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Experimental investigation of golf driver club head drag reduction through the use of aerodynamic features on the driver crown

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Abstract

There are a number of primary design elements of a golf club driver that contribute to performance, including moment of inertia (MOI), coefficient of restitution (COR), and the placement of the driver center of gravity (CG). Although it is not necessarily a primary design objective when compared to MOI or COR, the reduction of aerodynamic drag during a driver swing has also become a design focus due to increasingly larger driver heads and their blunt geometries. The use of aerodynamic features to help reduce pressure drag experienced by a body in a flow field by delaying flow separation has been explored for a wide range of applications, and if used properly could reduce the aerodynamic drag experienced by a driver head. This reduction in aerodynamic drag could lead to increased club head speeds and greater distances off the tee.

Presented are the experimental results of wind tunnel testing conducted in order to quantify the effects of applying aerodynamic features to the crown of a golf driver. Results from player tests quantifying the effect of these features on actual club head speed, and predicted distance gains based on measured drag reduction, are also presented. Overall, the use of these aerodynamic features has shown significant decreases in energy loss due to aerodynamic drag, which has led to significant increases in delivered club head speed and total distance.

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1. Introduction

When designing any golf club, particularly drivers, the primary design elements that have the biggest impact on performance are the moment of inertia (MOI), the coefficient of restitution (COR), and the placement of the center of gravity (CG). Recent driver designs have looked to optimize these primary factors by continually modifying geometric designs and incorporating advanced materials and manufacturing processes. As a result, the aerodynamic drag experienced by a driver during the downswing has also become an important design factor due to increasingly larger driver heads and their blunt geometries. This introduces an important trade-off during the design process, since in many instances design elements that tend to improve the aerodynamics of a club head lead to the non-optimal placement of CG or geometries that do not maximize MOI.

Some previous work by Henrikson et al. (2012) simulated the aerodynamic drag experienced by two different driver head designs and suggested that a significant contributor to the drag experienced by a driver head was due to the early separation of the boundary layer over the crown, which is the top/upper region of the head. The ability of surface features and/or roughness to influence the boundary layer of fluid flow over a body, delaying separation, has been well documented (Bearman and Harvey (1975), Werlé (1980)). This approach to influencing aerodynamic drag has been used in a number of different applications, including aerospace and sport. The use of aerodynamic features to help reduce pressure drag experienced by a body in a flow field by delaying flow separation could, if used properly, reduce the drag forces experienced by a driver head by delaying flow separation over the crown portion of a driver head. This reduction in aerodynamic drag could lead to increased club head speeds and greater distances off the tee.

Presented are the experimental results of wind tunnel testing conducted in order to quantify the effects of applying aerodynamic features to the crown of a driver with the goal of reducing overall drag. These aerodynamic features will be referred to as turbulators for this specific application. In addition to the wind tunnel results, player tests were conducted using the same driver heads quantifying the effect of these features on actual club head speed, the results of which are also presented. Lastly, the distance gains in total carry resulting from any increases in club head speed are estimated and presented.

Fig. 1. Standard driver head (left) and prototype driver head with turbulators

2. Experimental Method

Two driver heads of identical loft and geometry were designated for testing. One of the heads was left alone while the other had features added to the leading area of the crown. These two heads are pictured above in figure 1. The placement of the features was determined based on previous CFD simulation results (Henrikson et al. (2012)), and were placed in a way that would act to energize the boundary layer, causing a boundary layer transition to turbulent and delaying separation. The mass of the standard driver head was 198 grams. The addition of turbulators relocated 1.4 grams of head mass and moved the center of mass upward by 0.010” and forward 0.010”.

2.1. Wind Tunnel Testing

Testing took place at Arizona State University in the School of Energy, Matter, Transport, and Energy’s wind tunnel facility. The tunnel is an open-loop tunnel able to achieve maximum speeds near 104 mph (46.5 m/s) and the octagonal test section’s minor dimension is 24 inches. The heads were mounted to a 3/8 inch diameter steel rod, which was in turn fixed to the force balance with a clamp oriented orthogonally to the setup. A Phantom

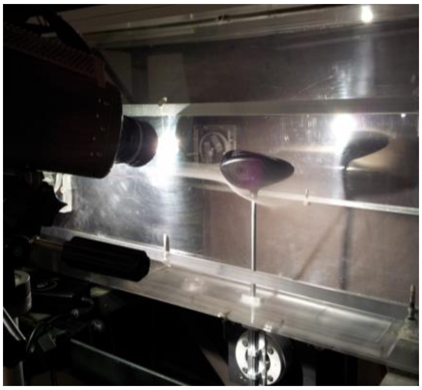

Fig. 2. Experimental Setup

camera was utilized to capture video of the smoke visualization over the crown of the driver heads. Figure 2 above displays the setup utilized to obtain the results presented in this paper. The head was rotated over a number of angles and drag measurements were obtained for each orientation at various speeds. The angles and corresponding speeds presented in the results section are listed in table 1, and are representative of some of the orientations and speeds seen in a typical driver downswing.

Table 1. Club Head Orientation and Flow Speed

Angle, deg	Flow Speed, mph (m/s)
90 (impact)	96 (42.9)
60	84 (37.5)
30	72 (32.1)
0	40 (17.9)

2.2. Player Testing

Player tests were conducted in order to compare the performance, including swing speed, of the standard and the prototype driver heads. Two club heads contained interchangeable hosel geometries, so the same shaft was used in each head during testing. The head masses were confirmed to match, which ensured the built clubs matched with respect to total weight and swing weight. The test used 40 players with a handicap at or below 10 and with typical swing speeds for the target market. Players hit a number of shots with each driver; with care taken to ensure the players were properly warmed up and that no bias was introduced. Performance data was recorded using both the Trackman radar system and a high-speed phantom camera during the test.

3. Results

3.1. Wind Tunnel Results

Wind tunnel testing revealed that both club heads, with and without turbulators, were characterized by comparable amounts of lift and drag for all tested orientations (and corresponding speeds), except at 90 degrees. The significant difference seen when the driver was square to the air flow showed a 2.3 N decrease in drag was observed for the prototype driver head compared to the standard head. A difference in lift/down force was also observed when comparing force balance values for the standard and prototype driver heads when the club head was square. The standard driver head experienced a little over 1.5 N of down force at the impact orientation while the prototype experienced about 0.5 N of lift. Figure 3 displays the lift and drag measurements for both heads.

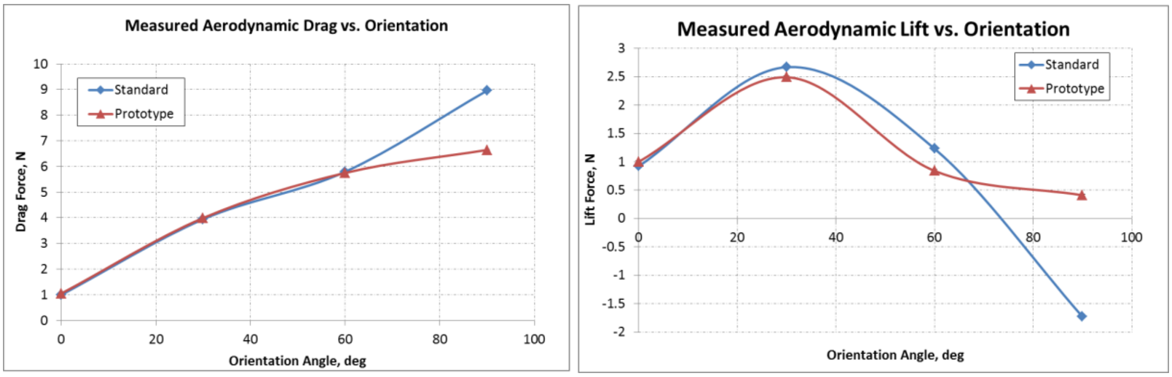

Fig. 3. Measured Aerodynamic Drag and Lift for the Standard and Prototype Driver Heads

Flow visualization was also conducted in the wind tunnel using a stream of smoke in order to verify visually what was being observed through the force balance. Figure 4 displays the smoke visualization of the flow for the standard driver and the prototype driver with turbulators at 83 mph. From these snap shots, it is clear that there is a laminar separation of the flow over the standard head, occurring at the leading edge of the crown. For the prototype driver head, it is clear that flow separation has been delayed significantly, which verifies the decrease in drag force

Fig. 4. Smoke visualization over the standard driver head (left) and prototype driver head (right)

measured on the driver head with turbulators. The recorded Phantom camera video also showed that the driver head without turbulators displayed some unsteady behavior, bobbing up and down, while the prototype with turbulators was more stable.

3.2. Player Testing Results

Although the overall performance of each driver was of interest, including total distance and dispersion, the resulting swing speeds were of primary interest in order to evaluate the effect of the prototype features on aerodynamic drag. The club head speed measurements utilizing the high-speed phantom camera are presented here, as they correlated well with those obtained from Trackman. Figure 5 shows the difference in club head speed between the two different models, and displays an increase in average club head speed of about 1 mph for a test

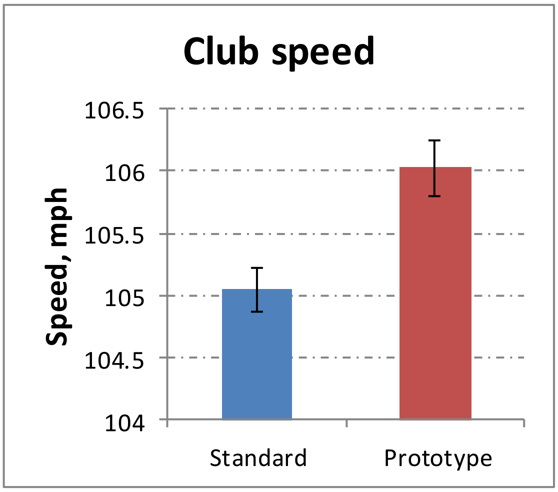

Fig. 5. Club head speed measurements obtained during player testing.

group where the average overall club head speed was in the 105 mph range. For PGA Tour level players who achieve relatively optimal impacts, the ratio of ball speed to club head speed (smash factor) averages around 1.5 (Trackman 2010), which suggests that the resulting increase in ball speed due to the turbulators would be ~1.5 mph for near optimal impacts. Qualitative feedback on looks, feel, and performance, was also obtained from the players who participated in the testing. None of the players stated they could perceive any differences in performance or feel between the two test clubs, though 80% of the players preferred the look of the features while 20% were indifferent.

Utilizing a measured launch angle and spin rate along with the increases in ball speed for near-optimal impacts, the distance gains from aerodynamic improvement can be estimated from a ball flight model. The average spin rate and launch angle with each club during the player test were 3060 rpm and 12.5 degrees, respectively. Utilizing these values along with the corresponding ball speeds, the distance gains due to the turbulators were estimated through the use of a proprietary internal golf ball trajectory model, which produces comparable results to some other published models (Smits 1994). The environmental conditions were set to a temperature of 22 ^{o}C, an altitude of 300 meters, and 10% humidity. The results show a carry distance with the standard driver head of 270 yards while the carry with the prototype head was 274 yards, suggesting a distance gain of 4 yards.

4. Conclusion

Turbulators placed on the driver crown with the purpose of reducing aerodynamic drag have been validated through empirical wind tunnel measurement, flow visualization, and player testing. These features are proven to delay flow separation over the driver crown by influencing the behavior of the boundary layer. The quantitative drag measurements indicated about a 25% reduction in drag for orientations and speeds toward the end of a typical downswing with a 100 mph impact club head speed. Results from player testing show that an increase in driver swing speed can be observed as a result of this reduction in aerodynamic drag. The observed increases in swing speed were on the order of 1 mph. Modeled ball flight resulting from the increased club head speed showed that the aerodynamic improvement, on average, leads to an increase of 4 yards in carry distance. In addition to the decrease in aerodynamic drag, wind tunnel testing showed a change in lift force on the order of 2 N. Changes in lift and drag forces were not perceived by any of the players who participated in testing, as there magnitudes were smaller than 1% of the total forces acting on the club head during the final stages of the downswing.

Overall, this study has provided and validated an understanding of the effects that turbulators would have on the drag of a driver head if placed at the leading edge of a driver crown. Turbulators can indeed delay flow separation over the crown of a driver for orientation near impact. This reduction in the overall drag can lead to higher swing speeds and increased carry distances. This enables designers to apply these types of features to reduce drag, while not having to alter the overall geometry in a way that could reduce MOI or move the CG in an undesirable direction. There is also some evidence suggesting these features also reduce the unsteady behavior of the airflow over the head, which may lead to a reduction in periodic forces on the club head and more stable delivery.

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