



(12) **United States Patent**  
**Chinavare**

(10) **Patent No.:** **US 9,834,035 B2**  
(45) **Date of Patent:** **\*Dec. 5, 2017**

- (54) **AERODYNAMICALLY EFFICIENT SPOKE DESIGN FOR A VEHICLE WHEEL**
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- (\* ) 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.

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- (21) Appl. No.: **15/166,834**
- (22) Filed: **May 27, 2016**
- (65) **Prior Publication Data**  
US 2016/0272000 A1 Sep. 22, 2016

**Related U.S. Application Data**

- (63) Continuation-in-part of application No. 14/212,914, filed on Mar. 14, 2014, now Pat. No. 9,352,612.  
(Continued)

- (51) **Int. Cl.**  
**B60B 3/10** (2006.01)  
**B60B 7/18** (2006.01)  
(Continued)

- (52) **U.S. Cl.**  
CPC ..... **B60B 3/10** (2013.01); **B60B 1/12** (2013.01); **B60B 3/007** (2013.01); **B60B 7/0066** (2013.01);  
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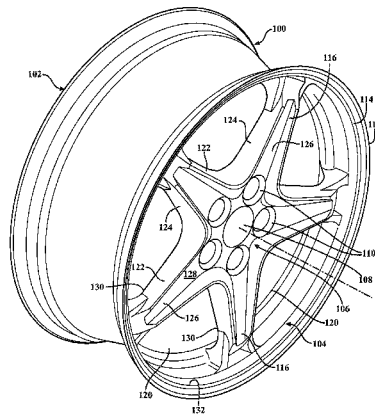
- (58) **Field of Classification Search**  
CPC .... B60B 3/10; B60B 1/08; B60B 1/12; B60B 3/007; B60B 7/0066; B60B 7/02; B60B 7/06

See application file for complete search history.

(57) **ABSTRACT**

A wheel including an inner hub portion configured to receive a vehicle axle therethrough and defining an axis of rotation at a center thereof. A plurality of wheel spoke portions extend generally between the inner hub portion and an outer rim portion. A clad spoke overlies each of the wheel spoke portions. Each of the clad spokes includes an outboard surface overlying an outboard side of the wheel spoke portion, a leading side surface overlying a leading side surface of the wheel spoke portion, and a trailing side surface overlying a trailing side surface of the wheel spoke portion. At least a segment of one of the leading side and trailing side surfaces of the clad spoke has a non-planar shape. A foam adhesive is disposed between the wheel spoke and the clad spoke and may overly the inboard surface of each of the wheel spokes.

**19 Claims, 11 Drawing Sheets**



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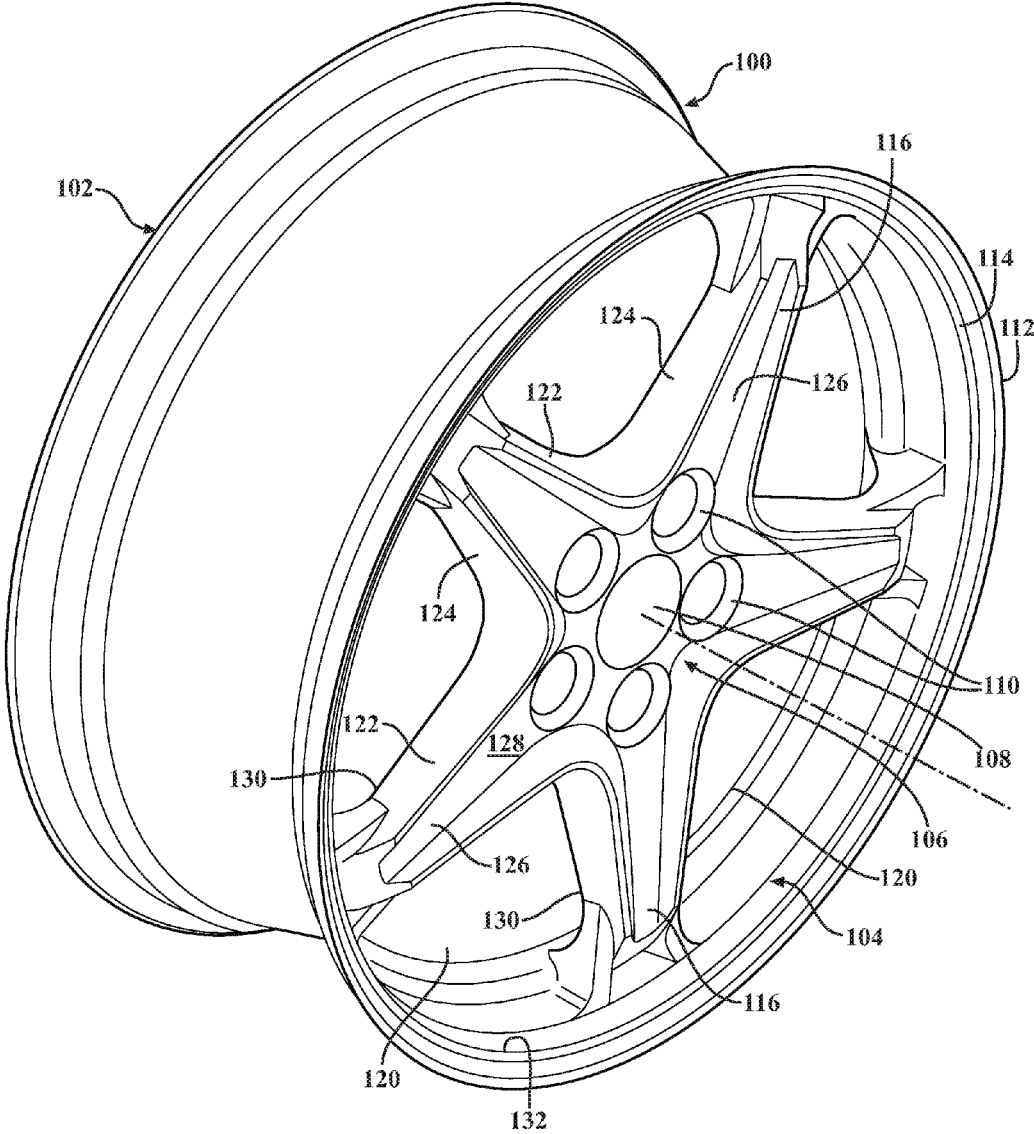


FIG. 1

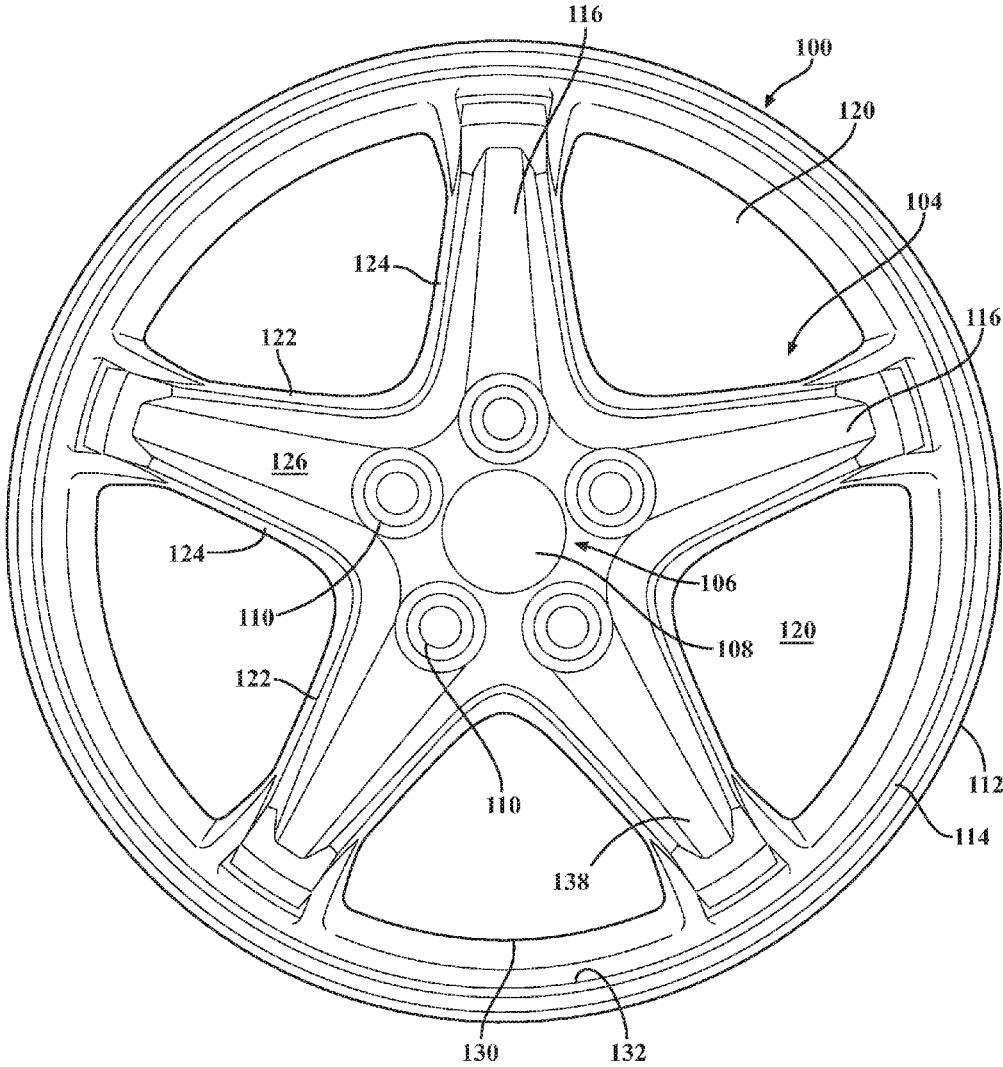


FIG. 2

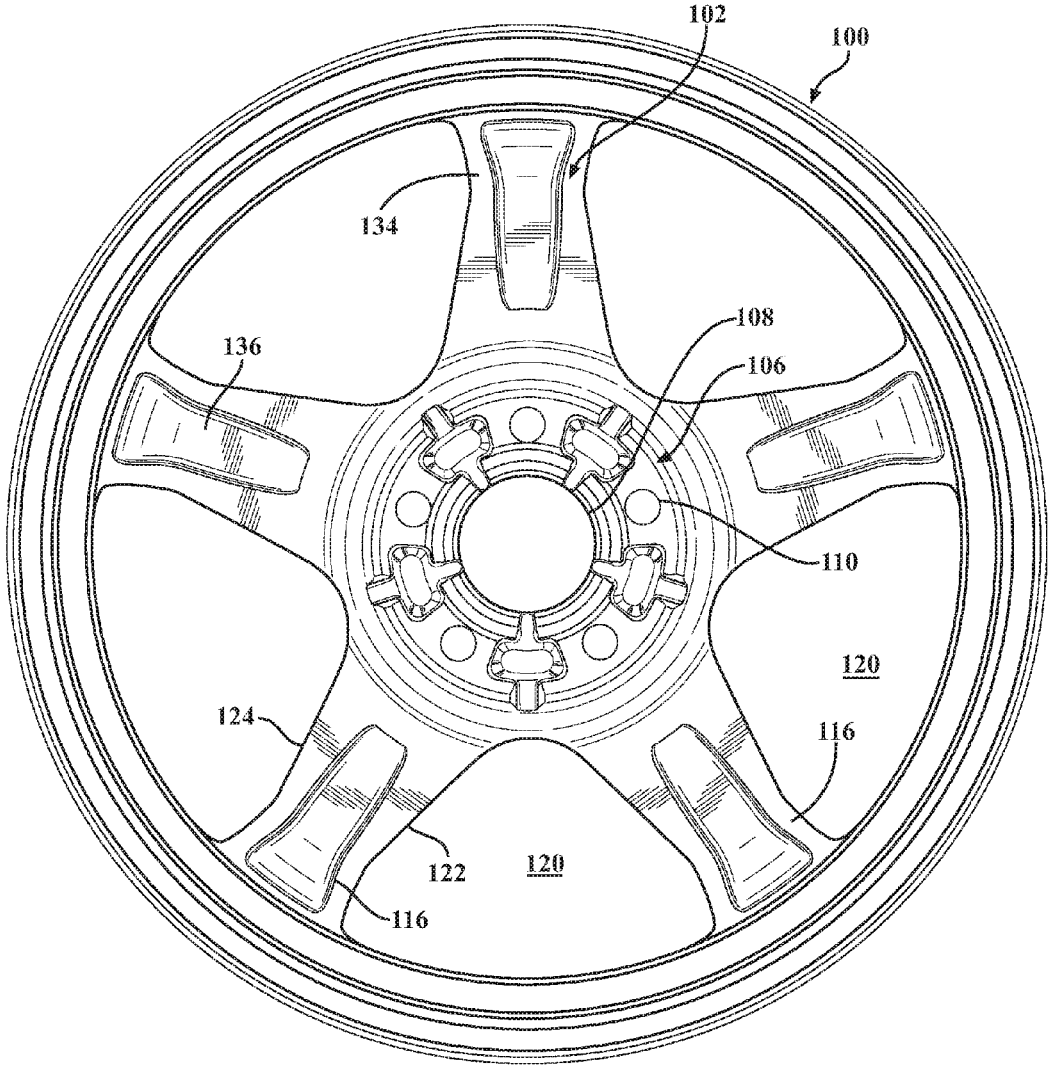


FIG. 3

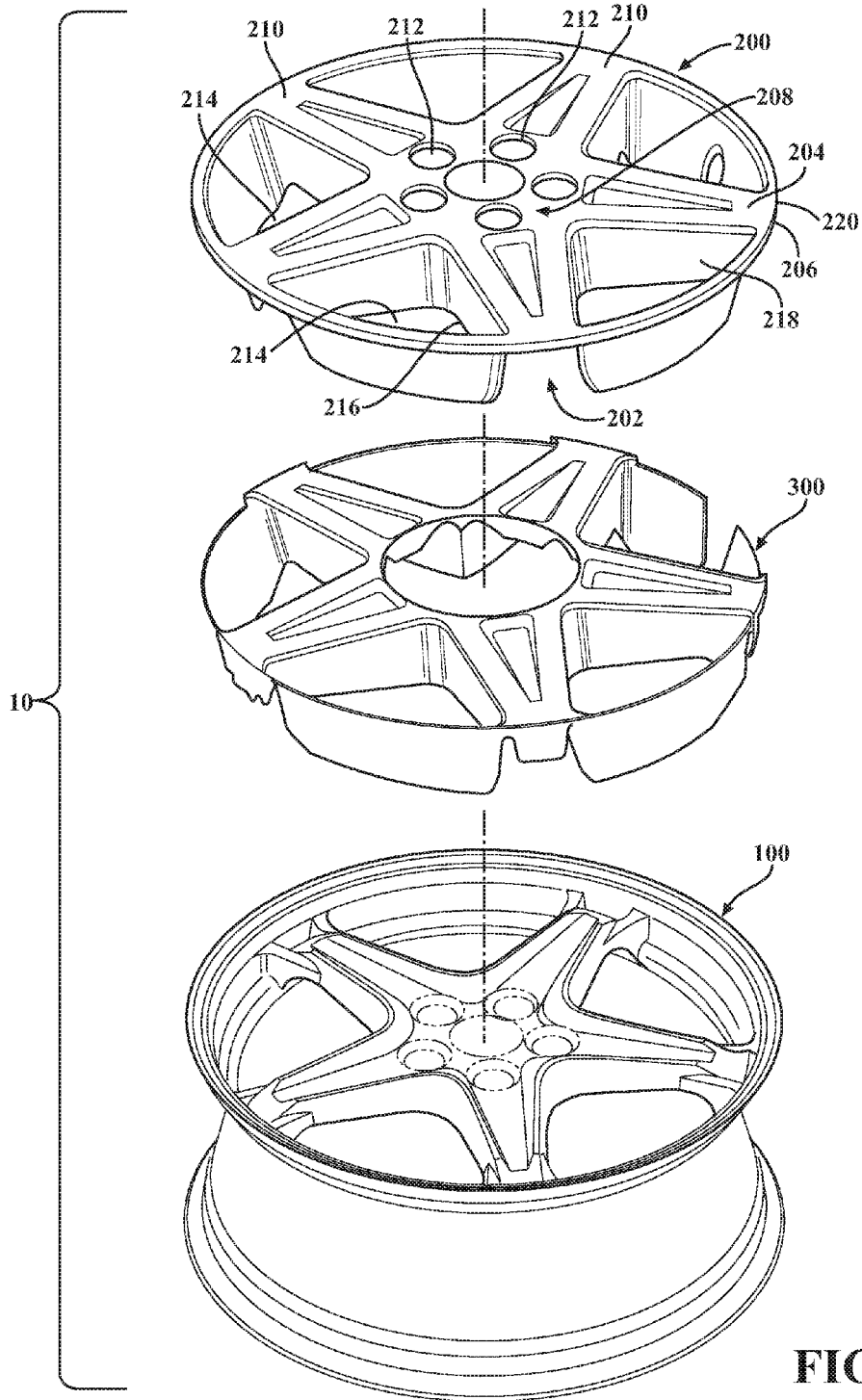
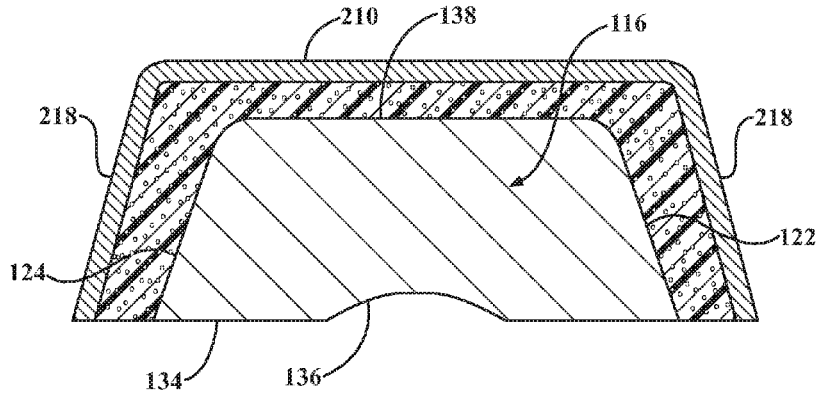
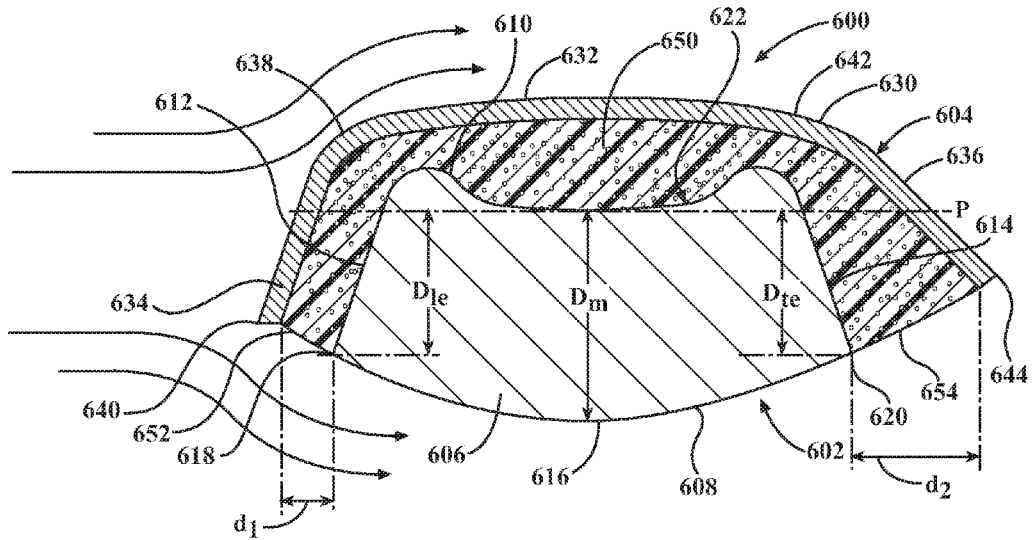


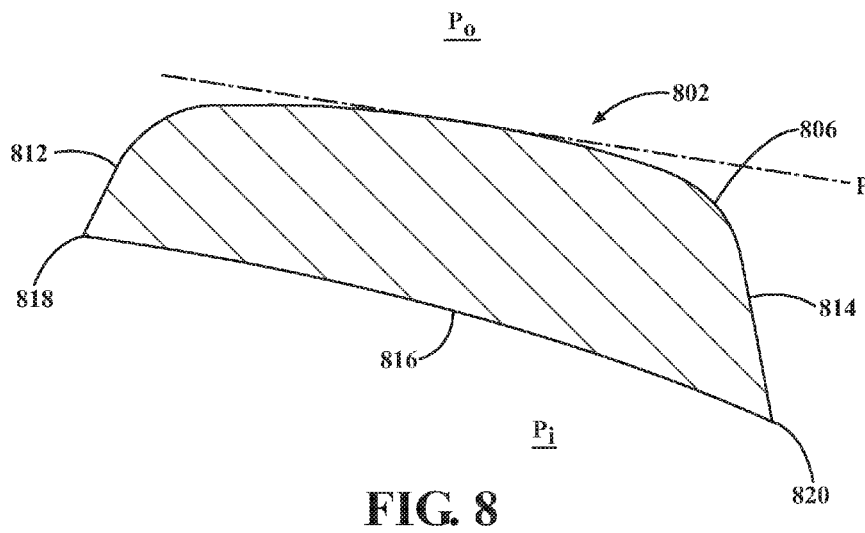
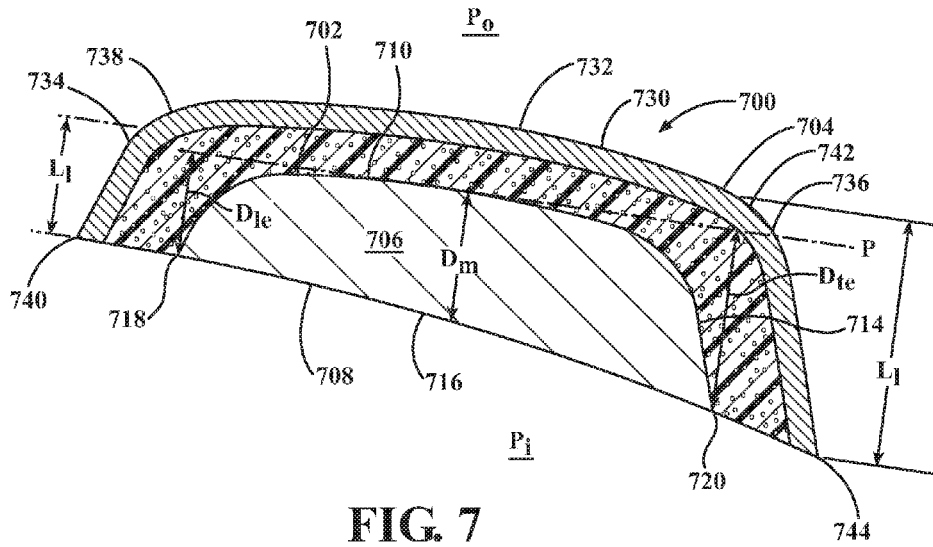
FIG. 4



**FIG. 5**  
PRIOR ART



**FIG. 6**





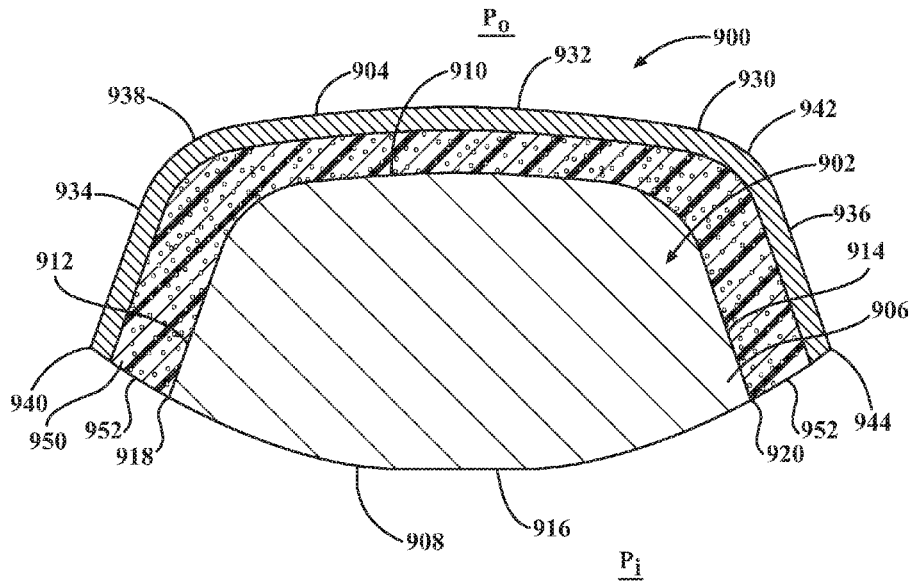


FIG. 9

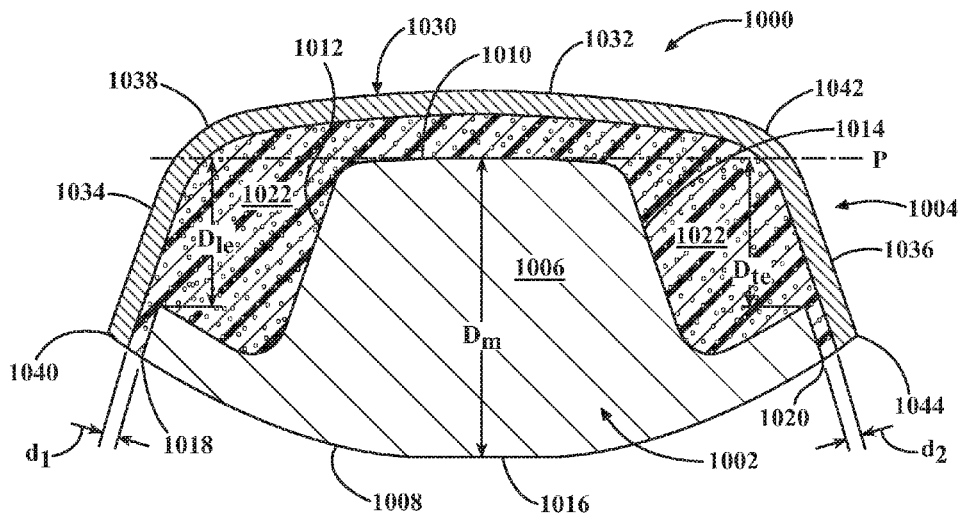


FIG. 10

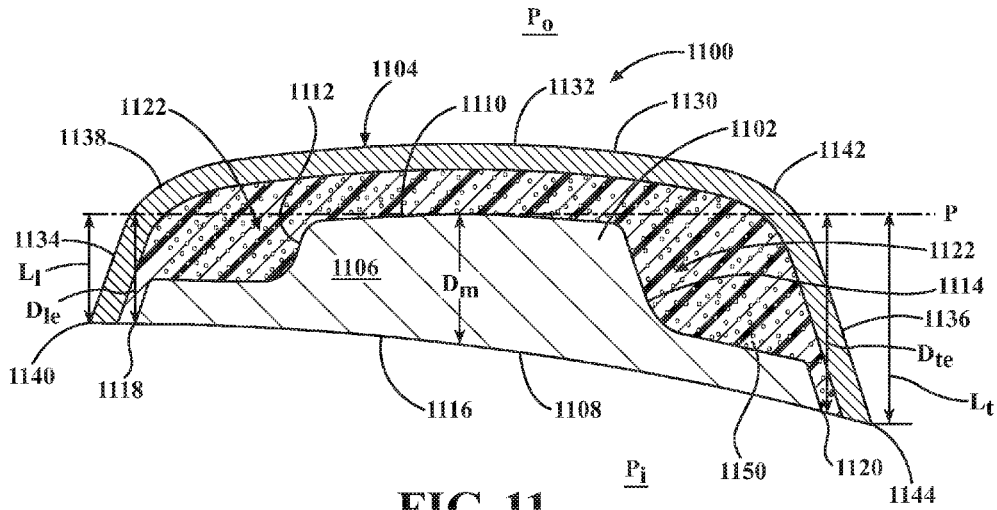


FIG. 11

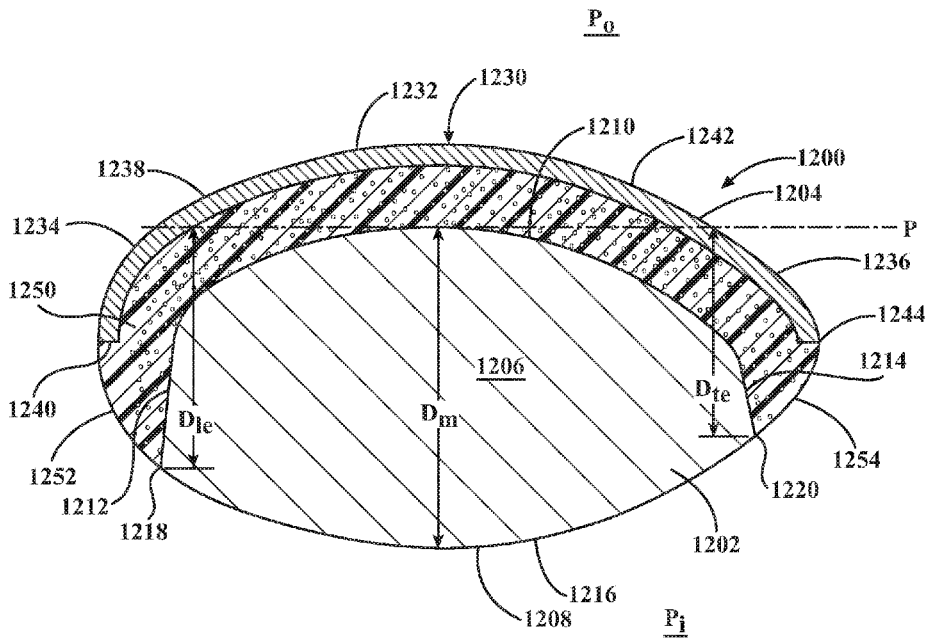


FIG. 12

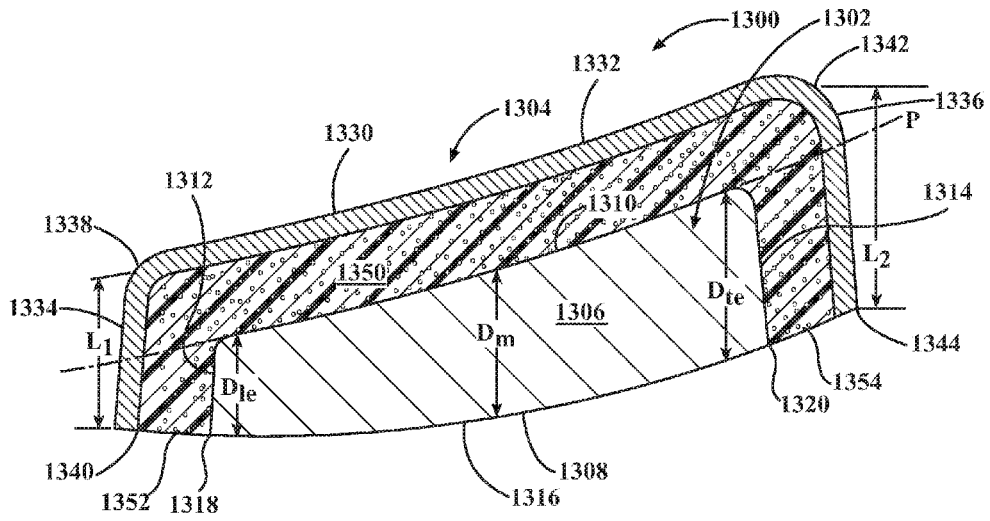


FIG. 13

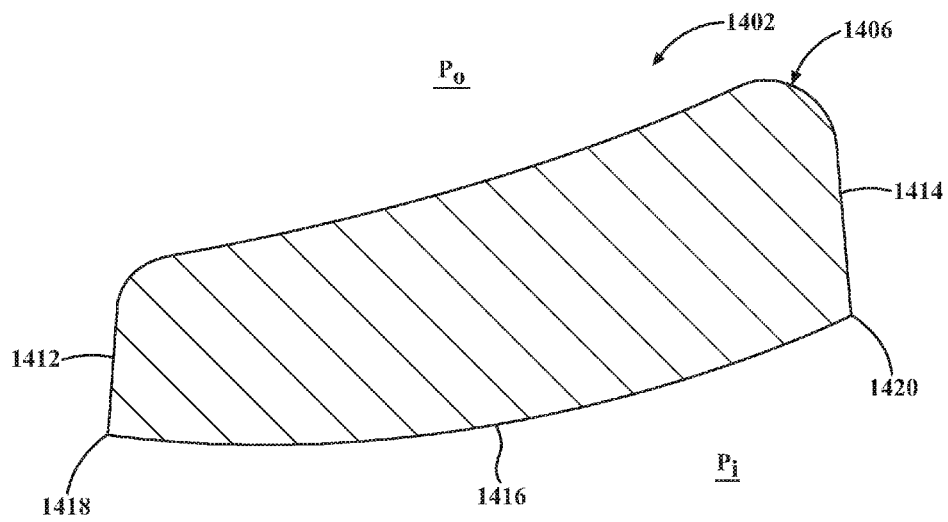


FIG. 14

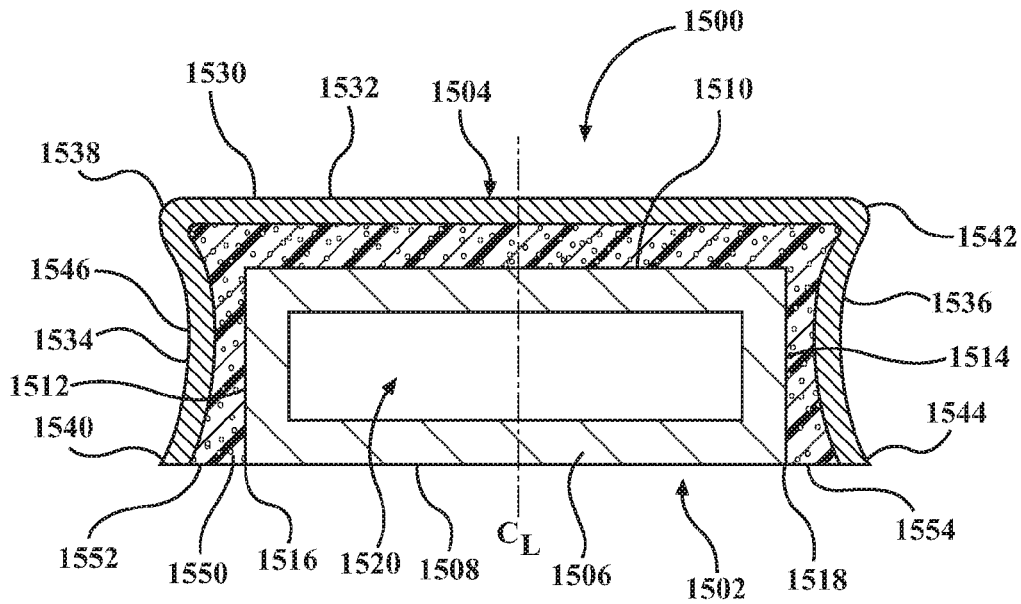


FIG. 15

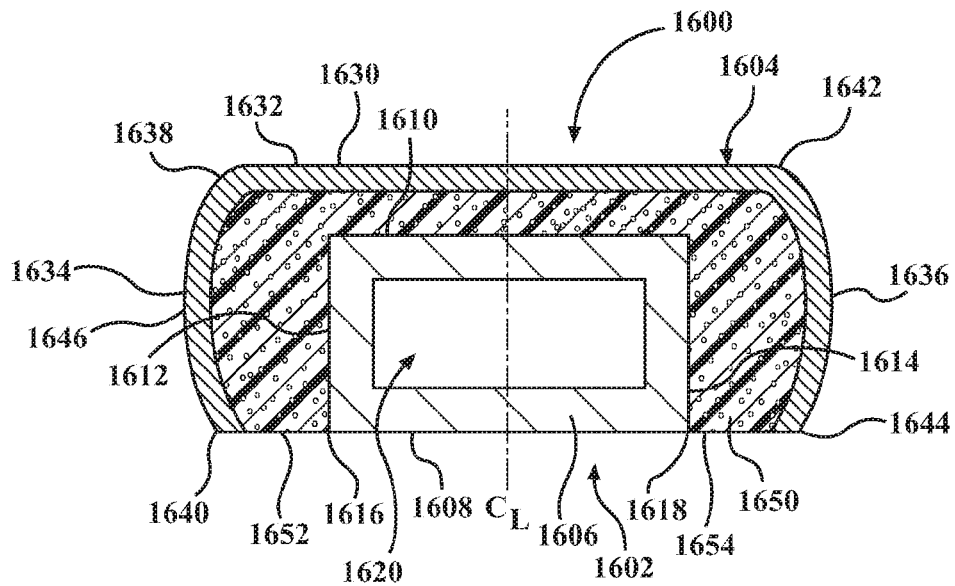


FIG. 16

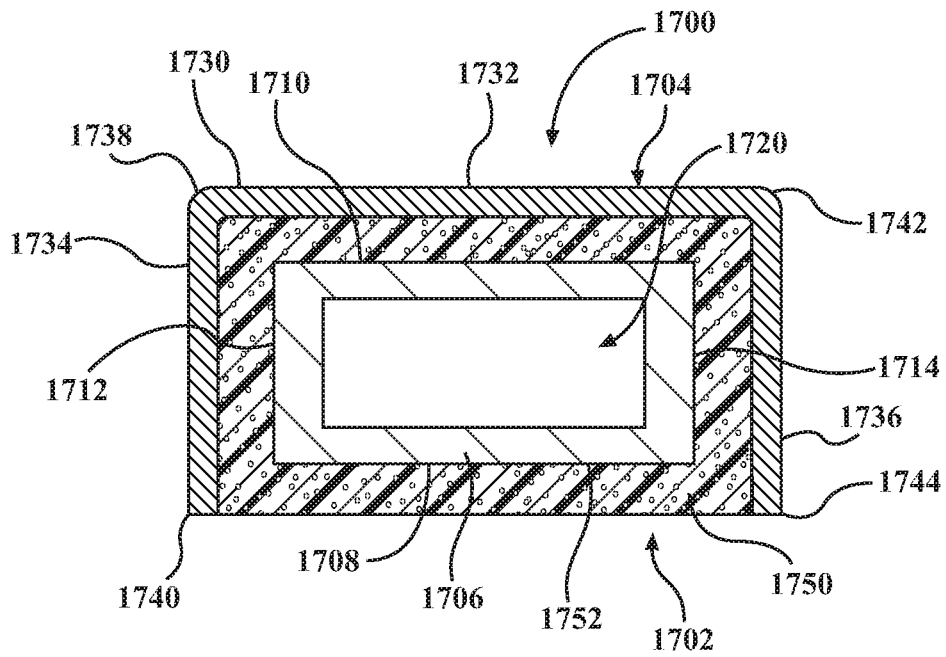


FIG. 17

## AERODYNAMICALLY EFFICIENT SPOKE DESIGN FOR A VEHICLE WHEEL

### CROSS-REFERENCE TO RELATED APPLICATIONS

The present U.S. Continuation-in-Part application claims priority to U.S. Utility patent application Ser. No. 14/212,914 entitled "Aerodynamically Efficient Spoke Design for A Vehicle Wheel" filed on Mar. 14, 2014, which claims priority to U.S. Provisional Patent Application Ser. No. 61/793,605, filed on Mar. 15, 2013, and entitled "Aerodynamically Efficient Wheel Spoke Design", the disclosure of which is hereby incorporated by reference as though set forth fully herein.

### TECHNICAL FIELD

The present disclosure relates generally to a wheel design that provides improved aerodynamic performance. More specifically, the present disclosure relates to (a) a design of a wheel spoke that yields minimal power usage from the pumping of air during rotation to provide improved aerodynamics and (b) a design of a wheel spoke that optimizes the air pressure gradients under and around the vehicle affecting overall vehicle coefficient of drag.

### BACKGROUND OF THE INVENTION

With recent efforts directed toward energy conservation along with the continuing escalation of fuel prices, the automotive industry has put an emphasis on increasing the fuel economy of vehicles that are put onto the road. Efforts to improve the fuel economy of vehicles have resided in improving the operation and efficiency of their engines, reducing the weight of their bodies and chassis, and improving the aerodynamic characteristics of their bodies. While great strides have been made in enhancing vehicle fuel economy as a result of improvements in these areas, there is still significant room for further advancement.

Currently, the impact of the wheels and their effect on vehicle aerodynamics as well as fuel economy has been largely unappreciated. While there have been efforts to design and manufacture lighter weight wheels, such as through the removal of material from the spokes or the backsides of the wheel, the primary goal of these efforts has generally been cost considerations and not aerodynamics or fuel economy. Indeed, the prior efforts to remove material from the back side of the wheel spokes likely negatively affected the wheel aerodynamics.

More recently, the potential aerodynamic impact of vehicle wheels themselves has been considered and has focused on the size and shape of the wheel turbine openings. These considerations have largely ignored the fact that most wheel assemblies today employ covers or other structures over the wheel outboard surface that are designed to enhance the aesthetics of the wheel. Any aerodynamic benefit that may result from the design of the wheel alone is not maximized when a wheel cover or other aesthetic feature is secured to the outboard surface of the wheel that does not take into account the aerodynamics of the overall wheel assembly.

It would thus be desirable to provide a wheel that overcomes the disadvantages associated with current wheels and helps contribute to improved fuel efficiency of a vehicle.

## SUMMARY OF THE INVENTION

It is therefore an aspect of the present disclosure to provide a wheel for a vehicle that provides improved aerodynamics.

It is a related aspect of the present disclosure to provide a wheel assembly for a vehicle that provides improved aerodynamics.

It is a further aspect of the present disclosure to provide a wheel that yields improved fuel economy for a vehicle.

It is another related aspect of the present disclosure to provide a wheel assembly that yields improved fuel efficiency for a vehicle.

According to these and other aspects of the disclosure, a wheel for a vehicle is provided. The wheel includes an inner hub portion configured to receive a vehicle axle therethrough and defining an axis of rotation at a center thereof. The wheel also includes an outer rim portion, and a plurality of wheel spoke portions extending generally between the inner hub portion and the outer rim portion. The inner hub portion, the outer rim portions, and the plurality of wheel spoke portions cooperate to form a wheel outer surface having a plurality of turbine openings. Each of the plurality of wheel spoke portions has an outboard side adjacent the wheel outer surface, an inboard side opposite the spoke outboard side, a leading side surface extending generally in a direction between the inner hub portion and the outer rim portion and between the outboard side and the inboard side, and a trailing side surface extending generally in a direction between the inner hub portion and the outer rim portion and extending between the outboard side and the inboard side. A plurality of clad spokes each overlie one of the wheel spoke portions. The clad spokes each include an outboard surface overlying the outboard side of the wheel spoke portion, a leading side surface overlying the leading side surface of the wheel spoke portion, and a trailing side surface overlying the trailing side surface of the wheel spoke portion. At least a segment of one of the leading side and trailing side surfaces of each of the clad spokes has a non-planar shape.

According to a further aspect of the disclosure, a wheel for a vehicle is provided. The wheel includes an inner hub portion configured to receive a vehicle axle therethrough and defining an axis of rotation at a center thereof. The wheel also includes an outer rim portion, and a plurality of wheel spoke portions extending generally between the inner hub portion and the outer rim portion. The inner hub portion, the outer rim portions, and the plurality of wheel spoke portions cooperate to form a wheel outer surface having a plurality of turbine openings. Each of the plurality of wheel spoke portions has an outboard side adjacent the wheel outer surface, an inboard side opposite the spoke outboard side, a leading side surface extending generally in a direction between the inner hub portion and the outer rim portion and between the outboard side and the inboard side, and a trailing side surface extending generally in a direction between the inner hub portion and the outer rim portion and extending between the outboard side and the inboard side. A plurality of clad spokes each overlie at least a segment of one of the wheel spoke portions. A foam adhesive is disposed between each of the wheel spoke and the overlying clad spoke. The foam adhesive overlies the inboard surface of each of the wheel spokes.

### BRIEF DESCRIPTION OF THE DRAWINGS

Other aspects of the present disclosure will be readily appreciated, as the same becomes better understood by

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reference to the following detailed description when considered in connection with the accompanying drawings wherein:

FIG. 1 is a perspective view of an exemplary wheel;

FIG. 2 is a front view of an exemplary wheel;

FIG. 3 is a back view of an exemplary wheel;

FIG. 4 is an exploded view of an exemplary wheel assembly;

FIG. 5 is schematic cross-sectional illustration of a configuration of a wheel spoke in accordance with the prior art;

FIG. 6 is a schematic cross-sectional illustration of a wheel spoke for a wheel assembly in accordance with an aspect of the present disclosure;

FIG. 7 is a schematic cross-sectional illustration of a wheel spoke for a wheel assembly in accordance with another aspect of the present disclosure;

FIG. 8 is a schematic cross-sectional illustration of a wheel spoke design in accordance with still another aspect of the present disclosure;

FIG. 9 is a schematic cross-sectional illustration of a wheel spoke design for a wheel assembly in accordance with yet another aspect of the present disclosure;

FIG. 10 is a schematic cross-sectional illustration of a wheel spoke design for a wheel assembly in accordance with a further aspect of the present disclosure;

FIG. 11 is a schematic cross-sectional illustration of a wheel spoke design for a wheel assembly in accordance with yet another aspect of the present disclosure;

FIG. 12 is a schematic cross-sectional illustration of a wheel spoke design for a wheel assembly in accordance with yet a further aspect of the present disclosure;

FIG. 13 is a schematic cross-sectional illustration of a wheel spoke design for a wheel assembly in accordance with still another aspect of the present disclosure;

FIG. 14 is a schematic cross-sectional illustration a wheel spoke design in accordance with still yet a further aspect of the present disclosure;

FIG. 15 is a schematic cross-sectional illustration of a wheel spoke design in accordance with still another aspect of the present disclosure;

FIG. 16 is a schematic cross-sectional illustration of a wheel spoke design in accordance with yet a further aspect of the present disclosure; and

FIG. 17 is a schematic cross-sectional illustration of a wheel spoke design in accordance with yet another aspect of the present disclosure.

#### DETAILED DESCRIPTION OF THE INVENTION

For purposes of description herein, the terms “upper”, “lower”, “right”, “left”, “rear”, “front”, “vertical”, “horizontal”, and derivatives thereof shall relate to the disclosure as oriented in the FIGs and are intended merely for purposes of illustration and are not intended to be limiting. It is to be understood that the disclosure may assume various alternative orientations and features, except where expressly specified to the contrary. It is also to be understood that the specific devices and processes illustrated in the attached drawings, and described in the following specification are exemplary embodiments of the inventive concepts defined in the appended claims. The specific dimensions and other physical characteristics relating to the aspects disclosed herein are not to be considered as limiting, unless the claims expressly state otherwise.

The present disclosure relates generally to a wheel and a wheel assembly for an automobile that can provide reduced

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power usage as well as improved vehicle aerodynamics and fuel economy. The amount of fuel economy savings can vary based upon other factors, including the configuration of the vehicle and whether the savings may be measured based on city or highway driving. According to an aspect, assuming the same vehicle, the disclosed wheel and wheel assembly can provide benefits over conventional wheels and wheel assemblies. The disclosed wheel and wheel assembly are intended for use with an automotive vehicle, such as a car or truck. In accordance with another aspect, the wheel and wheel assembly could alternatively be used in connection with other types of vehicles.

FIGS. 1 through 3 generally illustrate a wheel 100 in accordance with an aspect of the disclosure. According to an aspect, the wheel 100 has an inboard side 102 and an outboard side 104 and includes an inner hub portion 106 having an opening 108 for receipt of an axle (not shown) therethrough. The center of the opening 108 defines an axis of rotation. The hub portion 106 also includes a plurality of lug openings 110 formed therein which receive lug bolts (not shown), for securing the wheel 100 for rotation with a vehicle axle. The wheel 100 also includes a peripheral rim portion 112 with an outer peripheral flange surface 114. The wheel 100 additionally includes a plurality of wheel spokes 116 extending generally radially between the outer peripheral flange surface 114 and the inner hub portion 106. The outer peripheral flange surface 114, the inner hub portion 106, and the plurality of spokes 116 together define a plurality of wheel turbine openings 120. The wheel turbine openings 120 are generally defined by an inner boundary or footprint. The spokes and turbine openings may have a variety of different sizes, shapes and geometries and may be defined by a variety of different surfaces. Additionally, the wheel may employ any number of spokes.

As shown, the wheel turbine opening perimeter 130 may be generally defined by inner side surfaces 122, 124 of adjacent spokes 116 and an inner periphery 132 of the outer peripheral flange surface 114. The wheel turbine openings 120 can have a variety of different shapes and sizes, including non-uniform shapes. Additionally, any number of turbine openings 120 can be formed in the wheel surface 110. According to an aspect, the wheel 100 can be formed from any suitable material, such as aluminum or steel, as is conventional in the automotive industry. Other materials may alternatively be employed. Additionally, any conventional forming or manufacturing process may be employed.

FIG. 4 generally illustrates a wheel assembly 10 in accordance with an aspect of the disclosure. Pursuant to an aspect, the wheel assembly 10 includes a wheel 100 and a wheel cover or clad 200 designed to overlie the outboard side 104 of the wheel such as for aesthetic purposes. The wheel clad 200 can be permanently secured to the wheel 100 by a suitable adhesive to form a completed wheel assembly 10. According to an aspect, the wheel clad 200 may be secured to the wheel 100 by foam adhesive, as generally designated by reference number 300. According to another aspect, any other suitable adhesive may be employed. For example, a silicon adhesive, such as a one part or two part RTV adhesive, may be employed.

As generally shown, the wheel clad 200 has an inboard surface 202 and an outboard surface 204. The wheel clad 200 has a clad outer peripheral portion 206 that is intended to axially align with or overlie at least a portion of the wheel outer peripheral flange surface 114. The wheel clad 200 also includes a hub portion 208 that can be axially aligned with at least a portion of the wheel inner opening portion 106. The wheel clad 200 also can include a plurality of clad spokes

**210** that extend radially between the clad outer peripheral portion **206** and the clad inner opening portion **208**. The clad spokes **210** may at least partially align with and overlap the wheel spokes **116**. The clad outer peripheral portion **206**, the clad inner opening portion **208**, and the clad spokes **210** cooperate to define a plurality of clad turbine openings **214**. The clad **200** also can include a plurality of lug bolt receiving holes **212** formed therein for receiving lugs. It will be appreciated that the clad turbine openings **214** according to the present disclosure can have a variety of different sizes and shapes and can be located in different places on the clad **200**.

The wheel clad **200** may be permanently secured to the wheel **100** such that the clad inboard surface **202** faces the wheel outboard side **104**. The plurality of clad turbine openings **214** can each have a clad turbine opening perimeter **216** that may be defined by opposing side surfaces **218** of adjacent clad spokes **210** and an inner periphery **220** of the clad outer rim portion **206**. As shown, the opposing side surfaces **218** may extend downward toward the wheel outboard surface **104** in a generally planar fashion. The plurality of clad turbine openings **214** may be generally axially aligned with the wheel turbine openings **120**, such that each clad turbine opening perimeter **216** may be disposed entirely within a respective one of the wheel turbine openings **120**.

According to a further aspect, the wheel clad **200** may be constructed of plastic or composite material. However, other suitable materials may be employed as may be preferred or dictated by the design constraints of the particular application. According to another aspect, the wheel clad **200** may have a metal plated outer surface, such as a chrome plated surface, to provide desirable aesthetics and to yield an appearance that the clad is an integral part of the wheel. Numerous structural combinations of wheel dads with chrome-plated outboard surfaces have attracted great interest from vehicle manufacturers, because they are light-weight, aesthetically pleasing and offer designers complete flexibility with regard to the aesthetic effect that can be created for a specific vehicle regardless of whether these vehicles use steel or aluminum wheels. The clad **200** may be formed by suitable injection molding processes.

Known efforts to reduce the weight of conventional wheels and wheel assemblies has involved removing weight from the inboard side of the wheel. One such exemplary weight removal structure is as a weight reduction pocket which is formed on the inner surface **134** of the wheel spokes **116**. Exemplary weight reduction pockets **136** formed on the inner surface **134** of the wheel spoke **116** are generally illustrated in FIG. 3.

A weight reduction pocket **136** is also illustrated in FIG. 5, which schematically illustrates a conventional wheel spoke design for a wheel assembly. As shown in FIG. 5, the wheel spoke **116** may be a generally cast metal structure that has a generally uniform cross-section. The wheel spoke **116** has an inner surface **134**, an outer surface **138** and a pair of spoke inner side surfaces **122**, **124**, which extend between the inner surface **134** and the outer surface **138**. As shown, a clad spoke **210** can overlie the wheel spoke **116** and encapsulates it on three sides. An adhesive, generally designated by reference number **300**, can fill the area between the inboard surface **202** of the clad spoke **210** and the outboard side **104** of the wheel spoke **116**. The inner surface **134** of the wheel spoke **116** may be machined and have a weight reduction pocket **136** formed therein through the removal of material. As shown, the weight reduction pocket **136** can be formed as a depression or recess generally in the middle portion of the inner surface **134** of the wheel spoke

**116**. While this feature serves to lighten the wheel, it negatively impact aerodynamics of the inboard side **104** of the wheel **100**.

According to an aspect of the present disclosure, the aerodynamics of the wheel may be improved by altering the shape of the back, rear or inboard side of the wheel spoke. More specifically, according to an aspect, the inboard side of the wheel spoke can be formed to create an efficient surface that does not pump air, in the same fashion as a propeller or fan would. According to another aspect, the inboard side of the wheel can be formed to minimize the power used to rotate the wheel through the air or can be formed to create an effect that provides a pressure differential between the inboard side and the outboard side of the wheel, allowing the evacuation of high pressure air from underneath the vehicle, thereby reducing the overall drag coefficient of the wheel and vehicle. According to another aspect, the orientation of each of the spokes may be changed to provide an aerodynamic benefit, as discussed above.

FIG. 6 illustrates one exemplary design for a wheel assembly that yields improved aerodynamics. As shown, FIG. 6 is a cross-section of a portion of wheel assembly **600** according to an aspect of the present disclosure, which yields improved aerodynamics through altering the configuration of the inboard side of the wheel. As shown, the wheel assembly **600** can include a wheel **602** and a wheel clad **604** and the basic components of the wheel and wheel clad may be configured as discussed above. The differences may reside in the configuration of the wheel spoke and the clad spoke.

According to an aspect, the wheel spoke **606** has an inboard surface **608**, an outboard surface **610**, a leading surface **612** extending between the inboard surface **608** and the outboard surface **610**, and a trailing surface **614** extending between the inboard surface **608** and the outboard surface **610**. According to another aspect, the inboard surface **608** may be configured as a generally convex shape such that it is generally arcuate in a direction from the leading surface **612** to the trailing surface **614** with a generally middle portion **616** of the inboard surface **608** is bowed away from the outboard surface **610** of the spoke **606**. Put another way, the generally middle portion **616** may be disposed a distance ( $D_m$ ) away from a reference plane (P) defined by the outboard surface **610** of the spoke **606**. An inner edge **618** of the leading surface **612** may be disposed a distance ( $D_{le}$ ) from the reference plane (P). An inner edge **620** of the trailing surface **614** may be disposed a distance ( $D_{te}$ ) from the reference plane (P). According to an aspect, the distance ( $D_m$ ) may be greater than each of distance ( $D_{le}$ ) and distance ( $D_{te}$ ). According to another aspect, distance ( $D_{le}$ ) may be equal to distance ( $D_{te}$ ). However, distances ( $D_{le}$ ) and ( $D_{te}$ ) do not need to be equal.

According to an aspect, the outboard surface **610** of the wheel spoke **606** can include a weight reduction pocket **622**, which can serve to decrease the amount of material that is required to form the wheel spoke thus making the wheel spoke lighter and less expensive. The weight reduction pocket **622** may be sized and shaped in order to maximize the removal of material without compromising the strength or structural integrity of the wheel spoke. The weight reduction pocket may obviously take on a variety of different shapes. Alternatively, instead of a weight reduction pocket, other weight reducing or relief structures may be employed. According to an aspect, the inboard surface of the wheel spoke may be left as-cast. Alternatively, the inboard surface of the spoke could include machining to achieve brake clearance tolerances. Additionally, by placing the weight



reduction pocket on the outboard surface **610** of the spoke **606**, the inboard side of the spoke can be shaped to have increased aerodynamic effect. According to a still further aspect, the spoke **606** could be rotated either clockwise or counterclockwise (as viewed in FIG. 6) about its center such that the inboard surface **608** is angled either downwardly or upwardly with respect to the clad leading surface **634**.

According to another aspect, a clad spoke **630** can overlie the wheel spoke **606**. The clad spoke **630** can include an outboard surface **632**, a leading side surface **634**, and a trailing side surface **636**. According to a further aspect, the leading side surface **634** has an outer edge **638** and an inner edge **640**. The trailing side surface **636** also has an outer edge **642** and an inner edge **644**. As shown, the inner edge **638** of the leading side surface **634** of the clad spoke **630** may be spaced a first distance ( $d_1$ ) from the inner edge **618** of the leading surface **612** of the wheel spoke **606**. As also shown, the inner edge **644** of the trailing side surface **636** of the clad spoke **630** may be spaced a second distance ( $d_2$ ) from the inner edge **620** of the trailing surface **614** of the wheel spoke **606**. According to an aspect, the first distance ( $d_1$ ) may be greater than the second distance ( $d_2$ ). According to another aspect, the first distance ( $d_1$ ) may be substantially greater than the second distance ( $d_2$ ). According to a further aspect, the leading surface **612** of the wheel spoke **606** may be oriented substantially parallel to the leading side surface **634**. As also shown, the trailing surface **614** of the wheel spoke **606** may be oriented such that it is not parallel to the trailing side surface **636**. Put another way, the leading side surface **634** can be disposed at an angle ( $\alpha$ ) with respect to the outboard surface **632** which angle may be less than an angle ( $\theta$ ) as measured between the trailing side surface **636** and the outboard surface **632**.

According to another aspect, foam adhesive **650** may be utilized to fill an area between the wheel spoke **606** and the clad spoke **630**. According to another aspect, foam adhesive can be utilized to assist in forming at least a portion of an inboard surface **608** of the wheel spoke **606**. As shown, a first foam portion **652** can extend between the inner edge **640** of the leading side surface **634** of the clad surface **630** and the inner edge **618** of the leading surface **612** of the wheel spoke **606**. According to an aspect, the first foam portion **652** may be disposed flush to the edges **618**, **640** and configured to match a contour of the inboard surface **608** of the wheel spoke **606**. As also shown, a second foam portion **654** can extend between the inner edge **644** of the trailing side surface **636** of the clad spoke **630** and the inner edge **620** of the trailing surface **614** of the wheel spoke **606**. According to another aspect, the second foam portion **654** may be disposed flush to those edges **620**, **644** and also configured to match a contour of the inboard surface **608** of the wheel spoke **606**. In other words, the foam exposed on the back side of the wheel can be shaped to provide an aero-efficient surface as the front-side to rear-side surface geometry is achieved.

A spoke inboard surface **608** having this configuration can provide an aero-efficient shape that results from the configuration of both the outboard surface and the inboard surface to reduce pumping losses.

FIG. 7 illustrates another exemplary design for a wheel assembly that yields improved vehicle aerodynamics through altering the configuration of the rear side of the wheel spoke. As shown, FIG. 7 is a cross-section of a portion of a wheel assembly **700** according to an aspect of the present disclosure. The wheel assembly **700** can include a wheel **702** and a wheel clad **704**. The basic components of the wheel and the wheel clad may be configured as discussed

above. The differences may reside in the configuration of the wheel spoke and the clad spoke.

According to an aspect, the wheel **702** includes the wheel spoke **706** having an inboard surface **708**, an outboard surface **710**, and a leading surface **712** extending between the inboard surface **708** and the outboard surface **710**, and a trailing surface **714** extending between the inboard surface **708** and the outboard surface **710**. According to another aspect, the inboard surface **708** may be configured as a generally concave shape such that it is generally arcuate in a direction from the leading surface **712** to the trailing surface **714** where a generally middle portion **716** of the inboard surface **708** is bowed toward from the outboard surface **710** of the spoke **706**. Put another way, the generally middle portion **716** may be disposed a distance ( $D_m$ ) away from a reference plane (P) defined by the outboard surface **710** of the spoke **706**. An inner edge **718** of the leading surface **712** can be disposed a distance ( $D_{le}$ ) from the reference plane (P). An inner edge **720** of the trailing surface **714** may be disposed a distance ( $D_{te}$ ) from the reference plane (P). According to an aspect, the distance ( $D_m$ ) may be greater than the distance ( $D_{le}$ ) and less than the distance ( $D_{te}$ ). However, the relative distances can vary. By this configuration, the leading surface **712** may be shorter than the trailing surface **714**. According to an aspect, the outboard surface **710** of the wheel spoke **706** as defined by the reference plane may be oriented at an angle with respect to the wheel outer surface. According to a further aspect, the wheel spoke **706** could be rotated (either clockwise or counter-clockwise) about a center point so that one of the leading surface **712** or the trailing surface **714** is lower with respect to the Plane (P) than the other. By this configuration, the length of these surfaces **712**, **714** could be equal  $L_1=L_2$ .

According to another aspect, a clad spoke **730** can overlie the wheel spoke **706**. The clad spoke **730** can include an outboard surface **732**, a leading side surface **734**, and a trailing side surface **736**. According to a further aspect, the leading side surface **734** has an outer edge **738** and an inner edge **740**. The trailing side surface **736** also has an outer edge **742** and an inner edge **744**. According to this aspect, the inner edge **738** of the leading side surface **734** of the clad spoke **730** may be spaced apart generally the same distance as the distance between the inner edge **744** of the trailing side surface **736** of the clad spoke **730** and the inner edge **720** of the trailing surface **714** of the wheel spoke **706**. According to an aspect, the leading side surface **734** of the clad spoke **730** may have a shorter length ( $L_1$ ) than the length ( $L_2$ ) of the trailing side surface **736**. This configuration can yield a pitch in the wheel spoke that creates a pressure differential between outboard pressure zone ( $P_o$ ) and the inboard pressure zone ( $P_i$ ). Again, the pitch of the spoke could be created through rotation of the spoke about its center.

According to another aspect, foam adhesive **750** may be utilized to fill an area between the wheel spoke **706** and the clad spoke **730**. According to another aspect, foam adhesive can be utilized to assist in forming an inboard surface **708** of the wheel spoke **706**. As shown, a first foam portion **752** can extend between the inner edge **740** of the leading side surface **734** of the clad surface **730** and the inner edge **718** of the leading surface **712** of the wheel spoke **706**. According to an aspect, the first foam portion **752** may be disposed flush to the edges **718**, **740** are configured to match a contour of the inboard surface **708** of the wheel spoke **706**. As also shown, a second foam portion **754** can extend between the inner edge **744** of the trailing side surface **736** of the clad spoke **730** and the inner edge **720** of the trailing surface **714**

of the wheel spoke **706**. According to another aspect, the second foam portion **754** may be disposed flush to those edges **720**, **744** and also configured to match a contour of the inboard surface **708** of the wheel spoke **706**. In other words, the foam exposed on the back side of the wheel can be shaped to provide an aero-efficient surface as the front-side to rear-side surface geometry is achieved.

A spoke inboard surface **708** having this configuration can provide an aero-efficient shape that results from the configuration of both the outboard surface and the inboard surface to reduce pumping losses.

FIG. **8** illustrates an exemplary design for a wheel that yields improved aerodynamics through altering the configuration of the inboard side of the wheel spoke. As shown, FIG. **8** is a cross-section of a portion of wheel **802** according to an aspect of the present disclosure. The basic components of the wheel may be configured, as discussed above. The differences may reside in the configuration of the wheel spoke. As shown, the wheel spoke **806** of FIG. **8** has the same configuration as the wheel spoke of FIG. **7**. However, with respect to FIG. **8**, there is no wheel clad disposed overtop of the wheel surface. The outboard surface **810** of the wheel spoke and thus the wheel is exposed. According to an aspect, the outboard surface of the wheel, including the wheel spoke geometry, are configured to provide the aerodynamic benefits.

FIG. **9** illustrates still another exemplary design for a wheel assembly that yields improved aerodynamics through altering the configuration of the inboard side of the wheel spoke. As shown, FIG. **9** is a cross-section of a portion of wheel assembly **900** according to an aspect of the present disclosure. The wheel assembly **900** can include a wheel **902** and a wheel clad **904**. The basic components of the wheel and wheel clad may be configured as discussed above. The differences can reside in the configuration of the wheel and clad spoke.

According to an aspect, the wheel spoke **906** has an inboard surface **908**, an outboard surface **910**, and a leading surface **912** extending between the inboard surface **908** and the outboard surface **910**, and a trailing surface **914** extending between the inboard surface **908** and the outboard surface **910**. According to another aspect, the inboard surface **908** can be configured as a generally convex shape such that it is generally arcuate in a direction from the leading surface **912** to the trailing surface **914** with a generally middle portion **916** of the inboard surface **908** that is bowed away from the outboard surface **910** of the spoke **906**. Put another way, the generally middle portion **916** may be disposed a distance ( $D_m$ ) away from a reference plane (P) defined by the outboard surface **910** of the spoke **906**. According to another aspect, the middle portion **916** can be configured with at least a generally planar section for manufacturing purposes without altering the overall convex shape of the inboard surface **908**. An inner edge **918** of the leading surface **912** may be disposed a distance ( $D_{le}$ ) from the reference plane (P). An inner edge **920** of the trailing surface **914** may be disposed a distance ( $D_{te}$ ) from the reference plane (P). According to an aspect, distance ( $D_m$ ) may be greater than each of distance ( $D_{le}$ ) and distance ( $D_{te}$ ). According to another aspect, distance ( $D_{le}$ ) may be equal to distance ( $D_{te}$ ). However, distances ( $D_{le}$ ) and ( $D_{te}$ ) do not need to be equal.

According to another aspect, a clad spoke **930** can overlie the wheel spoke **906**. The clad spoke **930** can include an outboard surface **932**, a leading side surface **934**, and a trailing side surface **936**. According to a further aspect, the leading side surface **934** has an outer edge **938** and an inner

edge **940**. The trailing side surface **936** also has an outer edge **942** and an inner edge **944**. As shown, the inner edge **938** of the leading side surface **934** of the clad spoke **930** may be spaced a first distance ( $d_1$ ) from the inner edge **918** of the leading surface **918** of the wheel spoke **906**. As also shown, the inner edge **944** of the trailing side surface **936** of the clad spoke **930** may be spaced a second distance ( $d_2$ ) from the inner edge **920** of the trailing surface **912** of the wheel spoke **906**. According to an aspect, the first distance ( $d_1$ ) and the second distance ( $d_2$ ) may be generally equal. According to a further aspect, the leading surface **918** of the wheel spoke **906** may be oriented substantially parallel to the leading side surface **934** of the wheel spoke. As also shown, the trailing surface **914** of the wheel spoke **906** may also be oriented substantially parallel to the trailing side surface **936** of the clad spoke.

According to another aspect, foam adhesive **950** may be utilized to fill an area between the wheel spoke **906** and the clad spoke **930**. According to another aspect, foam adhesive can be utilized to assist in forming an inboard surface **908** of the wheel spoke **906**. As shown, a first foam portion **952** may extend between the inner edge **940** of the leading side surface **934** of the clad surface **930** and the inner edge **918** of the leading surface **912** of the wheel spoke **906**. According to an aspect, the first foam portion **952** can be disposed flush to the edges **918**, **940** and configured to match a contour of the inboard surface **908** of the wheel spoke **906**. As also shown, a second foam portion **954** can extend between the inner edge **944** of the trailing side surface **936** of the clad spoke **930** and the inner edge **920** of the trailing surface **914** of the wheel spoke **906**. According to another aspect, the second foam portion **954** may be disposed flush to those edges **920**, **944** and also configured to match a contour of the inboard surface **908** of the wheel spoke **906**. In other words, the foam exposed on the back side of the wheel can be shaped to provide an aero-efficient surface as the front-side to rear-side surface geometry is achieved.

A wheel spoke having this configuration can provide an aero-efficient shape that results from the configuration of both the outboard surface and the inboard surface to reduce pumping losses. According to an aspect, the surface shape of the inboard surface, the outboard surface, and the side surfaces can create a shape for efficient ventilation drag by reducing the pumping effect.

FIG. **10** illustrates still a further exemplary design for a wheel assembly that yields improved aerodynamics through altering the configuration of the inboard side of the wheel spoke. As shown, FIG. **10** is a cross-section of a portion of a wheel assembly **1000** according to an aspect of the present disclosure. The wheel assembly **1000** can include a wheel **1002** and a wheel clad **1004**. The basic components of the wheel and wheel clad may be configured, as discussed above. The differences can reside in the configuration of the wheel and clad spoke.

According to an aspect, the wheel spoke **1006** has an inboard surface **1008**, an outboard surface **1010**, and a leading surface **1012** extending between the inboard surface **1008** and the outboard surface **1010**, and a trailing surface **1014** extending between the inboard surface **1008** and the outboard surface **1010**. According to another aspect, the inboard surface **1008** is configured with a generally convex shape such that it is generally arcuate in a direction from the leading surface **1012** to the trailing surface **1014** where a generally middle portion **1016** of the inboard surface **1008** is bowed away from the outboard surface **1010** of the spoke **1006**. Put another way, the generally middle portion **1016** may be disposed a distance ( $D_m$ ) away from a reference

plane (P) defined by the outboard surface **1010** of the spoke **1006**. According to another aspect, the middle portion **1016** can be configured with at least a generally planar portion for manufacturing purposes without altering the overall convex shape of the inboard surface **1008**. An inner edge **1018** of the leading surface **1012** may be disposed a distance ( $D_{ie}$ ) from the reference plane (P). An inner edge **1020** of the trailing surface **1014** may be disposed a distance ( $D_{ie}$ ) from the reference plane (P). According to an aspect, distance ( $D_m$ ) can be greater than each of distance ( $D_{ie}$ ) and distance ( $D_{te}$ ). According to another aspect, distance ( $D_{ie}$ ) may be equal to distance ( $D_{te}$ ). However, distances ( $D_{ie}$ ) and ( $D_{te}$ ) do not need to be equal. Again, as discussed above, the spokes could be rotated about its center to change its pitch.

According to an aspect, the outboard surface **1010** of the wheel spoke **1006** can include a pair of weight reduction structures **1022**, which can serve to decrease the amount of material that is required to form the wheel spoke. As shown, the weight reduction structures **1022** may be formed in the leading surface **1012** and the trailing surface **1014**. The weight reduction structures **1022** may be sized and shaped in order to maximize the removal of material without compromising the strength or structural integrity of the wheel spoke. The weight reduction structures **1022** may obviously take on a variety of different shapes. Alternatively, other weight reducing or relief structures may be employed. Additionally, by placing the weight reduction structures on the outboard side and side surfaces of the spoke, the inboard side of the spoke can be shaped to have increased aerodynamic effect.

According to another aspect, a clad spoke **1030** can overlie the wheel spoke **1006**. The clad spoke **1030** can include an outboard surface **1032**, a leading side surface **1034**, and a trailing side surface **1036**. According to a further aspect, the leading side surface **1034** has an outer edge **1038** and an inner edge **1040**. The trailing side surface **1036** also has an outer edge **1042** and an inner edge **1044**. As shown, the inner edge **1038** of the leading side surface **1034** of the clad spoke **1030** may be spaced a first distance ( $d_1$ ) from the inner edge **1018** of the leading surface **1012** of the wheel spoke **1006**. As also shown, the inner edge **1044** of the trailing side surface **1036** of the clad spoke **1030** may be spaced a second distance ( $d_2$ ) from the inner edge **1020** of the trailing surface **1014** of the wheel spoke **1006**. According to an aspect, the first distance ( $d_1$ ) and the second distance ( $d_2$ ) may be generally equal. According to a further aspect, the first distance ( $d_1$ ) and the second distance ( $d_2$ ) may be very small such that there is little space between the inner edges **1018**, **1020** of the wheel spoke **1006** and the inner edges **1040**, **1044** of the clad spoke **1030**. By this configuration, the inboard surface **1008** of the wheel spoke **1006** may be almost entirely responsible for the spoke shape. According to an aspect, the foam exposed on the back side of the wheel can be shaped to provide an aero-efficient surface as the front-side to rear-side surface geometry is achieved.

According to another aspect, foam adhesive **1050** may be utilized to fill an area between the wheel spoke **1006** and the clad spoke **1030**.

A wheel spoke having this configuration can provide an aero-efficient shape that results from the configuration of both the outboard surface and the inboard surface to reduce pumping losses. According to an aspect, the surface shape of the inboard surface, the outboard surface, and the side surfaces can create a shape for efficient ventilation drag by reducing the pumping effect.

FIG. **11** illustrates one exemplary design for a wheel assembly that yields improved aerodynamics through alter-

ing the configuration of the inboard side of the wheel spoke. As shown, FIG. **11** is a cross-section of a portion of a wheel assembly **1100** according to an aspect of the present disclosure. The wheel assembly **1100** includes a wheel **1102** and a wheel clad **1104**. The basic components of the wheel and the wheel clad may be configured as discussed above. The differences can reside in the configuration of the wheel and clad spoke.

According to an aspect, the wheel **1102** includes the wheel spoke **1106** having an inboard surface **1108**, an outboard surface **1110**, and a leading surface **1112** extending between the inboard surface **1108** and the outboard surface **1110**, and a trailing surface **1114** extending between the inboard surface **1108** and the outboard surface **1110**. According to another aspect, the inboard surface **1108** may be configured as a generally concave shape such that it is generally arcuate in a direction from the leading surface **1112** to the trailing surface **1114** where a generally middle portion **1116** of the inboard surface **1108** is bowed toward from the outboard surface **1110** of the spoke **1106**. Put another way, the generally middle portion **1116** may be disposed a distance ( $D_m$ ) away from a reference plane P defined by the outboard surface **1110** of the spoke **1106**. An inner edge **1118** of the leading surface **1112** may be disposed a distance ( $D_{ie}$ ) from the reference plane (P). An inner edge **1120** of the trailing surface **1114** may be disposed a distance ( $D_{te}$ ) from the reference plane (P). According to an aspect, distance ( $D_m$ ) may be greater than distance ( $D_{ie}$ ) and less than distance ( $D_{te}$ ). However, the relative distances can vary. By this configuration, the leading surface **1112** may be shorter than the trailing surface **1114**. According to an aspect, the outboard surface **1110** of the wheel spoke **1106** as defined by the reference plane (P) may be oriented at an angle with respect to the wheel outer surface, as shown. According to a further aspect, the wheel spoke **1106** could be rotated (either clockwise or counter-clockwise) about a center point so that one of the leading surface **1112** or the trailing surface **1114** is lower with respect to the Plane (P) than the other. By this configuration, the length of these surfaces **1112**, **1114** could be equal  $L_1=L_2$ .

According to an aspect, the outboard surface **1100** of the wheel spoke **1106** can include a pair of weight reduction structures **1122**, which can serve to decrease the amount of material that is required to form the wheel spoke. As shown, the weight reduction structures may be formed in the leading surface **1112** and the trailing surface **1114**. The weight reduction structures **1122** may be sized and shaped in order to maximize the removal of material without compromising the strength or structural integrity of the wheel spoke. The weight reduction structures **1122** may obviously take on a variety of different shapes. Alternatively, other weight reducing or relief structures may be employed. Additionally, by placing the weight reduction structures on the outboard side and side surfaces of the spoke, the inboard side of the spoke can be shaped to have increased aerodynamic effect.

According to another aspect, a clad spoke **1130** can overlie the wheel spoke **1106**. The clad spoke **1130** can include an outboard surface **1132**, a leading side surface **1134**, and a trailing side surface **1136**. According to a further aspect, the leading side surface **1134** has an outer edge **1138** and an inner edge **1140**. The trailing side surface **1136** also has an outer edge **1142** and an inner edge **1144**. According to this aspect, the inner edge **1138** of the leading side surface **1134** of the clad spoke **1130** may be spaced apart generally the same distances as the distance between the inner edge **1144** of the trailing side surface **1136** of the clad spoke **1130** and the inner edge **1120** of the trailing surface **1112** of the

wheel spoke **1106**. According to an aspect, the leading side surface **1134** of the clad spoke **1130** may have a shorter length ( $L_1$ ) than the length ( $L_2$ ) of the trailing side surface **1136**. This configuration can yield a pitch in the wheel spoke that creates a pressure differential between outboard pressure zone (Po) and the inboard pressure zone (Pi). As first distance ( $d_1$ ) between the inner edge **1118** of the wheel spoke leading surface **1112** and the inner edge **1138** of the clad spoke leading side surface **1134** may be very small. Similarly, a second distance ( $d_2$ ) between the inner edge **1144** of the clad spoke trailing side surface **1134** and the inner edge **1120** of the wheel spoke trailing surface **1112** is also very small. By this configuration, the inboard surface **1108** of the wheel spoke **1106** may be almost entirely responsible for the shape if the inner side of the spoke. According to a further aspect, the wheel spoke **1106** could be rotated (either clockwise or counter-clockwise) about a center point so that one of the leading surface **1112** or the trailing surface **1114** is lower with respect to the Plane (P) than the other. By this configuration, the length of these surfaces **1112**, **1114** could be equal  $L_1=L_2$ .

According to another aspect, foam adhesive **1150** may be utilized to fill an area between the wheel spoke **1106** and the clad spoke **1130**. A spoke inboard surface **1108** having this configuration can provide an aero-efficient shape that results from the configuration of both the outboard surface and the inboard surface to reduce pumping losses.

FIG. **12** illustrates one exemplary design for a wheel assembly that yields improved aerodynamics through altering the configuration of the inboard side of the wheel spoke. As shown, FIG. **12** is a cross-section of a portion of a wheel assembly **1200** according to an aspect of the present disclosure. The wheel assembly **1200** includes a wheel **1202** and a wheel clad **1204**. The basic components of the wheel and the wheel clad may be configured as discussed above. The differences can reside in the configuration of the wheel and the clad spoke.

According to an aspect, the wheel spoke **1206** has an inboard surface **1208**, an outboard surface **1210**, and a leading surface **1212** extending between the inboard surface **1208** and the outboard surface **1210**, and a trailing surface **1214** extending between the inboard surface **1208** and the outboard surface **1210**. According to another aspect, the inboard surface **1208** can be configured as a generally convex shape such that it is generally arcuate in a direction from the leading surface **1212** to the trailing surface **1214** with a generally middle portion **1216** of the inboard surface **1208** being bowed away from the outboard surface **1210** of the spoke **1206**. Put another way, the generally middle portion **1216** may be disposed a distance ( $D_m$ ) away from a reference plane (P) defined by the outboard surface **1210** of the spoke **1206**. An inner edge **1218** of the leading surface **1212** may be disposed a distance ( $D_{ie}$ ) from the reference plane (P). An inner edge **1220** of the trailing surface **1214** may be disposed a distance ( $D_{ie}$ ) from the reference plane (P). According to an aspect, distance ( $D_m$ ) may be greater than each of distance ( $D_{ie}$ ) and distance ( $D_{ie}$ ). According to another aspect, distance ( $D_m$ ) may be equal to distance ( $D_{ie}$ ). However, distances ( $D_{ie}$ ) and ( $D_{ie}$ ) do not need to be equal. According to a further aspect, the wheel spoke **1206** could be rotated (either clockwise or counter-clockwise) about a center point so that one of the leading surface **1212** or the trailing surface **1214** is lower with respect to the Plane (P) than the other. By this configuration, the length of these surfaces **1212**, **1214** could be equal  $L_1=L_2$ .

According to another aspect, a clad spoke **1230** can overlie the wheel spoke **1206**. According to an aspect, the

clad spoke **1230** may be generally egg-shaped. As shown, the clad spoke **1230** can include an outboard surface **1232**, a leading side surface **1234**, and a trailing side surface **1236**. According to a further aspect, the leading side surface **1234** has an outer edge **1238** and an inner edge **1240**. The trailing side surface **1236** also has an outer edge **1242** and an inner edge **1244**. As shown, the leading side surface **1234** and the trailing side surface **1234** may terminate at their inner edges **1240**, **1244** adjacent the outboard surface **1232** of the wheel spoke **1206**. Additionally, the shapes and degrees of curvature of the leading side surface **1234** and the trailing side surface **1236** may vary. As shown, the leading side surface **1234** may extend inwardly with respect to the clad spoke outboard surface **1232** such that its downturn (as viewed in the FIG) is relatively sharp. According to an aspect, this can generally match the orientation of the wheel spoke leading surface **1212**. As also shown, the trailing side surface **1236** may extend inwardly with respect to the clad spoke outboard surface **1232** such that its downturn (as viewed in the FIG) is more gradual. According to an aspect, this can generally match the orientation of the wheel spoke trailing edge **1214**.

According to another aspect, foam adhesive **1250** may be utilized to fill an area between the wheel spoke **1206** and the clad spoke **1230**. According to another aspect, foam adhesive can be utilized to assist in forming an inboard surface **1208** of the wheel spoke **1206**. As shown, a first foam portion **1252** may extend between the inner edge **1240** of the leading side surface **1234** of the clad surface **1230** and the inner edge **1218** of the leading surface **1212** of the wheel spoke **1206**. According to an aspect, the first foam portion **1252** can be disposed flush to the edges **1218**, **1240** and configured to match a contour of the inboard surface **1208** of the wheel spoke **1206**. As also shown, a second foam portion **1254** can extend between the inner edge **1244** of the trailing side surface **1236** of the clad spoke **1230** and the inner edge **1220** of the trailing surface **1214** of the wheel spoke **1206**. According to another aspect, the second foam portion **1254** may be disposed flush to those edges **1220**, **1244** and also configured to match a contour of the inboard surface **1208** of the wheel spoke **1206**. In other words, the foam exposed on the back side of the wheel can be shaped to provide an aero-efficient surface as the front-side to rear-side surface geometry is achieved.

A wheel spoke having this configuration can provide an aero-efficient shape that results from the configuration of both the outboard surface and the inboard surface to reduce pumping losses. According to an aspect, the surface shape of the inboard surface, the outboard surface, and the side surfaces can create a shape for efficient ventilation drag by reducing the pumping effect.

FIG. **13** illustrates one exemplary design for a wheel assembly that yields improved aerodynamics through altering the configuration of the inboard side of the wheel spoke. As shown, FIG. **13** is a cross-section of a portion of a wheel assembly **1300** according to an aspect of the present disclosure. The wheel assembly **1300** can include a wheel **1302** and a wheel clad **1304**. The basic components of the wheel and the wheel clad may be configured as discussed above. The differences can reside in the configuration of the wheel and the clad spoke.

According to an aspect, the wheel **1302** includes the wheel spoke **1306** having an inboard surface **1308**, an outboard surface **1310**, and a leading surface **1312** extending between the inboard surface **1308** and the outboard surface **1310**, and a trailing surface **1314** extending between the inboard surface **1308** and the outboard surface **1310**. According to another aspect, the inboard surface **1308** may

be configured as a generally convex shape such that it is generally arcuate in a direction from the leading surface **1312** to the trailing surface **1314** where a generally middle portion **1316** of the inboard surface **1308** is bowed toward the outboard surface **1310** of the spoke **1306**. The outboard surface **1310** may have a similar shape. Put another way, the generally middle portion **1316** may be disposed a distance ( $D_m$ ) away from a reference plane (P) defined by the outboard surface **1310** of the spoke **1306**. An inner edge **1318** of the leading surface **1312** may be disposed a distance ( $D_{ie}$ ) from the reference plane (P). An inner edge **1320** of the trailing surface **1314** may be disposed a distance ( $D_{ie}$ ) from the reference plane (P). According to an aspect, the distance ( $D_m$ ) may be greater than the distance ( $D_{ie}$ ) and less than the distance ( $D_{ie}$ ). However, the relative distances can vary. By this configuration, the leading surface **1312** may be shorter than the trailing surface **1314**. According to an aspect, the outboard surface **1310** of the wheel spoke **1306** as defined by the reference plane may be oriented at an angle with respect to the wheel outer surface. According to a further aspect, the wheel spoke **1306** could be rotated (either clockwise or counter-clockwise) about a center point so that one of the leading surface **1312** or the trailing surface **1314** is lower with respect to the Plane (P) than the other. By this configuration, the length of these surfaces **1312**, **1314** could be equal  $L_1=L_2$ .

According to another aspect, a clad spoke **1330** can overlie the wheel spoke **1306**. The clad spoke **1330** can include an outboard surface **1332**, a leading side surface **1334**, and a trailing side surface **1336**. According to a further aspect, the leading side surface **1334** has an outer edge **1338** and an inner edge **1340**. The trailing side surface **1336** also has an outer edge **1342** and an inner edge **1344**. According to this aspect, the inner edge **1338** of the leading side surface **1334** of the clad spoke **1330** may be spaced apart generally the same distances as the distance between the inner edge **1344** of the trailing side surface **1336** of the clad spoke **1330** and the inner edge **1320** of the trailing surface **1312** of the wheel spoke **1306**. According to an aspect, the leading side surface **1334** of the clad spoke **1330** may have a shorter length ( $L_l$ ) than the length ( $L_r$ ) of the trailing side surface **1336**. This configuration can yield a pitch in the wheel spoke that creates a pressure differential between outboard pressure zone (Po) and the inboard pressure zone (Pi).

According to another aspect, foam adhesive **1350** may be utilized to fill an area between the wheel spoke **1306** and the clad spoke **1330**. According to another aspect, foam adhesive can be utilized to assist in forming an inboard surface **1308** of the wheel spoke **1306**. As shown, a first foam portion **1352** may extend between the inner edge **1340** of the leading side surface **1334** of the clad surface **1330** and the inner edge **1318** of the leading surface **1312** of the wheel spoke **1306**. According to an aspect, the first foam portion **1352** may be disposed flush to the edges **1318**, **1340** and configured to match a contour of the inboard surface **1308** of the wheel spoke **1306**. As also shown, a second foam portion **1354** can extend between the inner edge **1344** of the trailing side surface **1336** of the clad spoke **1330** and the inner edge **1320** of the trailing surface **1314** of the wheel spoke **1306**. According to another aspect, the second foam portion **1354** may be disposed flush to those edges **1320**, **1344** and also configured to match a contour of the inboard surface **1308** of the wheel spoke **1306**. In other words, the foam exposed on the back side of the wheel can be shaped to provide an aero-efficient surface as the front-side to rear-side surface geometry is achieved.

A spoke inboard surface **1308** having this configuration can provide an aero-efficient shape that results from the configuration of both the outboard surface and the inboard surface to reduce pumping losses.

FIG. **14** illustrates an exemplary design for a wheel that yields improved aerodynamics through altering the configuration of the inboard side of the wheel spoke. As shown, FIG. **14** is a cross-section of a portion of wheel **1302** according to an aspect of the present disclosure. The basic components of the wheel may be configured, as discussed above. The differences may reside in the configuration of the wheel spoke. As shown, the wheel spoke **1306** of FIG. **14** has the same configuration as the wheel spoke of FIG. **13**. However, with respect to FIG. **14**, there is no wheel clad disposed overtop of the wheel surface. According to an aspect, the outboard surface **1410** of the wheel spoke and thus the wheel is exposed. The outboard surface of the wheel, including the wheel spoke geometry are configured to provide the aerodynamic benefits.

FIG. **15** illustrates another exemplary design for a wheel assembly that yields improved aerodynamics through altering the configuration of the leading edge and trailing edge of the wheel clad. As shown, FIG. **15** is a cross-section of a portion of a wheel assembly **1500** according to an aspect of the present disclosure. The wheel assembly **1500** can include a wheel **1502** and a wheel clad **1504**. The basic components of the wheel and the wheel clad may be configured as discussed above. The differences can reside in the configuration of the wheel and the clad spoke.

According to an aspect, the wheel **1502** includes a wheel spoke **1506** having an inboard surface **1508**, an outboard surface **1510**, a leading surface **1512** extending between the inboard surface **1508** and the outboard surface **1510**, and a trailing surface **1514** extending between the inboard surface **1508** and the outboard surface **1510**. According to another aspect, the inboard surface **1508** and the outboard surface **1510** may each be generally planar and parallel to one another. Similarly, the wheel leading surface **1512** and the wheel trailing surface **1514** may be configured as generally planar surfaces that are parallel to one another. However, the surfaces could each have a variety of different configurations. For example, the wheel spoke surfaces can match the configuration of the clad spoke surfaces, as discussed below. According to a further aspect, the wheel spoke **1506** can include one or more pockets **1520** formed in its interior. For example, the wheel spoke **1506** may be formed by a hollow core casting process such that the pockets **1520** are formed in the spoke interiors such that they spokes are generally hollow. As will be appreciated, interior spoke pockets can decrease the weight of the wheel without affecting its structural integrity, which can provide a lighter wheel assembly resulting in improved fuel economy for a vehicle as well as other aerodynamic benefits. It will be appreciated that hollow pockets in the spokes can be formed in a variety of different ways by a variety of different processes. It will further be appreciated that the pockets **1520** can have a variety of different configurations.

According to another aspect, a clad spoke **1530** can overlie the wheel spoke **1506**. The clad spoke **1530** can include an outboard surface **1532**, a leading side surface **1534**, and a trailing side surface **1536**. According to a further aspect, the leading side surface **1534** has an outer edge **1538** adjacent the outboard surface **1532** and an inner edge **1540** opposite the outer edge **1538**. The trailing side surface **1536** also has an outer edge **1542** adjacent the outboard surface **1532** and an inner edge **1544** opposite the outer edge **1538**. According to this aspect, the leading side surface **1534** may

be configured as a generally concave shape such that it is generally arcuate in a direction from the outer edge **1538** to the inner edge **1540** where a generally middle portion **1546** of the leading side surface **1534** is bowed inwardly. The trailing side surface **1536** may have a similar shape. According to a still further aspect, the trailing side surface **1536** may have a different shape than the leading side surface **1534**. Further, the trailing and leading side surfaces **1536**, **1534** may have other non-planar shapes.

According to another aspect, foam adhesive **1550** may be utilized to fill an area between the wheel spoke **1506** and the clad spoke **1530**. According to another aspect, foam adhesive can be utilized to assist in forming the inboard surface **1508** of the wheel spoke **1506**. As shown, a first foam portion **1552** may extend between the inner edge **1540** of the leading side surface **1534** of the clad surface **1530** and an inner edge **1516** of the leading surface **1512** of the wheel spoke **1506**. According to an aspect, the first foam portion **1552** may be disposed flush to the edges **1518**, **1540** and configured to match a contour of the inboard surface **1508** of the wheel spoke **1506**. As also shown, a second foam portion **1554** can extend between the inner edge **1544** of the trailing side surface **1536** of the clad spoke **1530** and an inner edge **1518** of the trailing surface **1514** of the wheel spoke **1506**. According to another aspect, the second foam portion **1554** may be disposed flush to those edges **1520**, **1544** and also configured to match a contour of the inboard surface **1508** of the wheel spoke **1506**. In other words, the foam exposed on the back side of the wheel can be shaped to provide an aero-efficient surface as the front-side to rear-side surface geometry is achieved.

A spoke leading side surface **1534** having this configuration can provide an aero-efficient shape that results from the configuration of both the outboard surface and the inboard surface to reduce pumping losses.

FIG. **16** illustrates another exemplary design for a wheel assembly that yields improved aerodynamics through altering the configuration of the leading edge and trailing edge of the wheel clad. As shown, FIG. **16** is a cross-section of a portion of a wheel assembly **1600** according to an aspect of the present disclosure. The wheel assembly **1600** can include a wheel **1602** and a wheel clad **1604**. The basic components of the wheel and the wheel clad may be configured as discussed above. The differences can reside in the configuration of the wheel and the clad spoke.

According to an aspect, the wheel **1602** includes a wheel spoke **1606** having an inboard surface **1608**, an outboard surface **1610**, a leading surface **1612** extending between the inboard surface **1608** and the outboard surface **1610**, and a trailing surface **1614** extending between the inboard surface **1608** and the outboard surface **1610**. According to another aspect, the inboard surface **1608** and the outboard surface **1610** may each be generally planar and parallel to one another. Similarly, the wheel leading surface **1612** and the wheel trailing surface **1614** may be configured as generally planar surfaces that are parallel to one another. However, the surfaces could each have a variety of different configurations. For example, the wheel spoke surfaces can match the configuration of the clad spoke surfaces, as discussed below. According to a further aspect, the wheel spoke **1606** can include one or more pockets **1620** formed in its interior. For example, the wheel spoke **1606** may be formed by a hollow core casting process such that the pockets **1620** are formed in the spoke interiors such that they spokes are generally hollow. As will be appreciated, interior spoke pockets can decrease the weight of the wheel without affecting its structural integrity, which can provide a lighter wheel

assembly resulting in improved fuel economy for a vehicle as well as other aerodynamic benefits. It will be appreciated that hollow pockets in the spokes can be formed in a variety of different ways by a variety of different processes. It will further be appreciated that the pockets **1620** can have a variety of different configurations.

According to another aspect, a clad spoke **1630** can overlie the wheel spoke **1606**. The clad spoke **1630** can include an outboard surface **1632**, a leading side surface **1634**, and a trailing side surface **1636**. According to a further aspect, the leading side surface **1634** has an outer edge **1638** adjacent the outboard surface **1632** and an inner edge **1640** opposite the outer edge **1638**. The trailing side surface **1636** also has an outer edge **1642** adjacent the outboard surface **1632** and an inner edge **1644** opposite the outer edge **1638**. According to this aspect, the leading side surface **1634** may be configured as a generally convex shape such that it is generally arcuate in a direction from the outer edge **1638** to the inner edge **1640** where a generally middle portion **1646** of the leading side surface **1634** is bowed outwardly. The trailing side surface **1636** may have a similar shape. According to a still further aspect, the trailing side surface **1636** may have a different shape than the leading side surface **1634**. Further, the trailing and leading side surfaces **1636**, **1634** may have other non-planar shapes.

According to another aspect, foam adhesive **1650** may be utilized to fill an area between the wheel spoke **1606** and the clad spoke **1630**. According to another aspect, foam adhesive **1650** can be utilized to assist in forming the inboard surface **1608** of the wheel spoke **1606**. As shown, a first foam portion **1652** may extend between the inner edge **1640** of the leading side surface **1634** of the clad surface **1630** and an inner edge **1616** of the leading surface **1612** of the wheel spoke **1606**. According to an aspect, the first foam portion **1652** may be disposed flush to the edges **1618**, **1640** and configured to match a contour of the inboard surface **1608** of the wheel spoke **1606**. As also shown, a second foam portion **1654** can extend between the inner edge **1644** of the trailing side surface **1636** of the clad spoke **1630** and an inner edge **1618** of the trailing surface **1614** of the wheel spoke **1606**. According to another aspect, the second foam portion **1654** may be disposed flush to those edges **1620**, **1644** and also configured to match a contour of the inboard surface **1608** of the wheel spoke **1606**. In other words, the foam exposed on the back side of the wheel can be shaped to provide an aero-efficient surface as the front-side to rear-side surface geometry is achieved.

A spoke leading side surface **1634** having this configuration can provide an aero-efficient shape that results from the configuration of both the outboard surface and the inboard surface to reduce pumping losses.

FIG. **17** illustrates another exemplary design for a wheel assembly that yields improved aerodynamics through altering the configuration of the inboard side and outboard side of the wheel clad. As shown, FIG. **17** is a cross-section of a portion of a wheel assembly **1700** according to an aspect of the present disclosure. The wheel assembly **1700** can include a wheel **1702** and a wheel clad **1704**. The basic components of the wheel and the wheel clad may be configured as discussed above. The differences can reside in the configuration of the wheel and the clad spoke.

According to an aspect, the wheel **1702** includes a wheel spoke **1706** having an inboard surface **1708**, an outboard surface **1710**, a leading surface **1712** extending between the inboard surface **1708** and the outboard surface **1710**, and a trailing surface **1714** extending between the inboard surface **1708** and the outboard surface **1710**. According to another

aspect, the inboard surface **1708** and the outboard surface **1710** may each be generally planar and parallel to one another. Similarly, the wheel leading surface **1712** and the wheel trailing surface **1714** may be configured as generally planar surfaces that are parallel to one another. However, the surfaces could each have a variety of different configurations. According to a further aspect, the wheel spoke **1706** can include one or more pockets **1720** formed in its interior. For example, the wheel spoke **1706** may be formed by a hollow core casting process such that the pockets **1720** are formed in the spoke interiors such that they spokes are generally hollow. As will be appreciated, interior spoke pockets can decrease the weight of the wheel without affecting its structural integrity, which can provide a lighter wheel assembly resulting in improved fuel economy for a vehicle as well as other aerodynamic benefits. It will be appreciated that hollow pockets in the spokes can be formed in a variety of different ways by a variety of different processes. It will further be appreciated that the pockets **1720** can have a variety of different configurations.

According to another aspect, a clad spoke **1730** can overlie the wheel spoke **1706**. The clad spoke **1730** can include an outboard surface **1732**, a leading side surface **1734**, and a trailing side surface **1736**. According to a further aspect, the leading side surface **1734** has an outer edge **1738** adjacent the outboard surface **1732** and an inner edge **1740** opposite the outer edge **1738**. The trailing side surface **1736** also has an outer edge **1742** adjacent the outboard surface **1732** and an inner edge **1744** opposite the outer edge **1738**. According to this aspect, the leading side surface **1734** and the trailing side surface **1736** may have a variety of different configurations.

According to another aspect, foam adhesive **1750** may be utilized to fill an area between the wheel spoke **1706** and the clad spoke **1730**. According to another aspect, foam adhesive can be utilized to assist in forming the inboard side of the wheel assembly **1700**. As shown, the inboard surface **1752** of the wheel **1708** may be recessed with respect to the inner edge **1740** of the leading side surface **1734** and the inner edge **1744** of the trailing side surface **1736**. According to this aspect, the foam adhesive **1750** may fully encapsulate the wheel spoke **1706** such that it forms the inboard side **1752** of the wheel assembly. According to another aspect, the adhesive foam **1750** may be disposed flush with the inner edge **1740** of the leading side surface **1734** and the inner edge **1744** of the trailing side surface **1736**. Utilization of the foam adhesive **1750** to form the inboard side of the wheel assembly **1700** allows the inboard side **1752** to be formed in a variety of shapes, including planar, curved, convex, and concave. A variety of other shapes may also be employed.

A wheel assembly **1700** having this configuration can provide an aero-efficient shape that results from the configuration of both the outboard surface and the inboard surface to reduce pumping losses.

Other variants could also be employed as well as any combination of features from the aspects above. As will be appreciated according to the disclosure wheel and the cladding collectively can provide aero-efficient surface geometry on the front and the back side of the wheel. According to an aspect, the shape of the spoke can be achieved by moving the parting line of a wheel mold, or forging die, to the center section of the spoke relative to the face and back surface of the spoke. The parting line left on the wheel spoke surface could be covered by a cladding or other decorative insert that would also provide a decorative and aero-efficient shape to the front side of the spoke. The efficient surface geometry transitions and the shape of the wheel backbone,

enabled by the move of the mold or die parting line on the backbone wheel to a more center location on the spoke relative to the spoke face and rear surface, can be achieved on either the leading-edge, trailing edge, or on both edges of the spoke.

The specification and illustrations of the embodiments described herein are intended to provide a general understanding of the structure of the various embodiments. The specification and illustrations are not intended to serve as an exhaustive and comprehensive description of all of the elements and features of apparatus and systems that use the structures or methods described herein. Many other embodiments may be apparent to those of skill in the art upon reviewing the disclosure. Other embodiments may be used and derived from the disclosure, such that a structural substitution, logical substitution, or another change may be made without departing from the scope of the disclosure. Accordingly, the disclosure is to be regarded as illustrative rather than restrictive.

Certain features are, for clarity, described herein in the context of separate embodiments, may also be provided in combination in a single embodiment. Conversely, various features that are, for brevity, described in the context of a single embodiment, may also be provided separately or in any sub combination. Further, reference to values stated in ranges includes each and every value within that range.

Benefits, other advantages, and solutions to problems have been described above with regard to specific embodiments. However, the benefits, advantages, solutions to problems, and any feature(s) that may cause any benefit, advantage, or solution to occur or become more pronounced are not to be construed as a critical, required, or essential feature of any or all the claims.

The above-disclosed subject matter is to be considered illustrative, and not restrictive, and the appended claims are intended to cover any and all such modifications, enhancements, and other embodiments that fall within the scope of the present invention. Thus, to the maximum extent allowed by law, the scope of the present invention is to be determined by the broadest permissible interpretation of the following claims and their equivalents, and shall not be restricted or limited by the foregoing detailed description.

Although only a few exemplary embodiments have been described in detail above, those skilled in the art will readily appreciate that many modifications are possible in the exemplary embodiments without materially departing from the novel teachings and advantages of the embodiments of the present disclosure. Accordingly, all such modifications are intended to be included within the scope of the embodiments of the present disclosure as defined in the following claims. In the claims, means-plus-function clauses are intended to cover the structures described herein as performing the recited function and not only structural equivalents, but also equivalent structures.

What is claimed is:

1. A wheel for a vehicle, comprising:

an inner hub portion configured to receive a vehicle axle therethrough and defining an axis of rotation at a center thereof;

an outer rim portion;

a plurality of wheel spoke portions extending generally between the inner hub portion and the outer rim portion;

the inner hub portion, the outer rim portions, and the plurality of wheel spoke portions cooperate to form a wheel outer surface having a plurality of turbine openings;

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wherein each of the plurality of wheel spoke portions has an outboard side adjacent the wheel outer surface, an inboard side opposite the outboard side, a leading side surface extending generally in a direction between the inner hub portion and the outer rim portion and between the outboard side and the inboard side, and a trailing side surface extending generally in a direction between the inner hub portion and the outer rim portion and extending between the outboard side and the inboard side in spaced relationship with the leading side surface and opposite the leading side surface;

a plurality of clad spokes each overlying one of the wheel spoke portions, each of the clad spokes including an outboard surface overlying the outboard side of the wheel spoke portion, a leading side surface overlying the leading side surface of the wheel spoke portion, and a trailing side surface overlying the trailing side surface of the wheel spoke portion; and

at least one of the leading and trailing side surfaces of each of the clad spokes has a concave shape arcing toward the other of the leading and trailing side surfaces substantially across its length to provide improved aerodynamic performance of the wheel.

2. A wheel as set forth in claim 1 wherein the other of the leading and trailing side surfaces of each of the clad spokes has a convex shape arcing away from the other of the leading and trailing side surfaces substantially across its length.

3. A wheel as set forth in claim 1 wherein the leading side surface of each of the clad spokes has an outer edge adjacent to the outboard surface and an inner edge opposite the outer edge, and the trailing edge surface of each of the clad spokes has an outer edge adjacent to the outboard surface and an inner edge opposite the outer edge.

4. A wheel as set forth in claim 3 wherein the leading side surface has a generally concave shape from the outer edge to the inner edge, and wherein a middle portion of the leading side surface is arced inwardly toward the trailing side surface.

5. A wheel as set forth in claim 3 wherein the leading side surface has a generally convex shape from the outer edge to the inner edge, and wherein a middle portion of the leading side surface is arced outwardly away from the trailing side surface.

6. A wheel as set forth in claim 3 wherein the trailing side surface has a generally concave shape from the outer edge to the inner edge, and wherein a middle portion of the trailing side surface is arced inwardly toward the leading side surface.

7. A wheel as set forth in claim 3 wherein the trailing side surface has a generally convex shape from the outer edge to the inner edge, and wherein a middle portion of the trailing side surface is arced outwardly away from the leading side surface.

8. A wheel as set forth in claim 1 wherein each of the wheel spoke portions defines at least one pocket.

9. A wheel as set forth in claim 3 wherein a foam adhesive is disposed between each of the wheel spoke portions and the overlying clad spoke.

10. A wheel as set forth in claim 9 wherein the foam adhesive includes a first foam portion extending between the inner edge of the leading side surface of the clad spoke and an inner edge of the leading surface of the wheel spoke portion.

11. A wheel as set forth in claim 10 wherein the first foam portion is disposed flush to the inner edges and is configured to match a contour of the inboard surface of the wheel spoke.

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12. A wheel as set forth in claim 9 wherein a second foam portion extends between the inner edge of the trailing side surface of the clad spoke and an inner edge of the trailing side surface of the wheel spoke portion.

13. A wheel as set forth in claim 12 wherein the second foam portion is disposed flush to the inner edges and also configured to match a contour of the inboard surface of the wheel spoke.

14. A wheel for a vehicle, comprising:

- an inner hub portion configured to receive a vehicle axle therethrough and defining an axis of rotation at a center thereof;
- an outer rim portion;
- a plurality of wheel spoke portions extending generally between the inner hub portion and the outer rim portion;

the inner hub portion, the outer rim portions, and the plurality of wheel spoke portions cooperate to form a wheel outer surface having a plurality of turbine openings;

wherein each of the plurality of wheel spoke portions has an outboard side adjacent the wheel outer surface, an inboard side opposite the spoke outboard side, a leading side surface extending generally in a direction between the inner hub portion and the outer rim portion and between the outboard side and the inboard side, and a trailing side surface extending generally in a direction between the inner hub portion and the outer rim portion and extending between the outboard side and the inboard side in spaced relationship with the leading side surface and opposite the leading side surface;

- a plurality of clad spokes each overlying at least a segment of one of the wheel spoke portions;
- a foam adhesive disposed between each of the wheel spokes and the overlying clad spoke; and

the foam adhesive overlying the inboard surface of each of the wheel spokes, thereby improving the aerodynamic performance of the wheel.

15. A wheel for a vehicle as set forth in claim 14 wherein each of the clad spokes includes an outboard surface overlying the outboard side of the wheel spoke portion, a leading side surface overlying the leading side surface of the wheel spoke portion, and a trailing side surface overlying the trailing side surface of the wheel spoke portion; and wherein the leading side surface of the clad spoke has outer edge adjacent the outboard surface and an inner edge opposite the outer edge; and wherein the trailing side surface of the clad spoke has an outer edge adjacent the outboard surface and an inner edge opposite the outer edge.

16. A wheel for a vehicle as set forth in claim 15 wherein the foam adhesive encapsulates the entire wheel spoke portion.

17. A wheel for a vehicle as set forth in claim 15 wherein the inboard surface of each of the wheel spoke portions is recessed with respect to the inner edge of the leading side surface of the overlying clad spoke and the inner edge of the trailing side surface of the overlying clad spokes; and wherein the adhesive foam is disposed between the inboard surface of each of the wheel spoke portions and the inner edge of the leading side surface of the overlying clad spoke and the trailing edge of the trailing side surface of the clad spoke.

18. A wheel for a vehicle as set forth in claim 17 wherein the adhesive foam is disposed flush with the inner edge of the leading side surface of the clad spoke and the inner edge of the trailing side surface of the clad spoke.



19. A wheel as set forth in claim 14 wherein each of the wheel spoke portions defines at least one pocket.

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