

Experimental Verification of Effect of Density of the Material on Drag Coefficient for Spherical Body

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Abstract

Drag coefficient is the non-dimensional parameters commonly denoted as C_D , C_X or C_W . It is used to quantify the drag or resistance of an object in a fluid such as air or water. One of the primary functions of aerodynamicists is to reduce this coefficient. The drag coefficient is used in the drag equation, where the lower drag coefficient indicates that the object will have less aerodynamics or hydrodynamic drag. The drag coefficient of any object comprises the effects of the two basic contributors to fluid dynamics drag, skin friction and form drag. This unique drag comes from the fact that the drag coefficient is a function of the reference area. Therefore, if we select a small reference area, the drag coefficient will be large, but if we choose a large reference area, the drag coefficient will be small. This paper intends to provide effect of density of materials on drag coefficient of spherical shaped body. The experiment is performed by taking sphere of concrete 50 mm diameter and sphere of rubber 60mm diameter in Wind Tunnel and drag coefficient is determined.

KeyWords: Drag Reynolds number, Density, Spherical body.

1.0 INTRODUCTION

For determining the motion of a solid object in a air medium, one has to know the drag coefficient of the considered object. It is therefore significant research has been carried out and published on this matter during the past century. In experimental investigations aimed at finding the drag coefficient of a solid sphere moving through a fluid, various techniques were employed. These different techniques were used for evaluating the drag coefficient over a wide range of Reynolds and Mach numbers. Among the frequently used methods, one should mention freely falling spheres in a liquid or air, spheres placed in wind tunnels, spheres mounted on flying aircraft, spheres towed in water channels and spheres flying in aero-ballistic range. In many of these experiments, the relative velocity of the sphere was constant or almost constant. Based on the results from experiments conducted using the above-mentioned technique, a 'standard drag coefficient' curve has been derived for a sphere.

Measurements of sphere drag coefficients for non-stationary flows were conducted during the past four decades. Among the published results, one should mention the work of Buckley (1968), Selberg & Nicholls (1968), Rudinger (1970), Karanfilian & Kotas (1978), Outa et al. (1981), Sommerfeld (1985), Igra & Takayama (1993), Boiko et al. (1997), Tano et al. (2003) and Sun et al. (2004). Selberg & Nicholls (1968) used a shock tube for accelerating single particles and photographed their displacement from which the particle trajectory was reconstructed and the drag coefficient was deduced.

Buckley (1968) investigated the drag force acting on a particles cloud that was accelerated to a transonic slip flow, using a light-extinction technique.

Rudinger (1970) accelerated a particles cloud in a vertical shock tube and deduced the particles' velocity from their trajectories recorded by streak photography. Since it was hard to establish an accurate particle trajectory, which is the basis for obtaining the particles' velocity and acceleration needed for evaluating the particles' C_D , a different method was adopted. In the new approach, Rudinger (1970) evaluated the particle velocity via the deflection of a light beam passing through the particle cloud. From the ratio of the scattered light intensity before the passage of the incident shock wave to that during the passage of

the particle cloud, the suspension density ratio across the shock can be estimated. This in turn, for a steady one-dimensional flow, is equal to the ratio between the shock velocity and the particles' velocity. This, at best, would yield an average velocity of the dust cloud, not the velocity of a specific particle. Furthermore, the assumption that the post-shock flow is steady and one-dimensional is questionable. In order that this assumption will not be grossly violated,

Rudinger (1970) was forced to limit his experiments to very weak incident shock waves. His suggested correlation for C_D was therefore limited to the range $50 < Re < 300$. Henderson (1976) proposed three different correlations for C_D : (i) for a subsonic flow, (ii) for a supersonic flow at Mach numbers $M_{is} > 1.75$, and (iii) a linear interpolation equation for the intervening region. While considering the effects of physical variables, such as Reynolds number, Mach number and whether or not the flow is continuum or free molecular flow, on the sphere drag coefficient, no attention was given to whether or not the relative flow is steady.

Karanfilian & Kotas (1978) measured the drag force on a sphere experiencing a simple harmonic (unsteady) motion in a liquid at rest. Their measurements were limited to the range $10 < Re < 6000$. Outa et al. (1981) deduced the particle drag from a streak record of dispersed glass spheres in the air inside a shock tube. Sommerfeld (1985) essentially repeated Rudinger's experiments. He used laser Doppler anemometry to find a drag law describing the particle acceleration behind an incident shock wave, in a vertical shock tube filled with a uniform gas-particle suspension. His proposed correlation for the particle C_D was limited to the range $50 < Re < 500$. An attempt to propose a correlation for the particle drag coefficient over a wide range of Reynolds numbers is found in the paper by

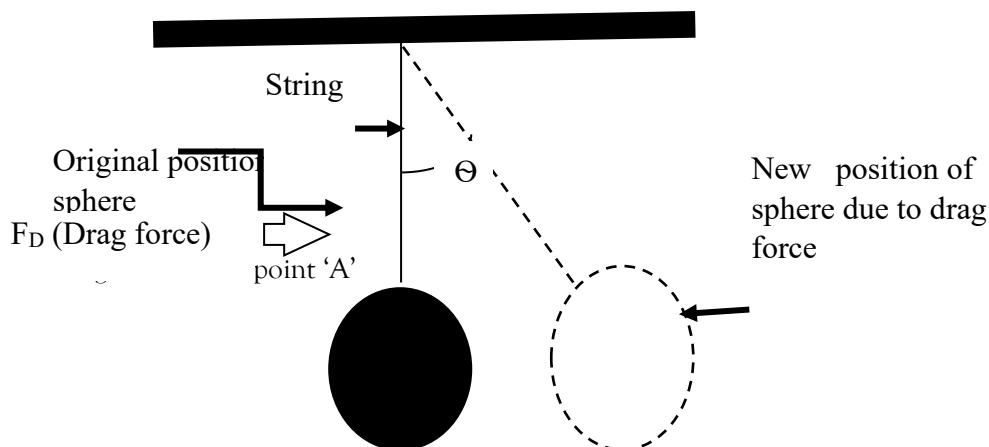
Later, Rodriguez et al. (1993) investigated both the steady and unsteady drag coefficients of a sphere initially free-falling in a vertical shock tube, using a rapid camera shadowgraph technique. More recently, Suzuki et al. (1999) developed a technique enabling the injection of a spherical particle into the middle of a horizontal shock tube test section, just before the incident shock wave reached the injected sphere

The significant achievement of the present experimental study described subsequently is the method used for the drag force measurement by tracing the trajectory of a single spherical particle suspended in mid-air by a fine filament (spider web) from the roof of a shock tube. Multiple shadowgraphs (several tens) were acquired at each shot, eliminating the serious repeatability-related inaccuracy encountered in former studies where only a single or a few shadowgraphs were recorded per shot. Moreover, by employing multiple-sphere shots (up to four different particles), the repeatability-associated inaccuracy was further reduced. In nine experiments, the post-shock flow was subsonic and in seven supersonic. In four of the subsonic experiments, two different spheres were tested simultaneously and, in one, three different spheres were tested simultaneously. In one of the supersonic experiments, two different spheres were tested simultaneously; in two experiments three different spheres were tested simultaneously; and, in one run, four different spheres were tested simultaneously. Furthermore, in the presently reported results, the field of view was 300mm long, enabling a very accurate construction of the investigated particle trajectory during each test.

2.METHODOLOGY

The methodology adopted for the study is described below:

A sphere (ball) of two different materials, that is, concrete and rubber are taken. The diameter of concrete ball was 50mm and diameter of rubber ball was 60mm. Then the test on each ball was conducted separately in wind tunnel. For the test, balls were suspended with string in testing chamber of wind tunnel as shown in Fig-3. Due to the drag force developed by the flowing air in wind tunnel the sphere gets shifted from its original position to new position and thus the string angle gets changed as shown in Fig-2. The effect of drag force on string angle and the corresponding Reynolds's number, drag coefficient was noted down.



3. Experimental setup

The experimental set up consists of a wind tunnel. A wind tunnel is a chamber through which air is blown at controlled speeds to simulate the motion of objects placed in the chamber through the air. Wind Tunnel is used to study the aerodynamic properties of objects such as automobiles, airplanes, and missiles, which is also used in research to study the effects of air past solid objects.

A wind tunnel consists of a closed tubular passage with the object under test mounted in the middle. A powerful fan system moves air past the object; the fan must have straightening vanes to smooth the airflow. Full-scale aircraft or vehicles are sometimes tested in large wind tunnels, but these facilities are expensive to operate and some of their functions have been taken over by computer modeling. In addition to vehicles, wind tunnels are used to study the airflow around large structures such as bridges or office buildings.

Wind tunnel used in the study consists of four sections i.e. Bell mouth with air straightener, Settling chamber and contraction cone, Transparent test section and Diffuser section. Bell mouthed entry is shaped to guide the air smoothly into the tunnel. Tunnel is having 300mm x 300mm x 1000mm test section with two windows to insert the models or probes. The working section is followed by a divergent duct. A five-blade fan is coupled to a motor and motor is fitted on a sturdy MS frame & is controlled by a Variable Frequency Drive.

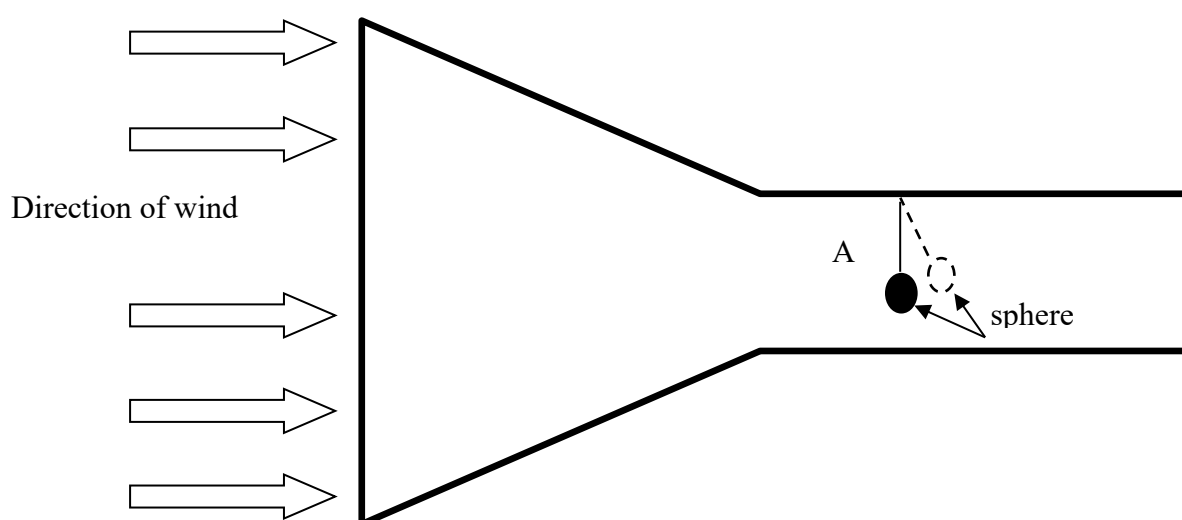


Fig.2 Experimental set up (wind tunnel)

4. RESULTS AND DISCUSSIONS

This testing was conducted in order to become more familiar with the relationship between drag coefficient and density of sphere. The calculations show that for spheres, concrete and rubber, the string angle increased as the drag force. Velocity and Reynolds number increased. By analyzing the results of

the both spheres, it is easy to see that the drag coefficient is in the range of 0.44-0.45, The largest coefficient of drag values occurred at Reynolds number 71764 is 0.48 and 32549 is 0.45, as well as the lowest coefficient of drag values occurred at Reynolds number 58901 is 0.44 and 18823 is 0.44 for concrete ball and rubber ball respectively. Plotting the Reynolds numbers vs. coefficient of drag for each sphere showed similar curves. It is clear to see that the drag coefficient values are closely same even though the densities of the both spheres are different.

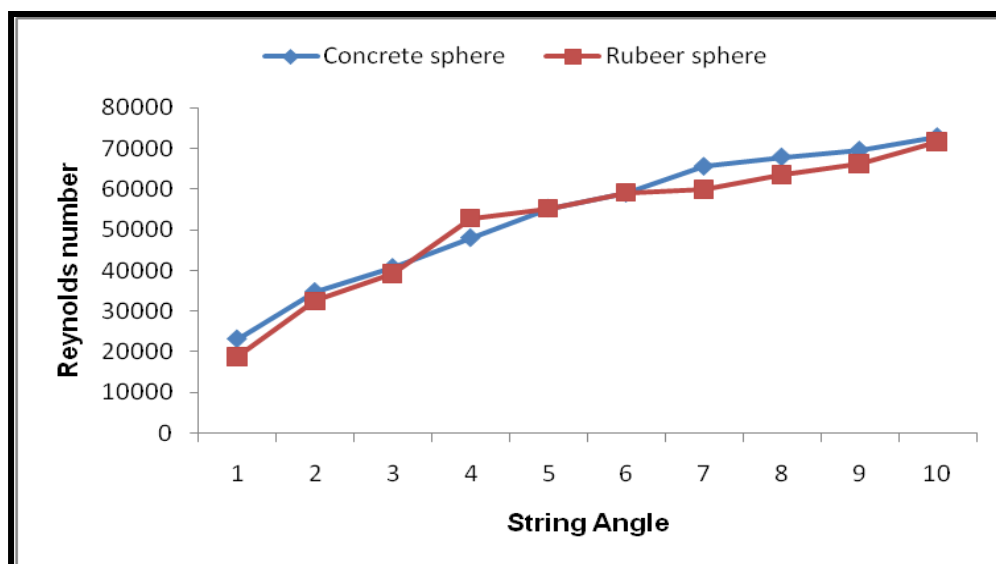
String angle	Reynolds number	Drag coefficient
1	23163	0.45
2	34745	0.45
3	40701	0.46
4	47981	0.45
5	55261	0.45
6	58901	0.44
7	65519	0.45
8	67835	0.45
9	69490	0.45
10	72799	0.48

Table 1: Concrete Sphere

String angle	Reynolds number	Drag coefficient
1	18823	0.44
2	32549	0.45
3	39215	0.45
4	52941	0.45
5	55294	0.45
6	59215	0.45
7	60000	0.45
8	63529	0.45
9	66274	0.45
10	71764	0.45

Table 2: Rubble Sphere

Figure.3- Variations of Re for different sphere with string angle



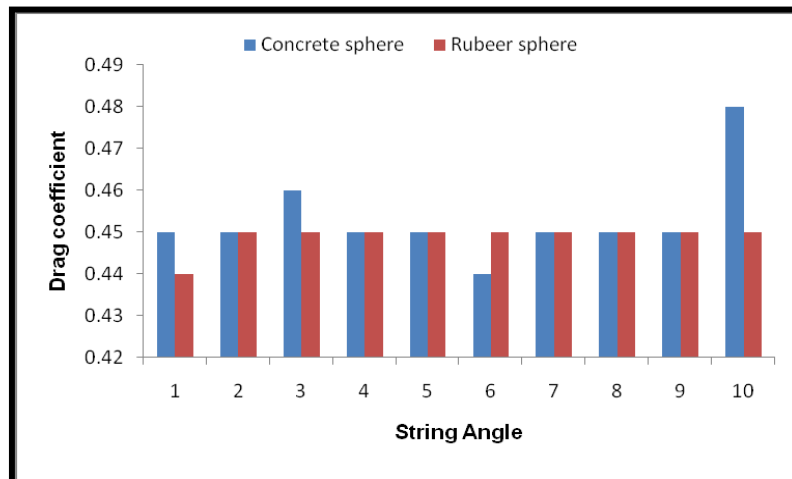


Figure.4 Variations of C_D for different sphere with string angle

5. CONCLUSION:

There are general observations that are important. Sphere density does not play a large factor in drag coefficient. Drag coefficient is in the range of 0.44-0.45 for both spheres. From Fig. 3, the string angle increases with increase in velocity of air. Reynolds number is also increasing, when string angle is 1° , Reynolds number is 23163 & at 10° , it is 72799 for concrete sphere. For same string angles mentioned above for rubber ball, the Reynolds numbers are 18823 & 71764 respectively. From Fig. 4 Drag coefficient observed is constant for all the string angle considered, except for string angles 1° for rubber ball and $3^\circ, 6^\circ$ and 10° for concrete ball.

Authorship Contributions

The authors contributed equally to this work.

Conflict Of Interest

The authors declare no potential conflicts of interest regarding the research, authorship, or publication of this manuscript.

Ethics

No ethical issues were associated with the publication of this manuscript.

REFERENCES

1. Butkar, U. D., & Gandhewar, D. N. (2022). ALGORITHM DESIGN FOR ACCIDENT DETECTION USING THE INTERNET OF THINGS AND GPS MODULE. *Journal of East China University of Science and Technology*, 65(3), 821-831.
2. Butkar, U. D., & Gandhewar, N. (2022). AN RESULTS OF DIFFERENT ALGORITHMS FOR ACCIDENT DETECTION USING THE INTERNET OF THINGS. *Harbin Gongye Daxue Xuebao/Journal of Harbin Institute of Technology*, 54(10), 209-221.
3. N. V. A. Ravikumar, R. S. S. Nuvvula, P. P. Kumar, N. H. Haroon, U. D. Butkar and A. Siddiqui, "Integration of Electric Vehicles, Renewable Energy Sources, and IoT for Sustainable Transportation and Energy Management: A Comprehensive Review and Future Prospects," 2023 12th International Conference on Renewable Energy Research and Applications (ICRERA), Oshawa, ON, Canada, 2023, pp. 505-511, doi: 10.1109/ICRERA59003.2023.10269421
4. A. K. Bhaga, G. Sudhamsu, S. Sharma, I. S. Abdulrahman, R. Nittala and U. D. Butkar, "Internet Traffic Dynamics in Wireless Sensor Networks," 2023 3rd International Conference on Advance Computing and Innovative Technologies in Engineering (ICACITE), Greater Noida, India, 2023, pp. 1081-1087, doi: 10.1109/ICACITE57410.2023.10182866.
5. Butkar, U. (2015). User Controlling System Using LAN. *Asian Journal of Convergence in Technology*, 2(1).
6. Butkar, U., Pokale, N.B., Thosar, D.S. and Potdar, S.R. 2024. THE JOURNEY TO SUSTAINABLE DEVELOPMENT VIA SOLAR ENERGY: A RECAP. *ShodhKosh: Journal of Visual and Performing Arts*. 5, 2 (Feb. 2024), 505-512. DOI:<https://doi.org/10.29121/shodhkosh.v5.i2.2024.2544>.
7. Vaishali Rajput. (2024). "Quantum Machine Learning Algorithms for Complex Optimization Problems". *International Journal of Intelligent Systems and Applications in Engineering*, 12(4), 2435 -. Retrieved from <https://ijisae.org/index.php/IJISAE/article/view/6663>
8. Butkar, U. D., Sabale, R. P., & Patil, P. C. (2024). THE FUTURE OF TRANSPORTATION: A COMPREHENSIVE ANALYSIS OF ELECTRIC VEHICLES AND THEIR IMPACT ON SUSTAINABILITY, ECONOMY, AND SOCIETY. *ShodhKosh: Journal of Visual and Performing Arts*, 5(3), 900-907. <https://doi.org/10.29121/shodhkosh.v5.i3.2024.3431>
9. D. S. Thosar, R. D. Thosar, P. B. Dhamdhare, S. B. Ananda, U. D. Butkar and D. S. Dabhade, "Optical Flow Self-Teaching in Multi-Frame with Full-Image Warping via Unsupervised Recurrent All-Pairs Field Transform," 2024 2nd DMIHER

International Conference on Artificial Intelligence in Healthcare, Education and Industry (IDICAIEI), Wardha, India, 2024, pp. 1-4, doi: 10.1109/IDICAIEI61867.2024.10842718.

10. P. B. Dhamdhere, D. S. Thosar, S. B. Ananda, R. D. Thosar, D. S. Dabhade and U. D. Butkar, "A Semantic Retrieval System Using Imager Histogram Computation to reduce Trademark infringement based on the conceptual similarity of text," 2024 2nd DMIHER International Conference on Artificial Intelligence in Healthcare, Education and Industry (IDICAIEI), Wardha, India, 2024, pp. 1-6, doi: 10.1109/IDICAIEI61867.2024.10842701.
