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An automated system for navigating object mounts within a wind tunnel facility

Adithya Sundar[1,*], *Aafrein Begam* Faazil[2,**], *Sundar Rajan Arjunan* Achary[3,***], and *Kizhakkelan Sudhakaran* Siddharth[1,****]

[1]Department of Mechanical Engineering, Amity University Dubai (AUD), Dubai International Academic City, Dubai 345019, United Arab Emirates
[2]Department of Aerospace Engineering, Amity University Dubai (AUD), Dubai International Academic City, Dubai 345019, United Arab Emirates
[3]Royal Arab Metal Works L.L.C, Ras Al Khor Industrial Area, Dubai, United Arab Emirates

Abstract. From an engineering point of view, understanding how the flow behaves downstream from solid objects is essential. The current configuration of the Armfield subsonic wind tunnel (computer controlled C15 – 10 model) does not provide uniform guidance for objects in the test section, which is essential for collecting data on flow behavior at varying downstream locations. The paper elaborates on the characteristics of an automatic mechanism designed to facilitate the traversal of objects in the wind tunnel facility. The configuration consists of an altered base plate within the test section of the wind tunnel, on which the mounting system for the appropriate objects is attached. A belt mechanism located beneath the plate, external to the test section, enables movement of mounted objects. The motor configuration employed to drive the belt allows the mounted object to traverse at the necessary speed, which is determined by the application used to measure flow dynamics. Measures taken to prevent air flow leakage from the wind tunnel facility are also outlined.

1 Introduction

The wake generated behind various models of interest has been the subject of extensive study in the past. Bodies with blunt shapes frequently produce significant wakes and are commonly utilized in the investigation of wake phenomena. Various instruments have been documented as successful in analogous research. In 1984, Ostowari developed a swinging pressure sensor to explore the entire region of separation. [1] G. W. Brune examined the wake analysis technique formulated for wind tunnel tests at Boeing, detailing the principal aspects of the methodology, which included a pneumatic probe. The noteworthy characteristics of this developed technique were also discussed in the article. [2] M. Kiya et al. characterized the instabilities and vortex structure observed in the wake of three-dimensional bluff bodies. The authors noted that, in the wake of a sphere, no helical structures were observed at high *Re* numbers. [3] In 2006, G. Yun et al. examined the wake behind a sphere in turbulent flow

*e-mail: adithya704@gmail.com
**e-mail: aafreinfaazil@gmail.com
***e-mail: sales@royalarabme.com
****e-mail: ssudhakaran@amityuniversity.ae

at subcritical *Re* values. It was reported that at the higher *Re* considered, the flow near the wake was turbulent, whereas at the lower *Re*, fewer vortices were detected in the sphere's wake. [4] Subsequently, flow visualization techniques were employed by some researchers to investigate the flow downstream of a sphere and a cylinder. It was reported that more concentrated vortices were observed in the wake of a sphere than in that of a cylinder. [5] In 2013, the wake produced by a three-blade wind turbine was analyzed experimentally through wind tunnel testing and using the hot-wire method to characterize the wake resulting from it. [6] Trevor S. Orr et al. conducted experiments in a linearly stratified fluid, investigating the wake of a spherical body in horizontal motion within the fluid. For experiments conducted at $Re = 1000$, the authors reported that buoyancy effects are evident in all regions of the sphere wake. [7]

Initial research utilizing a wake rake was reported to have been conducted on the Beech Starship prototype within a wind tunnel environment. The author noted that measurements obtained via the wake survey rake could be applied to investigate localized sections rather than evaluating the absolute drag on a surface. [8] Experimental analyses were undertaken on NACA 0012 and NACA 0015 aerofoils at high angles of attack.*Re* The investigation employed a standard rake typically used in wind tunnel tests in conjunction with a dynamic wake rake. [9] Subsequently, an analysis employing rakes was executed to effectively characterize the wake behind a disk. These rakes were harnessed to gather hot-wire data, which was subsequently utilized for a comparative study alongside results from an analogous experimental study on the turbulent wake of a far jet. [10] A study aimed at examining the forces and moments impacting a NACA 0018 aerofoil utilized a rake system to investigate the separation region and its pattern. The rake employed in the study featured fifty pressure taps for measuring total pressure and twelve for measuring static pressure head. It was observed that beyond a certain angle of attack, the separation region progressed further downstream. [11] Subsequently, another study employed a rake to examine the wake characteristics of a C-17 Globemaster III within a wind tunnel. Results derived from wake survey measurements suggested that as the angle of attack was increased, the low-pressure separation regions remained relatively unchanged. Furthermore, these results were preserved for future application in the validation of CFD analysis. [12] Additional pertinent wind tunnel studies include those cited in [13] and [14], which utilized diverse measurement methodologies to quantify flow dynamics across various applications.

The present study endeavors to implement a mechanism for traversing objects within a wind tunnel facility. This arrangement is designed to effectively facilitate the examination of flow behavior at various downstream locations.

2 Experimental Set-up

In the present study, an Armfield® subsonic wind tunnel was employed. The maximum velocity achievable within the test section, in the absence of any objects obstructing the flow, is $34 ms^{-1}$. The introduction of an object into the flow reduces the attainable free stream velocity. The test section measures approximately $455 mm$ in length along the flow direction. It features a square cross-section with dimensions $150 mm \times 150 mm$. The entirety of the test section is constructed from clear acrylic, facilitating any flow visualization experiments. Figure 1 illustrates a schematic of the front view of the wind tunnel used in the study, where a cricket ball is shown as the object of investigation. Additionally, the coordinate axes utilized in this study are depicted in Fig. 1.

The current configuration of the wind tunnel, as supplied by manufacturers, includes provisions for the mounting of solid objects with suitable geometries along the length of the test section. This study focuses on improving the mounting capability by incorporating a

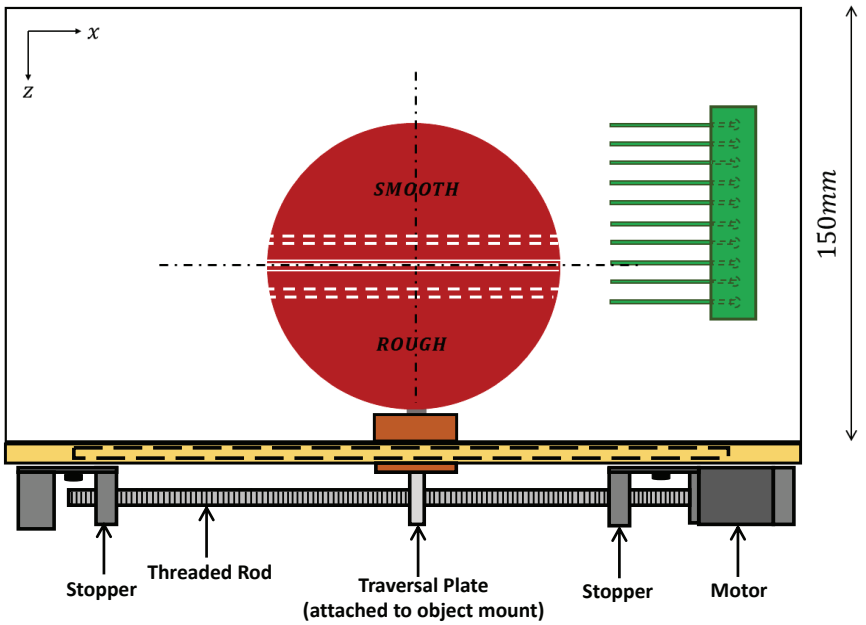


Figure 1. A schematic representation of the front view of the wind tunnel test section is provided, showcasing the developed traversal mechanism affixed to the base plate. The object is maneuvered in the negative $x-$ direction. The wake-rake system is employed to ascertain instantaneous spatio-temporal information pertaining to pressure values.

mechanism to traverse objects at a constant speed in the $x-$direction during experiments. This traversal can be advantageous when used in conjunction with flow quantification techniques typically employed in wind tunnel facilities, such as the imaging method applied by Faazil et al. [15–17] More advanced techniques, such as particle imaging velocity, would also benefit from the proposed modification in assessing the dynamics of flow around solid objects. [18] The proposed configuration is illustrated schematically in Fig. 1. The setup comprises a modified base plate, a traversal plate to which the object mount is affixed, and a motorized arrangement for object mount traversal. All components are installed externally to the test section to prevent intrusion during flow analysis.

Figure 2 illustrates the photograph of the wake survey rake system, a measurement device utilized in this study. When operated in conjunction with a manometer setup, this equipment provides pressure values at specific spatial locations within the test section. As depicted in Figure 2, the rake system comprises ten stainless steel tubes (SS), which are aligned parallel along the $z-$ direction, with Tube 1 positioned at the top. Each tube is connected to a manometer within an inclined manometer bank facility, thus enabling the acquisition of pressure values at ten distinct spatial locations along the $z-$ direction. It is important to highlight that the tubes are oriented perpendicularly to the flow direction ($x-$ direction). The arrangement of the tubes is precisely symmetrical in both the y and z directions. The configuration of the tubes is additionally represented schematically in Figure 1. These tubes detect the pressure values of the flow occurring downstream of an object mounted inside the test section, contingent upon the $x-$ distance between the object and the tubes.

A significant consideration pertaining to the positioning of the wake survey rake system involves its immobility within the tunnel environment. Thus, to capture pressure data at

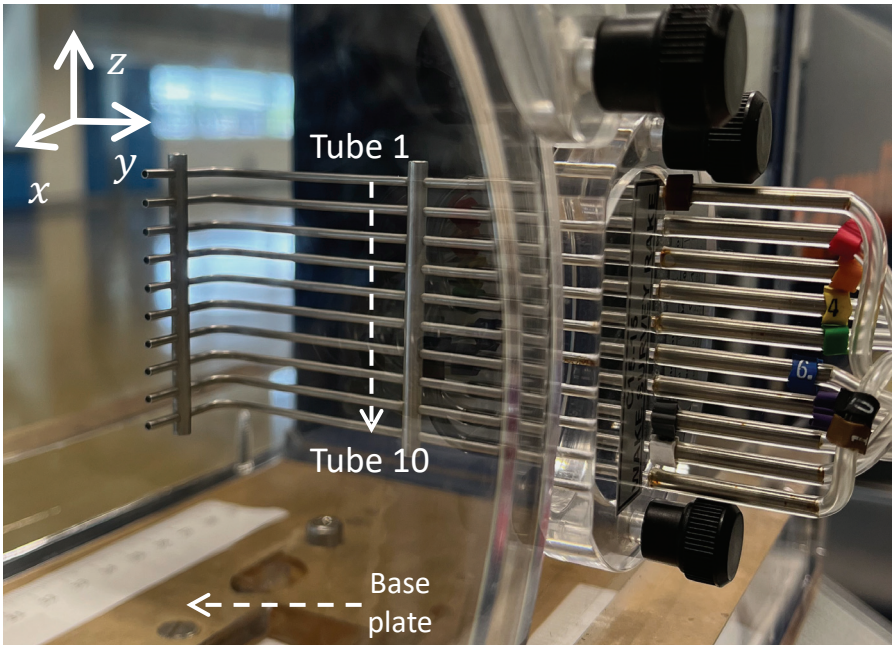


Figure 2. The positioning of the wake rake system in the wind tunnel facility. The system comprises of ten SS tubes facing the flow occurring in the negative $x-$direction as shown. The placing of the tubes in the $z-$direction is also shown.

various downstream points, the ball must be repositioned in the negative $x-$ direction. The objective of the current study is to establish a traversal mechanism for the object in the $x-$direction, drawing motivation from the technique articulated by Faazil and co-authors [15]. It should be emphasized that the traversal mechanism can potentially be integrated with other flow measurement methodologies commonly employed in wind tunnels [19], although the existing setup is specifically designed to function with the rake system available in Armfield® subsonic wind tunnels. The traversal mechanism comprises a mounting configuration for the solid object, which can be propelled using a motor system at a predetermined constant speed. All components of the system are affixed to a modified acrylic base plate. Comprehensive details of the setup are provided below.

2.1 Base plate

The primary component of the mechanism is an acrylic plate, with a thickness of $8mm$, precisely positioned at the bottom of the test section. Holes are incorporated along the plate's edge to facilitate bolting to the test section. A longitudinal rectangular slot, measuring $250mm \times 20mm$, is drilled centrally along the plate. This width ensures minimal air leakage through the slot while allowing for the secure clamping of the object mount onto the traversing rod. Figure 3 displays a photograph of the modified base plate, where the central drilling of the slot is evident. The mounting arrangement can also be observed in Fig. 3, with further details available in Section 2.2. A measuring scale is adhered to the top of the base plate to measure the distance covered during each experiment. The test section's transparency aids in manually verifying this distance.

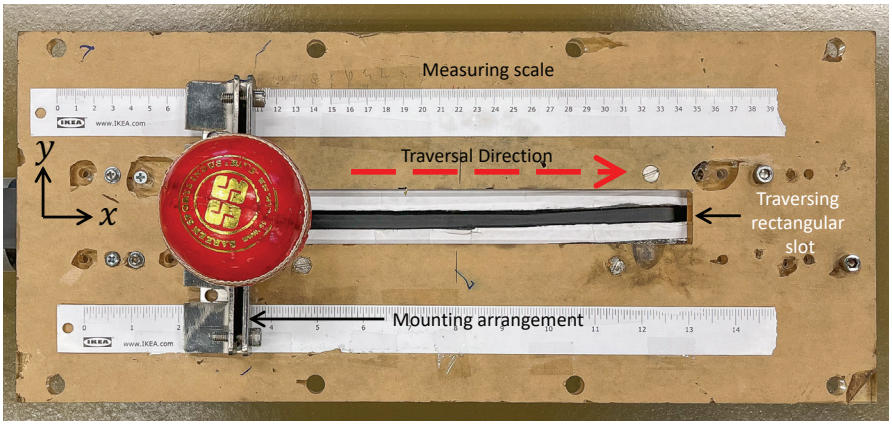


Figure 3. A photograph depicting the top view of the modified base plate. The object of interest is fixed upon the mounting assembly. The movement of the object can be executed in the positive $x-$ direction along the depicted rectangular slot.

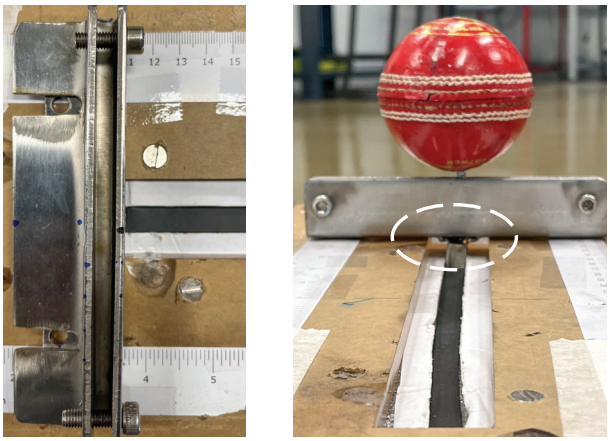
2.2 Mounting arrangement

The mounting configuration for the object comprises two parallel plates, as illustrated in Fig. 3. A rod, affixed to the object, is securely positioned between the plates by a bolting mechanism on both sides, facilitating the retention of the object within the test section. A magnified image of this setup is presented in Fig. 4(a). The photograph reveals that the two plates can be fastened together using an Allen key arrangement at both ends of the plate. Figure 4 (b) shows the configuration with the object mounted (a cricket ball, in this instance), when observed from the front. The object is capable of being mounted at any $y-$ location and traversing in the $x-$ direction. The highlighted section illustrates the connection between the mounting plates and the traversal plate located beneath the test section. (For further clarity, refer to Fig. 1). The traversal plate features a drilled hole permitting the passage of a threaded rod, the specifics of which are provided in the next subsection.

2.3 Threaded rod and motor

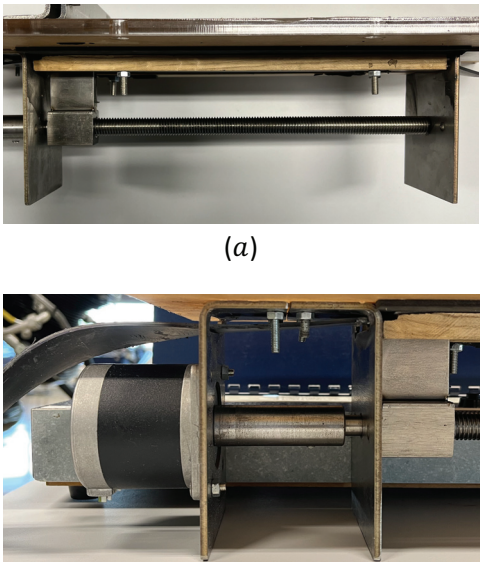
The mounting arrangement, connected through the traversal plate, is maneuvered along the rectangular slot by a motor that actuates movement on a threaded rod. Figures 5 (a) and (b), respectively, present photographs of the threaded rod and motor within the assembled configuration. The motor enables the traversal plate to move along the threaded rod. The velocity of the traversal depends on the measurement methodology used in each investigation. The selected motor covers an extensive spectrum of speeds, which makes it suitable for various measurement techniques.

Figure 5(a) illustrates the threaded rod located beneath the base plate, with the traversal plate visible in the image. Visible at both ends of the rod are two stoppers, which are installed to prevent unintentional overshoot of the object within the test section. A front view representation is also available in Fig. 1. The stopper on the right serves to prevent a collision between the object and the rake system. Furthermore, Fig. 5(b) depicts the motor arrangement beyond the stopper, which is integral to the entire mechanism.



(*a*) (*b*)

Figure 4. Top and front views of the mounting arrangement are shown in (a) and (b), respectively. The object is secured by tightening the two plates with an allen screw on the edges. The plates connect to the threaded rod on the bottom of the base plate via the central slot, as shown in (b).



(*a*)

(*b*)

Figure 5. The threaded rod for traversal of the object mount is shown in (a), the motor arrangement at one end of the threaded rod is shown in (b).

2.4 Moving rubber belt

Despite substantial efforts to minimize the width of the central slot to prevent air leakage, it remains impossible to achieve a completely airtight seal. This is attributed to the residual space within the slot, in addition to the area occupied by the rod and traversal plate that connect the mounting mechanism to the threaded rod. An enhancement of the system was achieved by incorporating a moving belt affixed to the base of the slot, which travels in unison with the mount's traversal. This configuration ensured that the slot remained fully sealed throughout the movement, thereby preventing any air flow from escaping the test section through the slot. The end of the moving belt is visible in Fig. 5(b). It is observed that the belt stretches beyond the plate through the slot when the mount moves towards either end.

3 Conclusion

An experimental setup has been developed that facilitates the traversal of the object mount within a wind tunnel facility. This setup includes a belt mechanism situated beneath a rectangular slot that is symmetrically drilled along the acrylic base plate of the test section. The dimensions and weight of the base plate have been meticulously selected to ensure compatibility with the base of the wind tunnel test section and to prevent transmission of vibrations to the facility. A clamping system is used to accurately position the object within the test section. The mounting mechanism is designed to allow the object to be positioned at any specified location in the lateral direction during experimentation. The externally positioned motor configuration enables the longitudinal movement of the mounted object along the predetermined location. The selection of traversal speed is contingent on the measurement technique employed in the experiment, with a wake survey rake and a manometer set-up having been utilized in the present study. The constructed arrangement allows for the following functionalities within the wind tunnel:

- Measurement of pressure and velocity at any point within the test section.
- Acquisition of three-dimensional data on downstream flow dynamics around solid objects.
- Utilization of most contemporary intrusive and non-intrusive techniques for flow measurement.

References

[1] C. Ostowari, A rapid technique for measuring and visualizing the extent of separated flow, Experiments in fluids **2**, 67 (1984).
[2] G. Brune, Quantitative low-speed wake surveys, Journal of Aircraft **31**, 249 (1994).
[3] M. Kiya, H. Ishikawa, H. Sakamoto, Near-wake instabilities and vortex structures of three-dimensional bluff bodies: a review, Journal of Wind Engineering and Industrial Aerodynamics **89**, 1219 (2001).
[4] G. Yun, D. Kim, H. Choi, Vortical structures behind a sphere at subcritical reynolds numbers, Physics of Fluids **18**, 015102 (2006).
[5] M. Ozgoren, E. Pinar, B. Sahin, H. Akilli, Comparison of flow structures in the downstream region of a cylinder and sphere, International Journal of Heat and Fluid Flow **32**, 1138 (2011).
[6] H. Schümann, F. Pierella, L. Sætran, Experimental investigation of wind turbine wakes in the wind tunnel, Energy Procedia **35**, 285 (2013).

[7] T.S. Orr, J.A. Domaradzki, G.R. Spedding, G.S. Constantinescu, Numerical simulations of the near wake of a sphere moving in a steady, horizontal motion through a linearly stratified fluid at re= 1000, Physics of Fluids **27**, 035113 (2015).

[8] N. PFEIFFER, Wake rake studies behind a swept surface, canard aircraft, in *6th Applied Aerodynamics Conference* (1993), p. 2552

[9] A. Seifert, L. Pack, Oscillatory excitation of unsteady compressible flows over airfoils at flight Reynolds numbers, in *37th Aerospace Sciences Meeting and Exhibit* (1999), p. 925

[10] P.B. Johansson, W.K. George, S.H. Woodward, Proper orthogonal decomposition of an axisymmetric turbulent wake behind a disk, Physics of Fluids **14**, 2508 (2002).

[11] W. Timmer, Two-dimensional low-reynolds number wind tunnel results for airfoil naca 0018, Wind engineering **32**, 525 (2008).

[12] K. Bergeron, M. Hayes, J. Aronoff, R. Charles, C-17 low speed wind tunnel wake-vortex study, in *47th AIAA Aerospace Sciences Meeting including The New Horizons Forum and Aerospace Exposition* (2009), p. 1482

[13] M.D. Maughmer, C.J. Axten, L.P. Metkowski, Experimental results for a low-reynolds-number airfoil in a low-turbulence wind tunnel, Journal of Aircraft pp. 1–7 (2023).

[14] J.P. Marcheggiani, S. Glegg, Noninvasive measurement methods for transient flows in wind tunnels, AIAA Journal **61**, 2208 (2023).

[15] A.B. Faazil, A.M. Eapen, K.S. Siddharth, An anomalous method of using a camera in determining the velocity distribution within a boundary layer, Flow Measurement and Instrumentation **90**, 102334 (2023).

[16] A.B. Faazil, A.R. Farhatnuha, K.S. Siddharth, Unraveling the near vicinity pressure field of a transversely spinning cricket ball, Physics of Fluids **36** (2024).

[17] C. Philip, M. Ayyub, M. Ajay, A.B. Faazil, K.S. Siddharth, Magnus regimes of a spinning table tennis ball: Insights into wake profile alteration, Physics of Fluids **37** (2025).

[18] R.J. Adrian, J. Westerweel, Particle image velocimetry, 30 (Cambridge university press, 2011)

[19] D. Bynum, R. Ledford, W. Smotherman, Wind tunnel pressure measuring techniques, Vol. 70 (North Atlantic Treaty Organization, Advisory Group for Aerospace Research . . . , 1970)