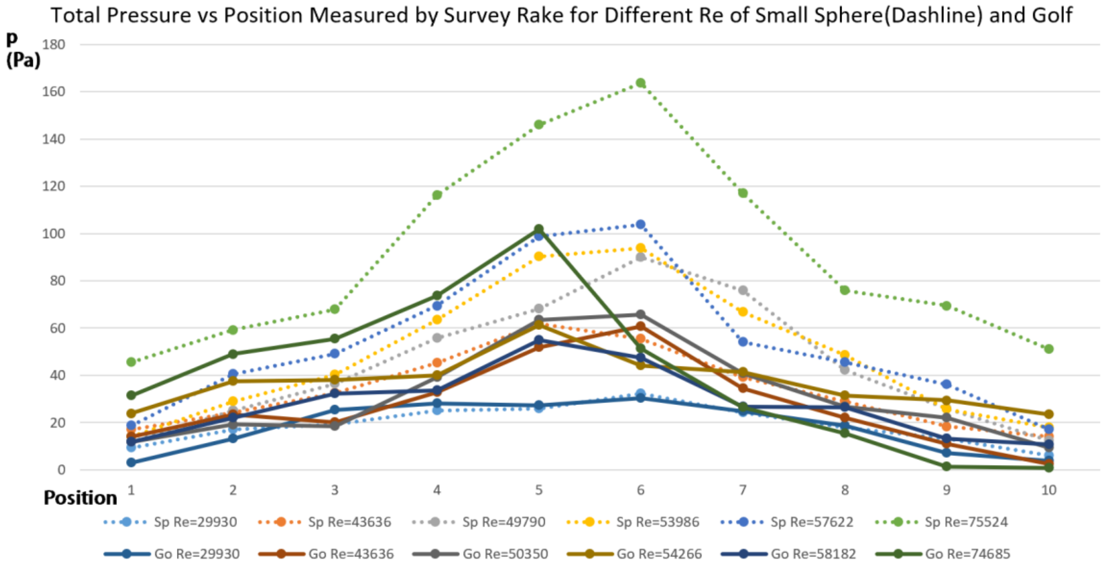
As demonstrated above, the drag coefficients of different models are almost constant under different Reynolds numbers, and in order from smallest to largest, they are streamlined shape, sphere/convex hemisphere, circular disk, and concave hemisphere. It is worth noting that the sphere and convex hemisphere models have the same shape and surface characteristics in the direction directly facing the incoming flow, so the drag coefficients are almost the same.

2. Plot D~Re for the two small sphere models on the same graph. Plot $C_D$~Re these two models on the same graph (the diameter is 43mm).




3. Plot the total pressure P vs. position measured by the wake survey rake for different Re on the same graph.




## IV. Questions

1. Compare the difference in results (parts 2 and 3 in section Ⅲ) for the small smooth and rough spheres and analyze the causes.

**D~Re and Cd~Re figure**

Difference:

When the Reynolds number is less than about 55000, the drag force experienced by the golf is greater than that of the small ball, and the increasing trend of both is almost the same with the increase of the Reynolds number. The drag coefficient of the golf ball is greater than that of the small ball.

When the Reynolds number is greater than about 55000, the drag of the golf ball is less than that of the small ball, and the tendency with the increase of the Reynolds number is weaker than that of the small ball. The drag coefficient of the golf ball decreases with the increase of the Reynolds number while that of the small ball increases.

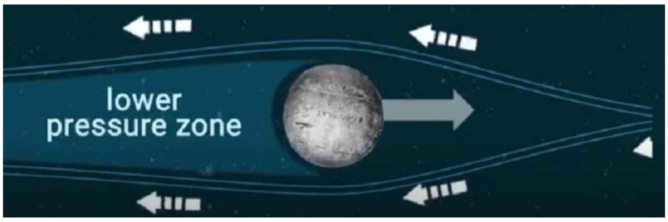
Causes:

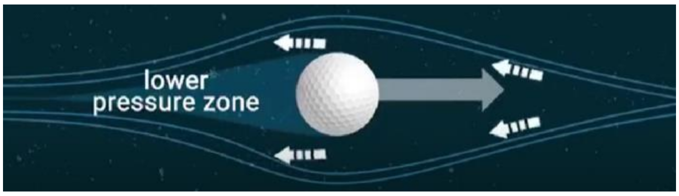
When the Reynolds number is less than about 55000, the friction force between the golf ball and the air on the surface is greater than that of the smooth ball due to the existence of dimples, so the measured drag of the golf ball is greater than that of the small ball.

When the Reynolds number is greater than about 55000, many small vortices can be generated by the dimples on the golf ball's surface, forcing the laminar boundary layer into a turbulent boundary layer, namely, 'tripping' the boundary layer into turbulent conditions.

Therefore, the boundary layer separates later, resulting in a smaller separation zone and low-pressure zone shown below, thus reducing the pressure drag.

Although the friction between the golf ball and the air is greater than that of the smooth ball, because the pressure drag of the golf ball is significantly less than that of the smooth ball, so the total drag measured is less than that of the smooth ball.




**Pressure at different position figure**

Difference:

The data measured by the wake rake is negative pressure, and the larger the value is, the smaller the actual pressure is. Therefore, the pressure of the golf ball's wake is higher than that of the smooth ball overall. Near the wake center, the pressure of the golf ball's wake is significantly higher than that of the smooth ball. Therefore, it can be verified that the golf ball has a smaller zone of low pressure than the smooth ball, and the total drag measured is less.

Causes:

There are many small dimples on the surface of the golf ball, and some small vortices are generated near the dimples during flight. Due to the suction force of these small vortices, the fluid molecules near the surface of the golf ball are attracted by the vortices, so the separation of boundary layer is delayed and the large vortices formed behind the golf ball are much smaller than those formed by the smooth ball. Namely, the low pressure zone of golf ball is smaller, the pressure in the wake area of the golf ball is greater than that of the smooth ball.

2. Check for information, analyze the causes of the "resistance crisis", and discuss the factors affecting the emergence of the "resistance crisis".

Causes:

The increase of Re causes the transition point of the turbulent boundary layer to move before the separation point. Due to the large kinetic energy of the fluid in the turbulent boundary layer, the separation point moves backward and the trailing vortex area narrows, thus significantly reducing the drag coefficient.

Affecting factors:

In order to have a "resistance crisis", turbulence is required to occur before the laminar separation point. The factors that affect the generation of turbulence are: Reynolds number, surface roughness, disturbance, object shape, and etc.

3. Referring to the results in part 1 in section Ⅲ, discuss the difference between streamlined and bluff bodies and their applications.

Drag: Concave > Circular Disk > Convex ≈ Sphere > Streamlined

Drag coefficient: Concave > Circular Disk > Convex ≈ Sphere > Streamlined

Difference between streamlined and blunt bodies:

Under the same equatorial diameter, the fluid flows along the contour of streamlined body, and there is little or no separation and wake, resulting the lower pressure drag compared with the blunt body, so the drag is the minimum.

Applications:

Streamlined body: aerodynamic optimization design of vehicle shape, such as: highspeed trains, airplanes, submarines and etc.

Blunt body: Speed reduction device, such as: fighter tail parachute for landing.