Golf club heads with turbulators and methods to manufacture golf club, heads with turbulators

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Henrikson et al.

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(45) **Date of Patent: Dec. 17, 2013**

(54) **GOLF CLUB HEADS WITH TURBULATORS AND METHODS TO MANUFACTURE GOLF CLUB HEADS WITH TURBULATORS**

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(73) Assignee: **Karsten Manufacturing Corporation**, Phoenix, AZ (US)

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Related U.S. Application Data

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

(52) **U.S. Cl.**
USPC **473/324**; 473/327; 473/328; 473/345; 473/409

(58) **Field of Classification Search**
USPC 473/324, 327, 328, 345, 409, 226, 228, 473/344; D21/733, 752, 759
See application file for complete search history.

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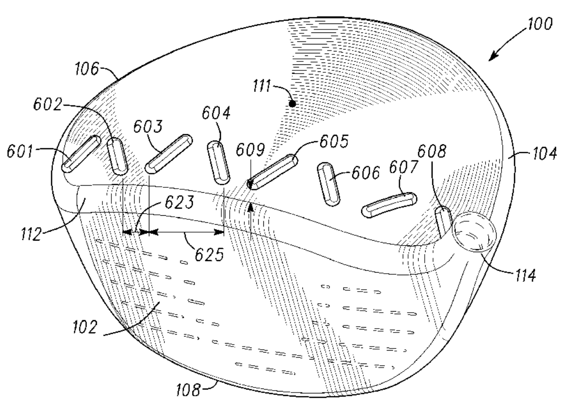
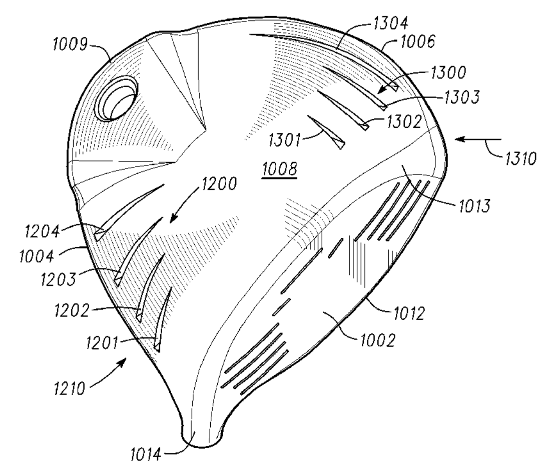
Primary Examiner — Sebastiano Passaniti

(57) **ABSTRACT**

A golf club head includes a crown surface extending between the face, the rear, the heel and the toe of the golf club head. A highest point on the surface of the crown defines an apex. The golf club head also includes a plurality of crown turbulators projecting from the surface of the crown. Each adjacent pair of crown turbulators is separate and spaced apart to define a space between the adjacent pair of crown turbulators, and each crown turbulator extends between the heel and the toe to define a width and extending between the face and the rear to define a length, which is substantially greater than the width. At least a portion of at least one crown turbulator is located between the face and the apex. The space between each adjacent pair of crown turbulators is substantially greater than the width of each of the adjacent pair of crown turbulators that define the space.

28 Claims, 13 Drawing Sheets





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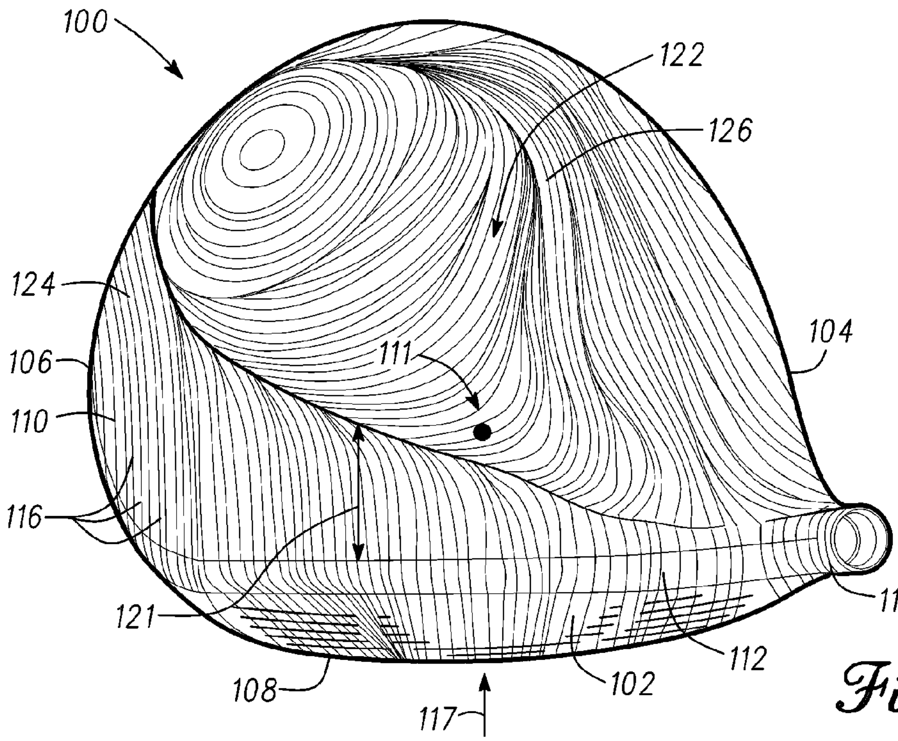
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Fig. 1

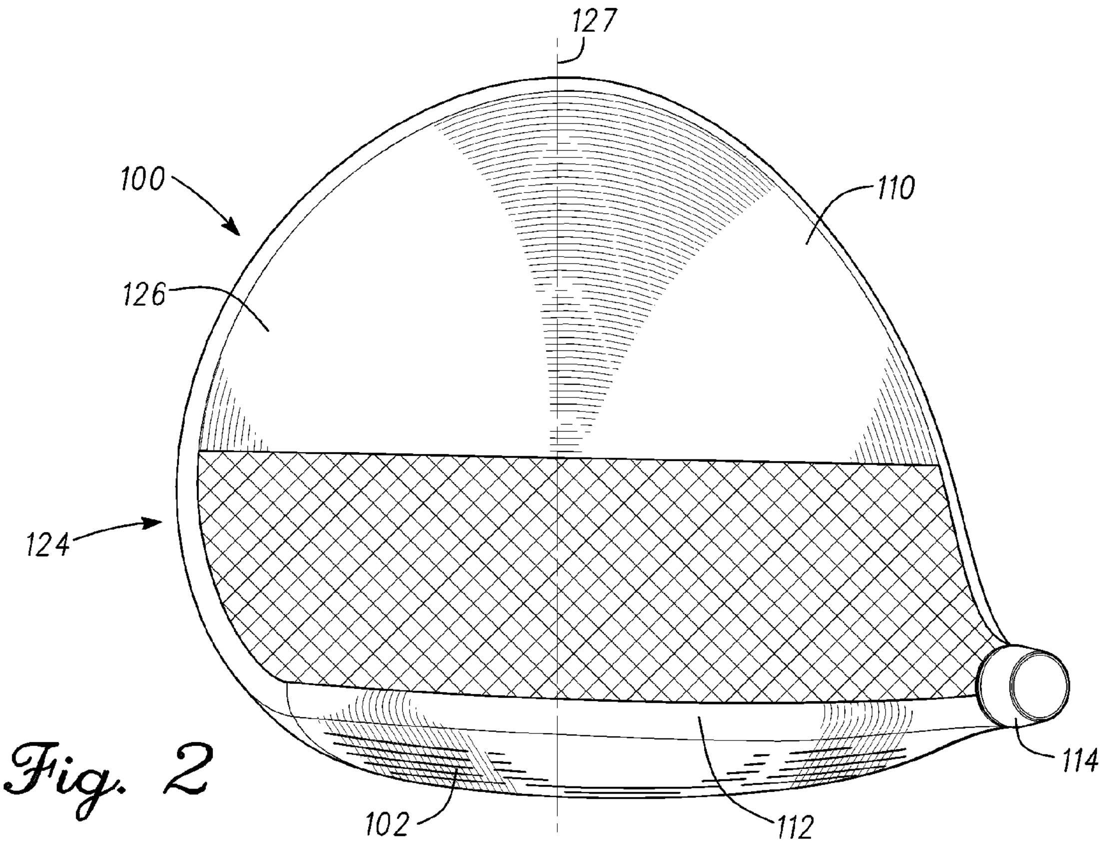
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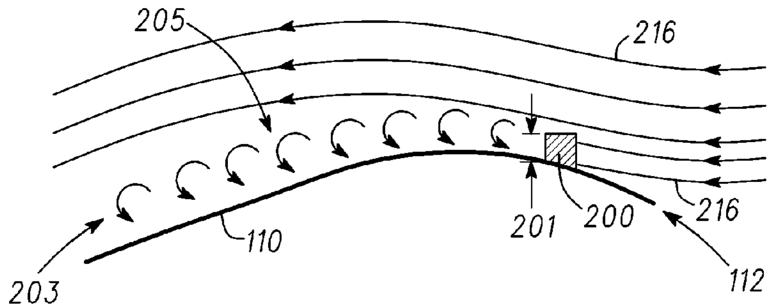
Fig. 2



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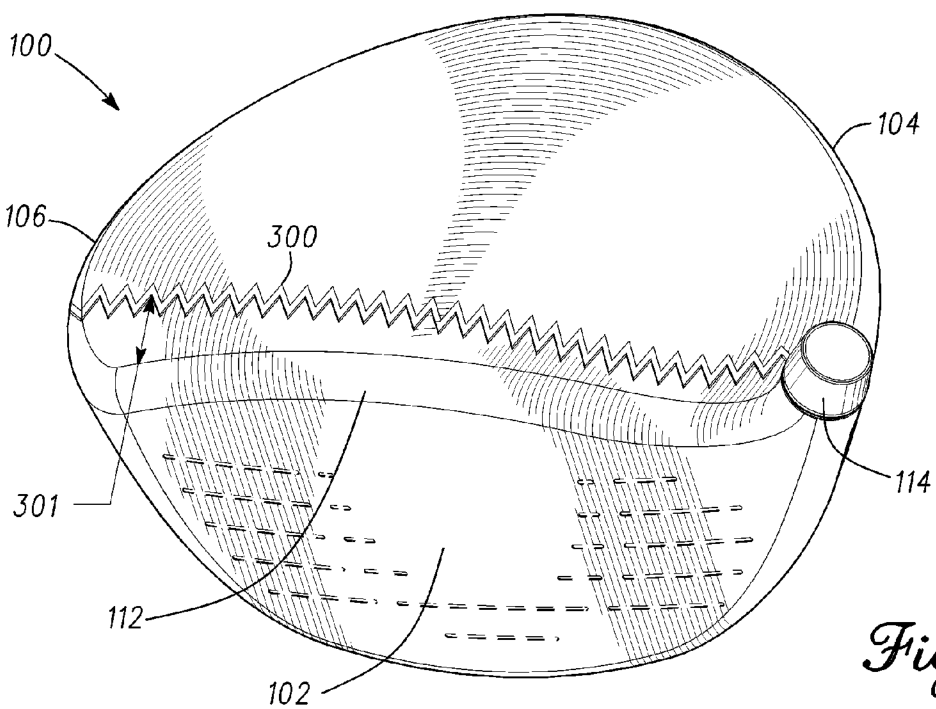

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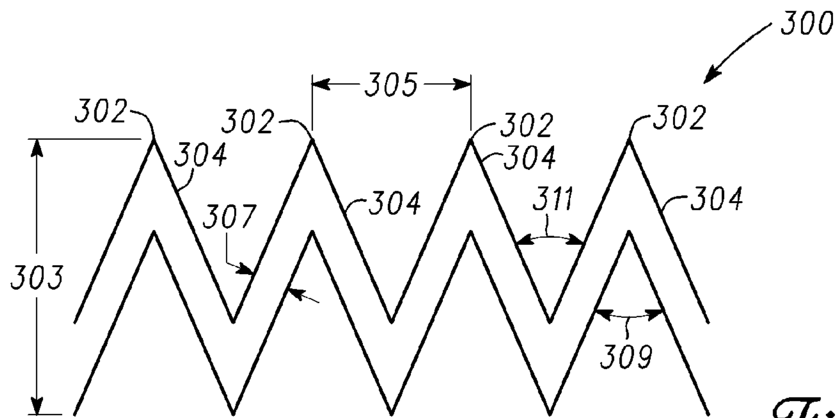

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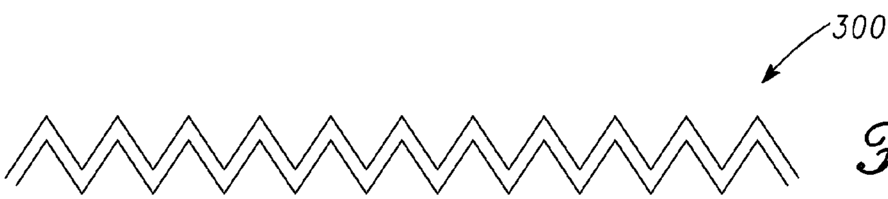

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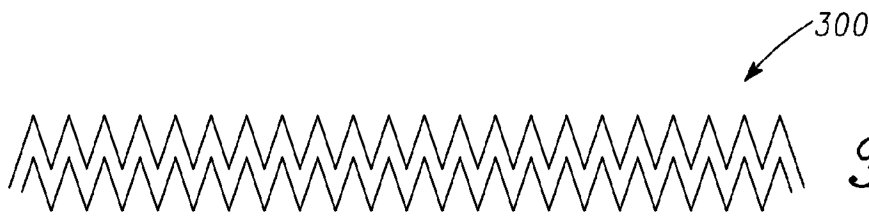

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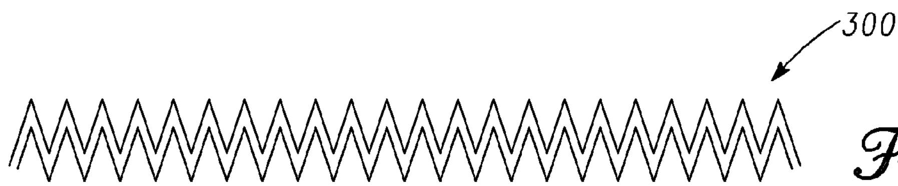
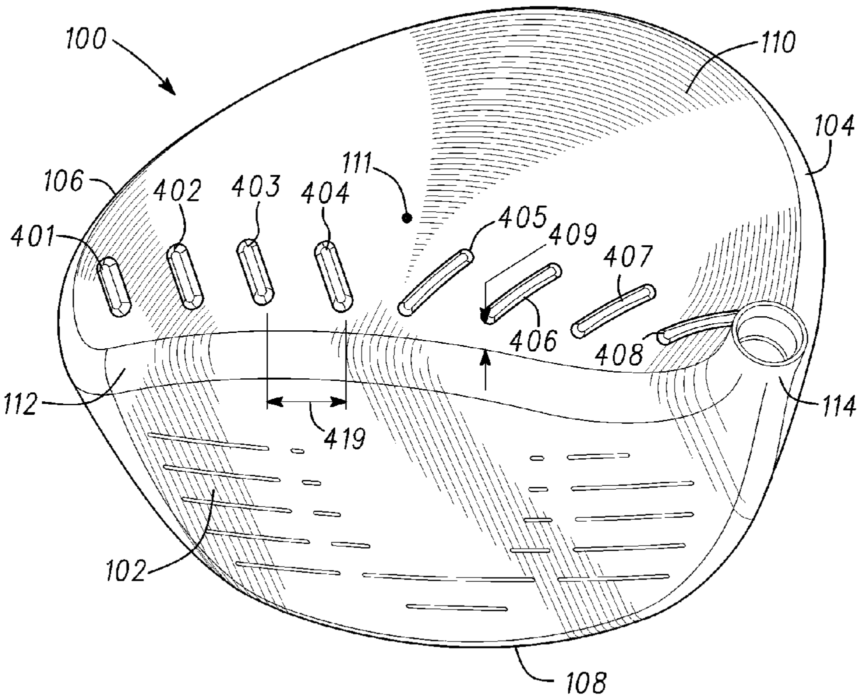


Fig. 8

Fig. 9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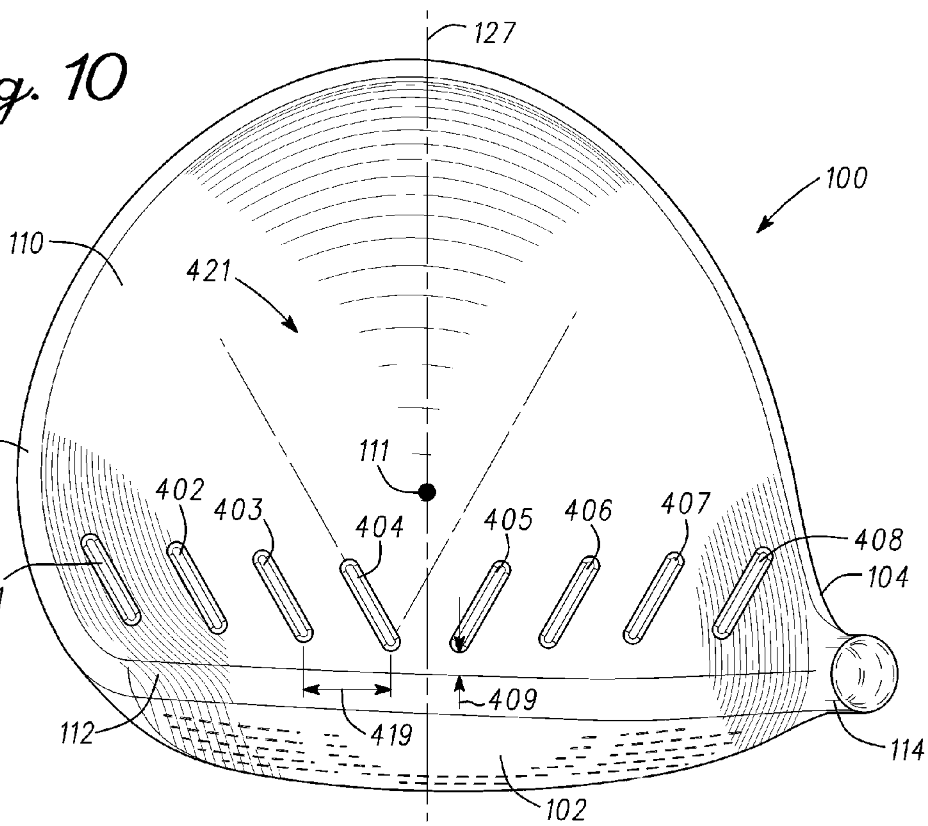
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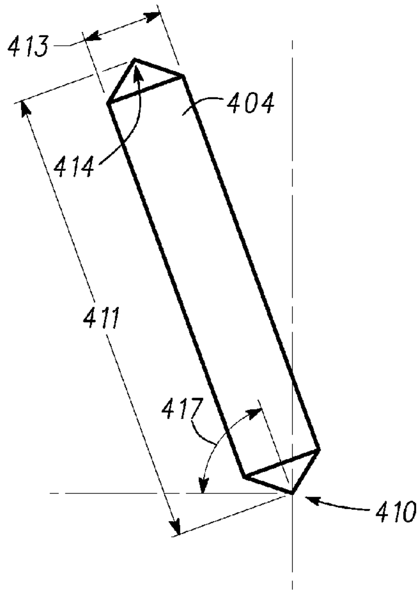

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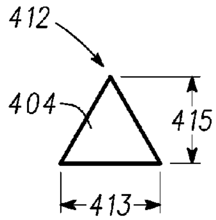

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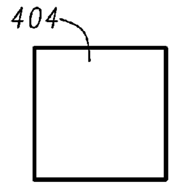

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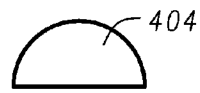

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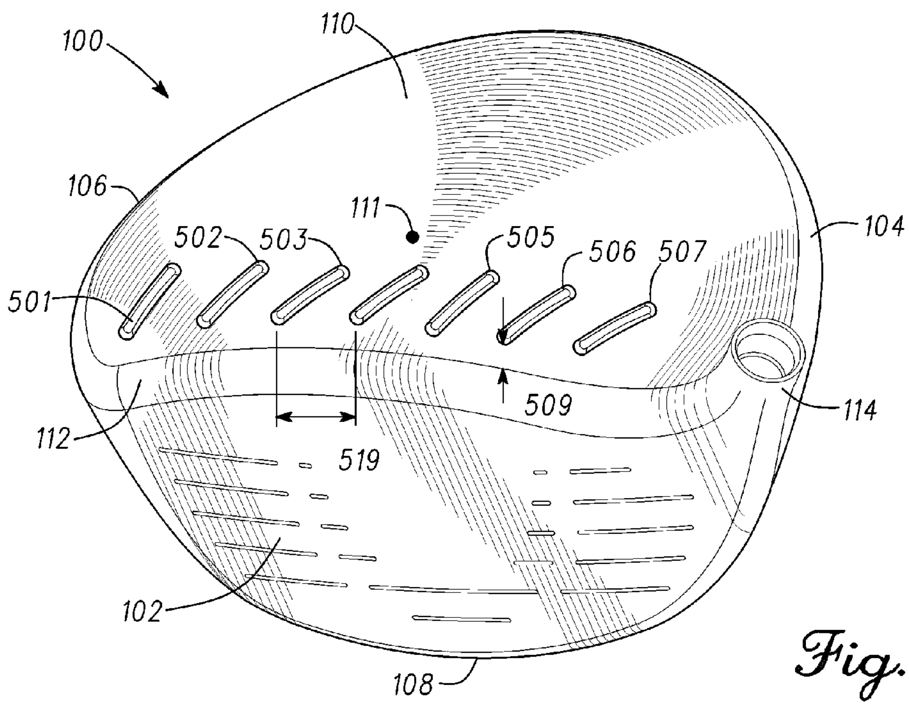

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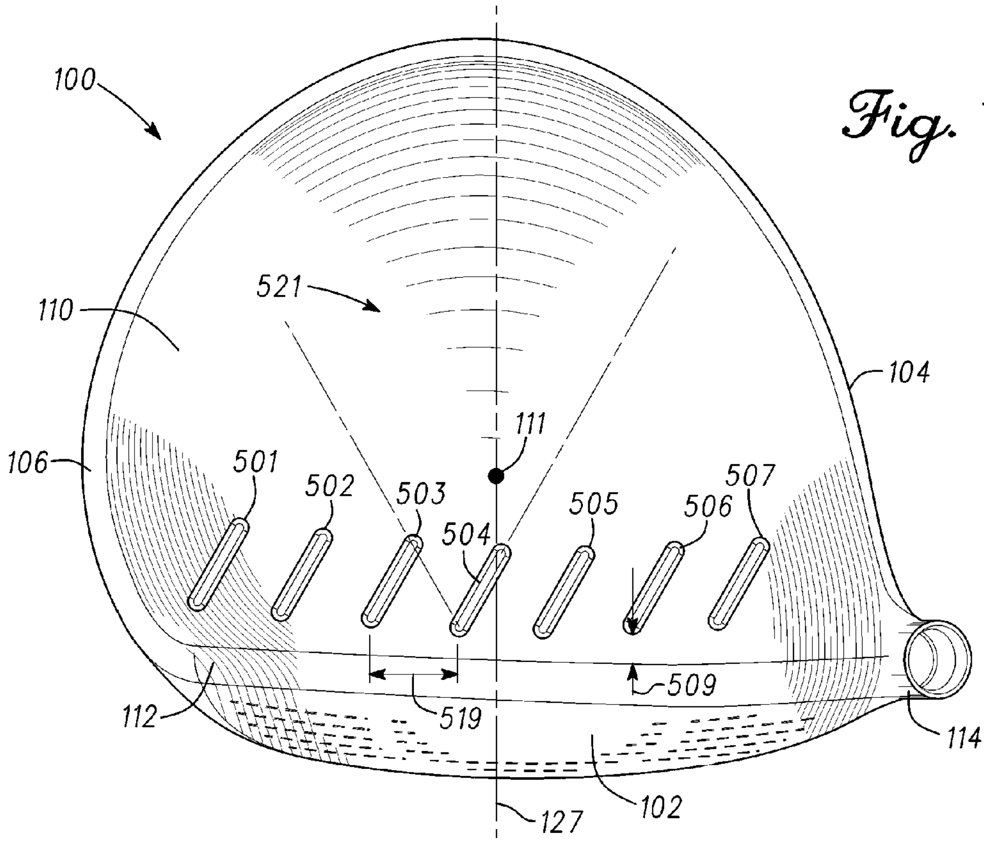

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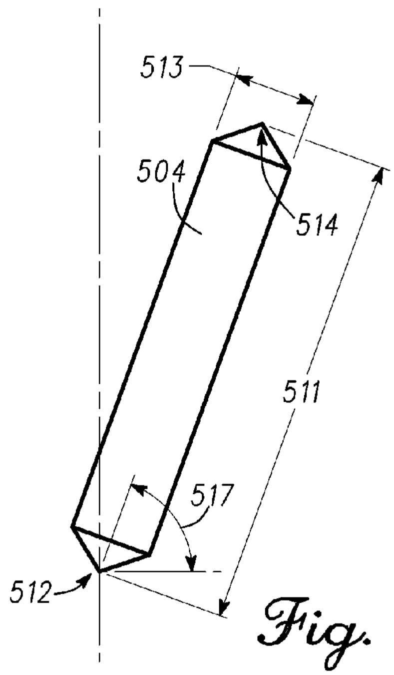

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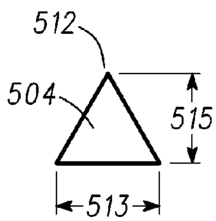

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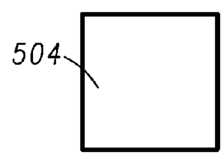

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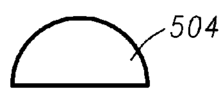

Fig. 20

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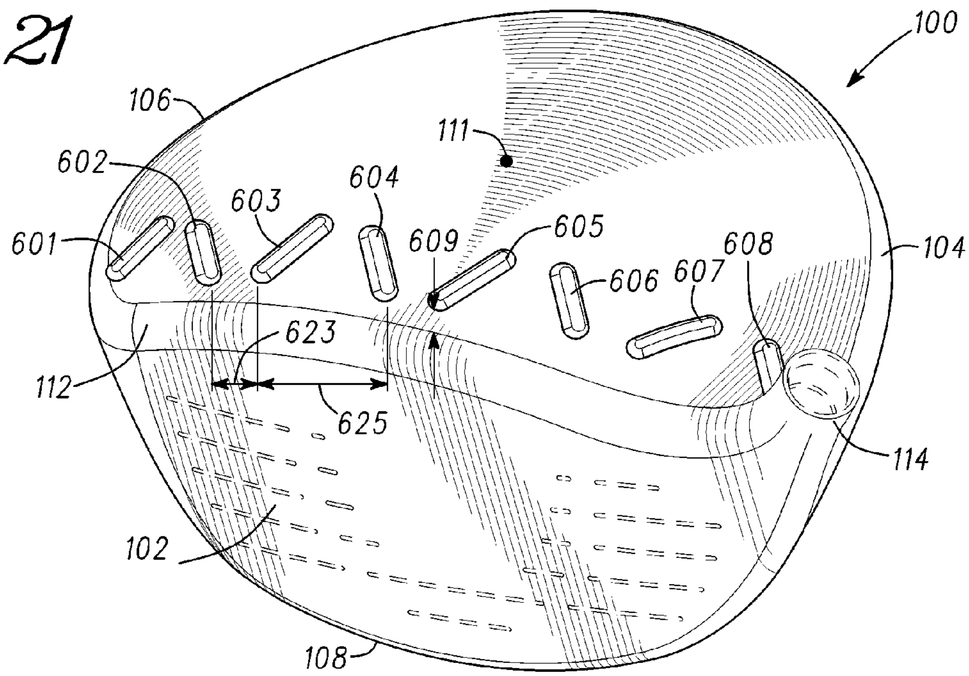
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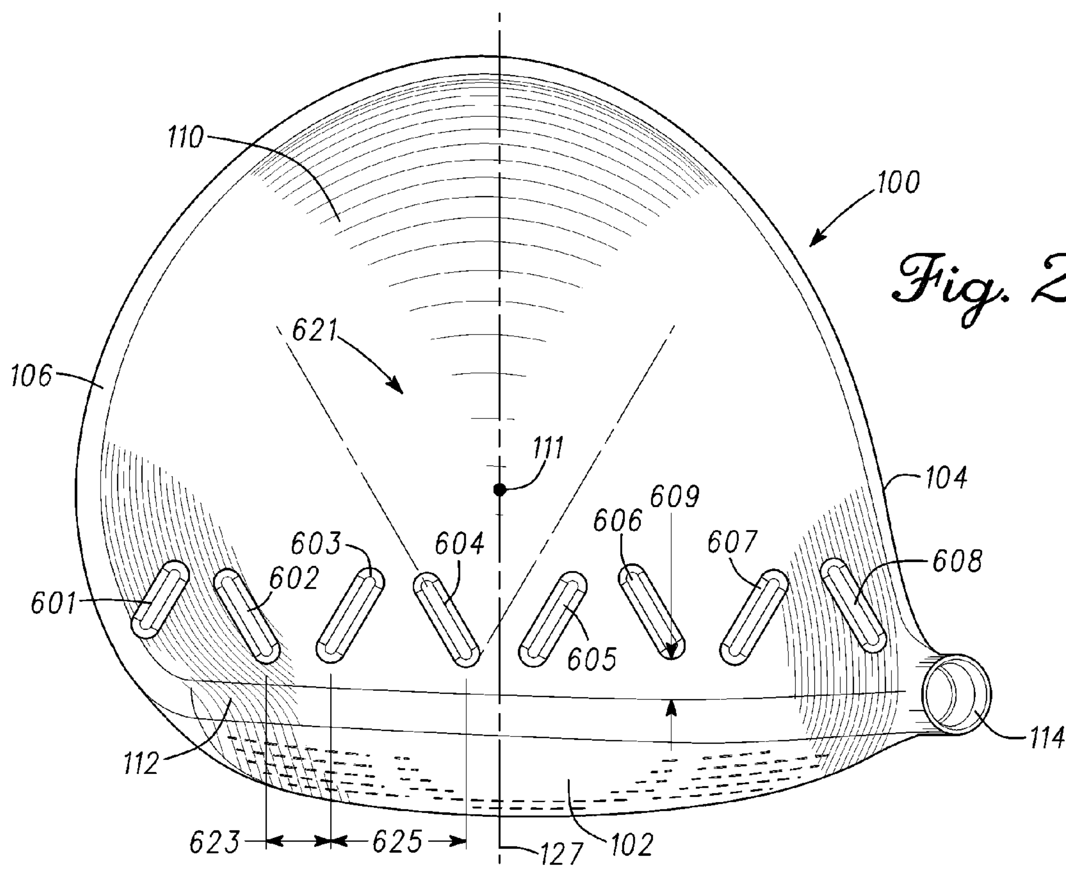
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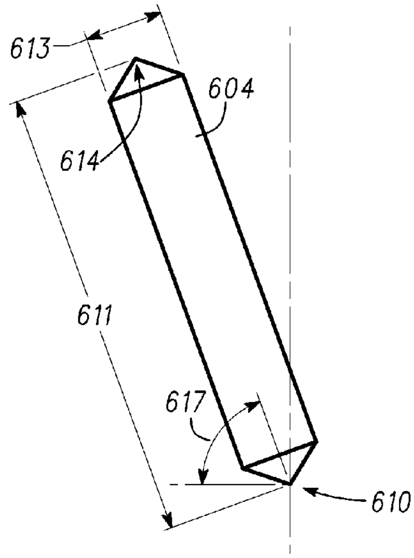
Fig. 22



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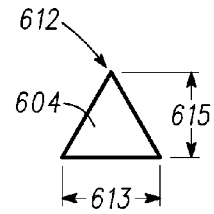

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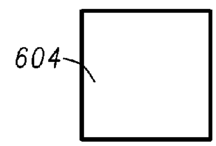

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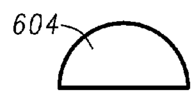

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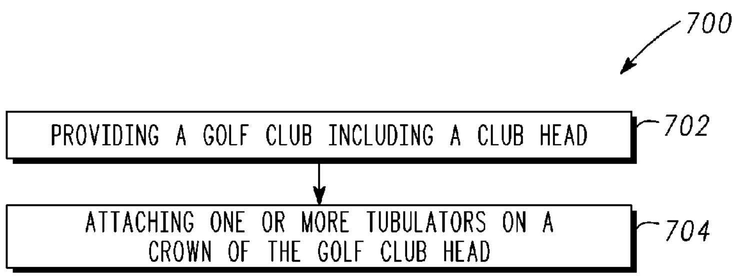

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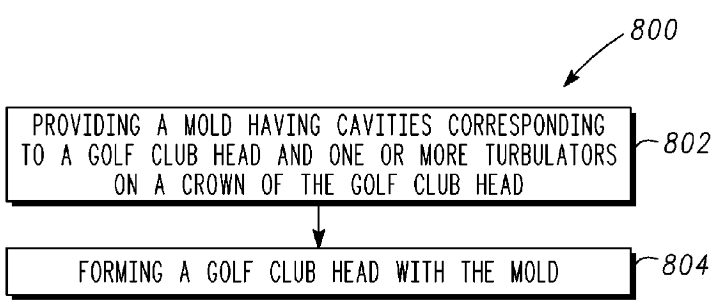

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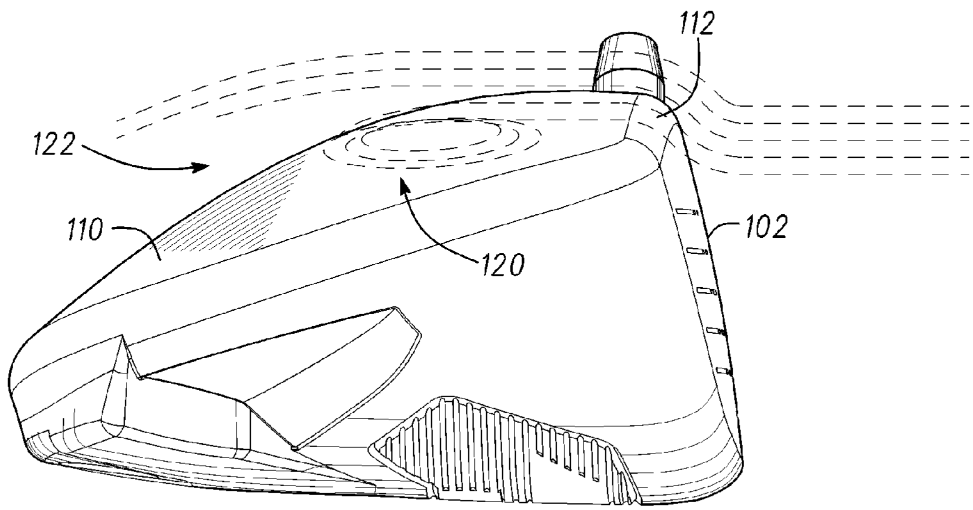

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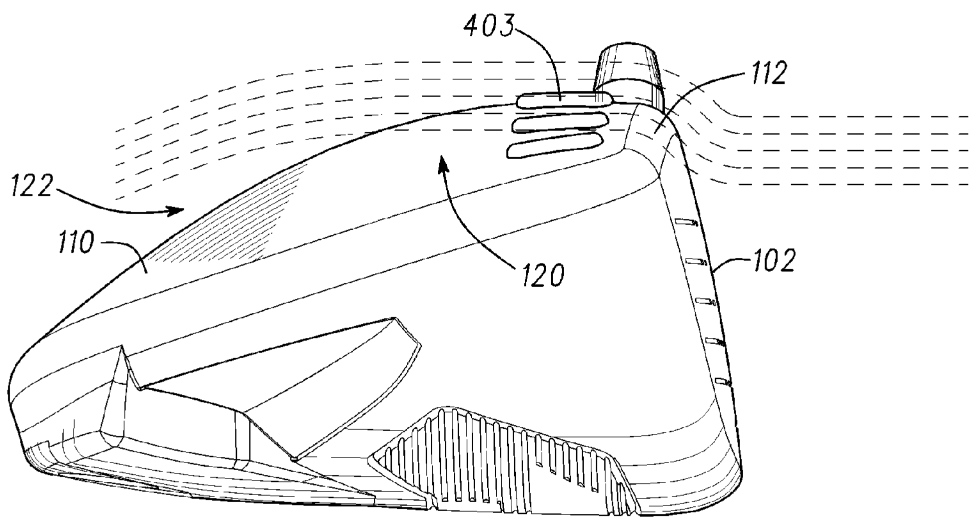

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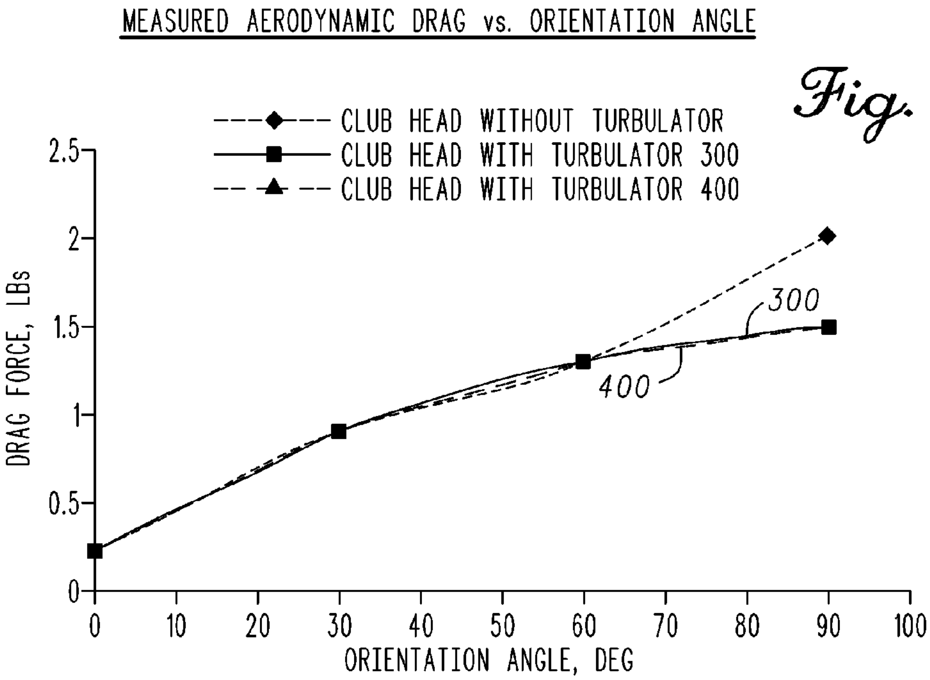
MEASURED AERODYNAMIC DRAG vs. ORIENTATION ANGLE
CLUB HEAD WITHOUT TURBULATOR
CLUB HEAD WITH TURBULATOR 300
CLUB HEAD WITH TURBULATOR 400
DRAG FORCE, LBs
ORIENTATION ANGLE, DEG
300
400
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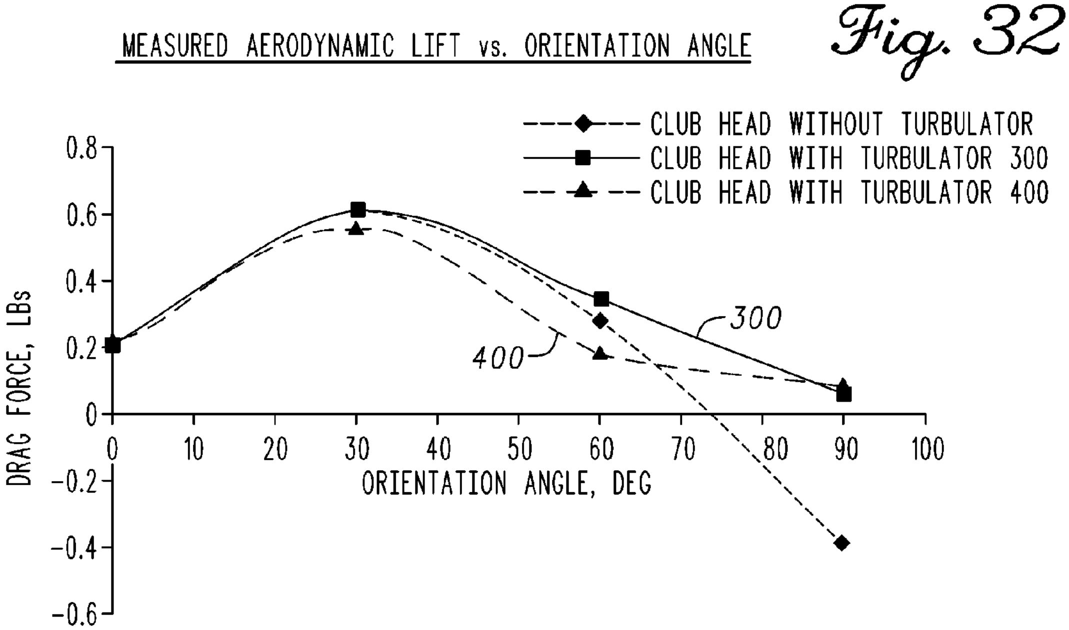
Fig. 31


MEASURED AERODYNAMIC LIFT vs. ORIENTATION ANGLE
CLUB HEAD WITHOUT TURBULATOR
CLUB HEAD WITH TURBULATOR 300
CLUB HEAD WITH TURBULATOR 400
DRAG FORCE, LBs
ORIENTATION ANGLE, DEG
300
400
0.8
0.6
0.4
0.2
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-0.6
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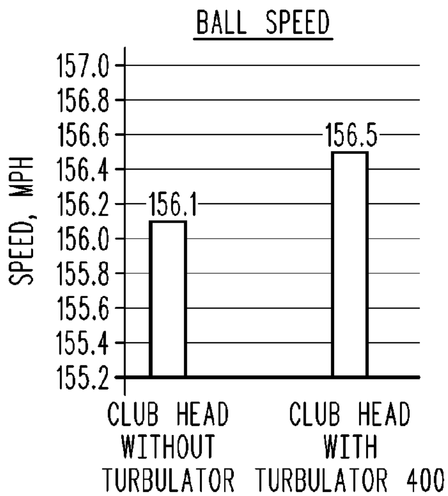
Fig. 32



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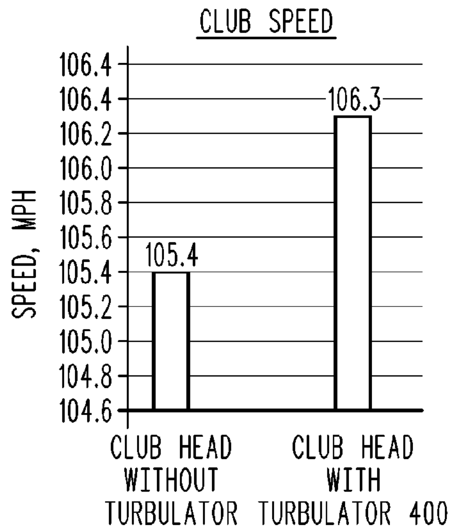
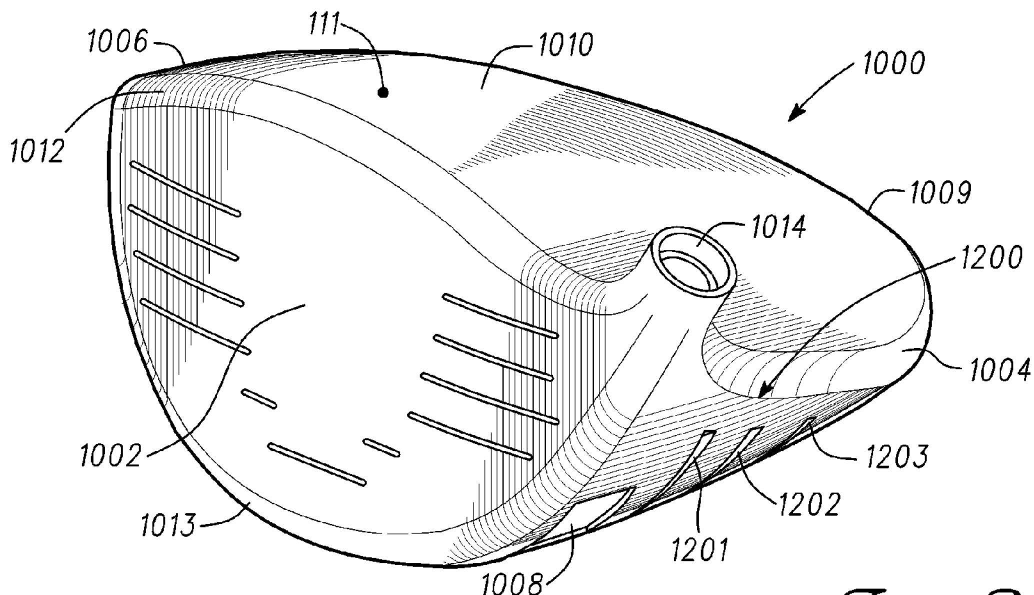


Fig. 34



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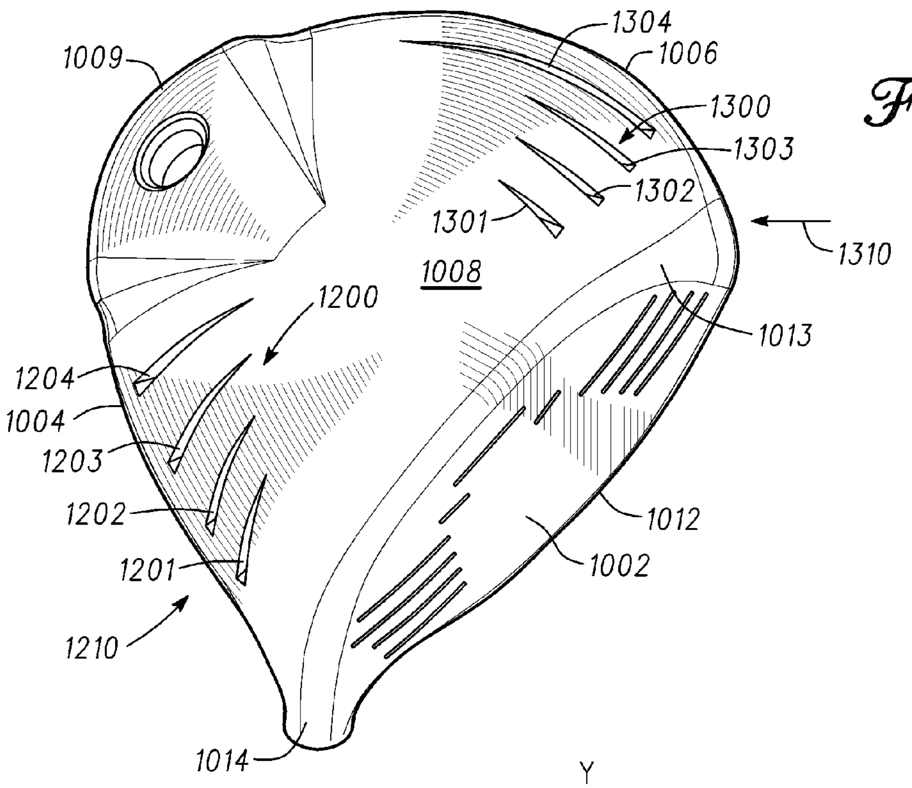
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Fig. 36

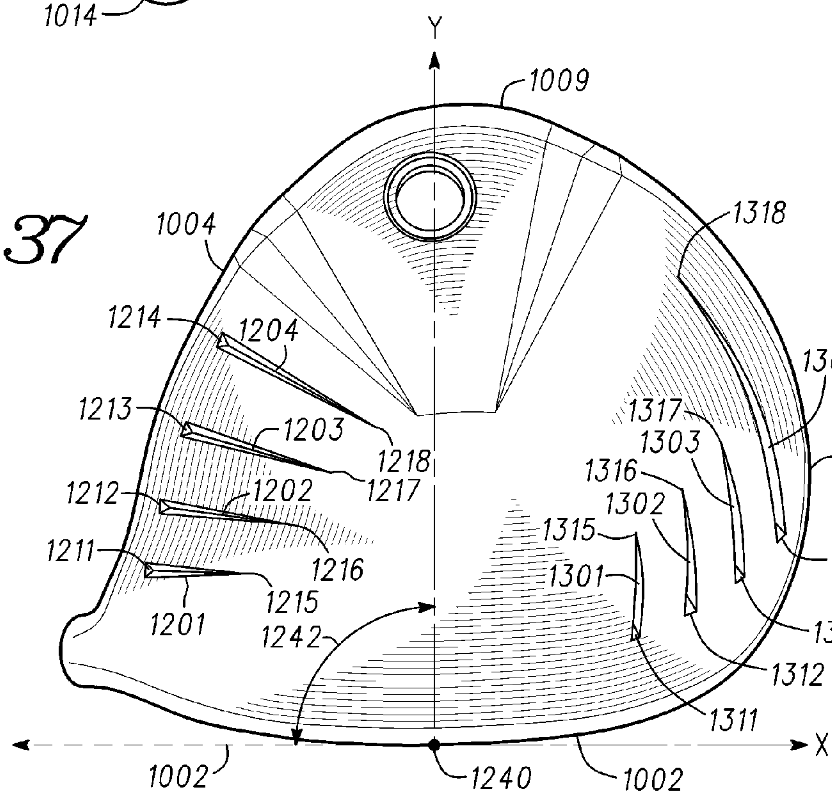
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Fig. 37

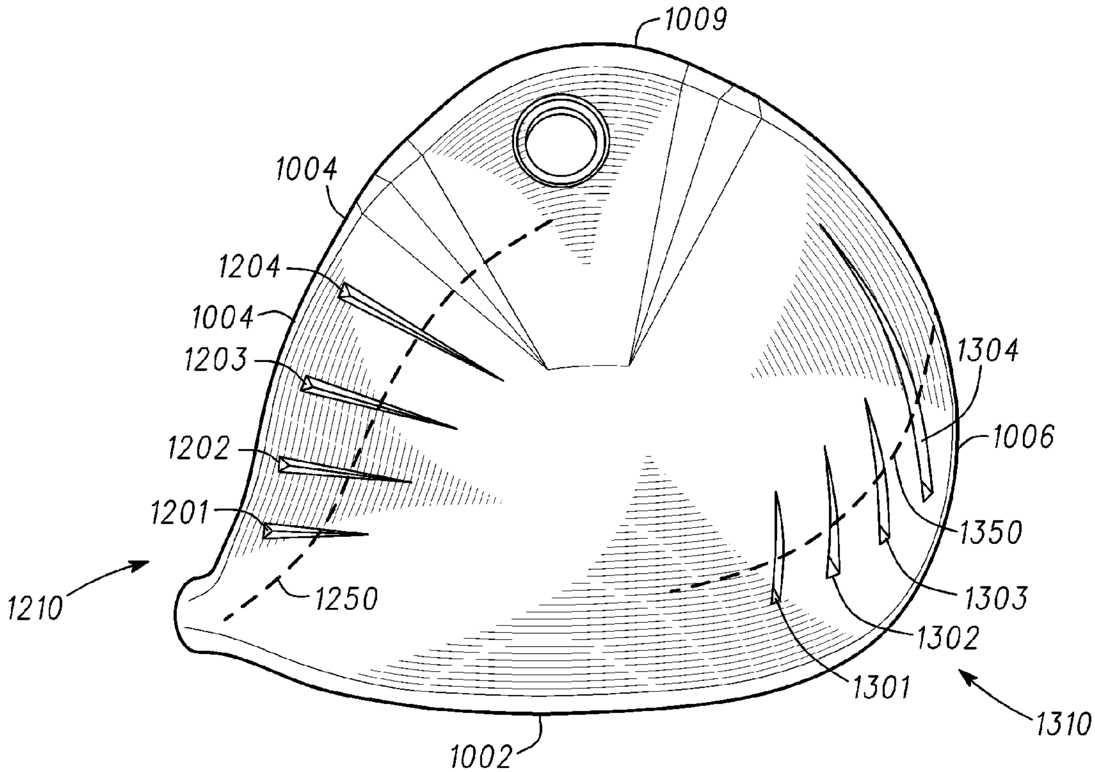
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Fig. 38

GOLF CLUB HEADS WITH TURBULATORS AND METHODS TO MANUFACTURE GOLF CLUB HEADS WITH TURBULATORS

CROSS-REFERENCE TO RELATED APPLICATIONS

The present application claims the benefit of U.S. Provisional Patent Application Ser. No. 61/553,428 filed on Oct. 31, 2011, and U.S. Provisional Patent Application Ser. No. 61/651,392 filed on May 24, 2012, the entire disclosures of which are incorporated herein by reference.

FIELD

The present application generally relates to golf clubs, and more particularly, to golf club heads with turbulators and methods to manufacture golf club heads with turbulators.

BACKGROUND

When air flows over a golf club head, viscous forces near the surface of the club head create a velocity gradient from the surface to the free stream region. Accordingly, air flow velocity near the surface may be relatively slow and gradually increases toward the free stream velocity, which is the air flow region where air velocity is not influenced by the club head. This velocity gradient region is called a boundary layer. Flow separation occurs when the boundary layer travels on the golf club head far enough against an adverse pressure gradient that the air flow velocity in the boundary layer relative to the surface of the club head falls almost to zero. The air flow becomes detached from the surface of the club head and takes the form of eddies and vortices. Flow separation may result in increased drag, which may be caused by the pressure differential between the front and rear surfaces of the club head. The increased drag may reduce the speed of the club head, which in turn may lower the velocity of a golf ball that is struck by the club head.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a top perspective view of a club head showing air flow streamlines on the club head.

FIG. **2** is a top perspective view of a club head shown front and aft regions of a crown of the club head.

FIG. **3** is a schematic cross-sectional diagram of a turbulator according to one embodiment.

FIG. **4** is a perspective view of a club head having a turbulator according to one embodiment.

FIG. **5** is a schematic diagram of the turbulator of FIG. **4**.

FIGS. **6-8** show examples of different turbulators according to the embodiment of FIG. **4**.

FIGS. **9** and **10** are perspective views of a club head having a turbulator according to one embodiment.

FIG. **11** is a schematic diagram of a section of the turbulator of FIGS. **9** and **10**.

FIGS. **12-14** show different cross-sectional diagrams of turbulators according to the embodiment of FIGS. **9** and **10**.

FIGS. **15** and **16** are perspective views of a club head having a turbulator according to one embodiment.

FIG. **17** is a schematic diagram of a section of the turbulator of FIGS. **15** and **16**.

FIGS. **18-20** show different cross-sectional diagrams of turbulators according to the embodiment of FIGS. **15** and **16**.

FIGS. **21** and **22** are perspective views of a club head having a turbulator according to one embodiment.

FIG. **23** is a schematic diagram of a section of the turbulator of FIGS. **21** and **22**.

FIGS. **24-26** show different cross-sectional diagrams of turbulators according to the embodiment of FIGS. **21** and **22**.

FIG. **27** is a flow chart showing a method of manufacturing a club head with turbulators according to one embodiment.

FIG. **28** is a flow chart showing a method of manufacturing a club head with turbulators according to another embodiment.

FIG. **29** shows a schematic view based on actual airflow visualization experiments of airflow over a club head without turbulators.

FIG. **30** shows a schematic view based on actual airflow visualization experiments of airflow over the club head of FIG. **29** with turbulators.

FIG. **31** is a graph showing measurements of drag force vs. orientation angle.

FIG. **32** is a graph showing measurements of lift force vs. orientation angle.

FIG. **33** is a graph showing measurements of ball speed.

FIG. **34** is a graph showing measurements of club speed.

FIGS. **35-38** are different perspective views of a club head having sole turbulators according to one embodiment.

DETAILED DESCRIPTION

Referring to FIG. **1**, a golf club head **100** is shown, which includes a face **102** that extends horizontally from a heel end **104** to a toe end **106** and vertically from a sole **108** to a crown **110**. A transition region between the face **102** and the crown **110** defines a leading edge **112**. The highest point on the crown **110** defines an apex **111**. The club head **100** also includes a hosel **114** for receiving a shaft (not shown). The club head **100** is a wood-type club head. However, the present disclosure is not limited to wood-type club heads and applies to any type of golf club head (e.g., a driver-type club head, a fairway wood-type club head, a hybrid-type club head, an iron-type club head, a wedge-type club head, or a putter-type club head). The apparatus, methods, and articles of manufacture described herein are not limited in this regard.

FIG. **1** shows an exemplary air flow pattern on the club head **100** with streamlines **116**. Air flowing in the direction of the arrow **117** flows over the crown **110** from the leading edge **112** toward the rear section of the crown **110**. The airflow may remain attached to the crown **110** from the leading edge **112** to a separation region **120** located at a certain separation distance **121** from the leading edge **112**. The separation may occur in a narrow strip on the crown **110**, hence the separation region **120** may also be referred to herein as a separation line **120**. As shown in FIG. **1**, the distance **121** may vary from the heel end **104** to the toe end **106** depending on the physical characteristics of the club head **100**. At the separation region **120**, the airflow detaches from the crown **110** and creates a wake region **122**, which is defined by the airflow becoming turbulent or forming eddies and vortices in the free stream region. The pressure differential between the wake region **122** and the attached flow region on the crown **110** creates a pressure drag on the club head **100**. The pressure drag reduces the speed of the club head **100**, hence affecting the speed by which a ball is hit with the club head **100**. To maintain the air flow attached on the crown **110** for a longer distance **121**, the air flow in the boundary layer before the separation region **120** can be energized to delay air flow detachment or to move the separation region **120** farther back on the crown **110**. To energize the boundary layer, which may be laminar upstream of the separation region **120**, the boundary layer can be made turbulent (or more turbulent if the flow is turbulent) upstream of the separation region **120**.

To delay air flow separation or detachment as described above, the golf club head **100** includes turbulators positioned on the crown **110** as described in detail below. Referring to FIG. **2**, the turbulators may be positioned in the front region **124** of the crown **110** and before the separation region **120** to delay air flow separation or move the separation region **120** toward the rear region **126** of the crown **110**. A schematic diagram of an exemplary turbulator **200** is shown in cross section in FIG. **3**. The turbulator **200** projects upward from the crown **110** at a height **201** such that it is inside the boundary layer **203**. The turbulator **200** trips the air flowing over the crown **110** as shown by the streamline **216** to create turbulence **205** inside the boundary layer **203**. The turbulence energizes the boundary layer **203** to delay separation of the air flow on the crown **110** and move the separation region **120** toward the aft region **126** of the crown **110**. In other words, the turbulators according to the disclosure increase the distance **121** shown in FIG. **1**.

An example of a turbulator **300** is shown in FIG. **4**. The turbulator **300** energizes the boundary layer on the crown **110** by generating turbulence in the boundary layer. The turbulator **300** is located on the crown **110** at a constant or variable distance **301** downstream of the leading edge **112** and may extend from the hosel **114** or the heel end **104** to the toe and **106**. The turbulator **300** provides a plurality of projected surfaces in discrete or continuous form on the surface of the crown **110** at a height (not showing FIGS. **4-8**, but generally shown with reference number **201** in FIG. **3**). When the air flowing over the crown **110** encounters the projected surfaces of the turbulator **300**, the air trips and becomes turbulent inside the boundary layer to energize the boundary layer.

The turbulator **300** shown in the example of FIG. **4** is formed by a strip having a zigzag pattern. Referring to FIG. **5**, the zigzag pattern provides peaks **302** and swept back surfaces **304**. The peaks **302** and the swept back surfaces **304** provide continuous tripping of the air flow across the width **303** of the turbulator **300**. The peaks **302** are spaced apart by a distance **305** and the turbulator **300** has a thickness **307**, a height (not shown in FIGS. **4-8**), and surface characteristics that may affect air flow. The peaks **302** are defined by a peak angle **309** and the angle between two adjacent peaks **302** is defined by a valley angle **311**. Referring to FIGS. **6-8**, the width **303**, the distance **305**, the thickness **307**, the height and/or the angles **309** and **311** may be different for each application to provide a particular flow pattern over the crown **110**. The surface characteristics of the turbulator **300** may also vary to provide a certain flow pattern over the crown **110**. The surface characteristics of the turbulator **300** may refer to the roughness or smoothness of the top surface of the turbulator **300**. In the examples of FIGS. **6-8**, the turbulator **300** shown in FIG. **7** may provide greater turbulence in a boundary layer than the turbulator **300** of FIG. **6**. Accordingly, the turbulator **300** of FIG. **7** may be suitable in a certain application depending on the physical characteristics of the club head **100**. However, the turbulator **300** of FIG. **6** may be suitable for another type of club head **100**. Accordingly, each of the exemplary turbulators **300** of FIGS. **6-8** may be suitable for different club heads **100**.

The turbulator **300**, for example, may have a height that does not exceed 0.5 inches (1.27 cm). In one embodiment, the turbulator **300** may have a height that is greater than 0.02 inches (0.05 cm) but less than 0.2 inches (0.51 cm). In one embodiment, the width **303** of the turbulator may be less than 0.75 inches (1.91 cm). The turbulator **300** may have a peak-to-peak distance **305** that contributes to the delay in airflow separation. The location of the turbulator **300** may vary depending on the physical characteristics of the club head **100** and the flow pattern on the crown **110**. The turbulator **300** may be located on the crown **110** at an oblique angle relative to the club face **102** as shown in FIG. **4**, or be parallel to the club face **102** between 0.25 inches (0.64 cm) and 4.5 inches (11.43 cm) from the club face **102**. The turbulator **300** may be located in a curvilinear manner on the crown **110** based on the separation region **120** of a particular club head **100**. In one embodiment, the turbulator **300** is located between the club face **102** and the apex **111** of the crown **110**. Accordingly, the turbulator **300** may be located between the leading edge **112** and the apex **111** of the crown **110**. The turbulator **300** may be located on the crown **110** such that the swept back surfaces **304** form an angle of between 20° and 70° degrees relative to the centerline **127** (shown in FIG. **2**) of the club head **100**.

Referring to FIG. **4**, for example, the turbulator **300** may be a strip that extends from the heel end **104** to the toe end **106**. Additionally, the distance **301** increases from the heel end **104** to the toe end **106**. This increase in the distance **301** positions the turbulator to approximately follow the shape of the separation region **120** shown in FIG. **1**. Alternatively, the turbulator **300** may be a curved strip (not shown) that substantially follows the shape of the separation region **120**.

The width **303**, the distance **305**, the thickness **307**, the height and/or the angles **309** and **311** may be constant along the length of the turbulator as shown in FIGS. **6-8**. However, any one or all of noted parameters may vary along the turbulator **300** from the heel end **104** to the toe end **106** to provide a particular airflow effect. Furthermore, the surface characteristics of the turbulator **300** may be constant or vary along the turbulator **300** from the heel end **104** to the toe end **106**. The turbulator **300** may have any pattern similar to the zigzag pattern described above or other patterns that can provide the boundary layer energizing function described above. Such patterns may include various geometric shapes such as square, rectangular, triangular, curved, circular, polygonal or other shapes in discrete or continuous configurations. The apparatus, methods, and articles of manufacture described herein are not limited in this regard.

The turbulator **300** is shown to be a continuous strip in FIG. **4**. However, the turbulator **300** may be formed by a plurality of turbulator segments that are positioned on the crown **110** in different configurations relative to each other such as aligned, offset and/or tandem. For example, the turbulator **300** may include three discrete zigzag strips that are positioned at different distances **301** on the crown **110**. Each of the discrete strips may have similar or different properties, such as similar or different height, width **303**, the distance **305**, the thickness **307**, the angles **309** and/or **311**.

The turbulator **300** may be constructed from any type of material, such as stainless steel, aluminum, titanium, various other metals or metal alloys, composite materials, natural materials such as wood or stone or artificial materials such as plastic. If the turbulator **300** is constructed from metal, it may be formed on the club head **100** or simultaneously with the club head **100** by stamping (i.e., punching using a machine press or a stamping press, blanking, embossing, bending, flanging, or coining, casting), injection molding, forging, machining or a combination thereof, or other processes used for manufacturing metal parts. With injection molding of metal or plastic materials, a one-piece or a multi-piece mold can be constructed which has interconnected cavities corresponding to the above-described parts of the club head **100** and/or the turbulator **300**. Molten metal or plastic material is injected into the mold, which is then cooled. The club head

100 and/or the turbulator 300 is then removed from the mold and may be machined to smooth out irregularities on the surfaces thereof or to remove residual parts. If the turbulator 300 is manufactured separately from the club head 100, the turbulator 300 can be fixedly or removably attached to the crown 110 with fasteners, adhesive, welding, soldering, or other fastening methods and/or devices. In one example, the turbulator 300 may be formed from a strip of material having an adhesive backing. Accordingly, the turbulator 300 may be attached to the club head 100 at any location on the crown with the adhesive backing.

Referring to FIGS. 9 and 10, another exemplary turbulator 400 is shown. The turbulator 400 includes a plurality of ridges 401-408 that are positioned downstream of the leading edge 112 and at least partly before the separation region 120. Each ridge 401-408 may be spaced from the leading edge 112 at the same distance 409 as another ridge or a different distance 409 than another ridge. While FIGS. 9 and 10 may depict a particular number of ridges, the apparatus, methods, and articles of manufacture described herein may include more or less number of ridges. Referring to FIGS. 11-14, in which examples of only the ridge 404 are shown, each ridge 401-408 has a length 411, a base width 413, a height 415 (shown in FIG. 12) and an angle 417 relative to the leading edge 112 of the club head 100. Each ridge 401-408 may be spaced apart from an adjacent ridge by a distance 419 (shown in FIGS. 9 and 10), which is measured from the leading edges 410 of the ridges 401-408 if the ridges are not parallel.

FIG. 11 illustrates an exemplary shape for the ridge 404 and does not in any way limit the shape of the ridges 401-408. The ridges 401-408 may have any cross-sectional shape. In FIGS. 12-14, three exemplary cross-sectional shapes for the ridges 401-408 are shown. The length 411 may be substantially greater than the base width 413. The ridges 401-408 function as vortex generators to energize the boundary layer that forms on the crown 110, hence moving the separation region 120 further aft on the crown 110. Thus, each ridge 401-408 functions as a turbulator. The height 415 of each ridge 401-408 may be such that the top 412 (shown in FIG. 12) of each ridge 402 remains inside the boundary layer. However, any one or more of the ridges may extend above the boundary layer.

The angle 417 for each ridge may be configured so that each ridge 401-408 is oriented generally perpendicular, parallel or oblique relative to the leading edge 112 and/or relative to each other. In one embodiment, the angle 417 may be between 20° and 70°. In the example of FIGS. 9 and 10, the turbulator 400 includes four ridges 401-404 on the toe end side of the club head 100 that are oriented generally at an angle 417 of about 60°-70° and parallel to each other. The turbulator 400 also includes four ridges 405-408 that are symmetric with respect to the angle 417 about a centerline 127 of the club head 100 relative to the ridges 401-404.

Each ridge 401-408 is shown to be a linear. However, each of the ridges 401-408 can be curved, have variable base width 413 along the length 411, have variable cross-sectional shapes, have variable height 415 along the length 411 and/or the base width 413, have sharp or blunt leading edges 410 or trailing edges 414, have sharp or blunt tops 412; have different surface textures, and/or have other physical variations along the length 411, the base width 413 and/or the height 415. The distance 409 may increase for each ridge 401-408 from the heel end 104 to the toe end 106 to approximately correspond with the location of the separation line 120 on the crown 110. However, as shown in FIGS. 9 and 10, each ridge 401-408 may be located on the crown 110 at substantially the same distance 409 from the leading edge 112. Furthermore, each of the ridges 401-408 may be placed anywhere on the crown 110 to provide the boundary layer effects described herein. The location of the ridges may vary depending on the physical characteristics of the club head 100 and the airflow pattern on the crown 110. Each of the ridges 401-408 may be located along a straight line or a curvilinear line on the crown 110 between 0.25 inches (0.64 cm) and 4.5 inches (11.43 cm) from the club face 110. Each ridge 401-408 may have a height 415 that does not exceed 0.5 inches (1.27 cm). In one embodiment, at least one ridge 401-408 may have a height 415 that is greater than 0.02 inches (0.05 cm) but less than 0.2 inches (0.51 cm). The ridges 401-408 may have a distance 419 that contributes to the delay in airflow separation. The ridges 401-408 may be arranged on the crown 110 in a curvilinear manner based on the location of the separation region 120 of a particular club head 100. In one embodiment, the ridges 401-408 are located between the face 102 and the apex 111 of the crown 110. Accordingly, the ridges 402 may be located between the leading edge 112 and the apex 111 of the crown 110.

Referring to FIG. 10, each ridge 401-408 trips the air flowing over the ridge to create small eddies or vortices along the length 411 for energizing the boundary layer downstream of the ridge 401-408 in an area 421 (shown only on ridge 404). Accordingly, the separation region 120 is moved farther aft on the crown 110. The distance 419 between each ridge 401-408, length 411, base width 413, height 415 and/or angle 417 may be configured so that the areas 421 slightly or greatly overlap, or do not overlap. As shown in the example of FIG. 10, the distance 419, the length 411 and the angle 417 of each ridge 401-408 are configured such that the leading edge 410 of each ridge 401-408 is generally aligned along the direction of airflow with the trailing edge 414 of an adjacent ridge 401-408. Thus, the arrangement of the ridges 401-408 on the crown 110 as shown in of FIGS. 9 and 10 provides overlapping areas 421 of boundary layer turbulence. However, the ridges 401-408 can be configured to have any physical characteristics and spaced apart at any distance 419. For example, if the ridges have shorter lengths than the length 411 of the ridges 401-408 shown in FIGS. 9 and 10, the distance 419 can be reduced to ensure overlap of areas 421 downstream of the ridges 401-408. In another example, if the angles 417 of the ridges 401-408 relative to the club face 100 are different than the angle 417 shown in FIGS. 9 and 10, the distance 419 or the lengths 411 of the ridges 401-408 can be accordingly modified to ensure that areas 421 overlap downstream of the ridges 401-408. In yet another example, multiple rows of ridges can be provided on the crown 110 in tandem or offset relative to each other. Thus, any number of ridges with each ridge having any physical characteristic and distance 409 relative to an adjacent ridge can be provided on the crown 110. For example, in certain application, overlapping of the areas 421 may not be suitable. Accordingly, the ridges 401-408 can be configured to reduce, minimize or prevent overlap of the areas 421.

Referring to FIG. 10, the ridges 401-404 are arranged to point toward the centerline 127, and the ridges 405-408 are also arranged to point toward the centerline 127. Accordingly, the ridges 401-408 can function as an alignment aid for a player to align the club face 102 with a ball. An individual standing in an address position may visually determine the position of the ball (not shown) relative to the centerline 127 with the aid of the ridges 401-408.

Referring to FIGS. 15 and 16, another exemplary turbulator 500 is shown. The turbulator 500 includes a plurality of ridges 501-507 that are positioned downstream of the leading edge 112 and at least partly before the separation region 120.

Each ridge **501-507** may be spaced from the leading edge **112** at the same distance **509** as another ridge or a different distance **509** than another ridge. While FIGS. **15** and **16** may depict a particular number of ridges, the apparatus, methods and articles of manufacture described herein may include more or less number of ridges. Referring to FIGS. **17-20**, in which examples of only the ridge **504** are shown, each ridge **501-507** has a length **511**, a base width **513**, a height **515** (shown in FIG. **18**) and an angle **517** relative to the leading edge **112** of the club head **100**. Each of the ridges **501-507** is spaced apart from an adjacent ridge by a distance **519** (shown in FIGS. **15** and **16**), which is measured from the leading edges **504** of the ridges **501-507** if the ridges are not parallel.

FIG. **17** illustrates an exemplary shape for the ridge **504** and does not in any way limit the shape of the ridges **501-507**. The ridges **501-507** may have any cross-sectional shape. In FIGS. **18-20**, three exemplary cross-sectional shapes for the ridges **501-507** are shown. The length **511** may be substantially greater than the base width **513**. The ridges **501-507** function as vortex generators to energize the boundary layer that forms on the crown **110**, hence moving the separation region **120** further aft on the crown **110**. Thus, each ridge **501-507** functions as a turbulator. The height **515** of each ridge **501-507** may be such that the top **512** (shown in FIG. **18**) of each ridge **501-507** remains inside the boundary layer. However, any one or more of the ridges may extend above the boundary layer.

The angle **517** for each ridge may be configured so that each ridge **501-507** is oriented generally perpendicular, parallel or oblique relative to the leading edge **112** and/or relative to each other. In one embodiment, the angle **517** may be between 20° and 70°. In the example of FIGS. **15** and **16**, the turbulator **500** includes seven ridges **501-507** that are oriented generally at an angle **517** of about 60°-70° and parallel to each other.

Each ridge **501-507** is shown to be a linear. However, each of the ridges **501-507** can be curved, have variable base width **513** along the length **511**, have variable cross-sectional shapes, have variable height **515** along the length **511** and/or the base width **513**, have sharp or blunt leading edges **510** or trailing edges **514**, have sharp or blunt tops **512**, have different surface textures, and/or have other physical variations along the length **511**, the base width **513** and/or the height **515**. The distance **509** may increase for each ridge **501-507** from the heel end **104** to the toe end **106** to approximately correspond with the location of the separation line **120** on the crown **110**. However, as shown in FIGS. **15** and **16**, each ridge **501-507** may be located at substantially the same distance **509** from the leading edge **112**. Furthermore, each of the ridges **501-507** may be placed anywhere on the crown **110** to provide the boundary layer effects described herein. The location of the ridges may vary depending on the physical characteristics of the club head **100** and the airflow pattern on the crown **110**. Each of the ridges **501-507** may be located along a straight line or a curvilinear line on the crown **110** between 0.25 inches (0.64 cm) and 4.5 inches (11.43 cm) from the club face **110**. Each ridge **501-507** may have a height **515** that does not exceed 0.5 inches (1.27 cm). In one embodiment, at least one ridge **501-507** may have a height **515** that is greater than 0.02 inches (0.05 cm) but less than 0.2 inches (0.51 cm). The ridges **501-507** may have a distance **519** that contributes to the delay in airflow separation. The ridges **501-507** may be arranged on the crown **110** in a curvilinear manner based on the location of the separation region **120** of a particular club head **100**. In one embodiment, the ridges **501-507** are located prior to the apex **111** of the crown **110**. Accordingly, the ridges **501-507** may be located between the leading edge **112** and the apex **111** of the crown **110**.

Referring to FIG. **16**, each ridge **501-507** trips the air flowing over the ridge to create small eddies or vortices along the length **511** for energizing the boundary layer downstream of the ridge **501-507** in an area **521** (shown only on ridge **504**). Accordingly, the separation region **120** is moved farther aft on the crown **110**. The distance **519** between each ridge **501-507**, length **511**, base width **513**, height **515** and/or angle **517** may be configured so that the areas **521** slightly or greatly overlap, or do not overlap. As shown in the example of FIG. **16**, the distance **519**, the length **511** and the angle **517** of each ridge **501-507** are configured such that the leading edge **510** of each ridge **501-507** is generally aligned along the direction of airflow with the trailing edge **514** of an adjacent ridge **501-507**. Thus, the arrangement of the ridges **501-507** on the crown **110** as shown in of FIGS. **15** and **16** provides overlapping areas **521** of boundary layer turbulence. However, the ridges **501-507** can be configured to have any physical characteristics and spaced apart at any distance **519**. For example, if the ridges have shorter lengths than the length **511** of the ridges **501-507** shown in FIGS. **15** and **16**, the distance **519** can be reduced to ensure overlap of areas **521** downstream of the ridges **501-507**. In another example, if the angles **517** of the ridges **501-507** relative to the club face **100** are different than the angle **517** shown in FIGS. **15** and **16**, the distance **519** or the lengths **511** of the ridges **501-507** can be accordingly modified to ensure that areas **521** overlap downstream of the ridges **501-507**. In yet another example, multiple rows of ridges can be provided on the crown **110** in tandem or offset relative to each other. Thus, any number of ridges with each ridge having any physical characteristic and distance **509** relative to an adjacent ridge can be provided on the crown **110**. For example, in certain application, overlapping of the areas **521** may not be suitable. Accordingly, the ridges **501-507** can be configured to reduce minimize or prevent overlap of the areas **521**.

Referring to FIGS. **21** and **22**, another exemplary turbulator **600** is shown. The turbulator **600** includes a plurality of ridges **601-608** that are positioned downstream of the leading edge **112** and at least partly before the separation region **120**. Each ridge **601-608** may be spaced from the leading edge **112** at the same distance **609** as another ridge or at a different distance **609** than another ridge. While FIGS. **21** and **22** may depict a particular number of ridges, the apparatus, methods, and articles of manufacture described herein may include more or less number of ridges. Referring to FIGS. **22-26**, in which examples of only the ridge **604** are shown, each ridge **601-608** has a length **611**, a base width **613**, a height **615** (shown in FIG. **24**) and an angle **617** relative to leading edge **112** of the club head **100**. Each of the ridges **601-608** is spaced apart from an adjacent ridge by either a first peak-to-peak distance **623** or a second peak-to-peak distance **625** (shown in FIGS. **21** and **22**), where **623** and **625** are measured from the leading edges **604** of adjacent ridges **601-608**.

FIG. **23** illustrates an exemplary shape for a ridge **604** and does not in any way limit the shape of the ridges **601-608**. The ridges **601-608** may have any cross-sectional shape. In FIGS. **24-26**, three exemplary cross-sectional shapes for the ridges **601-608** are shown. The length **611** may be substantially greater than the base width **613**. The ridges **601-608** function as vortex generators to energize the boundary layer forming on the crown **110**, hence moving the separation region **120** further aft on the crown **110**. Thus, each ridge **601-608** functions as a turbulator. The height **615** of each ridge **601-608** may be such that the top **612** (shown in FIG. **24**) of each ridge **601-608** remains inside the boundary layer.

The angle **617** for each ridge may be configured so that each ridge **601-608** is oriented generally perpendicular, parallel or oblique relative to the leading edge **112** and/or relative to each other. In one embodiment, the angle **617** may be between 20° and 70° in the absolute value. In the example of FIGS. **21** and **22**, the turbulator **600** includes eight ridges **601-608**. The ridges **601**, **603**, **605** and **607** are oriented generally at an angle **617** of about −60° to −70° (see FIG. **17** for a positive angle of a ridge) and parallel to each other. The turbulator **600** also includes four ridges **602**, **604**, **606** and **608** that are oriented at an angle **617** of about 60° to 70°. Thus, each pair of adjacent ridges **601** and **602**; **603** and **604**; **605** and **606**; and **606** and **608** is configured to resemble a V shape, a triangle or a similar shape.

The ridges **604** and **605** symmetrically straddle the centerline **127** and generally point toward the centerline **127**. Accordingly, the ridges **604** and **605** can function as an alignment device to assist a player in generally aligning the ball with the centerline **127**.

Each ridge **601-608** is shown to be a linear. However, each of the ridges **601-608** can be curved, have variable base width **613** along the length **611**, have variable cross-sectional shapes, have variable height **615** along the length **611** and/or the base width **613**, have sharp or blunt leading edges **610** or trailing edges **614**, have sharp or blunt tops **612**, have different surface textures, and/or have other physical variations along the length **611**, the base width **613** and/or the height **615**. The distance **609** may increase for each ridge **601-608** from the heel end **104** to the toe end **106** to approximately correspond with the location of the separation line **120** on the crown **110**. However, as shown in FIGS. **21** and **22**, each ridge **601-608** may be located at substantially the same distance **609** from the leading edge **112**. Furthermore, each of the ridges **601-608** may be placed anywhere on the crown **110** to provide the boundary layer effects described herein. The location of the ridges may vary depending on the physical characteristics of the club head **100** and the airflow pattern on the crown **110**. Each of the ridges **601-608** may be located along a straight line or a curvilinear line on the crown **110** between 0.25 inches (0.64 cm) and 4.5 inches (11.43 cm) from the club face **110**. Each ridge **601-608** may have a height **615** that does not exceed 0.5 inches (1.27 cm). In one embodiment, at least one ridge **601-608** may have a height **615** that is greater than 0.02 inches (0.05 cm) but less than 0.2 inches (0.51 cm). The ridges **601-608** may have a distance **623** or **625** that contributes to the delay in airflow separation. The ridges **601-608** may be arranged on the crown **110** in a curvilinear manner based on the location of the separation region **120** of a particular club head **100**. In one embodiment, the ridges **601-608** are located prior to the apex **111** of the crown **110** (highest point on the crown). Accordingly, the ridges **601-608** may be located between the leading edge **112** and the apex **111** of the crown **110**.

Referring to FIG. **22**, each ridge **601-608** trips the air flowing over the ridge to create small eddies or vortices along the length **611** for energizing the boundary layer downstream of the ridge **601-608** in an area **621** (shown only on ridge **604**). Accordingly, the separation region **120** is moved farther aft on the crown **110**. The distance **623** or **625** between each ridge **601-608**, length **611**, base width **613**, height **615** and/or angle **617** may be configured so that the areas **621** slightly or greatly overlap, or do not overlap. The arrangement of the ridges **601-608** on the crown **110** as shown in of FIGS. **21** and **22** provides overlapping areas **621** of boundary layer turbulence. However, the ridges **601-608** can be configured to have any physical characteristics and spaced apart at any distance **623** or **625**. For example, if the ridges have shorter lengths than the length **611** of the ridges **601-608** shown in FIGS. **21** and **22**, the distance **623** or **625** can be reduced to ensure overlap of areas **621** downstream of the ridges **601-608**. In another example, if the angles **617** of the ridges **601-608** relative to the club face **100** are different than the angle **617** shown in FIGS. **21** and **22**, the distance **623** or **625** or the lengths **611** of the ridges **601-608** can be accordingly modified to ensure that areas **621** overlap downstream of the ridges **601-608**. In yet another example, multiple rows of ridges can be provided on the crown **110** in tandem or offset relative to each other. Thus, any number of ridges with each ridge having any physical characteristic and distance **609** relative to an adjacent ridge can be provided on the crown **110**. For example, in certain application, overlapping of the areas **621** may not be suitable. Accordingly, the ridges **601-608** can be configured to reduce minimize or prevent overlap of the areas **621**.

The turbulator **400**, **500** or **600** may be constructed from any type of material, such as stainless steel, aluminum, titanium, various other metals or metal alloys, composite materials, natural materials such as wood or stone or artificial materials such as plastic. If the turbulator **400**, **500** or **600** is constructed from metal, it may be formed on the club head **100** or simultaneously with the club head **100** by stamping (i.e., punching using a machine press or a stamping press, blanking, embossing, bending, flanging, or coining, casting), injection molding, forging, machining or a combination thereof, or other processes used for manufacturing metal parts. With injection molding of metal or plastic materials, a one-piece or a multi-piece mold can be constructed which has interconnected cavities corresponding to the above-described parts of the club head **100** and/or the turbulator **400**, **500** or **600**. Molten metal or plastic material is injected into the mold, which is then cooled. The club head **100** and/or the turbulator **400**, **500** or **600** is then removed from the mold and may be machined to smooth out irregularities on the surfaces thereof or to remove residual parts. If the turbulator **400**, **500** or **600** is manufactured separate from the club head **100**, the turbulator **400**, **500** or **600** can be fixedly or removably attached to the crown **110** with fasteners, adhesive, welding, soldering, or other fastening methods and/or devices. In one example, the turbulator **400**, **500** or **600** may be formed from metallic material. The turbulator **400**, **500** or **600** can then be attached to the crown **110** with an adhesive. In another example, the turbulator **400** may include an elongated projection that slides into a correspondingly sized slot on the crown **110** to removably attached the turbulator **400**, **500** or **600** to the crown **110**. Thus, the turbulators **400**, **500** or **600** may include removable connection mechanisms so that each turbulator **400**, **500** or **600** can be selectively connected to or removed from the club head **100**. The turbulators on the crown **110** are described above to be defined by ridges. However, any one or more of the turbulators may be defined by grooves formed in the crown **110**. The turbulators may be formed by cutting grooves in the crown **110** by various methods such machining, laser cutting, or the like.

According to one example shown in FIG. **27**, a method **700** of manufacturing a golf club head having turbulators according to various embodiments includes at **702** providing a golf club having a club head, and at **704**, attaching one or more turbulators on a crown of the club head. According to another example shown in FIG. **28**, a method **800** of manufacturing a golf club head having turbulators according to various embodiments includes at **802** providing a mold having cavities corresponding to a golf club head and one or more turbulators, and at **804**, forming the club head and the turbulators with the mold.

FIG. **29** shows a schematic view based on actual airflow visualization experiments of airflow over the club head **100** without turbulators, and FIG. **30** shows a schematic view based on actual airflow visualization experiments of airflow over the same club head with the turbulators **400**. In FIG. **29**, the streamlines representing airflow approach the club had **100** and are diverted over the club face toward the leading edge. The streamlines traverse over the leading edge **112** and flow over the crown **110**. However, the airflow becomes detached from the crown **110** at the separation region **120**, and creates a turbulent wake **122** over a substantial section of the crown **110**. This turbulent wake **122** increases the drag thereby reducing the speed of the club head **100**. Referring to FIG. **30**, the ridges **401-408** are positioned downstream of the leading edge **112** and upstream of the separation region **120** of FIG. **29**. Accordingly, the flow remains attached on a substantial portion of the crown **110** as is shown by the streamlines in FIG. **30**. Therefore, the separation region **120** is moved farther aft on the crown **110**.

As described above, any of the physical characteristics of the turbulators **400**, **500** or **600**; the locations thereof on the crown; and/or the orientations thereof relative to any part of the crown, the centerline **127** and/or the leading edge **112** may be configured to provide a particular boundary layer effect. According to one embodiment, the turbulators may be located a distance Q from the leading edge **112** according to the following relation:

$$Q>0.05DA$$

where DA is the distance from the leading edge **112** to the apex **111** of the crown (i.e., the highest point on the crown). According to another embodiment, the angle γ, which is the angle of each ridge relative to the leading edge **112** may follow the relation:

$$\gamma>\text{Loft}$$

where Loft is the loft angle of the club head **100**. According to another embodiment, the distance P, which is the distance between each ridge, may follow the relation:

$$2L\cos(\gamma)>P>0.8L\cos(\gamma)$$

where L is the length of a ridge.

Tables 1 and 2 show experimental results for a golf club head **100** without any turbulators, with the turbulator **300**, and with turbulators **400**. Table 1 shows measured values of aerodynamic drag expressed in lbs for different orientation angles of the club head **100**. The speed of the club head **100** is directly affected by the orientation angle. An increase in orientation angle results in an increase in the speed of the club head **100**.

TABLE 1

Drag Force (lbs) vs. Orientation Angle (degrees)

Angle (in degrees)	Without turbulators	Turbulator 300	Turbulator 400
90	2.01496256	1.507344	1.495429
60	1.30344225	1.300062	1.293326
30	0.88754571	0.905306	0.898112
0	0.22323528	0.227507	0.235375

TABLE 2

Lift Force (lbs) vs. Orientation Angle (degrees)

Angle (in degrees)	Without turbulators	Turbulator 300	Turbulator 400
90	−0.3884699	0.061148	0.092846
60	0.27763904	0.343283	0.189739
30	0.6006895	0.608558	0.560674
0	0.20772346	0.205925	0.225259

As shown in Table 1, when the club head **100** has an orientation angle of greater than 60°, the aerodynamic drag force on the club head **100** is reduced for the club head **100** having the turbulator **300** or the turbulators **400**. The reduction in drag is much greater for an orientation angle of 90°. Referring to FIG. **31**, which is a graphical representation of the data in Table 1, the noted reduction in drag for orientation angles of greater than 60° is visually shown. Furthermore, the turbulator **400** (including one or more ridges **401-408**) is shown to reduce the drag force on the club head **100** more than the turbulator **300**.

Table 2 shows measured values of lift expressed in lbs for different orientation angles of the club head. When the club head **100** has an orientation angle of greater than 60°, the lift generated by the club head does not drop as sharply for the club head **100** having the turbulator **300** or the turbulators **400** as compared to the club head **100** without any turbulators. Referring to FIG. **32**, which is a graphical representation of the data in Table 2, the noted drop in lift for the club head **100** without any turbulators is visually shown. The noted drop in lift is due to the higher pressure differential caused by the earlier boundary layer separation on the crown for the club head **100** without any turbulators as compared to the club head **100** having turbulator **300** or turbulators **400**. Thus, Tables 1 and 2 and FIGS. **31** and **32** illustrate the adverse effects of early boundary layer separation on the crown for a golf club head without any turbulators and the effects of delaying the boundary layer separation on drag forces exerted on a golf club head.

FIGS. **33** and **34** graphically show measured ball speed and club head speed for a golf club head without any turbulators and a golf club head having the turbulators **400**. FIG. **33** shows that ball speed is higher when the golf club head includes the turbulators **400**. This increase in ball speed is due to the higher club head speed as shown in FIG. **34** due to the turbulators **400** delaying boundary layer separation on the crown, thereby reducing drag forces on the club head.

Referring to FIGS. **35-38**, another exemplary golf club head **1000** is shown, which includes a face **1002** that extends horizontally from a heel end **1004** to a toe end **1006** and vertically from a sole **1008** to a crown **1010**. The heel end **1004** and the toe end **1006** extend from the face **1002** to the rear **1009** of the club head **1000**. A transition region between the face **1002** and the crown **1010** defines an upper leading edge **1012** and a transition region between the face **1002** and the sole defines a lower leading edge **1013**. The club head **1000** also include a hosel **1014** for receiving a shaft (not shown). The club head **1000** is shown to be a wood-type club head. However, the present disclosure is not limited to wood-type club heads and applies to any type of golf club head (e.g., a driver-type club head, a fairway wood-type club head, a hybrid-type club head, an iron-type club head, a wedge-type club head, or a putter-type club head).

Club head **1000** includes a plurality of turbulators **1201-1204** and **1301-1304** on the sole **1008**, which may be generally referred to herein as turbulators **1200** and **1300**, respectively. The turbulators **1200** and **1300** energize the boundary layer on the sole **1008** during the downswing, the impact position, and the follow through phases of the golf swing. During the initial part of the downswing, the air that is upstream of the club head **1000** flows generally over the heel **1004** and onto the sole **1008** and the crown **1010**. During the intermediate part of the downswing, the air flows generally over the transition area between the heel **1004** and the face **1002** and onto the sole **1008** and the crown **1010**. During the final part of the downswing just prior to the impact position, the air flows generally over the face **1002** and onto the sole **1008** and the crown **1010**. Arrow **1210** of FIGS. **36** and **38** represents one exemplary direction of airflow during the downswing part of the golf swing. The air flowing over the sole **1008** forms a boundary layer on the sole. The turbulators **1200** energize the boundary layer to delay detachment of the flow downstream of the turbulators **1200**. Accordingly, the drag on the club head **1000** is reduced thereby increasing club speed during the downswing.

After the face **1002** strikes the ball in the impact position, the club head **1000** is rotated during the follow through. The air that is upstream of the club head **1000** flows generally over the face **1002** and onto the sole **1008** and the crown **1010** during the initial part of the follow through. During the intermediate part of the follow through, the air flows generally over the transition area between the toe **1006** and the face **1002** and onto the sole **1008** and the crown **1010**. During the final part of the follow through, the air may flow generally over the toe **1006** and onto the sole **1008** and the crown **1010**. As shown in FIGS. **36** and **38**, arrow **1310** represents one exemplary direction of airflow during the follow through part of the golf swing.

FIG. **37** shows x and y coordinate axes for describing the dimensions, locations on the sole **1008**, and orientations relative to the face **1002** of the turbulators **1200** and **1300**. The x and y coordinate axes have an origin **1240** (i.e., x=0, y=0), which may define a center point of the face **1002**. Accordingly, the y axis may define a center line for the club head **1000**. As described in detail below, the location of each turbulator **1200** and **1300** on the sole **1009** can be expressed by an x-location and a y-location. Furthermore, the orientations of the turbulators **1200** and **1300** can be expressed relative to the x axis by an angle **1242**.

The turbulators **1201-1204** may be defined by grooves that generally extend from near the heel end **1004** in a direction toward the toe end **1006**. Each turbulator **1201-1204** has a first end **1211-1214** and a second end **1215-1218**, respectively. The first ends **1211-1214** are located near the heel end **1004** and may generally follow the contour of the heel end **1004**. Accordingly, the first ends **1211-1214** of the turbulators **1201-1204** may have approximately the same distance from the heel end **1004**. However, the first ends **1211-1214** may be located anywhere on the sole **1008** to delay airflow separation on the sole **1008**.

The turbulators **1201-1204** may have the same dimensions and extend parallel to each other or may have different dimensions and extend non-parallel to each other. Depending on the position of the airflow separation region during the downswing, which is shown by example with line **1250** in FIG. **38**, the configurations of the turbulators **1200** can be varied to energize the airflow upstream of the separation region **1250**. For example, the turbulators **1201-1204** progressively increase in length in a direction from the face **1002** to the rear **1009**. Accordingly, the second ends **1215-1218** are progressively nearer to the y axis. Thus, the progressive length increase of the turbulators **1201-1204** may follow the contour of the separation region **1250** so as to provide detached flow on the sole **1008** downstream of the turbulators **1201-1204**. Similarly, the depth, the width and/or the angle **1242** of each turbulator **1201-1204** may be varied to provide a particular flow pattern. As shown in FIG. **37**, the angle **1242** progressively increases in a direction from the face **1002** to the rear **1009**. The angle **1242** for each turbulator **1201-1204** may correspond with a particular rotational position of the club head **1000** during the downswing. Accordingly, by varying the angle **1242** in the direction from the face **1002** to the rear **1009**, the turbulators **1201-1204** may energize the flow upstream of the separation region **S1** for generally all rotation angles of the club head **1000** during the downswing. The angle **1242** may be measured between any reference line on a turbulator and the x or y axis. In the disclosure, the angle **1242** is measured as the angle between the x-axis and a line connecting the ends of a turbulator.

The grooves defining the turbulators **1201-1204** may be wider at the first ends **1211-1214** and narrower at the second ends **1215-1218**, respectively. The depth of the grooves may also gradually decrease from the first ends **1211-1214** to the second ends **1215-1218**, respectively. The grooves may be formed in any shape on the sole **1008**. For example, the grooves can be narrow at the first ends **1211-1214** and the second ends **1215-1218** and then gradually or abruptly widen toward the centers of the grooves **1201-1204**. In contrast, the grooves can be wider at the first ends **1211-1214** and the second ends **1215-1218** and then gradually or abruptly narrow toward the centers of the grooves **1201-1204**. The depth of the grooves may also vary in any manner, such as according to the variation in width of the grooves.

The width, length, depth, location (i.e., x and y location), angle **1242**, and the shapes of the grooves that define the turbulators **1200** can be varied from the face **1002** to the rear **1009** to provide a particular flow pattern for generally all rotation angles of the club head **1000** during the downswing. Furthermore, the number of turbulators **1200** can also be varied to provide a particular flow pattern on the sole **1008**. For example, five, six or more turbulators **1200** can be provided on the sole **1008**. The turbulators **1200** may be located on the sole **1008** adjacent to each in a direction from the face **1002** to the rear **1009**, and/or may be in tandem.

Table 3 below shows exemplary configurations for the turbulators **1201-1204**. The x and y locations refer to the x and y locations of the second ends **1215-1218**. All of dimensions in Table 3 are expressed in inches. Furthermore, the depth and width of the grooves defining the turbulators **1201-1204** are measured at the first ends **1211-1214** of the turbulators **1201-1204**, respectively. Table 3 represents only an example of the turbulators **1201-1204** and in no way limits the properties of the turbulators **1200**.

TABLE 3

Turbulator	Depth	Length	Width	Location-X	Location-Y	Angle 1242°
1201	0.063	1.14	0.11	−1.31	1.28	2.95
1202	0.065	1.28	0.11	−1.01	1.67	7.97
1203	0.066	1.41	0.11	−0.68	2.05	16.98
1204	0.067	1.52	0.11	−0.35	2.39	30

The turbulators **1301-1304** may be defined by grooves that generally extend from near a portion of the face that is close to the toe end **1006** toward the rear **1009**. The grooves may also extend generally from near a transition area between the face **1002** and the toe end **1006** toward the rear **1009**. Additionally, the grooves may extend from near the toe end **1006** toward the rear **1009**. Each turbulator **1301-1304** has a first end **1311-1314** and a second end **1315-1318**, respectively. The first ends **1311-1314** are located near the face **1002** or the toe end **1006** and may either extend in a direction from the face **1002** toward the rear **1009** or generally follow the contour of the toe end **1006**. However, the first ends **1311-1314** may be located anywhere on the sole **1008** to delay airflow separation on the sole **1008**.

The turbulators **1301-1304** may have the same dimensions and extend parallel to each other or may have different dimensions and extend non-parallel to each other. Depending on the position of the airflow separation region, which is shown by example with line **1350** in FIG. **38**, the dimensional characteristics of the turbulators **1300** can be varied to energize the airflow upstream of the separation region **1350**. For example, the turbulators **1301-1304** progressively increase in length in a direction from the face **1002** toward the toe end **1006** and from the toe end **1006** toward the rear **1009**. Accordingly, the second ends **1315-1318** are progressively farther from the x axis and the y-axis. The progressive length increase of the turbulators **1301-1304** may follow the contour of the separation region **1350** to provide attached airflow downstream of the turbulators **1301-1304**. Similarly, the depth, the width and/or the angle **1242** of each turbulator **1301-1304** may vary to provide a particular flow pattern. As shown in FIG. **37**, the angle **1242** progressively decreases in a direction from the face **1002** toward the toe end **1006** and from the toe end toward the rear **1009**. The angle **1242** for each turbulator **1301-1304** may correspond with a particular rotational position of the club head **1000** during follow through. Accordingly, by varying the angle **1242** in the direction from the face **1002** toward the toe end **1006** and from the toe end **1006** toward the rear **1009**, the turbulators **1301-1304** may energize the flow upstream of the separation region **1350** for generally all rotation angles of the club head **100** during follow through. Further, each of the turbulators **1301-1304** may have a curvature that generally corresponds to the curvature of the toe end **1006**, and may represent the general direction of airflow over the sole **1008** during impact position and follow through. The angle **1242** may be measured between any reference line on a turbulator and the x or y axis. In the disclosure, the angle **1242** is measured as the angle between the x-axis and a line connecting the ends of a turbulator.

The grooves defining the turbulators **1301-1304** may be wider at the first ends **1311-1314** and narrower at the second ends **1315-1318**, respectively. The depth of the grooves may also gradually decrease from the first ends **1311-1314** to the second ends **1315-1318**, respectively. The grooves may be formed in any shape on the sole **1008**. For example, the grooves can be narrow at the first ends **1311-1314** and the second ends **1315-1318** and then gradually or abruptly widen toward the centers of the grooves **1301-1304**. In contrast, the grooves can be wider at the first ends **1311-1314** and the second ends **1315-1318** and then gradually or abruptly narrow toward the centers of the grooves **1301-1304**. The depth of the grooves may also vary in any manner, such as according to the variation in width of the grooves.

The width, length, depth, location (i.e., x and y location), angle **1242**, and the shapes of the grooves defining the turbulators **1300** can be varied from the face **1002** toward the toe end **1006** and from the toe end **1006** toward the rear **1009** to provide a particular flow pattern for generally all rotation angles of the club head **1000** during follow through. Furthermore, the number of turbulators **1300** can also be varied to provide a particular flow pattern on the sole **1008**. For example, five, six or more turbulators **1300** can be provided on the sole **1008**. The turbulators **1300** may be located on the sole **1008** adjacent to each other and/or in tandem.

Table 4 below shows exemplary configurations for the turbulators **1301-1304**. The x and y locations refer to the x and y locations of the second ends **1315-1318**. All of the dimensions shown in Table 4 are expressed in inches. Furthermore, the depth and width of the grooves defining the turbulators **1301-1304** are measured at the first ends **1311-1314** of the turbulators **1301-1304**, respectively. Table 3 is only an exemplary configuration of the grooves **1301-1304** and in no way limits the properties of the turbulators **1300**.

TABLE 4

Turbulator	Depth	Length	Width	Location-X	Location-Y	Angle 1242°
1301	0.05	0.80	0.12	1.60	1.60	90.09
1302	0.06	0.97	0.12	1.94	1.93	86.56
1303	0.07	1.09	0.12	2.24	2.27	83.03
1304	0.08	2.29	0.12	1.91	3.54	69.02

The turbulator **1200** and **1300** are described above to be defined by grooves in the sole **1008**. Accordingly, the turbulators **1200** and **1300** may be formed on the golf club **1000** by cutting the grooves into the sole **1008** of the golf club **1000** by various methods such machining, laser cutting, or the like. Alternatively, any one or more of the turbulators **1200** and/or the turbulators **1300** may be defined by ridges or projections on the sole **1008**. Such grooves or ridges may be formed simultaneously with the club head **1000** by stamping (i.e., punching using a machine press or a stamping press, blanking, embossing, bending, flanging, or coining, casting), injection molding, forging, machining or a combination thereof, or other processes used for manufacturing metal parts. With injection molding of metal or plastic materials, a one-piece or a multi-piece mold can be constructed which has interconnected cavities corresponding to the above-described parts of the club head **1000** and/or the turbulators **1200** and **1300**. Molten metal or plastic material is injected into the mold, which is then cooled. The club head **1000** and/or the turbulators **1200** and **1300** is then removed from the mold and may be machined to smooth out irregularities on the surfaces thereof or to remove residual parts. If the turbulators **1200** and **1300** are in the form of ridges and are to be manufactured separately from the club head **1000**, the turbulator **300** can be fixedly or removably attached to the sole **1008** with fasteners, adhesive, welding, soldering, or other fastening methods and/or devices. In one example, the turbulator **1200** or **1300** may be formed from a strip of material having an adhesive backing. Accordingly, the turbulators **1200** and **1300** may be attached to the club head **1000** at any location on the sole **1008** with the adhesive backing.

A club head may include one or a combination of the turbulators **300**, **400**, **500**, **600**, **1200** and/or **1300**. For example, a club head may include the turbulators **400** on the crown and turbulators **1200** on the sole. In another example, a club head may include the turbulators **500** on the crown and turbulators **1200** and **1300** on the sole. Thus, any combination of turbulators according to the disclosure may be provided on the crown and/or the sole to provide a particular flow pattern on the club head.

Although a particular order of actions is described above for making turbulators or club heads with turbulators, these actions may be performed in other temporal sequences. For example, two or more actions described above may be performed sequentially, concurrently, or simultaneously. Alternatively, two or more actions may be performed in reversed order. Further, one or more actions described above may not be performed at all. The apparatus, methods, and articles of manufacture described herein are not limited in this regard.

While the invention has been described in connection with various aspects, it will be understood that the invention is capable of further modifications. This application is intended to cover any variations, uses or adaptation of the invention following, in general, the principles of the invention, and including such departures from the present disclosure as come within the known and customary practice within the art to which the invention pertains.

What is claimed is:

1. A golf club head comprising:

a face, a rear opposite to the face, a heel, a toe opposite to the heel, a crown having a crown surface extending between the face, the rear, the heel and the toe, and a sole opposite to the crown and having a sole surface extending between the face, the rear, the heel and the toe, wherein a highest point on the surface of the crown defines an apex;

a plurality of crown turbulators projecting from the surface of the crown, each adjacent pair of crown turbulators being separate and spaced apart to define a space between the adjacent pair of crown turbulators, and each crown turbulator extending between the heel and the toe to define a width and extending between the face and the rear to define a length;

wherein the length is substantially greater than the width;

wherein at least a portion of at least one crown turbulator is located between the face and the apex; and

wherein the space between each adjacent pair of crown turbulators is substantially greater than the width of each of the adjacent pair of crown turbulators that define the space.

2. The golf club of claim **1**, wherein the plurality of turbulators comprises a first plurality of turbulators oriented relative to the face in generally a first direction and a second plurality of turbulators oriented relative to the face in generally a second direction different from the first direction.

3. The golf club of claim **1**, wherein the plurality of turbulators are oriented relative to the face in generally the same direction.

4. The golf club of claim **1**, wherein each turbulator is oriented relative to the face in generally a first direction and an adjacent turbulator is oriented relative to the face in generally a second direction different from the first direction.

5. The golf club of claim **1**, wherein the length of each turbulator is oriented relative to the face at an angle of greater than 0° and less than 90°.

6. The golf club of claim **1**, wherein the length of each turbulator is oriented relative to the face at an angle between around 20° and around 70°.

7. The golf club of claim **1**, wherein the space between each adjacent pair of turbulators is defined by a section of the surface of the crown.

8. The golf club head of claim **1**, further comprising a plurality of sole turbulators disposed on the sole surface.

9. The golf club head of claim **8**, wherein each of the sole turbulators is defined by a groove in the sole surface having a width and a length substantially greater than the width.

10. The golf club head of claim **8**, wherein at least one of the sole turbulators is located in a portion of the sole surface between the heel and a centerline extending from a center of the face to the rear.

11. The golf club head of claim **10**, wherein the at least one sole turbulator has a first end located near the heel and extending generally toward the toe to a second end.

12. The golf club head of claim **8**, wherein at least one of the sole turbulators is located in a portion of the sole surface between the toe and a centerline extending from a center of the face to the rear.

13. The golf club head of claim **12**, wherein the at least one sole turbulator has a first end located near the face or the toe and extending generally toward the toe to a second end.

14. A golf club head comprising:

a face, a rear opposite to the face, a heel, a toe opposite to the heel, a crown having a crown surface extending between the face, the rear, the heel and the toe, and a sole opposite to the crown and having a sole surface extending between the face, the rear, the heel and the toe;

a first plurality of sole turbulators defined by grooves disposed in a portion of the sole surface between the heel and a centerline extending from a center of the face to the rear, at least one sole turbulator of the first plurality of sole turbulators extending from near the heel in a direction generally toward the toe; and

a second plurality of sole turbulators defined by grooves disposed in a portion of the sole surface between the toe and the centerline on the sole surface, at least one sole turbulator of the second plurality of sole turbulators extending from near the face or the toe in a direction generally toward the rear;

wherein a width of at least one sole turbulator of the first plurality of sole turbulators or the second plurality of sole turbulators varies along a length of the at least one sole turbulator.

15. The golf club head of claim **14**, further comprising a plurality of crown turbulators disposed on the crown.

16. The golf club head of claim **15**, wherein at least a portion of at least one crown turbulator is located between the face and an apex defined by a highest point on the surface of the crown.

17. The golf club head of claim **15**, wherein each adjacent pair of crown turbulators is separate and spaced apart to define a space between the adjacent pair of crown turbulators, and wherein each space is substantially greater than a width of each of the adjacent pair of crown turbulators that define the space.

18. The golf club head of claim **14**, wherein each of the plurality of first sole turbulators comprises a first end and a second end, and wherein the first end and the second end define a line extending in the same general direction as the heel.

19. The golf club head of claim **14**, wherein the lengths of at least two sole turbulators of the first plurality of sole turbulators or the second plurality of sole turbulators are different.

20. The golf club head of claim **14**, wherein at least two sole turbulators of the plurality of first sole turbulators or the plurality of second sole turbulators are generally parallel.

21. The golf club head of claim **14**, wherein at least two sole turbulators of the plurality of first sole turbulators or the plurality of second sole turbulators are generally non-parallel.

22. The golf club head of claim **14**, wherein the lengths of the plurality of first sole turbulators progressively increase in a direction extending from the heel to the toe.

23. The golf club head of claim **14**, wherein the lengths of the plurality of second sole turbulators progressively increase in a direction extending from the face or the toe to the rear.

24. A method for providing turbulators on a club head comprising:

providing a club head comprising a face, a rear opposite to the face, a heel, a toe opposite to the heel, a crown having a crown surface extending between the face, the rear, the heel and the toe, and a sole opposite to the crown and having a sole surface extending between the face, the rear, the heel and the toe, wherein a highest point on the surface of the crown defines an apex;

forming a plurality of crown turbulators projecting from the surface of the crown, each adjacent pair of crown turbulators being separate and spaced apart to define a space between the adjacent pair of crown turbulators, and each crown turbulator extending between the heel and the toe to define a width and extending between the face and the rear to define a length;

wherein the length is substantially greater than the width;

wherein at least a portion of at least one crown turbulator is located between the face and the apex; and

wherein each space between an adjacent pair of crown turbulators is substantially greater than the width of each of the adjacent pair of crown turbulators that define the space.

25. The method of claim **24**, wherein forming the plurality of crown turbulators comprises forming the club head and the plurality of turbulators together.

26. The method of claim **24**, wherein forming the plurality of crown turbulators comprises attaching the plurality of crown turbulators on the crown.

27. The method of claim **24**, further comprising forming a first plurality of sole turbulators on the sole, wherein the first plurality of sole turbulators is defined by grooves disposed in a portion of the sole surface between the heel and a centerline extending from a center of the face to the rear, at least one sole turbulator of the first plurality of sole turbulators extending from near the heel in a direction generally toward the toe.

28. The method of claim **24**, further comprising forming a second plurality of sole turbulators on the sole, wherein the second plurality of sole turbulators is defined by grooves disposed in a portion of the sole surface between the toe and the centerline on the sole surface, at least one sole turbulator of the second plurality of sole turbulators extending from near the face or the toe in a direction generally toward the rear.

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