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Wind Tunnel Test of UTM Sport Complex

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Abstract – *Apart from sporting purposes, sport complexes are also increasingly being used for concerts and other events with large spectator attendance. As such, the safety of the sport complex is very important to ensure all spectators and occupants in and inside and nearby the stadium are safe. One of the initial work to ensure safety is to conduct an aerodynamic characteristic study of the forces and moments of the sport complex using a wind tunnel to provide data for the structural design engineers and architects. Hence, the objective of this project was to perform a wind tunnel testing on UTM sport complex mode to obtain its aerodynamics characteristics. The tests were conducted in the UTM Low Speed Wind Tunnel by using semi-span balance to obtain the forces and moments. The maximum coefficient drag of force is 0.115 occurs at 20^{0} yaw angle with the wind speed 5.56m/s, whereas the maximum coefficient of axial force is 0.025 occurs at 0^{0} yaw angle with the wind speed 8.33m/s. The maximum moment coefficient is 0.01 at -30^{0} for axial (rolling). Thus, with these values the UTM sport complex can be designed safely.*

Keywords: UTM sport complex, wind tunnel experiments

1.0 INTRODUCTION

The main objective of this study is to investigate the aerodynamic characteristic of the UTM sport complex. The comfort of the spectator is very important and it includes the protection of the spectators at the stands from wind and rain. The roof of the sport complex also should be strong to withstand the high speed of wind. This is to avoid catastrophic accident such as that happened to Welkom Stadium as shown in Fig. 1, whereby the roof of the stadium flew-off under unpredictable strong wind and tornado.

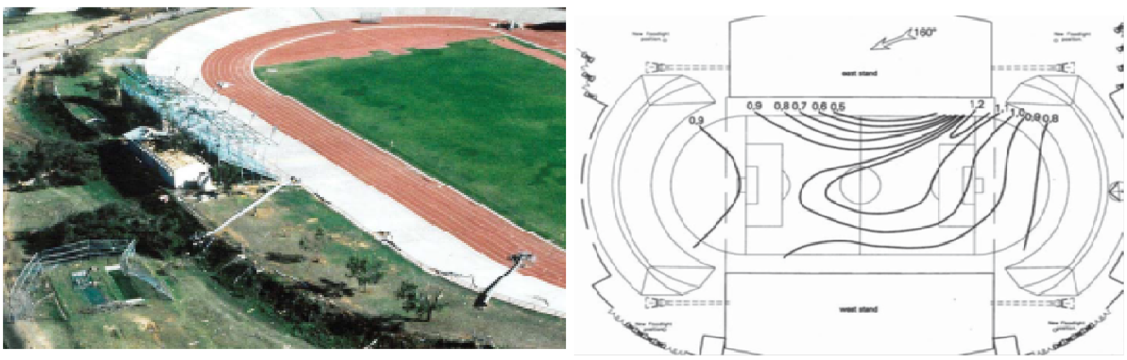

Figure 1: Devastation of the Welkom stadium and the airflow contour inside the stadium [1].

The highest mean daily wind speed at West Malaysia is 3.8 m/s was recorded at Mersing, Johor and the highest maximum wind speed is 41.7m/s was recorded at Kuching, Sarawak on 15 September 1992 [2]. At Senai, the highest wind speed recorded was 10.1m/s on January 2014 [2]. In the construction and testing of the UTM stadium, the wind speed recorded at Senai airport was taken as the reference design speed due to the proximity of Senai airport to UTM (about 6 km – direct distance). Senai airport has a dedicated Meteorological office with good quality and reliable wind measurements. The alignment of the runway on the North Easterly-South westerly direction (Runway 16-34) indicates that the general wind direction that changes every six-month period.

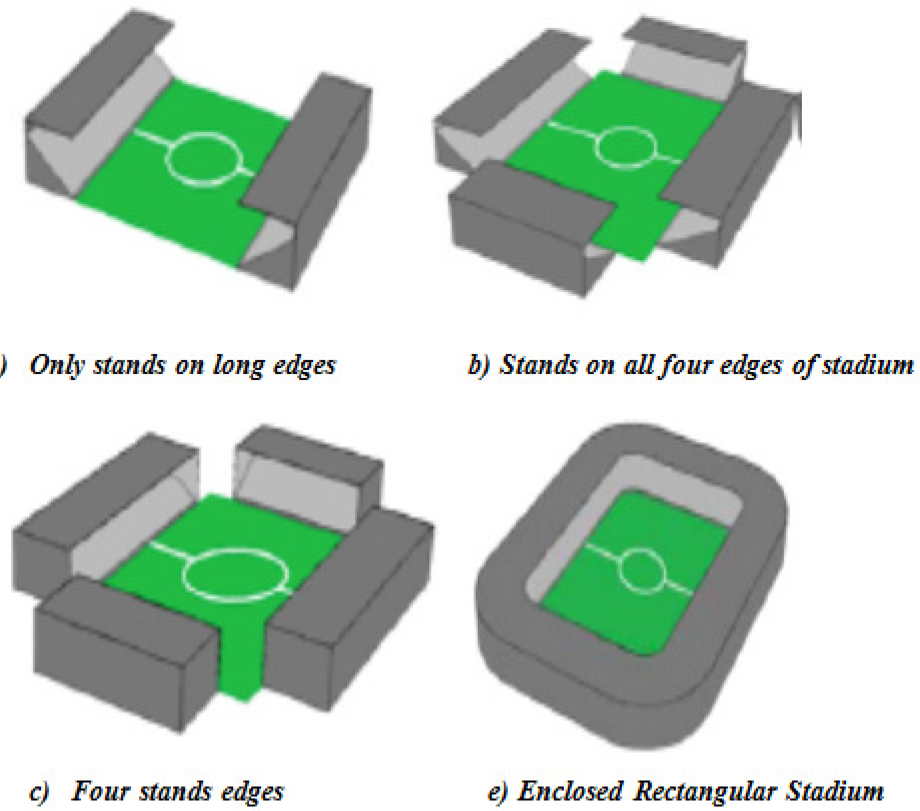

Figure 2: Various types of stadium design [3].

Many existing designs of sport complex rain shelter has not been adequately taken into consideration because most of the roofs are designed with vertical rainfall. This is because the designer does not give much attention to the wind flow and the rain that blows onto the stands and the roof. The protection from the wind and rain are the main aspect of spectator comfort in open sport complex. Further, generally, the bottom rows of many sport complexes are unpopular because of inadequate shelter from precipitation. Thus, some sport complexes have been tackling this problem by designing an excessively large roof overhang or by completely closing the stadium roof as shown in the different design of stadiums as in Fig. 2 [3]. Nevertheless, some disadvantages are occurred with these options, such as reduced lifetime of natural and semi-artificial grass covers due to insufficient daylight, excessive dampness and insufficient carbon dioxide (CO_2) supply, insufficient smoke removal from inside the stadium area [5]. Therefore, open sport complex is chosen and a compromise has to be found between a roof that performs well in the above mentioned issues, but that also

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provides sufficient shelter. Several type of sport complexes with such roofs are illustrated below in Fig. 3.

Figure 3: (a) Grotenburg Stadium, Uerdingen, Germany (b) Netanya Stadium, Netanya, Israel (c) Gwangju World Cup Stadium, Gwangju, South Korea and (d) Estadio Municipal de Braga, Portugal [4].

1.1 Design of UTM Sport Complex

The sport complex is an outdoor football stadium that located at the south campus of the University Teknologi Malaysia, Skudai. On September 2011 the stadium was officially opened and currently has a seating capacity of 4,000 [4]. The natural grass playing field runs in the traditional north-south configuration and sits at an elevation of 5100 feet (1554m) above sea level. Fig. 4 shows the overall view of the UTM stadium. Fig. 5(a) and 5 (b) the detail dimensions of the UTM sports complex design.

Figure 4: Overall view of the UTM sports complex.

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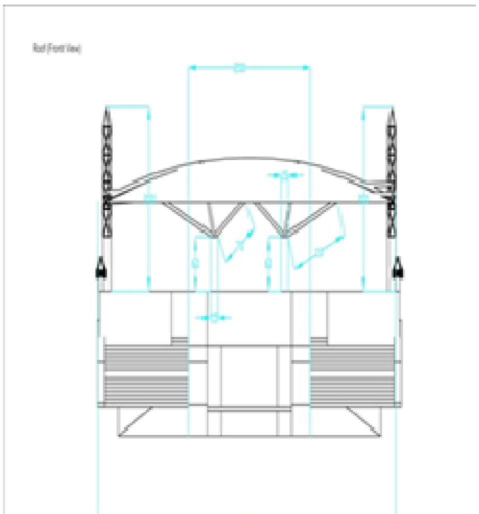

Figure 5 (a): Front view and dimensions of the UTM sport complex.

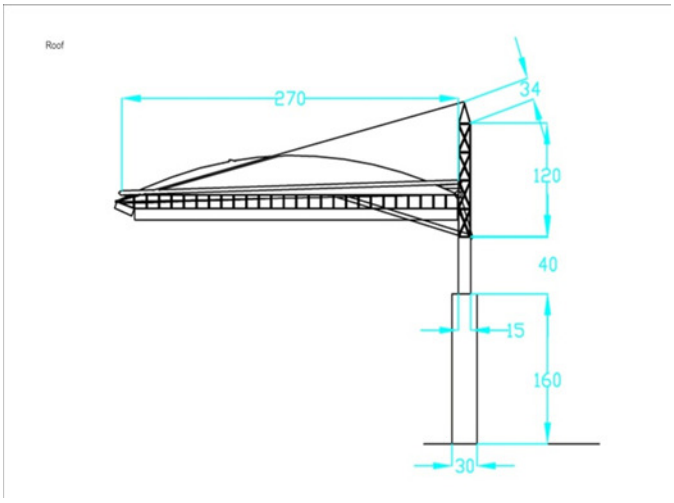

Figure 5(b): Side view and dimensions of the UTM sport complex.

2.0 METHODOLOGY

2.1 Experimental Setup

The investigation was conducted in the Universiti Teknologi Malaysia Low Speed Wind tunnel (UTM-LST) Aeronautical Laboratory facility. This wind tunnel facility is a closed-circuit, single-return, atmospheric wind tunnel capable of producing a maximum speed of 80 meter per second. Cross sectional dimension of the test section is 2m (breadth) x 1.5m (height) x 5.8m (length) (Note: It is the only and biggest of its kind in South East Asia) [5].

The model is made of wood and its scaled at 1:1000. However, the actual stadium was constructed mainly with concrete and steel structure. In a static wind tunnel model test, the important aspect is the shape of the model that will provide the forces and moments as required for the design purposes. Only certain strength of the model is required to withstand

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the wind speed. As such construction material does not influence the result. The results of the forces and moments are converted into co efficient.

The semi-span balance was used to obtain the measurement due to its ease for the assembly with the stadium model because the upper surface of the balance has many screw holes that ease the assembly. The diameter of the screw holes and the distance between the holes are measured. The measurement is transferred to the below surface of the model by marking it using a marker pen. The model is drilled by a drilling machine at the marked points used for assemble and ensure that the model is located at the middle of the wind tunnel. The model is assembled to the balance by using two screws to ensure the model will not move from the balance during the experimenting. The gap as shown in Fig. 6 between the model and the base of the test section is very important to get good results. The Fig. 7 below shows the model is assembled to the balance.

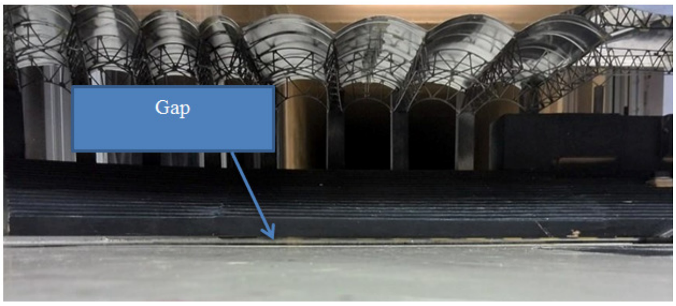

Figure 6: Gap between the Model and the Floor Surface.

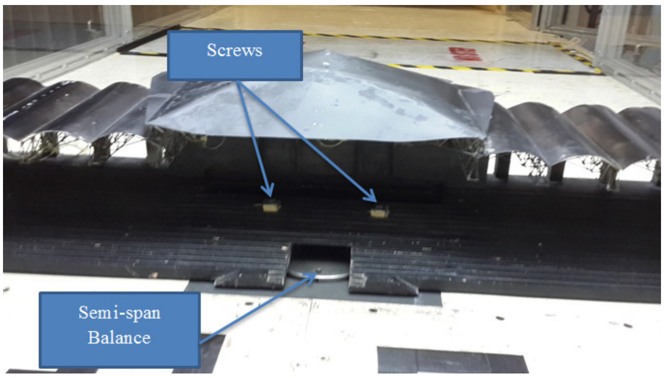

Figure 7: Attachment model to the Semi-Span Balance.

The axis of this experiment follows the balance axis as shown in Fig. 8.

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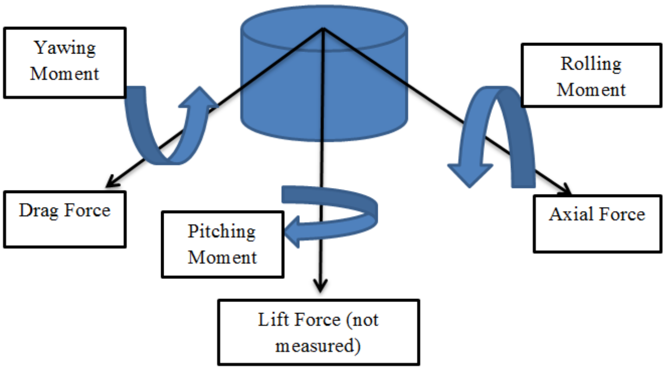

Figure 8: Coordinate system.

2.2 Test Configuration

i. Wind-off, the model's yaw angles were varying from -25° to 25°.
ii. Wind-on, at speed of 5.56 m/s, 8.33 m/s, 11.11m/s, and 13.89
iii. Model's yawing angles were varied from -25° to 25°.

The corresponding approximate wind speed as in Table 1. Seal level pressure and density are used. The model is tested at 4 different Reynolds number where is given as below,

$$\mathrm{Re} = \frac{Vc}{\nu}$$

The equation to obtain the coefficients are

$$C = \frac{F}{\frac{1}{2}\rho V^2 S}$$

Table 1: Reynolds number of the air flow.

Speed (m/s)	Reynolds number
5.56	88573.0711
8.33	132700.3026
11.11	176986.8381
13.89	221273.3737

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Table 2: Correction Factors and Moment Transfers [10].

Symbol	Meaning	Dimension
δ	Wall Correction	0.115
$\varepsilon\ sb_{wing}$	Wing Solid Blockage Correction	0.00012
$\varepsilon\ sb_{fuselage}$	Fuselage Solid Blockage Correction	0.00945
ε_{wake}	Wake Blockage Correction	0.02163
ΔX Fore/Aft	Moment Transfer	0.11 m
ΔY	Moment Transfer	0.04 m
ΔZ	Moment Transfer	0 m

3.0 RESULTS AND DISCUSSION

In Fig. 9, with a wind speed of 5.56m/s, the maximum drag force coefficient of 0.003 is reached at yaw angle 20^0 while the maximum axial force coefficient of 0.0 is reached at yaw angle of -10^0. At yaw angle -10^0 both drag and axial coefficient is almost equal to zero. The coefficient of axial force is steady and nearly equals to zero because at this speed the axial forces does not depend on the yaw angle. Fig. 10 shows the graph at wind speed 8.33m/s, the drag force is maximum at yaw angle 25^0 while the axial force is almost equal to zero. Fig. 10 shows the highest drag coefficient force is reached at 0^0 yaw angle when the longest part of the grandstand is exposed perpendicular to the wind. Fig. 11 shows the pattern of the drag and axial coefficient is almost equal. The maximum drag and axial coefficient is reached at 0^0 yaw angle.

Fig. 11, (5.56m/s) through Fig. 12 (13.89m/s) show the drag coefficient force is larger than the axial coefficient force because of the drag force produced by the stadium is larger than the axial force. The frontal surface area of the stadium model is bigger than the side surface area. Hence, the forces that are produced due to the frontal area (drag force) are larger than the forces produced from the side area (axial force). The force values are related to the mass of the model and the surface area exposed to the wind. The bigger the surface area of the model the larger the force is produced. The total frontal area is $0.36m^2$ while the side area is $0.054m^2$ with a ratio of 6.66. When the yaw angles changes to -25^0, the surface area that exposed to the wind is reduced because the body axis have move away from the wind axis and this causes the coefficient drag force to become smaller.

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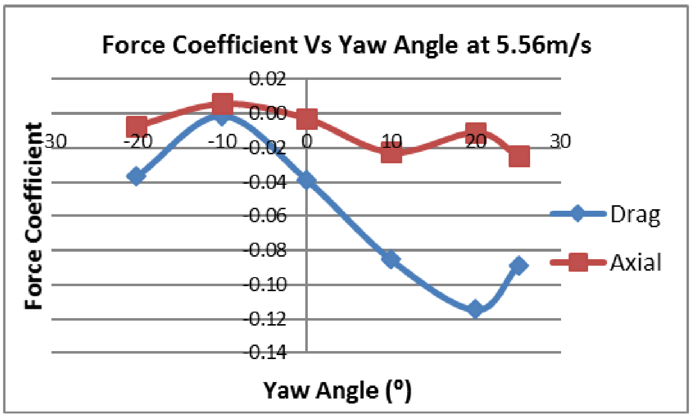

Figure 9: Force Coefficient at different Yaw Angle at 5.56m/s

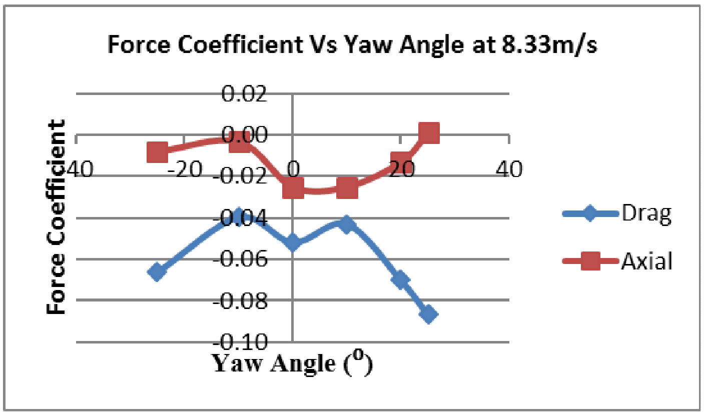

Figure 10: Force Coefficient at different Yaw Angle at 8.33m/s

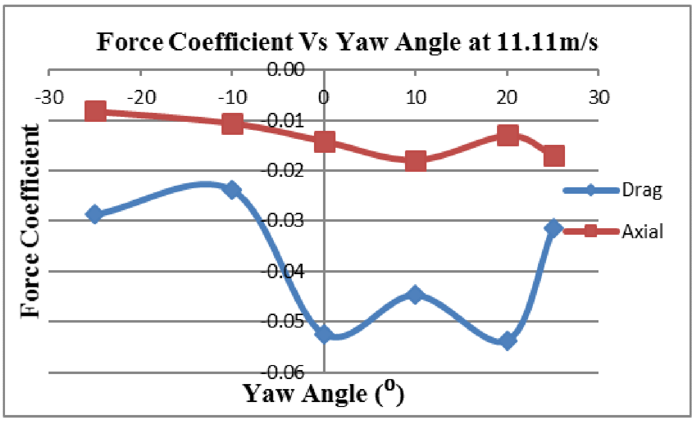

Figure 11: Force Coefficient at different Yaw Angle at 11.11m/s

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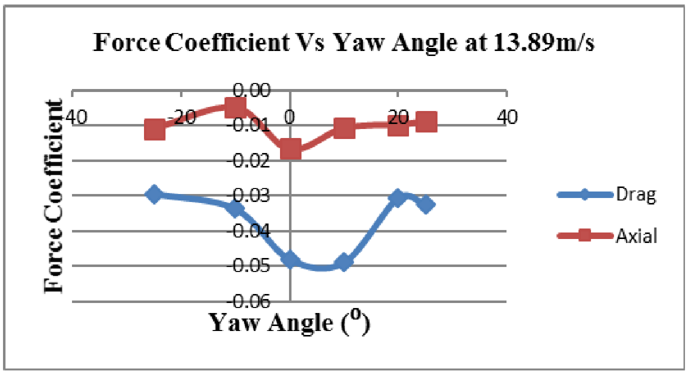

Figure 12: Force Coefficient at different Yaw Angle at 13.89m/s

Fig. 13-16 show the moment coefficients against the yaw angle at four different speeds. The pattern of all the graphs are similar. The moment coefficient lift is highest compared to the drag and axial moment. The moment of force is the product of a distance, d of force from an axis times the magnitude of force, F. The highest force is produced whenever larger from the frontal area and the longest distance.

The maximum moment coefficient lift is reached when the longest grandstand is exposed perpendicular to the wind. When the yaw angle increased the coefficient moment lift is decreased. At yaw angle -25^0, the moment lift coefficient is positive and starts to change the direction of the moment due to the decreasing of the length of the grandstand that is exposed to the wind direction. However, the drag and axial moment coefficients does not change very much due to the changes of the yaw angle.

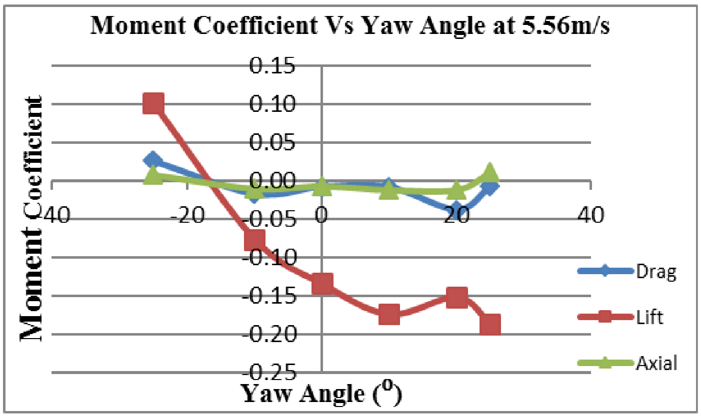

Figure 13: Moment Coefficient at different Yaw Angle at 5.56m/s.

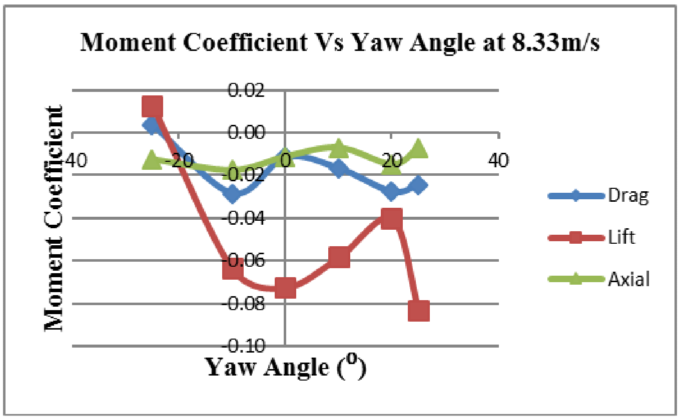

Figure 14: Moment Coefficient at different Yaw Angle at 8.33m/s

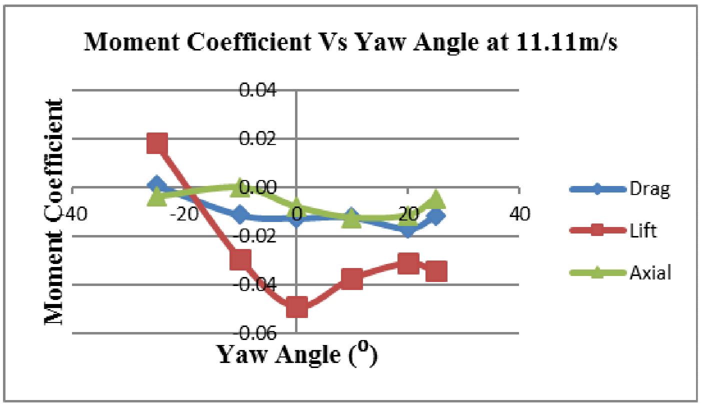

Figure 15: Moment Coefficient at different Yaw Angle at 11.11m/s.

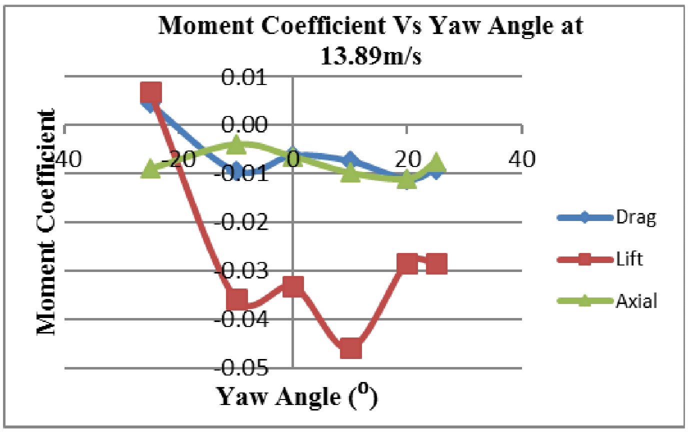

Figure 16: Moment Coefficient at different Yaw Angle at 13.89m/s

Fig. 17 shows the graph of drag force coefficient at different yaw angles with four different speeds. The highest coefficient drag force produced at the lowest speed, 5.56m/s and followed by the coefficient drag force at 8.33m/s, 11.11m/s and lastly 13.89m/s. From these results, the drag force of the UTM sport complex model design does not increase significantly with the increase in wind speed.

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With reference to equation (2), when force, F increases the coefficient, C increases linearly. While with the velocity, V increase the coefficient decreases in square root. Thus, wind velocity had greater effect coefficient force rather than the force of the model.

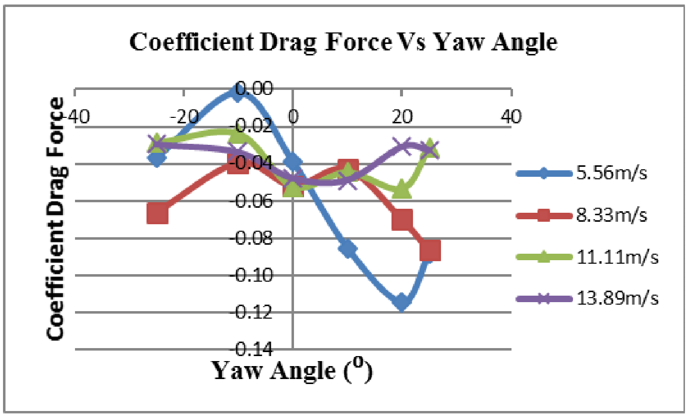

Figure 17: Coefficient of Drag Force at different Yaw Angles with 4 different speeds.

Fig. 18 shows the axial force versus yaw angle at different speeds. The pattern of the graph is not much different except for the wind speed 11.11ms^{-1}. At -10^0 and wind speed of 5.56ms^{-1} the model produces the force opposite direction compared to the other wind speeds. The maximum axial force is produced at 0^0 to 10^0 yaw angle at the 8.33ms^{-1} wind speed. From these results, the axial force produced from the model do not have much influence due to the increasing of the wind speed that impacting the model as previously discussed.

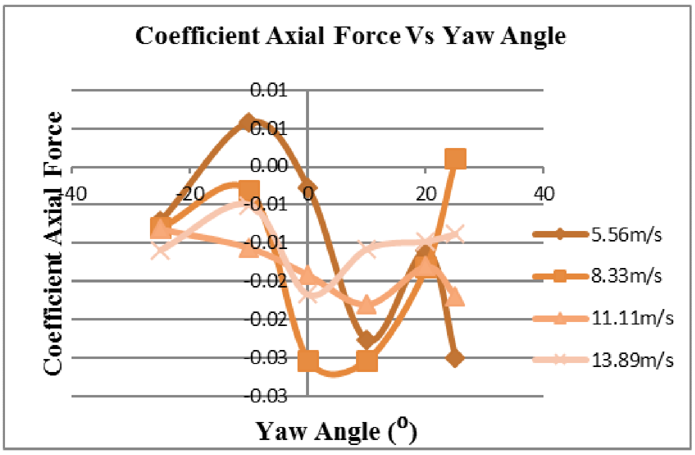

Figure 18: Coefficient of Lift Force at different Yaw Angles with 4 different speeds.

4.0 CONCLUSION

Wind tunnel testing by using semi-span balance has successfully carried out to analyse the aerodynamic characteristic on the UTM sport complex model. There are several factors that could contributes to the errors in the results such as the roughness of the test section wall of wind tunnel, the finishing of the model itself and the modelling of the surroundings of the actual sport complex area. The results obtained in terms of forces and moments are larger

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without these effects. As such this test gives the worst case scenario with higher safety factor for the design. The test also provides the general perspective of the influence of wind on the sports complex. The wind test methodology is a standard test, however, as each stadium are unique by design and its shape, the results from this test cannot be directly compared to other stadiums. Furthermore, the maximum coefficient drag of force is 0.115 occurs at 20^0 yaw angle with the wind speed 5.56m/s, whereas the maximum coefficient of axial forceis 0.025 occurs at 0^0 yaw angle with the wind speed 8.33m/s. The maximum moment coefficient is 0.01 at -30^0 foraxial (rolling). The coefficient force depends on the surface area that is exposed to the direction and the speed of the wind. The coefficient moment on the other hand, depends on the the coefficient force and the distance of the force acting to the axis of reference. Thus, using these values the UTM sport complex can be designed safely

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