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(12) **United States Patent**
Ehlers

(10) **Patent No.: US 8,177,659 B1**
(45) **Date of Patent: *May 15, 2012**

(54) GOLF CLUB HEAD WITH IMPROVED AERODYNAMIC CHARACTERISTICS

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(73) Assignee: **Callaway Golf Company**, Carlsbad, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **13/344,730**

(22) Filed: **Jan. 6, 2012**

Related U.S. Application Data

(63) Continuation of application No. 13/316,750, filed on Dec. 12, 2011, and a continuation-in-part of application No. 13/215,796, filed on Aug. 23, 2011.

(60) Provisional application No. 61/421,724, filed on Dec. 10, 2010.

(51) **Int. Cl.**
A63B 53/02 (2006.01)
A63B 53/04 (2006.01)

(52) **U.S. Cl.** **473/305**

(58) **Field of Classification Search** 473/324–350
See application file for complete search history.

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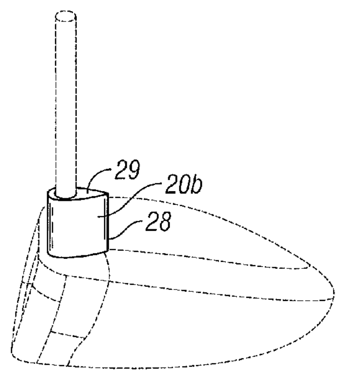
Primary Examiner — Alvin Hunter
(74) *Attorney, Agent, or Firm* — Rebecca Hanovice; Michael A. Catania; Sonia Lari

(57) ABSTRACT

A golf club head comprising an aerodynamic hosel is disclosed herein. In one embodiment, the hosel has an upper portion and a swept transition portion which connects to the golf club head, and all points at which the swept transition portion contacts the club head are spaced rearwardly from a vertical face plane. In a further embodiment, both the upper portion and the swept transition portion comprise coaxial shaft receiving bores. In yet another embodiment, the swept transition portion of the hosel has a trailing edge that is truncated, or that has one or more surface discontinuities. In yet another embodiment, the swept transition portion has a height and a diameter, each of which is less than or equal to one inch.

20 Claims, 14 Drawing Sheets



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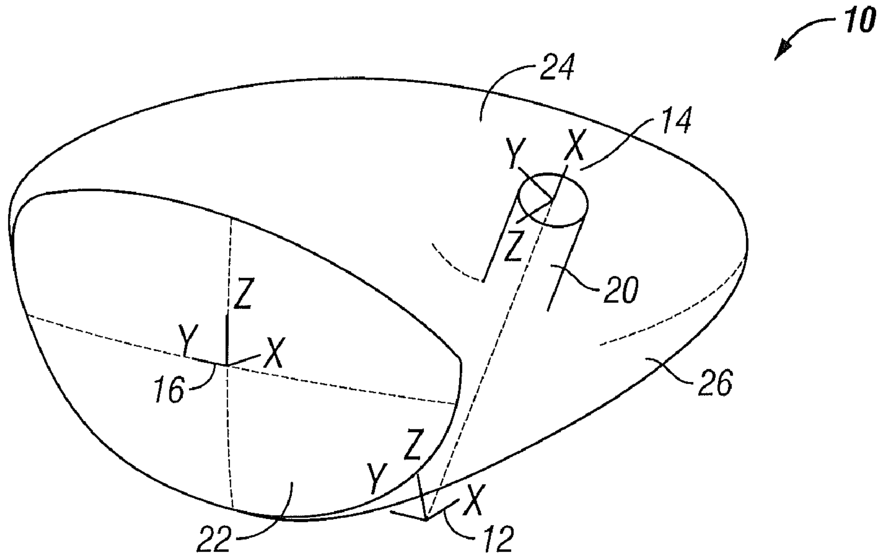


FIG. 1

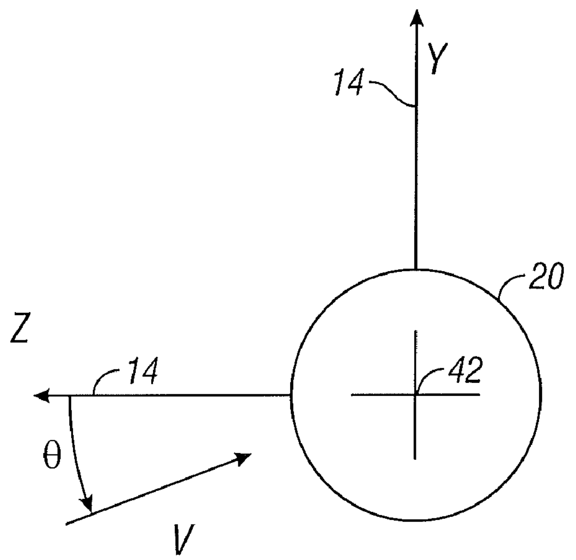


FIG. 2

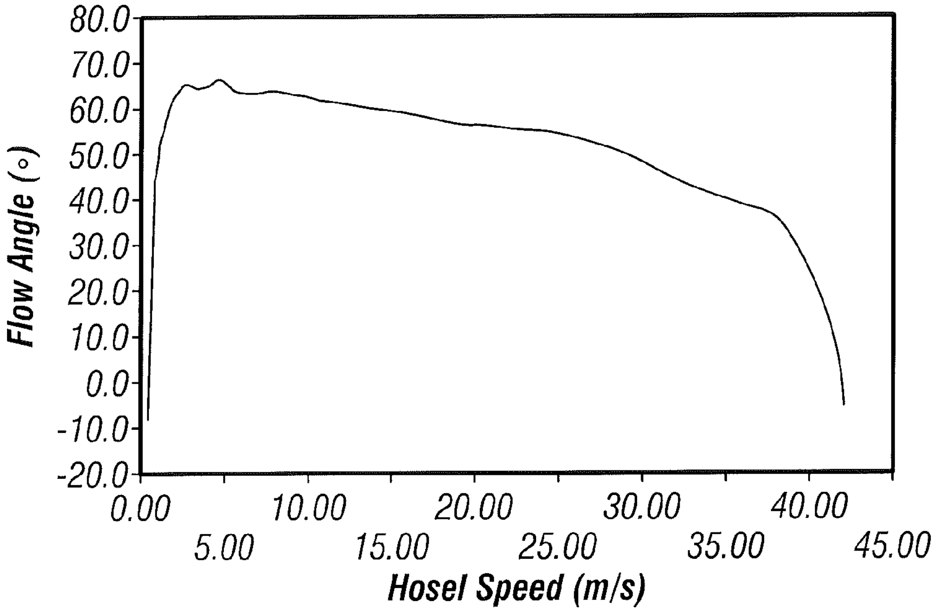

80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
-10.0
-20.0
Flow Angle (°)
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
Hosel Speed (m/s)

FIG. 3

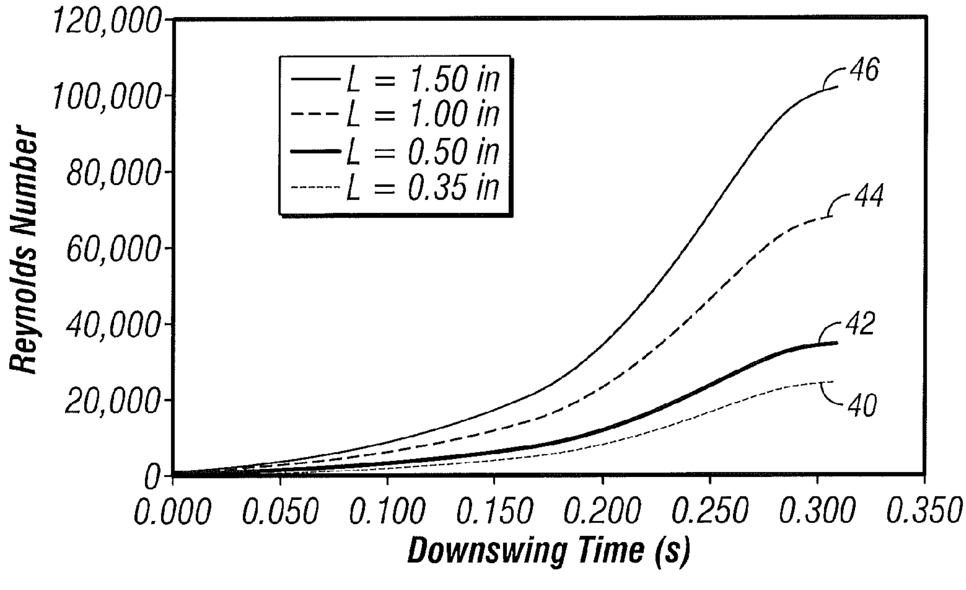

120,000
100,000
80,000
60,000
40,000
20,000
0
Reynolds Number
L = 1.50 in
L = 1.00 in
L = 0.50 in
L = 0.35 in
46
44
42
40
0.000
0.050
0.100
0.150
0.200
0.250
0.300
0.350
Downswing Time (s)

FIG. 4

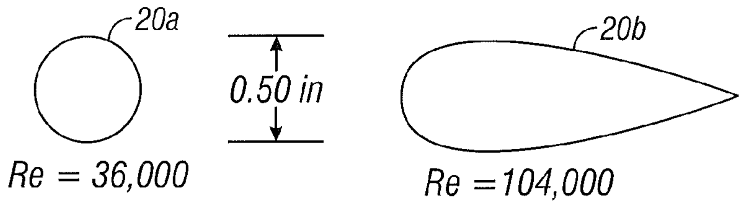

20a
0.50 in
20b
Re = 36,000
Re =104,000

FIG. 5

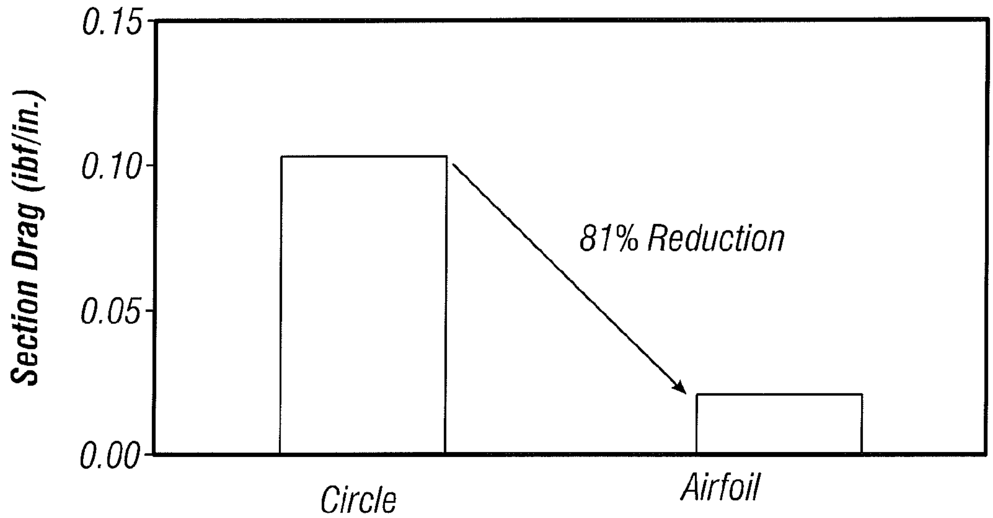

0.15
0.10
0.05
0.00
Section Drag (ibf/in.)
81% Reduction
Circle
Airfoil

FIG. 6

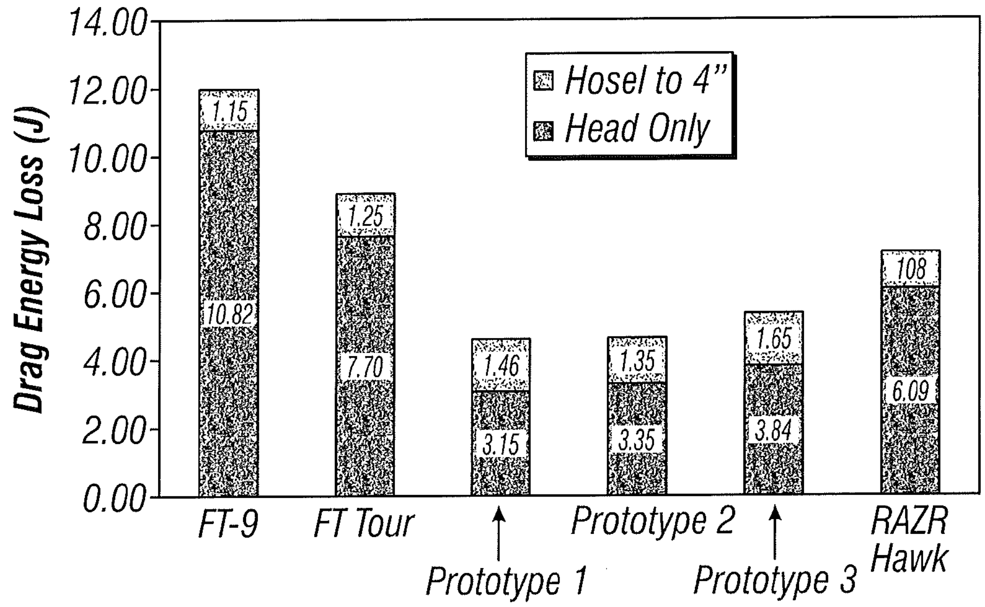

14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
Drag Energy Loss (J)
Hosel to 4"
Head Only
1.15
10.82
1.25
7.70
1.46
3.15
1.35
3.35
1.65
3.84
108
6.09
FT-9
FT Tour
Prototype 1
Prototype 2
Prototype 3
RAZR Hawk

FIG. 7

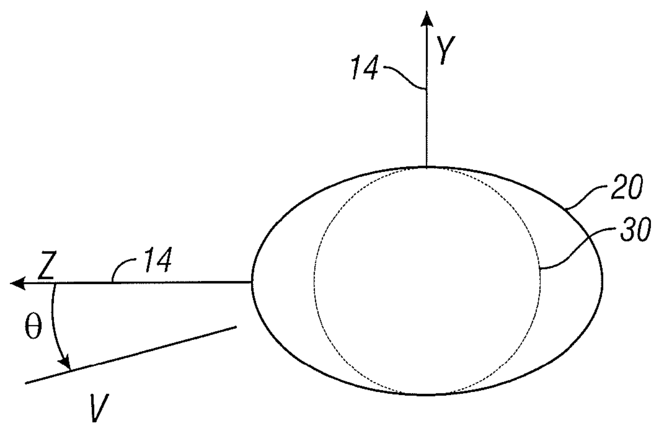

Y
14
20
30
Z
14
θ
V

FIG. 8

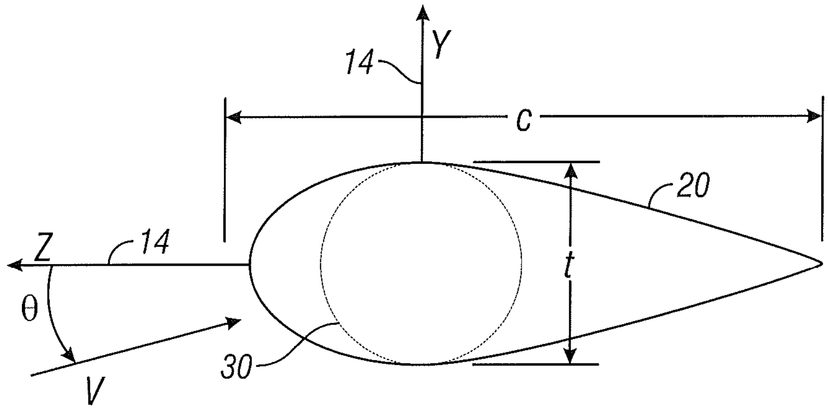


FIG. 9

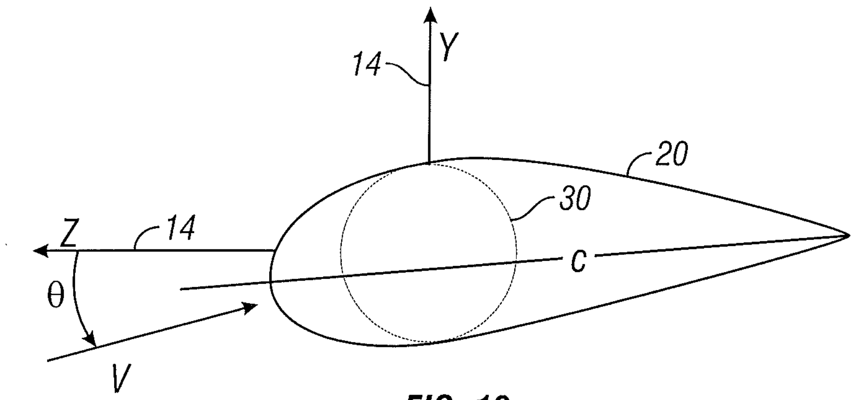


FIG. 10

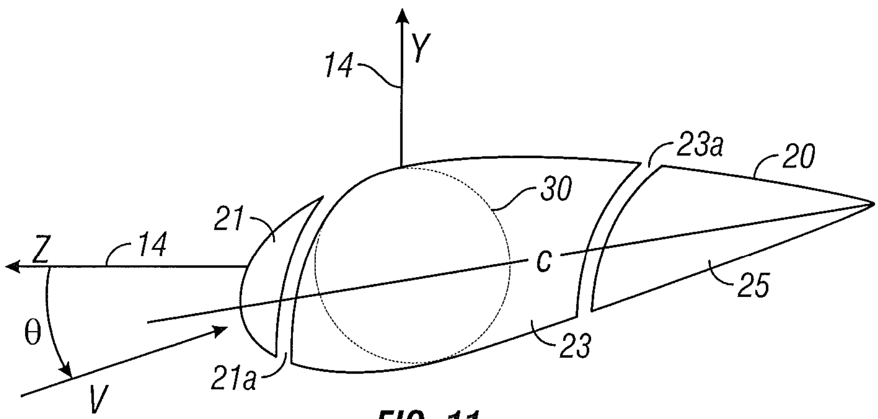


FIG. 11

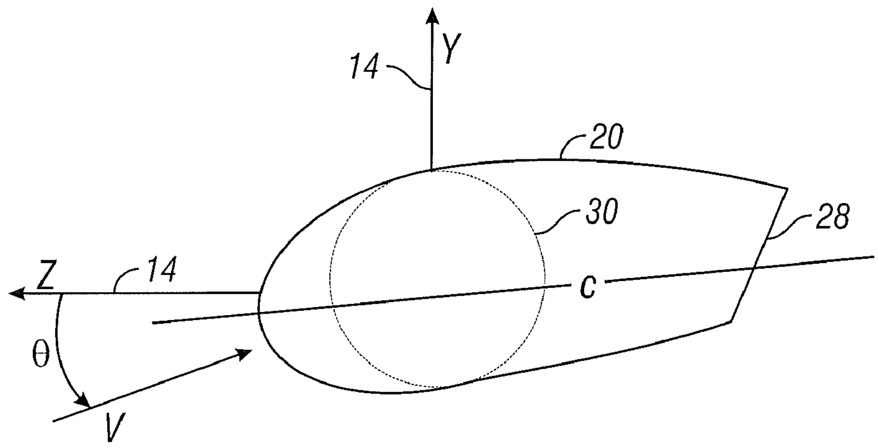


FIG. 12

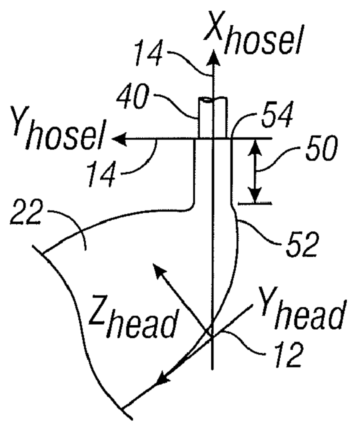


FIG. 13A

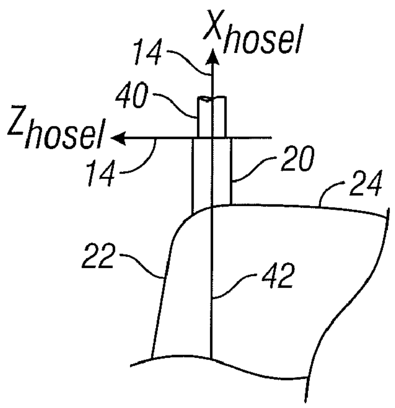


FIG. 13B

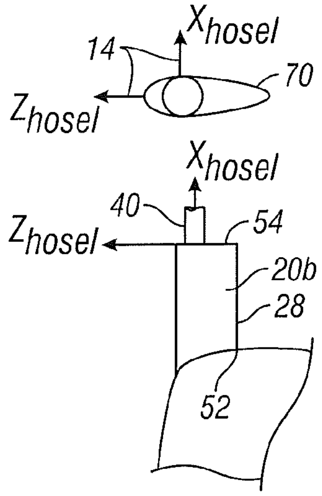


FIG. 14

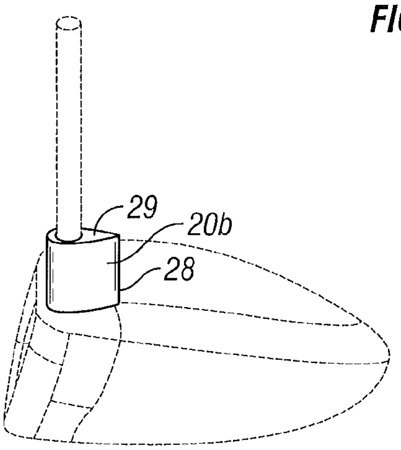


FIG. 15A

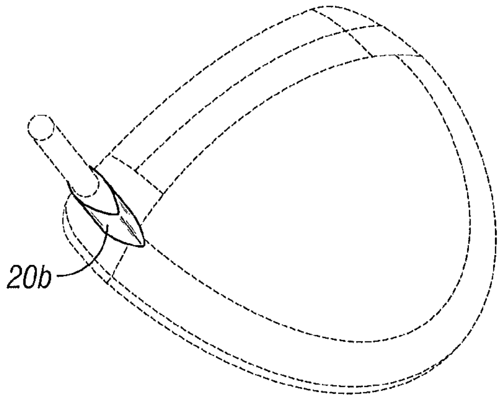


FIG. 15B

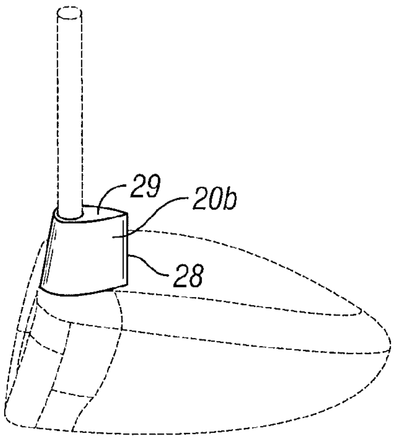


FIG. 16A

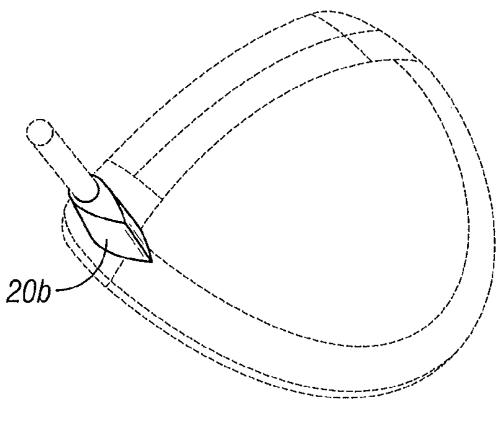


FIG. 16B

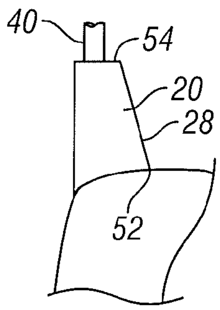


FIG. 17

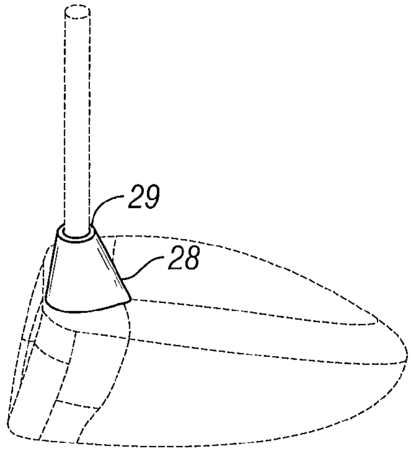


FIG. 18A

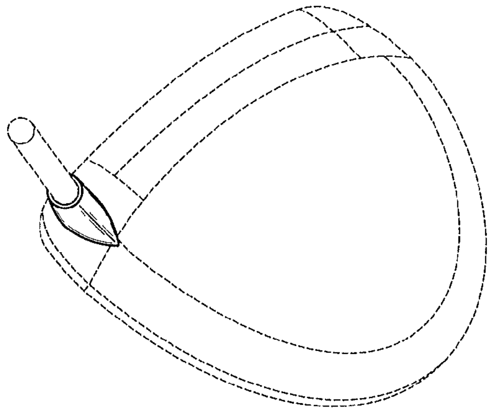


FIG. 18B

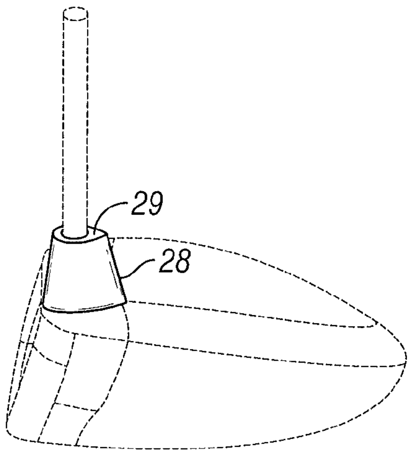


FIG. 19A

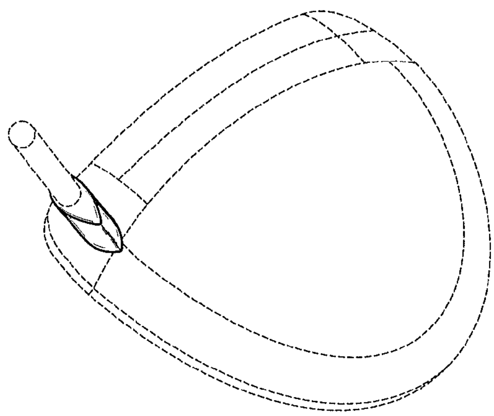


FIG. 19B

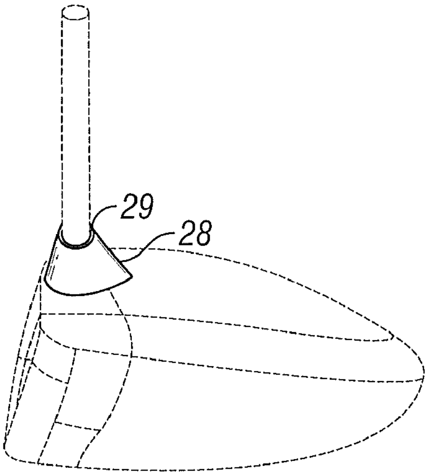


FIG. 20A

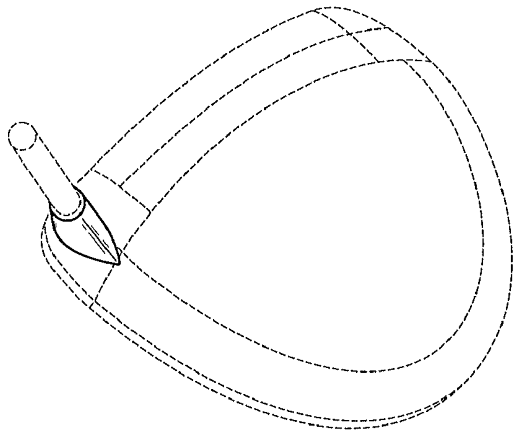
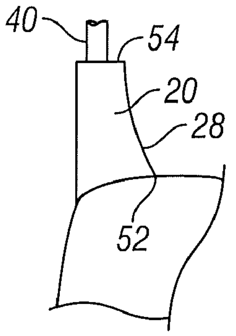


FIG. 20B



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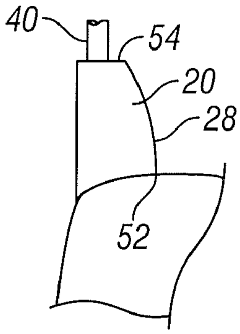

FIG. 22

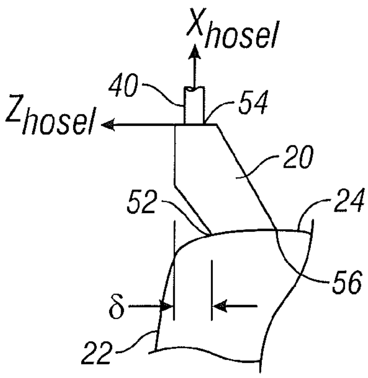

FIG. 23A

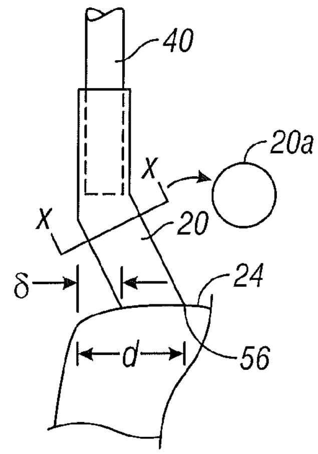

FIG. 23B

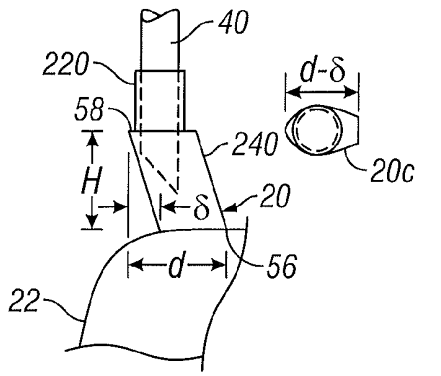

FIG. 23C

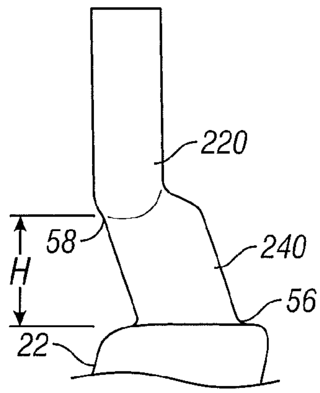

FIG. 23D

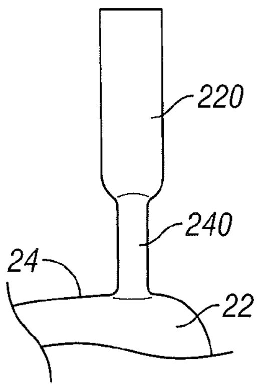

FIG. 23E

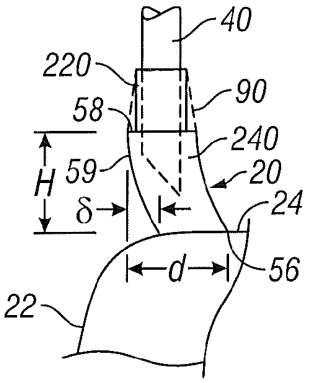

FIG. 24

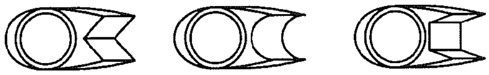

FIG. 25

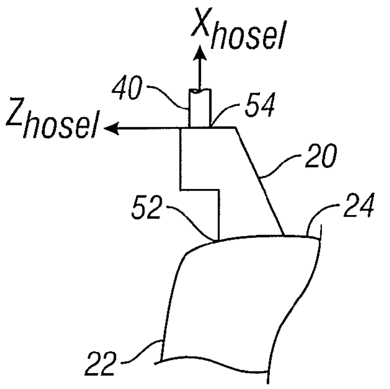

FIG. 26

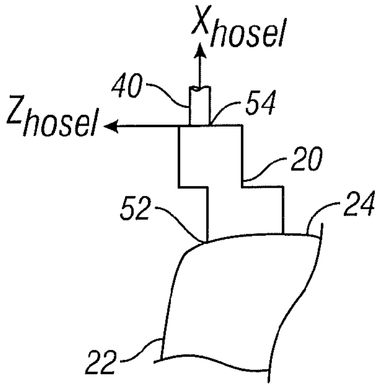

FIG. 27

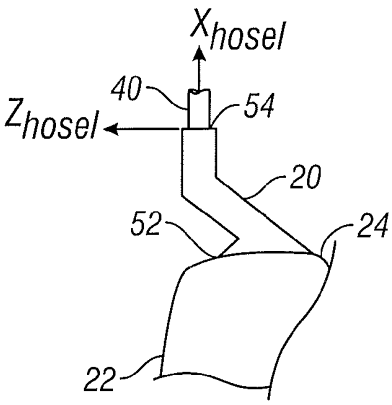

FIG. 28A

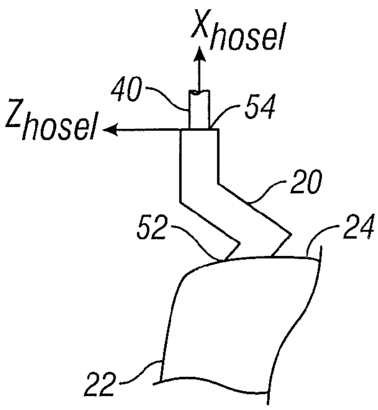

FIG. 28B

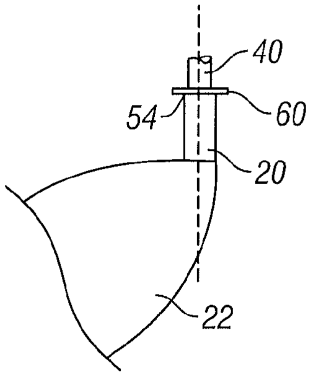

FIG. 29A

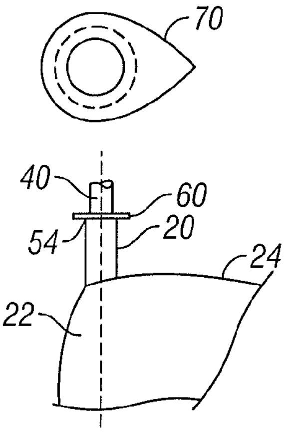

FIG. 29B

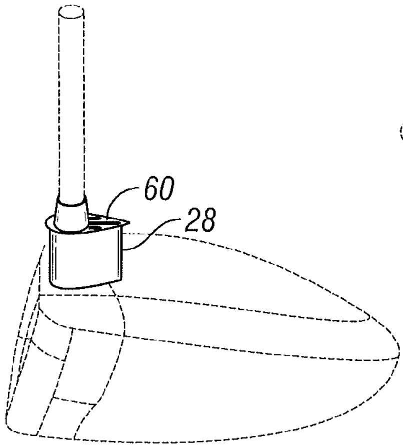

FIG. 30A

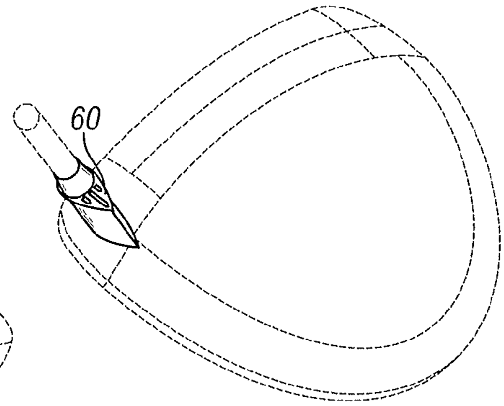

FIG. 30B

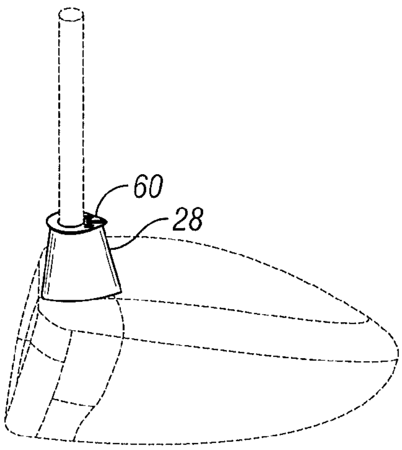

FIG. 31A

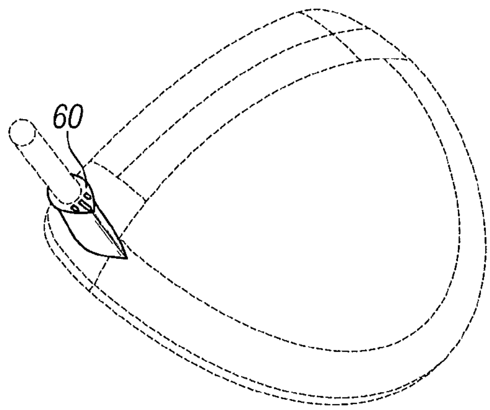

FIG. 31B

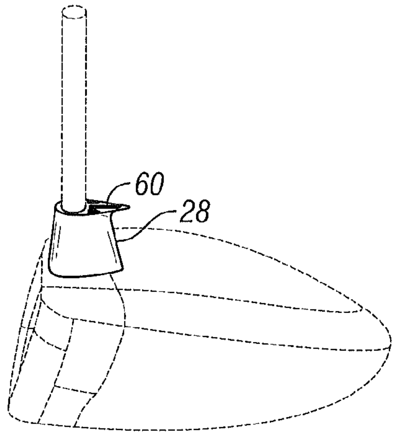

FIG. 32A

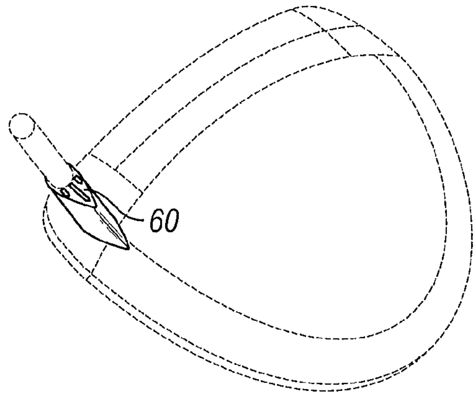

FIG. 32B

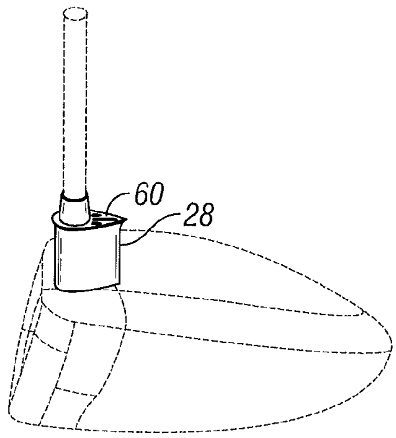

FIG. 33A

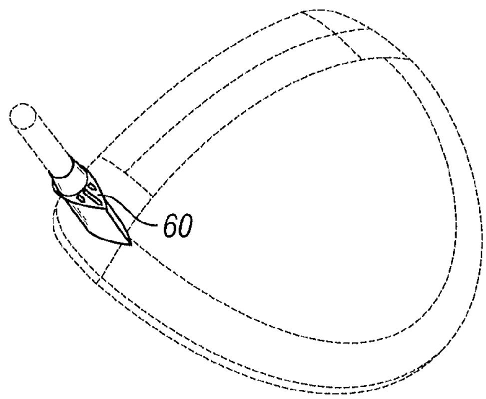

FIG. 33B

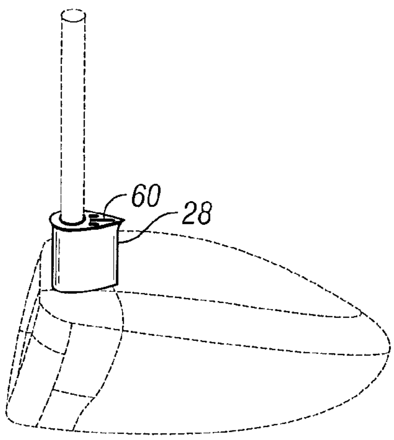

FIG. 34A

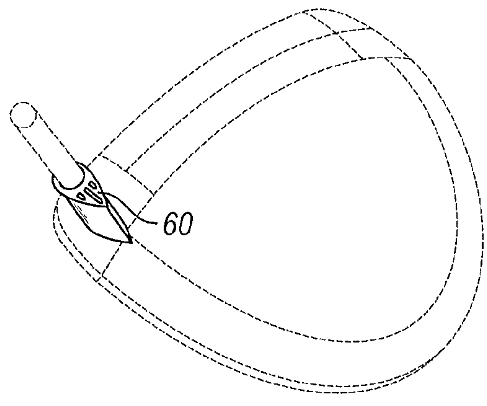

FIG. 34B

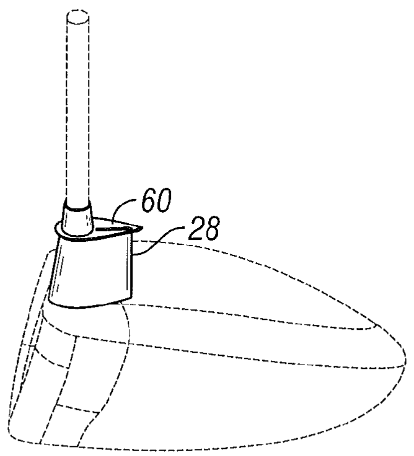

FIG. 35A

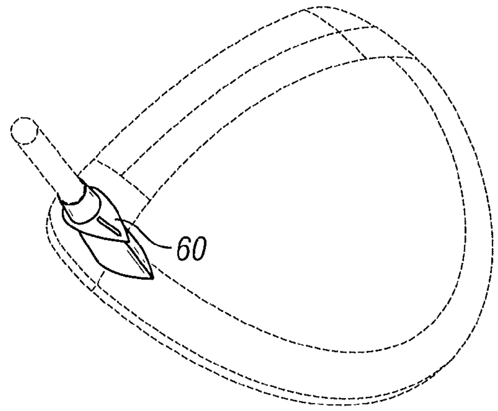

FIG. 35B

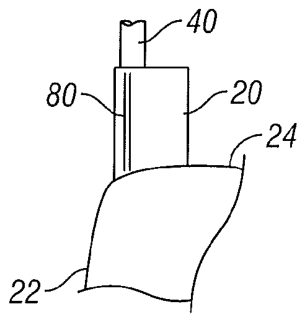

FIG. 36A

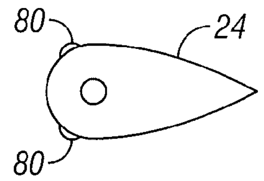

FIG. 36B

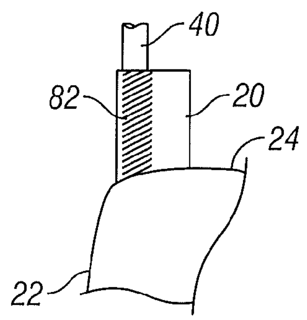

FIG. 37

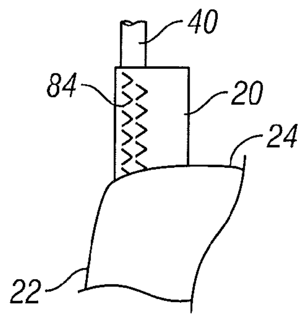

FIG. 38

GOLF CLUB HEAD WITH IMPROVED AERODYNAMIC CHARACTERISTICS

CROSS REFERENCES TO RELATED APPLICATIONS

The present application is a continuation of U.S. patent application Ser. No. 13/316,750, filed on Dec. 12, 2011, which is a continuation-in-part of U.S. patent application Ser. No. 13/215,796, filed on Aug. 23, 2011, which claims priority to U.S. Provisional Patent Application No. 61/421,724, filed on Dec. 10, 2010.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

Not Applicable

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a golf club head having a hosel configuration that improves the aerodynamic qualities of the golf club head.

2. Description of the Related Art

Technical innovation in the size, structure, configuration, material, construction, and performance of golf clubs has resulted in a variety of new products. The contribution of the hosel to overall drag of a club head can be significant, but it has largely been ignored by manufacturers and innovators even though the advent of adjustable hosel configurations with increased dimensions has resulted in a larger contribution to club head drag for some club head models. For low drag head shapes the contribution of the hosel becomes more important.

The hosel of a golf club head is the connection between the shaft and the head. It is typically circular in cross-section with a diameter that is larger than the shaft. Both tapered and constant cross-section approaches can be used. The hosel is a relatively small subcomponent of a golf club head, but it essentially travels at the same high speed as the head and is usually has a very aerodynamically inefficient shape. In addition, it operates in a flow field that is heavily influenced by larger club heads, particularly in drivers.

Although the prior art has disclosed many variations of golf club heads, including a variation disclosed in U.S. Pat. No. 1,587,758 (entitled "Golf Club") to Charavay, the prior art has failed to provide a club head with a hosel configuration that does not interfere with or have a negative effect on airflow during a swing.

BRIEF SUMMARY OF THE INVENTION

One aspect of the present invention is a golf club head comprising a face component, a crown, and a sole, and a hosel having a shaft connection point and a head connection point, wherein the face component has a vertical plane and the head connection point has a vertical plane, and wherein the shaft connection point of the hosel is closer to the face component vertical plane than the head connection point vertical plane. The hosel may further be notched or staggered.

Another aspect of the present invention is a golf club head comprising a face, a crown, a sole, and a hosel comprising an upper portion and a swept transition portion, wherein the upper portion comprises a shaft receiving bore, wherein the swept transition portion is disposed between and makes contact with the upper portion and the crown, wherein the face

comprises a vertical plane, wherein all points at which the swept transition portion contacts the crown are spaced rearwards from the face vertical plane, and wherein the swept transition portion has a height of one inch or less. The swept transition portion may further comprise a shaft receiving bore that is coaxial with the shaft receiving bore of the upper portion, and the golf club head may further comprise a shaft bonded to the shaft receiving bore of the upper portion and the shaft receiving bore of the swept transition portion. The shaft may have an angled tip, which may be disposed within the shaft receiving bore of the swept transition portion. The swept transition portion may comprise a non-circular cross-section, such as an airfoil cross-section, which may be truncated and have a trailing edge having one or more surface discontinuities.

In some embodiments, the upper portion may have a circular or a non-circular cross-section. The golf club head may be of any type, including a driver-type head. The swept transition portion may comprise a forward edge that is straight or curved, and may also comprise a curved or straight trailing edge. The swept transition portion may comprise a forward-most point located proximate the face and a rearward-most junction with the crown that is located 0.25 to 1.50 inches from the forward-most point. In some embodiments, the rearward-most junction with the crown is located one inch or less from the forward-most point. The swept transition portion may comprise a diameter of less than one inch, and may have a diameter that is smaller than a diameter of the upper portion. The swept transition portion may be formed by any means, but in some embodiments it is extruded.

Another aspect of the present invention is a driver-type golf club head comprising a face comprising a vertical plane, a crown, a sole, and a hosel comprising an upper portion and a swept transition portion having a height of one inch or less, wherein the swept transition portion is disposed between and makes contact with the upper portion and the crown, wherein the upper portion comprises a shaft receiving bore, wherein the swept transition portion comprises a truncated airfoil cross-section and a trailing edge having one or more surface discontinuities, wherein all points at which the swept transition portion contacts the crown are spaced rearwards from the face vertical plane, and wherein the swept transition portion comprises a forward-most point located proximate the face and a rearward-most junction with the crown located one inch or less from the forward-most point.

Yet another aspect of the present invention is a driver-type golf club comprising a body comprising a face, a crown, and a sole, a shaft comprising an angled, lower tip, and a hosel comprising an upper portion comprising a circular cross-section and a shaft receiving bore, and a swept transition portion comprising a height of one inch or less, a forward-most point located proximate the face, a rearward-most junction with the crown located one inch or less from the forward-most point, a non-circular cross-section, and a shaft receiving bore that is coaxial with the shaft receiving bore of the upper portion, wherein the angled, lower tip of the shaft is disposed within the shaft receiving bore of the swept transition portion.

Having briefly described the present invention, the above and further objects, features and advantages thereof will be recognized by those skilled in the pertinent art from the following detailed description of the invention when taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

FIG. **1** is a side perspective view of a golf club head having three coordinate systems.

FIG. **2** is a top, cross-section view of the hosel shown in FIG. **1** with a hosel coordinate system.

FIG. **3** is a graph showing hosel speed and flow angle variation during a downswing.

FIG. **4** is a graph showing Reynolds Number variation during downswing for several reference lengths.

FIG. **5** is a top view of cross-sections of a circular hosel and an airfoil hosel.

FIG. **6** is a chart showing the difference in section drag between a circular cross-section hosel and an airfoil cross-section hosel.

FIG. **7** is a chart showing drag energy loss, separated into head and hosel contributions, during the downswing of different clubs.

FIG. **8** is a top, cross-section view of an elliptical hosel with a hosel coordinate system.

FIG. **9** is a top, cross-section view of a symmetrical airfoil hosel with a hosel coordinate system.

FIG. **10** is a top, cross-section view of a cambered airfoil hosel with a hosel coordinate system.

FIG. **11** is a top, cross-section view of a multi-element, cambered airfoil with a hosel coordinate system.

FIG. **12** is a top, cross-section view of an airfoil with a truncated trailing edge and a hosel coordinate system.

FIGS. **13**A and **13**B are front and side views, respectively, of a typical circular cross-section hosel and club head with a hosel coordinate system.

FIG. **14** is a side view of a first hosel style having a non-circular airfoil cross-section with a hosel coordinate system.

FIG. **15**A is a side view of an embodiment of the hosel shown in FIG. **14**.

FIG. **15**B is a top, perspective view of the embodiment shown in FIG. **15**A.

FIG. **16**A is a side view of another embodiment of the hosel shown in FIG. **14**.

FIG. **16**B is a top, perspective view of the embodiment shown in FIG. **16**A.

FIG. **17** is a side view of a second hosel style having a non-circular airfoil cross section.

FIG. **18**A is a side view of an embodiment of the hosel shown in FIG. **17**.

FIG. **18**B is a top, perspective view of the embodiment shown in FIG. **18**A.

FIG. **19**A is a side view of another embodiment of the hosel shown in FIG. **17**.

FIG. **19**B is a top, perspective view of the embodiment shown in FIG. **19**A.

FIG. **20**A is a side view of another embodiment of the hosel shown in FIG. **17**.

FIG. **20**B is a top, perspective view of the embodiment shown in FIG. **20**A.

FIG. **21** is a side view of a third hosel style having a non-circular airfoil cross-section.

FIG. **22** is a side view of a fourth hosel style having a non-circular airfoil cross-section.

FIG. **23**A is a side view of a swept hosel configuration with a hosel coordinate system.

FIG. **23**B is a side view of another swept hosel configuration and a cross-section of said swept hosel.

FIG. **23**C is a side view of another swept hosel configuration and a cross-section of said swept hosel.

FIG. **23**D is a side view of another swept hosel configuration.

FIG. **23**E is a front view of the swept hosel configuration shown in FIG. **23**D.

FIG. **24** is a side view of another swept hosel configuration.

FIG. **25** is a top, cross-sectional view of different truncated, trailing edge surface discontinuities.

FIG. **26** is a side view of a swept, notched hosel configuration with a hosel coordinate system.

FIG. **27** is a side view of a swept, staggered hosel configuration with a hosel coordinate system.

FIGS. **28**A and **28**B are side views of double swept or "snag" hosel configurations with hosel coordinate systems.

FIGS. **29**A and **29**B are front and side views, respectively, of a club head having an airfoil cross-section hosel with an endplate.

FIG. **30**A is a side view of a first embodiment of the hosel shown in FIG. **29**A.

FIG. **30**B is a top, perspective view of the embodiment shown in FIG. **30**A.

FIG. **31**A is a side view of a second embodiment of the hosel shown in FIG. **29**A.

FIG. **31**B is a top, perspective view of the embodiment shown in FIG. **31**A.

FIG. **32**A is a side view of a third embodiment of the hosel shown in FIG. **29**A.

FIG. **32**B is a top, perspective view of the embodiment shown in FIG. **32**A.

FIG. **33**A is a side view of a fourth embodiment of the hosel shown in FIG. **29**A.

FIG. **33**B is a top, perspective view of the embodiment shown in FIG. **33**A.

FIG. **34**A is a side view of a fifth embodiment of the hosel shown in FIG. **29**A.

FIG. **34**B is a top, perspective view of the embodiment shown in FIG. **34**A.

FIG. **35**A is a side view of a sixth embodiment of the hosel shown in FIG. **29**A.

FIG. **35**B is a top, perspective view of the embodiment shown in FIG. **35**A.

FIG. **36**A is a side view of a club having a hosel with a trip step.

FIG. **36**B is a top, cross-sectional view of the hosel shown in FIG. **36**A.

FIG. **37** is a side view of a club having a hosel with surface roughness.

FIG. **38** is a side view of a club having a hosel with vortex generators.

DETAILED DESCRIPTION OF THE INVENTION

The present invention is generally directed to a golf club head with a novel hosel configuration that reduces interference with airflow and thus reduced drag during a swing in comparison with hosel configurations of the prior art. The present invention also may conform to the Rules of Golf, which are established and interpreted by the United States Golf Association ("USGA") and The Royal and Ancient Golf Club of Saint Andrews and set forth certain requirements for a golf club head. The requirements for a golf club head are found in Rule 4 and Appendix II. Complete descriptions of the Rules of Golf are available on the USGA web page at www.usga.org.

According to the Rules, the shaft **40** of a golf club must be attached to a wood club head **10** at the club head heel either directly or through a single plain neck and/or socket. The length from the top of the neck and/or socket to the sole **26** of the club must not exceed 5 inches (127 mm), measured along the axis of, and following any bend in, the neck and/or socket. "Hosel" **20**, as it is used herein, refers to a piece that connects the golf club head **10** with the shaft **40**. This piece may be integrally formed with the golf club head **10** or the shaft **40**, or may be a separately formed piece that is attached to the golf club head **10** and shaft **40** through means known to persons of ordinary skill in the art. The term "aerodynamic hosel portion" refers to a non-circular or aerodynamic portion of the hosel **20** than spans part, but not all, of the overall length of the hosel,

Hosel-Related Drag

The dominant contributor to hosel **20** drag is profile or pressure drag resulting from separated flow which creates a low pressure region on the aft portions of the hosel. Skin friction drag generally is minimal. This effect is typical of circular cross-sections operating below the critical Reynolds Number, which is a measure of the ratio of inertial to viscous forces in a fluid flow and is given by:

$$Re = \frac{\rho V L}{\mu}$$

where ρ is air density, V is flow speed, L is a reference length and μ is air viscosity. FIG. **4** shows Reynolds Number variation during a typical downswing for several values of reference length. Head **10** speed varies from zero to the maximum, which means the Reynolds Number does likewise.

Another element of hosel **20** drag is interference drag resulting from the proximity of the hosel **20** to the head **10**. There are two components of interference drag in a golf club. First, the wake of the hosel **20** impinges on the head **10**, altering the flow and typically creating a low pressure region on the crown **24**. Second, the hosel **20** is operating in a high velocity flow created by the presence of the head **10**. This amplifies the drag of the shaft **40**, creating an incremental drag force. Although interference drag is, in general, a small effect, it is worthy of consideration. Treatments that reduce profile drag of the hosel **20** will also typically reduce interference drag.

Flow Characteristics

As discussed above, the hosel **20** is positioned between the predominantly two dimensional flow about the shaft **40** and the highly three dimensional and very unsteady flow in the vicinity of the head **10**. During downswing, the hosel **20** is subjected to a wide range of speeds, with a peak speed very close to the maximum head speed. Of equal importance, however, is the range of flow angles. This aspect of the flow is very important for non-circular cross-sections.

FIG. **1** shows a golf club head **10** having a hosel **20**, a face **22**, a crown **24**, and sole **26**. The golf club head **10** of FIG. **1** has three major coordinate systems: the head coordinate system **12**; the hosel coordinate system **14**; and the impact coordinate system **16**. FIG. **2** shows a sectional view of a typical hosel **20** as seen looking down a shaft axis **42** towards the ground, as well as the x and y axes of the hosel coordinate system **14**. FIG. **2** also shows the relative flow speed, V, which is the opposite of hosel velocity, and the flow angle, θ.

FIG. **3** shows the variation of the flow angle θ with flow velocity during a typical downswing with a head speed at impact of 100 mph. At the very earliest stages of the downswing, flow speeds are very low as the flow angle increases markedly. This is followed by a period of increasing speed and a near linear decline in flow angle. Just prior to impact, at the very highest flow speeds there is a rapid drop in flow angle. Flow about the hosel **20** is also heavily influenced by the adjacent head **10**, which accelerates flow velocities and affects flow directions. This leads to a much higher drag than would be experienced by a hosel **20** alone on the end of a shaft **40** subjected to a standard swing profile.

Referring to FIG. **4**, the Reynolds Number for a shaft tip (L=0.35 inch) **40** stays below 25,000 while the value for a circular cross-section hosel (L=0.50 inch) **42** does not exceed 35,000. The Reynolds Number based on a reference length in the flow direction at impact is larger for noncircular cross-sections. For instance, a 2:1 ellipse with a thickness of 0.50 inch (the same as the circular hosel diameter) has a reference or chord length of 1.00 inch **44**. In this case, the Reynolds Number approaches 70,000 at impact. A Reynolds Number in excess of 100,000 occurs near impact for an airfoil cross-section with a thickness ratio of 33%, which yields a reference length of 1.50 inches **46**.

FIG. **5** illustrates the difference between Reynolds Numbers at 100 mph for a circular cross-section hosel **20***a* and one configuration of an airfoil cross-section hosel **20***b* having the same thickness. The present invention is not limited to this configuration. FIG. **6** demonstrates how an airfoil cross-section hosel **20***b* has less than one fifth of the drag of a circle cross-section hosel **20***a* of the same thickness at speeds of 100 to 160 mph.

Drag and Energy Loss

Aerodynamic drag of the hosel **20** is a factor in overall club drag, and becomes more significant as drag of the head **10** is reduced. As with the head **10**, drag of the hosel **20** varies significantly over the time of the downswing. Large changes are induced by significant changes in orientation. Overall drag force increases with the square of velocity.

Energy dissipated by drag is meaningful in that the goal of the downswing is to impart the maximum amount of energy to the club head, and hence the ball. Furthermore, this energy is supplied by a system with limited output: the golfer. Any energy lost to drag is not available at impact and degrades performance. In general, energy dissipated due to drag, or power loss, goes with the cube of velocity. This parameter is useful because it provides a weighting scheme, giving more weight to the higher velocity portions of the swing. Furthermore, by integrating power loss over the period of the downswing, a total energy loss can be computed, resulting in a single FIGURE of merit with which to compare various drag reduction methods. Different swings can also be compared with this approach.

FIG. **7** shows the drag energy loss for several different Callaway Golf Company clubs, all of which have standard hosels **20** and shafts **40**. The energy loss is broken down into two components: the head **10** only; and the hosel **20**, including portions of the shaft **40** up to a four inch slant length along the shaft axis. FIG. **7** demonstrates that hosel **20** drag becomes a more significant portion of overall drag as the drag of the head **10** itself is reduced.

Drag Reduction Hosel Designs—Cross-Sections

The primary function of the hosel **20** is attachment of the shaft to the club head **10**. An improved approach to drag reduction, while retaining this primary function, depends on making adjustments to cross-sectional shape subject to dimensional and mass limitations, and aesthetic considerations. FIGS. **2** and **8-12** show cross-sectional hosel **20** shapes and the y and x axes of the hosel coordinate system **14**.

When applied to circular cross-sections **20***a*, the most straightforward route to drag reduction is simply reducing the outer diameter to a minimum. Reduction of thickness, or diameter, is limited by the outer diameter of the shaft **40**, structural requirements of the shaft **40** to hosel **20** bond, and the hosel **20** itself. Reducing the length dimension along the shaft axis **42** is also possible with the limit being a no-hosel design. Some examples of reduced length hosels **20** are disclosed in U.S. Pat. Nos. 5,320,347 and D364,906 and in Callaway Golf Company's S2H2 products. However, the shortened hosel **20** is replaced by additional exposed shaft **40**. The resulting drag benefit is not as great as it could be due primarily to the circular cross-section of the shaft **40**. Furthermore, surface treatments that force transition of the boundary layer of a circular cross-section to turbulent flow and delay separation are not effective for typical hosel **20** diameters of 0.50 inches and head speeds in the neighborhood of 100 mph. The Reynolds Number is very low at this dimension and speed, and there is too little energy in the flow and not enough flow path length to make such surface treatments effective.

Golf club manufacturers have limited ability to reduce the diameter of a circular cross-section. As such, non-circular sections present more significant opportunities for performance improvements. Elliptical cross sections such as the hosel example 20 shown in FIG. **8**, however, do not yield a significant improvement in drag over a circular cross-section. A conventional circular hosel cross section **20***a* is represented in FIG. **8** with dashed lines. Various types of elliptical cross-sections have been studied for low speed applications, but their drag reduction potential is limited. Low aspect ratio sections behave similar to circular cross-sections. Higher aspect ratio elliptical cross-sections exhibit long chords which result in considerable blockage and separated flow at high flow angles experienced in the early and middle stages of downswing. Such cross-sections are also heavier and may have an adverse effect on head center of gravity position.

Use of an airfoil cross-section to reduce hosel **20** drag has been attempted in the past, as evidenced by club designs and U.S. Pat. No. 1,587,758. However, these prior art club structures were not designed to function when subjected to the wide range of flow incidence angles encountered during the high speed phases of a downswing. Generally, and as shown in FIG. **3**, the face is open in the late stages of the downswing resulting in a flow angle in the 30 to 60 degree range. Most airfoils will be in deep stall at these flow angles and exhibit very high drag.

FIG. **9** shows a cross-section of an exemplary symmetric airfoil hosel **20***b*, which can be contrasted with the conventional circular hosel cross section **20***a* represented with dashed lines. When incorporated with a hosel **20**, either as an aerodynamic hosel portion or encompassing the entire length of the hosel, the airfoil cross-section should also exhibit a relatively high thickness (t) to chord (c) ratio, t/c, to minimize chord length. This reduces the blockage effect at very high angles of incidence, reduces the weight of the hosel, and simplifies integration with the body design. A generous leading edge radius is also necessary to permit the airfoil to function at a wide range of flow incidence angles. This characteristic also minimizes the distance from the leading edge to the shaft axis **42** and facilitates meeting functional and rule limitations that require that the hosel **20** not protrude beyond the plane of the face **22**. The offset distance between the shaft axis **42** and face **22** of club head **10** is also important from a performance and playability standpoint.

Another approach to dealing with the wide range of flow angles is to rotate the airfoil such that it is oriented nose down with respect to the hosel z-axis, as shown in FIG. **10**. While this serves to maintain attached flow and lower drag over a greater proportion of the downswing, it also produces a force perpendicular to the swing plane near impact. This could severely affect playability by moving the club head from its intended path and altering the hit location.

A cambered airfoil hosel **20***b*, shown in FIG. **10**, can be used to bias the low drag flow angle range to coincide more closely with the angles experienced during the higher speed phase of the downswing immediately prior to impact. The cambered airfoil hosel **20***b* shown in FIG. **10** has 30% thickness, but is not limited to that thickness percentage. The cambered airfoil cross-section may be included in an aerodynamic hosel portion or may encompass the entire length of the hosel **20**. However, a cambered airfoil hosel **20***b* also produces a force perpendicular to the swing plane. To minimize this effect, a cambered airfoil should be oriented with its zero lift line (ZLL) parallel to the hosel z-axis to eliminate out of swing plane forces and to minimize lift induced drag. Orienting the hosel **20** airfoil cross-section in this manner will place the chord line at an angle to the target line at address. This may appear abnormal to the golfer, but using a reflex trailing edge may be helpful in eliminating this appearance while having minimal effect on the aerodynamic performance of the section.

With certain airfoils, it is likely that airflow will be separated over the aft portions of the airfoils at low Reynolds Numbers typical of a golf swing. One approach to delaying separation is creating a multi-element or slotted airfoil. A three element **21**, **23**, **25** version of such a hosel **20** having two slots **21***a*, **23***a* is shown in FIG. **11**. The hosel **20** shown in FIG. **11** is cambered and has a 30% thick cross section, but may have other thickness percentages. Two element versions, which can be obtained by filling in either of the slots **21***a*, **23***a* in the hosel **20** shown in FIG. **11**, are also viable configurations. This multi-element or slotted configuration can be further generalized to include many slots and elements. This multi-element or slotted configuration may further comprise the entire length of the hosel **20**, or be included as an aerodynamic hosel portion.

Another approach, shown in FIG. **12**, involves truncating the trailing edge **28** portion of the airfoil hosel **20***c*. This helps to reduce the blockage effect and resulting drag at high flow angles early in the swing. The mass of the hosel, and the resulting impact on head center of gravity, is also reduced by this approach. The chord-wise position and orientation of the truncation can be optimized to provide the maximum aerodynamic benefit at low mass and volume. The truncated trailing edge cross section may comprise the entire length of the hosel **20**, or be included as an aerodynamic hosel portion.

Drag Reduction Configurations—Hosel Profiles

Front and side views of a typical hosel **20** installation are shown in FIGS. **13**A and **13**B, respectively. The distance from the hosel base **52**, where it connects to the head, to the hosel tip **54**, where the shaft **40** protrudes along the shaft axis **42**, essentially constitutes the height **50** of the hosel **20**. The magnitude of this dimension and variation in the configuration of the hosel **20** along this dimension is important for both aesthetic and performance reasons.

Several candidate non-circular or airfoil configurations are shown in FIGS. **14** to **22**. The greatest aerodynamic benefit can be achieved with a full airfoil cross-section **20***b* extending from the base to the tip of the hosel **20** (constant chord) without tapering significantly in length, embodiments of which are shown in FIGS. **14**, **15**A, **15**B, **16**A, and **16**B. In these embodiments, the trailing edge **28** of the airfoil extends vertically upward from the crown **24** of the club head **10** at an approximately 90 degree angle with respect to the upper surface **29** of the hosel **20**. In these embodiments, the drag reduction benefits of the airfoil cross-section **20***b* are realized over the full height of the hosel **20**.

Such a configuration can adversely affect mass properties of the head **10**, however, by raising the center of gravity height, consuming valuable discretionary mass and possibly reducing key moment of inertia properties. This type of configuration may be also unacceptable from an aesthetic standpoint. As such, it is preferred that the aerodynamic hosel portion, the portion of the hosel having an airfoil cross section

20*b*, be between 0.25 and 1.5 inches in height, and more preferably no greater than 1 inch in height. The remainder of the hosel **20** may be cylindrical in cross-section.

From an aesthetic standpoint, a tapered hosel **20** is preferred. Tapering also leads to a lower mass configuration, with less impact on head center of gravity position. FIGS. **17** through **21** show several different trailing edge hosel **20** shapes, in contrast with FIG. **22**. In these embodiments, the trailing edge **28** of the airfoil extends vertically upwards at a non-90 degree angle with respect to the upper surface **29** of the hosel **20**. The trailing edge **28** of the airfoil may curve as it extends from the crown **24** to the upper surface **29** of the hosel **20**, as shown in FIGS. **21** and **22**.

The simplest form would taper from an airfoil section at the base **52** to a circular cross-section at the tip **54**. This approach, however, loses some of the benefit of the airfoil cross-section as the top of the hosel **20** is approached. An alternative is to taper from a low thickness ratio section at the base **52** to a higher thickness ratio section at the tip **54**. For instance a 33% thick airfoil at the hosel base **52** with a 0.5 inch thickness exhibits a 1.5 inch chord length. This tapers to a 50% thick airfoil at the top of the hosel, yielding a chord length of 1.00 inches for the same 0.50 inch thickness. The resulting taper ratio of 1.00/1.50 or 0.67 provides a more weight efficient and aesthetically pleasing hosel **20** shape while maintaining low drag properties over the full height of the hosel.

The presence of the club head **10** influences local flow directions and speeds, with the greatest effect occurring at the base of the hosel **20** and diminishing towards the top of the hosel **20**. As such, it is beneficial to change the airfoil orientation to compensate for differences in local flow direction along the hosel. This configuration appears as a twisting of the section from base to top.

A swept hosel **20**, with the tip **54** of the hosel **20** closer to the plane of the driver face **22** than the base **52** presents some aerodynamic advantages. A basic swept hosel **20** is shown in FIGS. **23**A, **23**B, and **23**C, and a modified swept hosel **20** having a curved forward edge **59** is shown in FIG. **24**. In a swept hosel **20** configuration, the junction of the hosel **20** and driver head **10** is moved aft by a distance δ into a lower velocity flow region. In doing so, the junction **56** of the rearward-most part of the hosel **20** with the head **10** is moved back a distance d from the forward-most point **58** of the hosel **20**, which moves the wake of the hosel base **52** further back on the crown **24**. This is important for a good portion of the downswing, especially when the flow speeds and angles are high. This modification also creates a span-wise component of flow towards the hosel base, which stabilizes the flow in the vicinity of the junction and results in reduced interference drag. The swept portion of this and other embodiments of the present invention may encompass the entire length of the hosel, or may be included as an aerodynamic hosel portion.

As shown in FIG. **23**B, the swept hosel **20** may have a circular cross-section **20***a*, but it preferably has an airfoil cross-section **20***b*, and more preferably a truncated airfoil cross-section **20***c*, as shown in FIG. **23**C. The trailing edge **28** of the hosel **20** may comprise various surface discontinuities, such as those shown in FIG. **25**, in addition to or instead of a truncation to further assist with flow stabilization and drag reduction. It is preferable to combine the truncation with the surface discontinuities to aid in drag reduction.

In some embodiments, shown in FIGS. **23**C, **23**D, **23**E, and **24**, the hosel **20** has an upper portion **220** and a transition portion **240**, one or both of which may have an aerodynamic cross-section such as an airfoil **20***b*. The shaft **40** may extend only into the upper portion **220**, but it preferably extends into at least a part of the transition portion **240**, thus reducing the height of the upper hosel portion **220**. If the upper hosel portion **220** is circular, this shaft configuration reduces the need for a long high drag region of the hosel to support the shaft **40**. The tip end of the shaft **40** may be angled or scarfed to increase bonding area, reduce overall club weight, and allow for a shorter overall hosel length **20**. The overall aerodynamics of these embodiments may be further improved by bonding a low profile shaft, having smaller tip diameter, to the hosel **20**, and particularly within the transition portion **240**.

As shown in FIGS. **23**C, **23**D, **23**E, and **24**, the transition portion **240** has a height H, which preferably is between 0.25 and 1.50 inches, and most preferably is approximately 1 inch. The transition portion **240** also has a rearward-most junction **56** with the crown **24** located a distance d from the forward-most point **58** of the hosel; this distance d preferably is between 0.25 and 1.50 inches, and most preferably is approximately 1 inch. The transition portion **240** has a chordwise dimension of d minus 8, which may be less than 1.50 inches, and most preferably less than 1 inch, and may further include one or more of the surface discontinuities on its trailing edge **28** shown in FIG. **25** and described herein. In one embodiment, the transition portion **240** has a thinner chordwise dimension than the upper portion **220**, as shown in FIGS. **23**D and **23**E, and may further be extruded. A ferrule **90** may be bonded to the top of the transition portion **240** to blend the outer edges of the transition portion **240** with the edges of the upper portion **220**.

The swept hosel **20** configuration provides more design freedom for the shape of the face and contouring the heel corner below the hosel because the base of the hosel is moved out of the way of the heel corner. This corner is essentially the "leading corner" for much of the downswing and it heavily influences aerodynamic behavior of the head. Proper shaping of this corner could result in significant drag reduction. For example, some of the same effects as a forward swept hosel can be achieved by notching the leading edge of the hosel base **52**, as shown in FIG. **26**. The height of the notch can be moderated to minimize aesthetic impact while preserving the aerodynamic benefits of sweep. A "staggered" configuration can also be achieved by notching the lower portion of the hosel leading edge near the base **52** as well as the upper portion of the trailing edge near the hosel tip **54**, as shown in FIG. **27**.

Another version of the swept hosel **20** might include a lower portion that is swept towards the back of the head and an upper portion that is swept forward towards the shaft axis. The resulting shape presents a double swept or "snag" leading edge, two examples of which are shown in FIGS. **28**A and **28**B. This approach provides aft sweep for the flow region nearest the crown **24** while maintaining the position of the shaft **40** tip and providing for rearward attachment of the hosel **20** to the head **10**.

Drag Reduction Configurations—Hosel Tip Treatments

The upper termination of the hosel, e.g., the hosel tip **54**, or the upper termination of the aerodynamic hosel portion, is also important from an aesthetic standpoint. Various versions of rounded tip fairings can be implemented, or a very basic and abrupt cutoff can be used. An endplate, such as the endplates **60** shown in FIGS. **29**A through **35**B, provides aerodynamic benefits to a hosel, which may also have an airfoil cross section **70** or aerodynamic hosel portion. The purpose of the endplate **60** is to isolate the head airflow from the shaft flow to reduce interference effects. A basic endplate **60** configuration is planar and extends beyond the dimensions of the hosel end-plane in all directions. Its plan-form does not necessarily need be symmetric, but it extends farthest beyond the hosel end-plane in the flow direction at impact (hosel negative z-axis direction). A non-planar version of the endplate **60** can be shaped to preferentially influence either the shaft **40** or hosel **20** side flows. This can be achieved by curving the lateral or trailing edges of the endplate **60**.

Drag Reduction Configurations—Hosel Surface Features and Base Treatments

Hosel dimensions in the flow direction generally are small relative to the head, but larger than the shaft. The resulting relatively low Reynolds Number operating range greatly restricts the type and effectiveness of surface features for reducing drag. Early in the swing, when the flow is at high incidence angles, an airfoil cross-section will experience mostly detached flow. That is, it is in a stalled condition, sometimes called deep stall. In this condition it is not functioning as an airfoil. The low drag benefits of the airfoil cross-section do not emerge until the flow is more closely aligned to the hosel Z-axis. It would be more beneficial for the hosel to act as a flow mixing device, much like a vortex generator, at high angles of incidence. This would inject higher energy air into the hosel wake and potentially reduce separation downstream of the hosel, which, in turn, would reduce drag. However, it is preferable for the hosel to retain its low drag airfoil characteristics at low incidence angles. The result is a "dual mode" hosel that is an airfoil at low incidence angles and a vortex generator at high angles of incidence.

One approach to achieving this functionality is to modify a hosel with an airfoil cross-section by the addition of certain features such as fins placed at appropriate orientations. The fins would cause flow mixing at high incidence angles but be aligned with the flow at low incidence angle to minimize drag and allow the airfoil cross-section of the hosel to function. As such, it is beneficial to add surface features such as trip strips **80**, shown in FIGS. **36**A and **36**B, roughness **82**, shown in FIG. **37**, or vortex generators **84**, shown in FIG. **38**, to the forward portions of an airfoil or elliptical shaped hosel. Flow induced by the presence of the head will increase the local Reynolds Number of the hosel. This effect can be used to an advantage in that some surface geometries may become effective, especially for the portions of the hosel adjacent to the head.

The intersection of the hosel **20** and the head **10** creates a corner, which leads to formation of a necklace vortex and results in additional drag. The most straightforward way to reduce this drag is to create a fillet from the hosel wall to the crown surface. However, a trip feature, surface roughness, or vortex generators forward of the hosel base may also be useful in promoting attached turbulent flow and reducing the wake of the hosel.

Club Structure

In some embodiments of the present invention, the golf club head is a wood, e.g., a driver, fairway wood, or hybrid club. The golf club head of the present invention may be made from various materials, including, but not limited to, titanium and titanium alloys, magnesium, aluminum, tungsten, carbon or graphite composite, plastic, stainless steel, etc. In some embodiments, the entire club head is made of one material. In other embodiments, the club head is made of two or more materials. The golf club of the present invention may also have material compositions such as those disclosed in U.S. Pat. Nos. 6,244,976, 6,332,847, 6,386,990, 6,406,378, 6,440,008, 6,471,604, 6,491,592, 6,527,650, 6,565,452, 6,575,845, 6,478,692, 6,582,323, 6,508,978, 6,592,466, 6,602,149, 6,607,452, 6,612,398, 6,663,504, 6,669,578, 6,739,982, 6,758,763, 6,860,824, 6,994,637, 7,025,692, 7,070,517, 7,112,148, 7,118,493, 7,121,957, 7,125,344, 7,128,661, 7,163,470, 7,226,366, 7,252,600, 7,258,631, 7,314,418, 7,320,646, 7,387,577, 7,396,296, 7,402,112, 7,407,448, 7,413,520, 7,431,667, 7,438,647, 7,455,598, 7,476,161, 7,491,134, 7,497,787, 7,549,935, 7,578,751, 7,717,807, 7,749,096, and 7,749,097, the disclosure of each of which is hereby incorporated in its entirety herein.

The golf club head of the present invention may be constructed to take various shapes, including traditional, square, rectangular, or triangular. In some embodiments, the golf club head of the present invention takes shapes such as those disclosed in U.S. Pat. Nos. 7,163,468, 7,166,038, 7,169,060, 7,278,927, 7,291,075, 7,306,527, 7,311,613, 7,390,269, 7,407,448, 7,410,428, 7,413,520, 7,413,519, 7,419,440, 7,455,598, 7,476,161, 7,494,424, 7,578,751, 7,588,501, 7,591,737, and 7,749,096, the disclosure of each of which is hereby incorporated in its entirety herein.

The golf club head of the present invention may also have variable face thickness, such as the thickness patterns disclosed in U.S. Pat. Nos. 5,163,682, 5,318,300, 5,474,296, 5,830,084, 5,971,868, 6,007,432, 6,338,683, 6,354,962, 6,368,234, 6,398,666, 6,413,169, 6,428,426, 6,435,977, 6,623,377, 6,997,821, 7,014,570, 7,101,289, 7,137,907, 7,144,334, 7,258,626, 7,422,528, 7,448,960, 7,713,140, the disclosure of each of which is incorporated in its entirety herein. The golf club of the present invention may also have the variable face thickness patterns disclosed in U.S. Patent Application Publication No. 20100178997, the disclosure of which is incorporated in its entirety herein.

From the foregoing it is believed that those skilled in the pertinent art will recognize the meritorious advancement of this invention and will readily understand that while the present invention has been described in association with a preferred embodiment thereof, and other embodiments illustrated in the accompanying drawings, numerous changes, modifications and substitutions of equivalents may be made therein without departing from the spirit and scope of this invention which is intended to be unlimited by the foregoing except as may appear in the following appended claims. Therefore, the embodiments of the invention in which an exclusive property or privilege is claimed are defined in the following appended claims.

We claim as our invention:

1. A driver-type golf club head comprising:

a metal face component comprising a striking face having a vertical plane, a return portion extending approximately perpendicular to the striking face, and a hosel;

a composite crown; and

a sole,

wherein the hosel is disposed on an upper surface of the return portion proximate the crown and comprises:

an upper portion having a shaft-receiving bore; and

a swept transition portion disposed between the upper portion and the return portion, the swept transition portion comprising:

a height of one inch or less; and

a non-circular cross-section,

wherein all points at which the swept transition portion contacts the return portion are spaced rearwards from the striking face vertical plane, and

wherein the head has a volume of at least 400 cubic centimeters and no more than 500 cubic centimeters.

2. The golf club head of claim **1**, wherein the swept transition portion further comprises a shaft receiving bore that is coaxial with the shaft-receiving bore of the upper portion.

3. The golf club head of claim **2**, further comprising a shaft bonded to the shaft receiving bore of the upper portion and the shaft receiving bore of the swept transition portion.

4. The golf club head of claim **3**, wherein the shaft has an angled tip, and wherein the angled tip is disposed within the shaft receiving bore of the swept transition portion.

5. The golf club head of claim **1**, wherein the swept transition portion comprises an airfoil cross-section.

6. The golf club head of claim **5**, wherein the airfoil cross-section is truncated.

7. The golf club head of claim **5**, wherein the airfoil cross-section comprises a trailing edge having one or more surface discontinuities.

8. The golf club head of claim **1**, wherein the upper portion has a circular cross-section.

9. The golf club head of claim **1**, wherein the upper portion has a non-circular cross-section.

10. The golf club head of claim **1**, wherein the swept transition portion comprises a forward edge, and wherein the forward edge is curved.

11. The golf club head of claim **1**, wherein the swept transition portion comprises a trailing edge, and wherein the trailing edge is curved.

12. The golf club head of claim **1**, wherein the swept transition portion comprises a forward-most point located proximate the striking face and a rearward-most junction with the face cup, and wherein the rearward-most junction is located 0.25 to 1.50 inches from the forward-most point.

13. The golf club head of claim **12**, wherein the rearward-most junction is located approximately 1 inch from the forward-most point.

14. The golf club head of claim **1**, wherein the swept transition portion comprises a chord length of less than 1 inch.

15. The golf club head of claim **1**, wherein the swept transition portion comprises a chord length that is smaller than a diameter of the upper portion.

16. The golf club head of claim **15**, wherein the swept transition portion is extruded.

17. The golf club head of claim **1**, wherein the face component is integrally formed from a titanium alloy.

18. The golf club head of claim **1**, wherein the sole is composed of a metal material.

19. The golf club head of claim **18**, wherein the sole is composed of a titanium alloy.

20. The golf club head of claim **18**, wherein the sole is integrally formed with the face component.

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