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(54) Title: ACTIVE GRILL SHUTTER VANE DESIGN AND VEHICLE SYSTEM

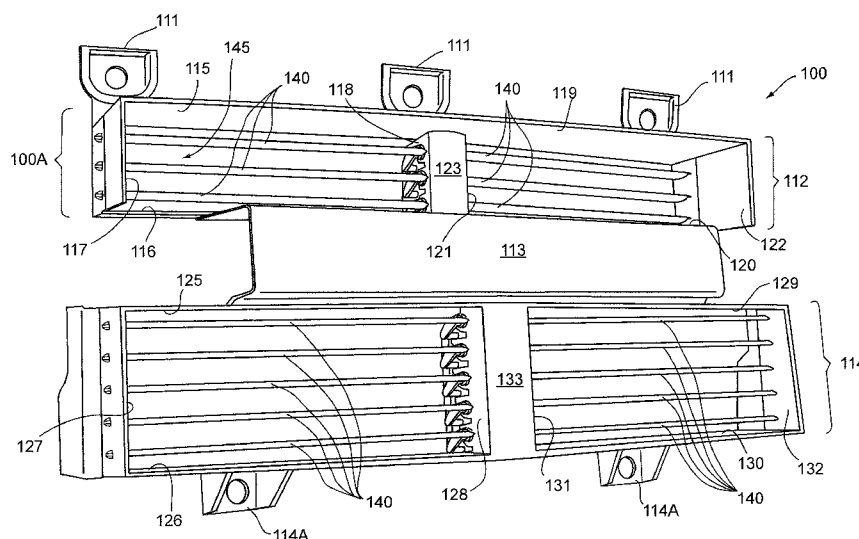


Fig. 2

(57) Abstract: An integrated assembly includes a vehicle bumper system, and upper and lower air shutter sections with sub-assembled shutter vanes movable between closed and open positions, an actuator mechanism for moving the shutter members between positions. When in the fully open position, the shutter vanes are aerodynamically designed to minimize air drag, both as air flows past the vanes and also during after-vane airflow (and during after-bumper-beam airflow). When in the fully closed vane position, the vanes seal against each other to provide a highly efficient and leak-resistant air-blocking assembly.



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ACTIVE GRILL SHUTTER VANE DESIGN AND VEHICLE SYSTEM**CROSS-REFERENCE TO RELATED APPLICATION**

[0001] This application claims benefit under 35 USC § 119(e) of provisional application Serial No. 61/603,003, filed February 24, 2012, entitled ACTIVE GRILL SHUTTER VANE DESIGN AND SYSTEM, and U.S. utility application Serial No. 13/772,886, filed February 21, 2013, entitled ACTIVE GRILL SHUTTER VANE DESIGN AND VEHICLE SYSTEM, the entire contents of which are incorporated herein.

BACKGROUND

[0002] The present invention relates to grill shutter systems for selectively controlling airflow to a vehicle engine/power plant or other vehicle cooled component, and more particularly relates to a shutter system with aerodynamic vanes for low drag pass through when open but also non-leaking air blockage when closed.

[0003] Components, such as grills and the like, that affect airflow around a vehicle front end and airflow into a vehicle engine compartment are important for several reasons. For example, the components must provide good airflow for engine cooling, stylistic appearance for customer satisfaction and acceptance, aerodynamic effect for good gas mileage, good impact characteristics (and good reparability) in case of a vehicle crash, and a competitive cost of manufacturing. This has traditionally been accomplished by using static components, such as grills, baffles, stylish fascia, and the like. However, some vehicle manufacturers are now looking for airflow systems that provide an ability to actively manage and selectively optimize airflow based on engine temperature and operating conditions (such as during an engine cold start or after engine warm up), vehicle speed (such as idle or at highway speeds), and environmental conditions (such as hot humid day versus sub-zero cold dry night). Notably, any such airflow control system must preferably be reliable, durable, robust, cost-competitive to manufacture and assemble, maintain design flexibility, not cause other problems (such as noise and/or rattle concerns), and be capable of integration into the overall vehicle design. Due to conflicting design requirements, the details of any such system are not clear.

SUMMARY OF THE PRESENT INVENTION

[0004] A shutter vane apparatus for use in an active grill shutter apparatus for a vehicle, comprising a vane body including opposing first and second aerodynamic surfaces forming a leading end, a middle, and a trailing end, with the trailing end tapering generally

to a pointed edge, the first surface including a concave region defining a concavity along the leading end, and extending from the concavity to a thickest part of the middle portion and then forming a first-narrowing tapering surface to the trailing end, the second surface including a convex region extending from the leading end downwardly and rearwardly to the thickest part and then forming a second-narrowing tapering surface to the trailing end.

[0005] An object of the present invention is to provide an active grill shutter system for a vehicle that is aerodynamic and provides minimal pressure drop when vanes are fully open, yet that resists air leakage and blow-by when vanes are fully closed.

[0006] An object of the present invention is to provide an active grill shutter system for a vehicle with vanes that are aerodynamically shaped, but also sufficiently rigid and having physical properties in terms of beam and bending and torsion strengths sufficient to avoid undesired bending and distortion under a wide range of operating conditions commonly encountered by modern vehicles.

[0007] An object of the present invention is to provide an active grill shutter system with vanes adapted to self-open via airflow from vehicle motion when an actuator controlling vane-position fails.

[0008] An object of the present invention is to provide an active grill shutter system for a vehicle that is an effective air block when vanes are closed but also provides minimal pressure drop when fully open, and where the vanes are resistant to freezing in a closed or open positions, and resistant to mud and dirt (or other contaminations) causing malfunction, and resistant to damage from object impacts.

[0009] An object of the present invention is to provide an active grill shutter system for a vehicle where vanes abuttingly engage when in a fully closed position to provide a strong seal against air leakage and blow-by.

[0010] These and other aspects, objects, and features of the present invention will be understood and appreciated by those skilled in the art upon studying the following specification, claims, and appended drawings.

BRIEF DESCRIPTION OF DRAWINGS

[0011] Fig. 1 is a side view of a vehicle with an active grill shutter vane system embodying the present invention;

[0012] Fig. 1A is a side exploded view of the bumper system and shutter system of Fig. 1;

[0013] Fig. 2 is a front view, slightly perspective, of the shutter system of Fig. 1;

- [0014] Figs. 3-4 are partial vertical cross-sectional (side) views showing two vanes interconnected by a common link, the vanes being shown in closed and open positions, respectively;
- [0015] Figs. 5-6 are perspective views, from opposite ends, of a vane from Fig. 2;
- [0016] Fig. 7 is a vertical cross-sectional view through the vane in Fig. 5;
- [0017] Figs. 8A-8C are views of three vanes, Fig. 8A being in the open position, Fig. 8B being in the halfway open position, and Fig. 8C being in a closed position;
- [0018] Fig. 9 is a cross-sectional view of a vane from Fig. 7, and showing airflow characteristics in the form of pressure gradient lines around the vane during significant vehicle speeds such as about 50 mph;
- [0019] Fig. 10 is a cross-sectional view of a vane from Fig. 7, and showing airflow characteristics in the form of velocity vectors around the vane during significant vehicle speeds such as about 50 mph; and
- [0020] Figs. 11-12 are side elevational views showing air flowing past a bumper reinforcement beam and across the present vanes and into a radiator.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

- [0021] It is to be understood that the present invention is not limited to the particular embodiments of the invention described below, as variations of the particular embodiments may be made and still fall within the scope of the appended claims. It is also to be understood that the terminology employed is for the purpose of describing particular embodiments, and is not intended to be unnecessarily limiting. Where a range of values is provided, it is understood that each intervening value is encompassed within the invention, including upper and lower limits, unless otherwise stated.
- [0022] The present invention is generally directed toward an aerodynamically enhanced active grill shutter apparatus 100 (also called an “assembly” or “system” herein) with improved aerodynamically designed vanes for use in connection with a vehicle, typically a passenger or commercial vehicle such as a car or truck. In the present innovation, a cross-sectional profile of the vanes has been developed so that when closed, the vanes effectively seal their airflow opening, with minimal air leakage. When the vanes are fully open, the vanes maximize airflow over and under the vanes as well as minimize the trailing wake conditions of airflow, thus minimizing drag, as will be discussed in more detail herein. The vane design allows significant airflow velocity increases as air flows across the vanes, thus decreasing air drag, when compared to previously used vane shapes.

The active grill shutter vane design/system of the present invention can contain one or more vanes. When a plurality of vanes are used, they make up a shutter system that operates to seat one vane against the other when the vanes are in a closed position.

[0023] The present disclosure focuses in particular on the present aerodynamically-shaped vanes, and their use in a shutter system that leads to a particularly advantageous vehicle grill shutter system. More specifically, the aerodynamic shape of the present vanes is believed to be very effective in assisting with improved gas mileage and engine/vehicle performance. By way of illustration, the Figs. 1-2 focus on the environment and placement of the present shutter system, and the Figs. 3-12 focus more specifically on the present aerodynamic vane shape. Notably, the present disclosure is sufficient for a person skilled in this art to understand the present invention and its potential uses. However, for the reader's benefit, reference is made to a modular shutter system with vanes as disclosed in pending U.S. Application No. 13/186,949, by inventors Evans et al, filed July 20, 2011, entitled INTEGRATED ENERGY ABSORBER AND AIRFLOW MANAGEMENT STRUCTURE. The entire contents of that application '949 are incorporated herein for its disclosure and teaching.

[0024] Figs. 1-2 illustrate an integrated active grill shutter assembly 100 as installed on a vehicle 101 having a vehicle front end with a bumper system (including fascia 102, rigid bumper reinforcement beam 103, polymeric energy absorber 104 with crush lobes, and an optional low-positioned pedestrian impact bar or air dam (not shown), a cooling component 106 (e.g. a radiator), a power plant 107 (e.g. internal combustion engine), a hood 108, and front wheels 109. The illustrated shutter assembly 100 includes a unitary molding that includes an upper support section 111 (such as an attachment flange or integral beam) for attachment to a front end structure, an upper air shutter perimeter frame section 112, bumper-attachment bracket members 113 (behind the beam 103), and a lower air shutter perimeter frame section 114 with lower attachment flanges 114A. It is noted that the components 111-114 can be a single molding or can be multiple moldings, and that they can be attached together as an assembly or supported independently on the vehicle 101 front end. For example, the illustrated sections 111-114 are molded of a polymeric material as a single molding, such as a structural polymer adapted for absorbing energy upon receiving a crushing impact. Such polymers are commercially available from several companies, including NetShape, a division of Shape Corporation in Grand Haven, Michigan. It is contemplated that the sections 111-114 could be molded as two or more separate moldings and assembled together as a unit, before or during vehicle assembly.

[0025] The illustrated grill shutter assembly 100 includes four airflow openings (also called “quadrants” herein), each holding a set of vanes 140 movable between open, partially-open, and closed positions. It is to be understood that a scope of the present invention includes fewer or more airflow openings, differently sized openings, and with each having more or fewer vanes therein. The illustrated upper perimeter frame section 112 (Fig. 2) includes walls 115-118 and 119-122 forming right and left openings, with the top walls 115 and 119 and the bottom walls 116 and 120 forming continuous frame-like structures across the vehicle’s front end. Multiple vanes 140 (three illustrated) include ends pivoted to the side walls 117-118 and to the side walls 121-122 in the right and left openings. A center wall 123 combines with inboard side walls 118 and 121 to form a cavity for receiving a vertical linkage 150 that attaches to an arm 141 on each vane 140. An actuator 154 is attached to a top of the linkage 150 for operating the vanes 140 in both right and left upper openings.

[0026] Similarly, the illustrated lower perimeter frame section 114 (Fig. 2) includes walls 125-128 and 129-132 forming right and left openings, with the top walls 125 and 129 and the bottom walls 126 and 130 forming continuous structures across the vehicle front end. Multiple vanes 140 (five illustrated) include ends pivoted to the side walls 127-128 and to the side walls 131-132 in the right and left openings. A center wall 133 combines with inboard side walls 128 and 131 to form a cavity for receiving a vertical linkage 134 that attaches to the arm 141 on each vane 140. (Depending on functional requirements, the system can be designed with a single arm only on one end of each vane, or potentially an arm on each end of the vanes 140.) The illustrated brackets 113 are U-shaped and form a rearwardly-facing (or forwardly-facing) cavity that mates onto the bumper beam 103 so that the bumper beam 103 is generally between the upper and lower frame sections 112 and 114. The brackets 113 extend between the lower wall 116 (on the upper frame section 112) and the top wall 125 (on the lower frame section 114). The brackets 113 include an attachment site 136 for attachment to a front of the bumper beam 103.

[0027] For convenience, only the upper left airflow opening and vanes therein of the present grill shutter apparatus 100 are described below. However, it is to be understood that the other openings include similar structure and are operated similarly. Notably the apparatus 100 can include a single actuating mechanism (e.g. a single AC stepper motor) that operates all quadrants (i.e. all vanes) simultaneously, or multiple actuating mechanisms that operate all quadrants individually, depending on vehicle function and

control requirements. Also, the openings can be different lateral widths or different heights.

[0028] For reference, the upper left quadrant/corner will be referred to as shutter section 100A, and it controls airflow through the opening in the left hand opening of shutter frame section 112 toward the cooling component 106 in the engine compartment of the vehicle 101 (i.e. a motor and/or generator and/or power generating unit and/or batteries). Control of the shutter section 100A (i.e. control of vane movement) is by the vehicle engine control system, and is intended to optimize operation of the vehicle's power plant.

[0029] Shutter section 100A includes a molded frame body comprising walls 115-118 interconnected to form a window opening 145. A plurality of horizontal shutter members (vanes 140) are positioned in the opening 145, and are pivoted at each end at pivot locations to rotate about an axis 146 (Figs. 3-4) for movement between a closed air-blocking position (Fig. 3) and an open air-passing position (Fig. 4). The vertical linkage 150 (Figs. 3-4) is attached to the arm 141 of each vane 140 at location 151 which is spaced from the vane's pivot location (axis 146), so that by pulling the linkage 150 vertically, the vanes 140 are selectively simultaneously rotated closed (Fig. 3) or opened (Fig. 4). A trailing end 152 of the vane 140 includes a thinned tip, and the relatively-thick-nosed leading end 153 includes a concavity 142 for matably engaging the thinned tip on an adjacent vane when in the closed position (Fig. 3). The engagement of the thinned tip into the concavity 142 causes a good air seal, which results in very low air leakage of the shutter section 100A when the vanes 140 are fully closed, such as over 80 percent increase in air restriction/blockage compared to earlier tested vanes.

[0030] An actuator mechanism includes the vertical linkage 150 and further includes the actuator 154 connected to the linkage 150 and operably connected to the vehicle engine control system, so that when actuated, the actuator 154 can lift (or lower) the linkage 150 vertically, thus rotating the vanes 140. When released, the linkage 150 drops, with the assistance of a spring bias (see spring 155, Figs. 3-4) and/or by gravity (and potentially assisted by a power-down movement by the actuator 154, if desired). It is contemplated that the actuator 154 can be any of a variety of different extendable devices, such as electrical, air, hydraulic, or other.

[0031] In the present innovation, the shutter members 140 are aerodynamically designed and their pivots arranged so that if the actuator 154 or linkage 150 becomes decoupled from the shutter members 140, or if the actuator 154 become non-functional for some reason, the pressure of airflow (from a moving vehicle) will tend to move the shutter

members 140 to an open position. This can be accomplished by placing the pivot near to but slightly above a center line of the vanes 140 so that a greater air pressure results slightly below the center line.

[0032] Each vane 140 typically has an integrally-formed pivot pin 160 formed on each end of the vane. The pivot pin 160 snaps into a mating pivot socket in the associated side wall of the frame section 112 to allow rotational movement of the individual vane 140 in its perimeter frame. Each vane 140 includes an angularly and upwardly extending drive arm 141 with offset pivot connection at drive arm pin 151 that connects to the actuator-driven mechanical linkage 150. As noted above, the linkage 150 and actuator 154 provide controlled movement of the individual vane 140 about the pivot axis defined by the pivot pins 160 on each end of the vane 140. The present vane's physical and cross-sectional properties are a significant improvement, not only in their ability to enhance airflow characteristics, but also to provide torsional and tensile and bending strength to the overall vane. Torsional, tensile and bending strength are necessary to overcome binding and vane-length-distortion due to severe environmental conditions such as snow, ice, and mud buildup, as well as extreme environmental factors such as temperature changes and conditions.

[0033] As discussed above, the individual vanes 140 of the present invention are aerodynamically designed for a variety of improved airflow characteristics including velocity and pressure gradients, strength, and functionality. We consider the cross-sectional shape of the present vanes to be particularly novel and unobvious because of its ability to provide a tight air-blocking seal when the vanes are in a fully closed position. Also, we consider the cross-sectional shape of the present vanes to be particularly novel and unobvious, because by using the present design, our testing shows that a grill opening can pass approximately the same amount of air whether the present vanes are present or not. In previous vane designs, the grill opening had to be increased if vanes were added due to resistance to air pass-through caused by those early vane designs. This is seen as a tremendous benefit since modern vehicles are becoming increasingly smaller and more aerodynamic. Thus, any shutter design that eliminates the need for a larger air pass-through opening is a significant advantage.

[0034] In particular, as shown in Fig. 7, each vane 140 has aerodynamically shaped upper and lower surfaces 147, 148 that form the bottle-nose-shaped leading end 153, a relatively thick but slowly-narrowing tapered middle section, and a relatively thin and more-rapidly-narrowing pointed trailing end 152 (also called "tail end" herein). The upper surface and

lower surfaces 147, 148 of the vanes 140 have an aerodynamic shape to efficiently and effectively pass air with minimal air drag when in the fully open position (Fig. 8A), but have a mating shape so that the tail of one and leading end of another abuts to efficiently and effectively matingly engage and block passage of air with minimal air leakage when closed (Fig. 8C). Specifically, as shown in Fig. 7, the upper surface 147 of the leading end 153 includes a concave region 170 extending rearwardly and then upwardly from a leading point 169 on the vane 140. The concave surface 170 thus forms a channel adjacent the leading tip of the vane 150. A convex surface 171 extends from the concave surface 170 rapidly building to a thickest cross-sectional point 172 on the vane 140, and then extends rearward and downward with a gradual taper to the tip of the tail end 152 with an aerodynamic continuously-curved shape.

[0035] The lower surface of the leading end 153 includes a convex surface 175 that extends vertically downward and then rearwardly from the leading point 169 on the vane 140, rapidly building thickness as it extends rearward toward a thickest point 176 (below the thickest cross-sectional point 172), and then extends with a gradual taper rearward and upward to the tip of the tail end 152. A combination of the upper and lower surfaces 147 is reminiscent of a cross-section of an airplane wing, with the exception that the vane 140 is designed for minimal air drag and easy pass-through of air when fully open (and the present vane 140 is not designed to create lift), and the vane 140 is designed for maximum blockage of air by abutting engagement with adjacent vanes 140 when fully closed.

[0036] Restated, the individual vane 140 includes a top portion that is smooth and aerodynamically shaped, for creating minimal drag and maximum-pass through including a leading edge curvilinear shape having a relatively early buildup of thickness and that gradually tapers to the relatively-thin tail end. The tail end is the leeward (wind-trailing) end of the vane, when the vane is in a fully open position. The vane 140 has a windward (upstream) surface that is generally bottlenose dolphin-shaped in the windward (upstream) direction, as shown in Fig. 7. The windward surface has an upper half that includes a convex downwardly extending portion that transitions into a concave downwardly extending portion that then transitions into the pointed tip portion. The tip portion receives and overlaps a segment of the tail end of a second vane when the vanes are in the closed position (see Fig. 8C). The tip portion is designed with a recess (also called a “channel” herein) to receive a segment of the bottom portion near the tail end of the vane, thus providing a good air seal preventing air leakage when the vanes are in a fully closed position. The bottom portion has an upwardly curvilinear section that forms a part of the

windward surface, and extends between the tail end receiving portion and the bottom portion of the vane 140. The vane 140 has a maximum thickness near a rear of the convex curved part (generally perpendicular to the bottom surface), and the surfaces have a curvilinear aerodynamic shape and combine to form an aerodynamic taper as they extend to the narrow trailing tip of tail end.

[0037] The pivot pin 160 (Fig. 6) on each vane 140 has a particular shape to avoid malfunction in the harsh environment often encountered by vehicles. The illustrated pivot pin 160 includes a collar portion 180 and an outwardly extending cylindrical shaped pin body 181. The pivot pin 160 further includes a cap portion 182. The cap portion 182 has a plurality of tapered protrusions 183 that meet at a circular center section 184 and form a generally plus-shape when the pivot pin 160 is viewed from its outer end. Each tapered protrusion 183 has a substantially flat top surface and extends from the outwardly extending cylindrical pin body 181 to the circular center section 184. An aerodynamic side 185 of the vane 140 has the upwardly extending angled planar drive arm 141 that extends from a location adjacent the pivot pin 160 on side 185 at an upward angle to a drive arm pin 151. A center of the drive arm pin 151 (also called “linkage attachment pivot” herein) is approximately above the tail end 152 of the vane 140 when the vane 140 is in a fully open position. The drive arm pin 151 has an outwardly extending cylindrical-shaped body 186 that is divided into two portions by a collar section 187. The outward facing surface of the drive arm pin 151 is planar with curved side sections extending circumferentially about the end to create a smooth transition between the cap and side wall of the outwardly extending body 186.

[0038] The linkage 150 (Figs. 3-4) connects to the drive arm pin 151, allowing the actuator 154 (which is connected to one end of the linkage 150, such as its upper end) to move the plurality of vanes 140 simultaneously. As illustrated, a single electrical actuator (e.g. an AC stepper motor) is connected to the upper end of the linkage. However, it is contemplated that a single actuator can be connected to any part of the linkage. Also, it is contemplated that multiple actuators can be used (simultaneously or as desired), or that a variety of different actuators (i.e. electrical motor, electrical solenoid, pneumatic, hydraulic, etc.) could be used. The illustrated arrangement includes a single actuator for moving all shutter vanes simultaneously, but it is contemplated that different actuators can be used to operate different sets of vanes, such as for selectively opening or closing one area (such as the area in front of a radiator) at a different time than another area (such as an area in front of a transmission cooler or air conditioner unit).

[0039] The present illustrated actuator 154 (Figs. 3-4) is a reversible AC electrical stepper motor capable of 2.5 N-m peak torque output, and it drives the linkage 150 in part through mechanical advantage. This peak torque allows the actuator 154 to move the vanes 140, even when the vanes 140 are “stuck” (or are resisting movement) in a given position due to mud, ice, or other condition. Notably, the vanes must have sufficient strength properties to endure such loads from the actuator 154 without failure and without undergoing permanent deformation or undesired bending. In short, the vanes must have sufficient physical structure and properties to satisfy beam strength, bending strength, torsion strength requirements, and impact requirements for use in a grill opening in a vehicle front end. For example, the illustrated present system is capable of freeing the vanes when “adhered” together in the closed position by a 1 mm (or more) thickness of mud. Notably, the present system controls will include a sensor or other feature that identifies when the shutter vanes fail to open.

[0040] A cross-sectional shape of a vane (also called a “blade” herein) and of a shutter system can be varied depending on functional requirements of particular applications/vehicles. As shown in Fig. 7, the cross-sectional dimensions of a preferred vane 140 for a typical passenger vehicle, according to the present invention, include an overall fore-aft length of the vane as approximately 30-40 mm (or more preferably about 35 mm) and the height of the vane as approximately 6-9 mm (or more preferably about 7mm). The channel (concavity 142) at the leading end 153 is typically about 2-4 mm (preferably 3 mm) in length and about 2-4 mm (preferably 3 mm) deep when compared to the thickest cross-sectional point 172. The ratio of these dimensions may also be employed to vary the size of the improved vane(s) for other vehicles or perhaps other uses. The illustrated vane pivots 160 and linkage attachment (pivot) 151 have a pivot diameter of about 6-9 mm or larger (or more preferably about 7 mm), and are designed to avoid material failure at extreme test conditions.

[0041] The pivots 160 are designed to permit (facilitate) snap assembly, as well as to reduce plugging and friction build-up within the assembled pivots. The material of the vanes (and the material of the mating components) can be varied to obtain the coefficient of friction and other component properties desired. The illustrated components were made from a glass-filled nylon or glass-filled polypropylene, depending on the system functional requirements. By way of example, the present illustrated vanes 140 successfully passed a 30 degree one-time twist test (assembly condition simulation), a 15 degree permanent twist, and a low speed bumper impact test, as well as passing airflow leakage/blockage

testing, an anti-squeak and rattle testing, splash testing (simulating flooded road conditions), and vane torsional stiffness and bending stiffness testing. Also, the illustrated vanes 140 were twisted 90 degrees over 6 seconds and showed a 61percent increase in torsional rigidity over a base line drive vane, and showed a 35 percent increase in deflection strength over a baseline drive vane, while providing improved/reduced sound pressure levels (dBAs of squeaks and rattles) over other systems.

[0042] It is contemplated that these vanes can be molded in a conventional manner out of glass filled nylon or polypropylene resin with no additional additives necessary. However, it is to be understood that the vanes 140 can be molded by alternative means. For example, our testing shows they also can be molded using an additive “foaming” or “blowing” agent, in pelletized form, blended with the plastic resin pellets prior to the molding operation. This is done to reduce a weight of the vane. During the molding process these pellets break down into a liquid under pressure in the screw barrel. Once this liquid enters the cavity and a pressure drop occurs, they change to a gaseous form. These micro-bubbles stay concentrated in the center of the mass and create a micro-porous structure. This reduces mass and increases part stiffness as indicated in the bar graphs. The vanes tend to skin and have a thicker/denser surface layer and a lower-weight less-dense internal structure, thus placing material at an outer area where the denser material has a greatest positive effect on beam tensile, bending, and torsion strength and physical properties, while also reducing overall weight.

[0043] Fig. 8A shows a plurality of vanes 140 (three illustrated) that operate in conjunction with each other to regulate airflow. Fig. 8A shows the three vanes in a fully open position. Fig. 8B shows the vanes in a 45 degree partial-open position, and Fig. 8C shows three vanes in a fully closed position with the tail end receiving portions of two of the vanes engaging the tail end portions of the vanes above them. Notably, the uppermost vane 140 will engage the upper-adjacent structure in the perimeter frame supporting the vanes, and the lowermost vane 140 will engage the lower-adjacent structure in the perimeter frame, such that the entire opening is closed and sealed against air pass-through when the vanes are closed. Where desired, the upper-adjacent structure and the lower-adjacent structure replicates the structure of a mating vane, so that the air seal is optimal. The vanes are interconnected by a linkage 150 to an actuator 154 (see Figs. 3-4); the actuator 154 being connected to vehicle electrical controls (or pneumatic or other controls) for optimal control and airflow based on engine and vehicle parameters. For example, in a

vehicle with a diesel (or gas) engine that is running in a very cold temperature, the engine control may keep the shutter system (i.e. vanes) closed for an extended period of time.

[0044] Fig. 9 schematically shows the airflow 138, and the airflow characteristics/pressure gradients that result from air blowing past a vane 140 according to an embodiment of the present invention. Significantly, a lowest measured pressure (vacuum) gradient 193 extends only a short distance past (e.g. a 2-3 mm) the trailing end 152 of the vane 140 (Fig. 9), a next pressure gradient 194 extends a relatively small distance further, and a last measured gradient 195 extends approximately 35 mm beyond the tail end, such that considerably less drag is created than when non-aerodynamic vanes (or less-aerodynamic vanes) are used. Note Figs. 11, 12 which compare similar pressure gradients in an inefficiently-shaped vane 204 (Fig. 11) and in an efficiently-shaped vane 140 (Fig. 12), which are discussed further below. Fig. 10 schematically shows the airflow characteristics by velocity vectors of airflow around a vane 140 according to the present invention, with short arrows leading up to the vane showing ambient air speed, and with the elongated arrows close to the vane 140 indicating an increased air speed, especially the doubly elongated arrows adjacent the vane 140.

[0045] This increased air speed caused by the vane 140 allows the present vane 140 to convey a same quantity of air past the vane 140 and through a “given opening size” without excessive resistance (as compared to the absence of a vane in the “given opening size”). Notably, our testing shows that the present system, including vanes 140, creates close-to-zero resistance to air pass-through when the vanes are in the fully open position. We consider this significant, because it is our understanding that some grill shutter systems were (or are) being designed with an enlargement factor so that sufficient air could pass through the shutter system and grill opening. In other words, known grill shutter systems were being designed larger than the “unobstructed” air opening would have to be in order to allow sufficient air pass-through, because of the air resistance present due to the grill shutter system. The present grill shutter system does not require any such “oversized” opening, which is a tremendous advantage in vehicle design since vehicles are continuing to be designed as more compact and with smaller “package space” for front end vehicle components.

[0046] Fig. 11 schematically shows a generally inefficient grill shutter with inefficiently designed vane 204 where air flowing through the inefficient shutter system forms small air dead spots 205, 206 for a considerable distance behind the vanes (i.e. the dead spots extending approximately to the radiator) and also forms a large dead spot 205 behind the

bumper beam. Fig. 11 is intended for comparative purposes to show inefficiencies that resulted when testing an inefficient “early” vane design (as compared to the present system shown in Fig. 12). Specifically in Fig. 11, a bumper fascia 200 is shown supported by a rigid bumper reinforcement beam 201 and polymeric energy absorber 202, with a grill shutter system with vanes 204 located above the beam 201. As shown in Fig. 11, the arrangement causes a large dead spot 205 of dead air behind the bumper system 200-202 (i.e. in front of the radiator/cooling system of the vehicle). Further, in the illustrated design of Fig. 11, smaller (but significant) dead spots 206 occur behind the (inefficient) vanes 204, since the (inefficient) vanes 204 cause small dead air spots of low pressure and non-uniform airflow into and through the air conditioning condenser/radiator 203 generally across the radiator 203, but especially behind the bumper system 200-202.

[0047] By contrast, as shown in Fig. 12, the present grill shutter system 100 with vanes 140 according to an embodiment of the present invention provides significantly increased mass airflow rate (see elongated arrows passing along the aerodynamic surfaces 147-148 of vane 140), and more uniform laminar distribution of airflow through the shutter system to the cooling component 106 (for any given grill opening size). Further, a curved-wall baffle 190 is attached to the bumper beam 103 and includes a curvilinear wall that extends along an aerodynamic line rearwardly and downwardly across the area behind the bumper beam 103. A curved-wall baffle 190 assists in directing airflow from a lower portion of the upper shutter downwardly into the area behind the bumper beam 103, thus greatly reducing a size and vacuum level in the dead space of air in that area. By the present shutter apparatus 100, a more uniform and effective stream of air is distributed to the cooling component 106, optimizing the cooling (heat transfer) process.

[0048] The present inventive vanes 140 can be made by many different means, but in a preferred form the vanes are produced from an injection mold of plastic utilizing an embedded carbon dioxide or nitrogen gas in a melt flow forming process. This process allows for internal expansion of the plastic and permits the greater cross-sectional thickness of the vanes according to the present invention.

[0049] The vanes of the present disclosure reduce drag in a number of ways including:

[0050] 1. Directly minimizing the drag associated with incoming airflow colliding with vanes and adjacent structures. Additionally, this collection of components keeps the incoming air from separating as the air flows past the vanes. Tips of the vanes reduce turbulent airflow and cause a more laminar airflow into the area of the vanes.

[0051] 2. Accelerating and compressing the incoming airflow as it travels between the vanes and collection of components. Also, the airflow over and between (and past) the vanes is more laminar and uniform.

[0052] 3. Directing the attached high velocity incoming airflow from the vanes as the air moves past the vanes keeps the airflow “attached”. Injecting this high velocity airflow into the wake reduces the size of the wake and adds energy to it. This increases the pressure in the wake, thereby reducing the resulting drag.

[0053] The present system offers several advantages. The aerodynamic shape of the vanes provides enhanced airflow characteristics, including secondary benefits of enhancing cooling system performance and vehicle aerodynamics. Also, the aero vane design includes a material modifier that enhances part characteristics, including better dimensional stability, minimization of part warpage, elimination of thick wall sink, reduction in scrap on unbalanced cavitations, and potential for density reduction. Also, the snap-fit design reduces assembly cost on vane insertion and requires no flexing of the vane bodies during insertion. The integrated duct/housing and perimeter frame design (Figs. 1-2) provides for reduced assembly cost post-molding. The spring-assisted linkage design provides opening delay for increased freeze break away, allows for mechanical advantage drive, eliminated need for drive vane, and promotes even torque distribution. The snap-in actuator design provides a robust motor location and retention, eliminates actuator retention clip, and otherwise facilitates assembly, reparability, durability, and robustness of assembly. The present shutter design is flexible, durable, robust, cost-competitive, and supports improved vehicle performance, while maintaining a minimum vehicle weight.

[0054] It is to be understood that variations and modifications can be made on the aforementioned structure without departing from the concepts of the present invention, and further it is to be understood that such concepts are intended to be covered by the following claims unless these claims by their language expressly state otherwise.

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. A shutter vane apparatus for use in an active grill shutter apparatus for a vehicle, comprising:

a vane body including opposing first and second aerodynamic surfaces forming a leading end, a middle, and a trailing end, with the trailing end tapering generally to a narrow edge;

the first surface including a concave region defining a concavity along the leading end, and extending along a convex region from a rear of the concavity to a thickest part of the middle portion and then forming a first narrowing tapering surface to the trailing end;

the second surface including a convex region extending from the leading end downwardly and rearwardly to the thickest part and then forming a second narrowing tapering surface to the trailing end.

2. An apparatus including first and second vanes each having a shape of the vane body defined in claim 1, wherein the second surface of the trailing end of the first vane is shaped to fit mateably into the concavity in the leading end of the first surface on the second vane.

3. The apparatus defined in claim 2, including a linkage connected to the first and second vanes, and an actuator connected to the linkage for selectively moving the first and second vane simultaneously.

4. The apparatus defined in claim 1, wherein the vane body includes outboard and inboard ends, each including a pivot pin for pivotally mounting the vane body for rotation about a longitudinal axis extending along the vane body.

5. The apparatus defined in claim 4, wherein at least one of the outboard and inboard ends includes an arm extending away from the longitudinal axis.

6. The apparatus defined in claim 5, wherein the arm includes a pivot and a linkage connected to the pivot.

7. The apparatus defined in claim 6, including an actuator connected to the linkage and adapted for connection to a vehicle electrical control unit.
8. The apparatus defined in claim 1, wherein the vane body has a cross section with a length to height ratio of 35:7.
9. The apparatus defined in claim 1, wherein the concavity is about 2-4 mm deep.
10. A grill shutter system for a vehicle having a front end including a bumper reinforcement beam, a power plant, and a cooling component, comprising:
 - a shutter frame defining an opening for passage of air and configured for attachment to the front end in front of the cooling component;
 - a plurality of vanes with aerodynamic upper and lower surfaces that are operably positioned in the shutter frame, the vanes being movable between a closed position where mating surfaces of adjacent vanes abut to block airflow through the shutter perimeter frame, an open position where the aerodynamic upper and lower surfaces allow airflow through the perimeter frame with minimal drag, and at least one partially-open position therebetween that allows limited airflow; and
 - an actuator and linkage connected to the vanes for moving the vanes between the operative positions.
11. The system defined in claim 10, including an engine control unit operably connected to the actuator for operating the plurality of vanes to optimize vehicle performance.
12. The system defined in claim 10, wherein one of the mating surfaces of the vanes includes a longitudinal concavity defined along a leading edge of each vane, and where another one of the mating surfaces includes a trailing end shaped to fit matingly into the concavity on an adjacent one of the vanes when in the closed position.
13. The system defined in claim 10, wherein each of the vanes includes a vane body with outboard and inboard ends, each including a pivot pin for pivotally mounting the vane body for rotation about a longitudinal axis extending along the vane body.

14. The system defined in claim 13, wherein one of the outboard and inboard ends includes an arm extending away from the longitudinal axis.
15. The system defined in claim 14, wherein the arm includes a pivot connected to the linkage.
16. The system defined in claim 13, wherein the vane body has a cross section with a length to height ratio of 35:7.
17. The system defined in claim 12, wherein the concavity is about 2-4 mm deep.
18. The system defined in claim 13, where an interior of the vane body includes polymeric material and also gas pockets which reduce a total weight of the vane body.
19. A method for a vehicle having a front end including a bumper reinforcement beam, a power plant, and a cooling component, comprising:
- providing a shutter frame defining an opening for passage of air to the cooling component and configured for attachment to the front end in front of the cooling component;
 - providing a plurality of vanes with aerodynamic upper and lower surfaces that are operably positioned in the shutter frame, the vanes being movable between a closed position where mating surfaces of adjacent vanes abut to block airflow through the shutter perimeter frame, an open position where the aerodynamic upper and lower surfaces allow airflow through the perimeter frame with minimal drag, and at least one partially-open position therebetween that allows limited airflow; and
 - selectively moving the vanes between the operative positions to control air flow to the cooling component.
20. The method defined in claim 19, wherein the mating surfaces include a longitudinal concavity on a leading edge of each of the vanes and a mating shape on a trailing edge of adjacent ones of the vanes, and where the step of moving the vanes to the closed position causes the trailing edge of the adjacent vanes to move into the concavity of the mating surfaces on adjacent vanes.

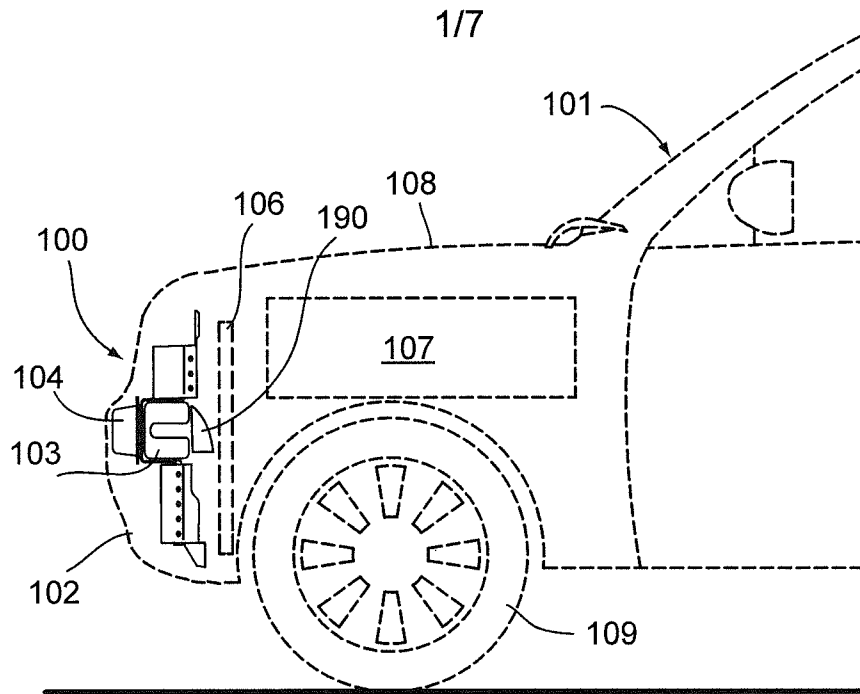


Fig. 1

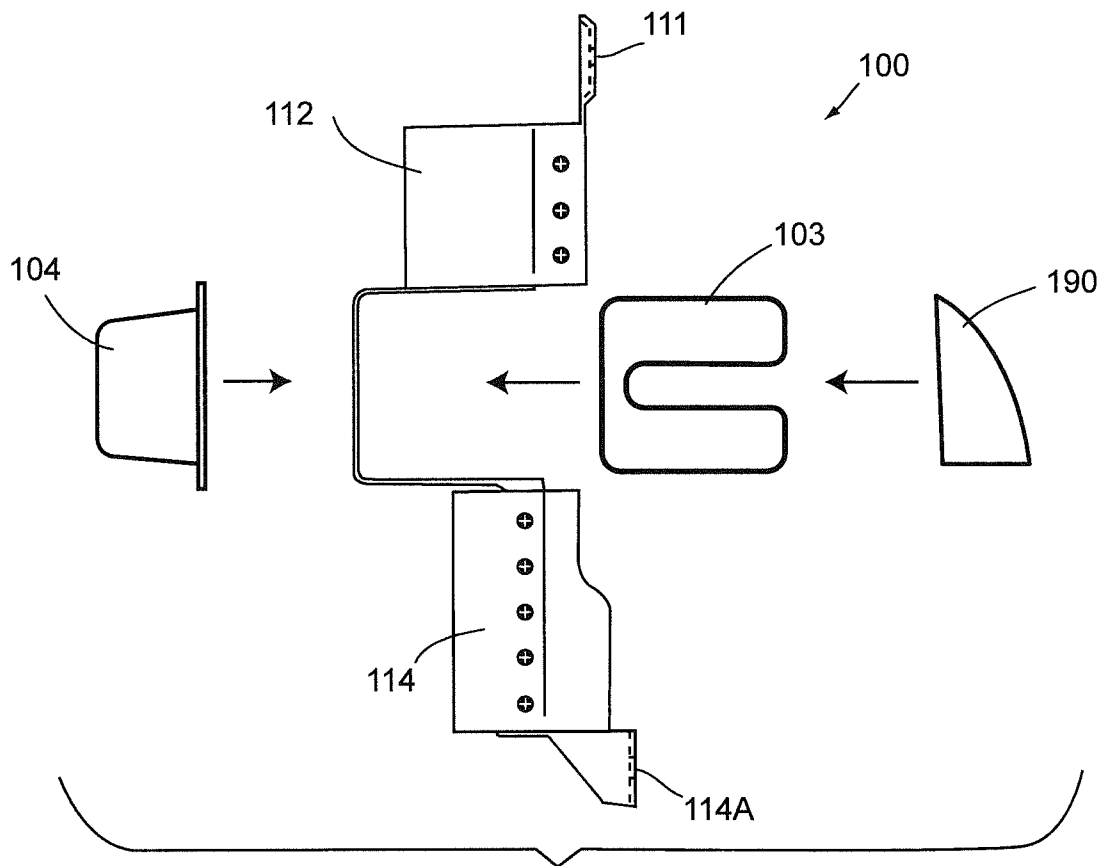


Fig. 1A

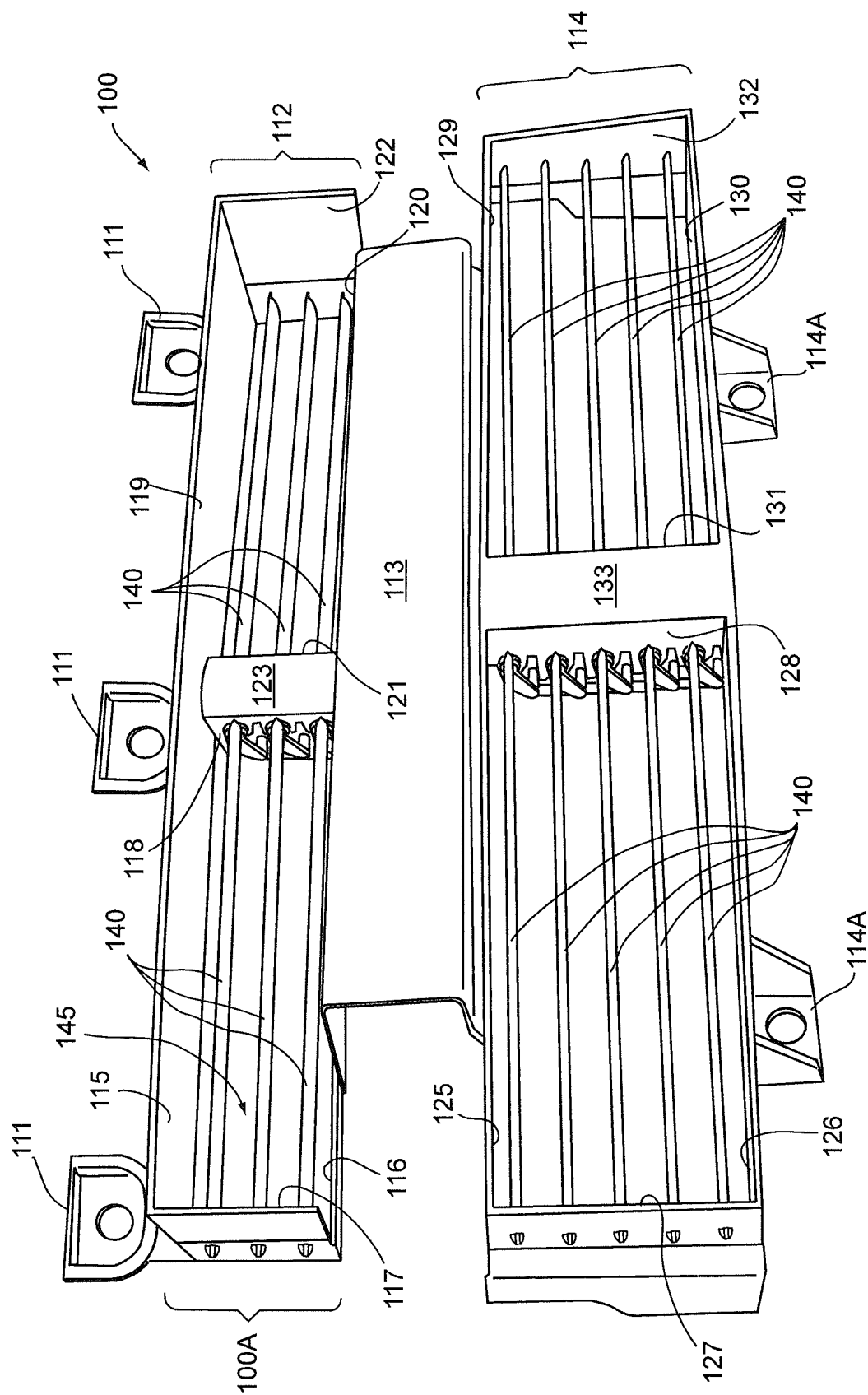
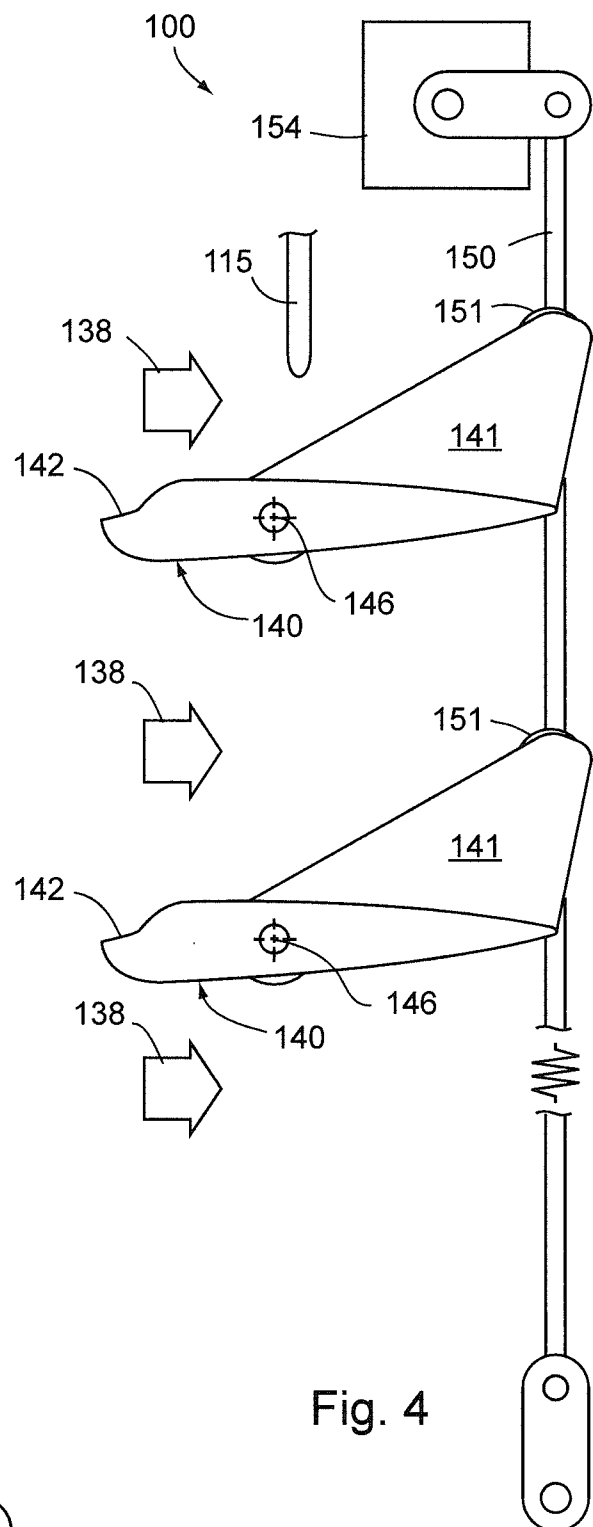
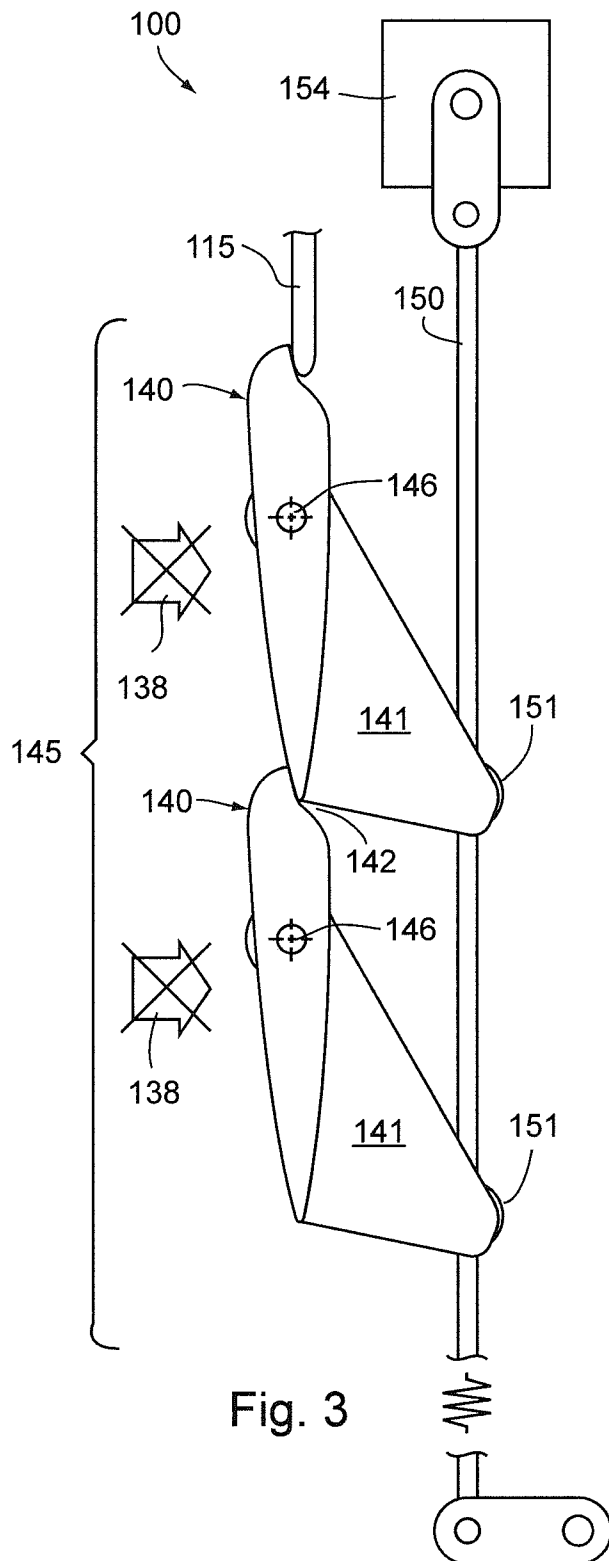


Fig. 2



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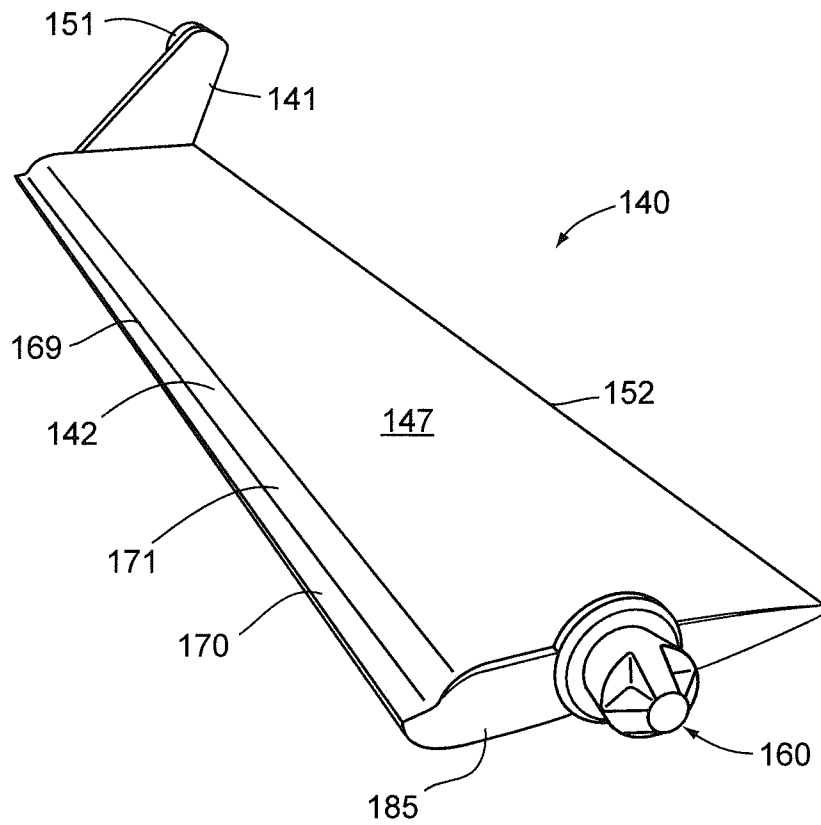


Fig. 5

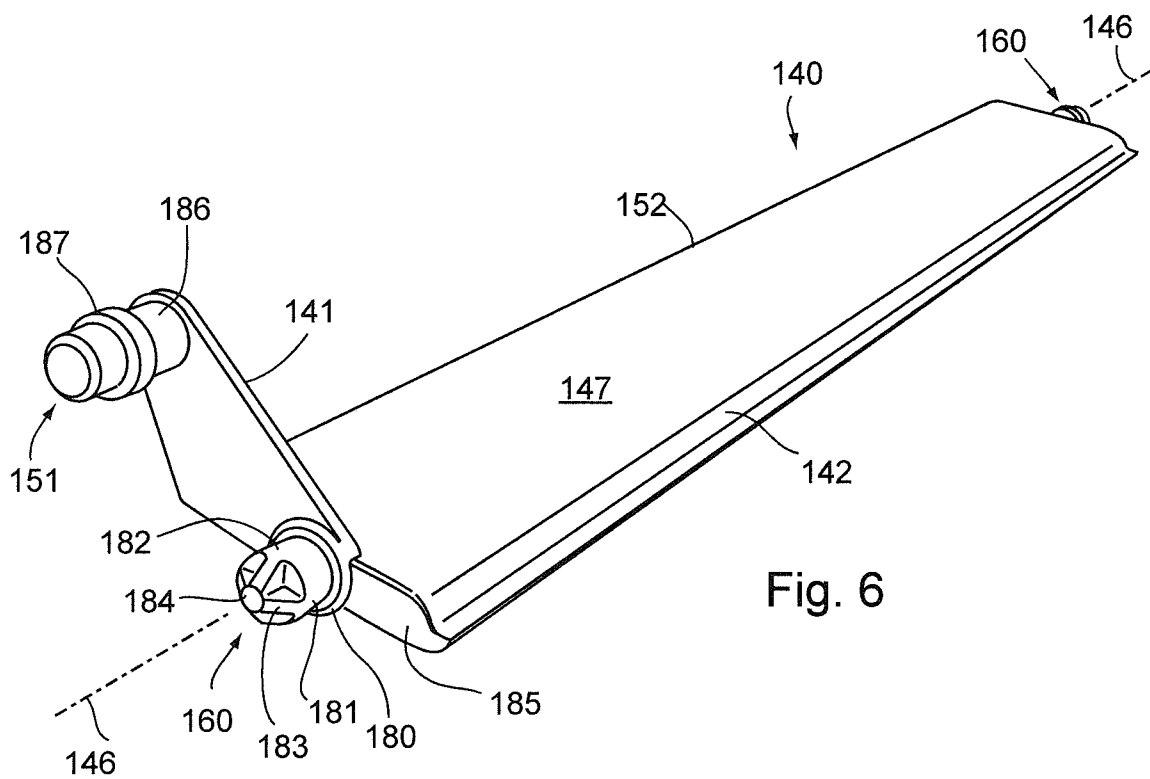


Fig. 6

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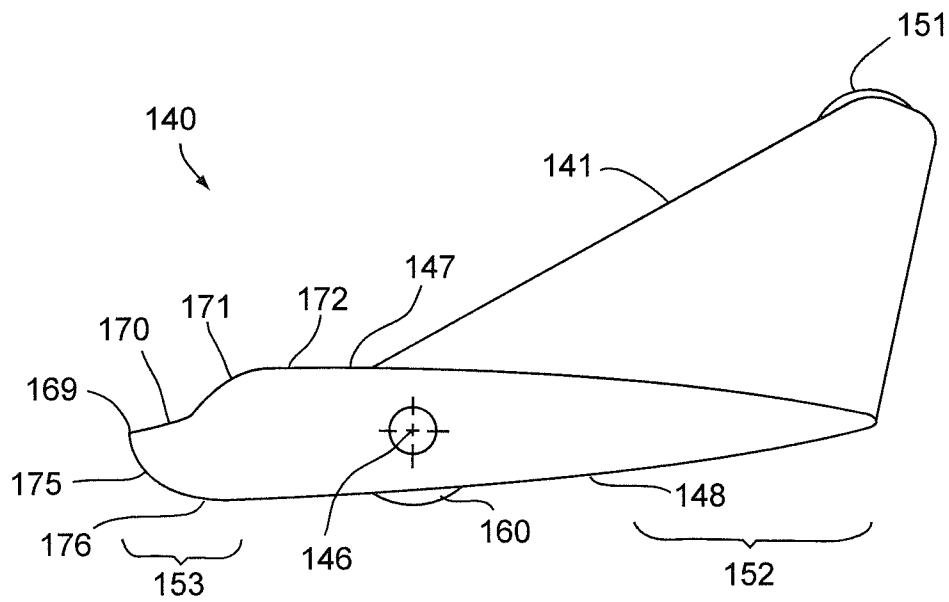


Fig. 7

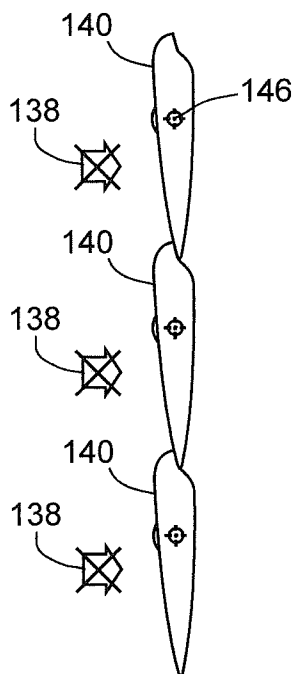


Fig. 8A

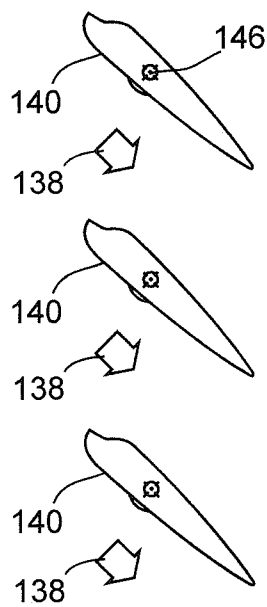


Fig. 8B

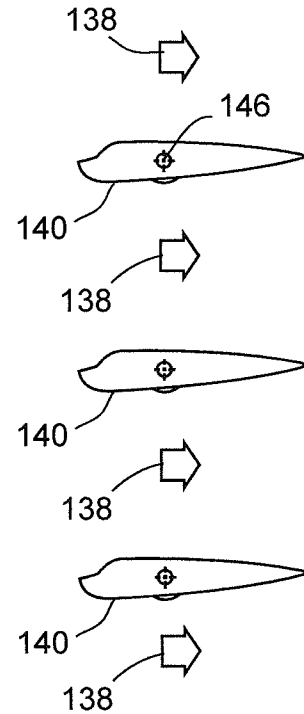
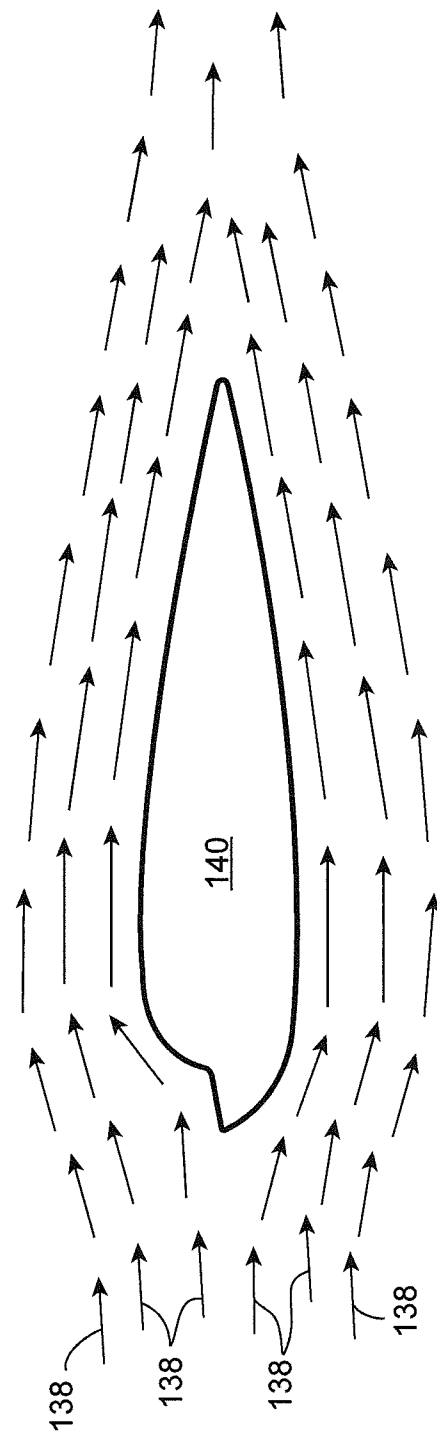
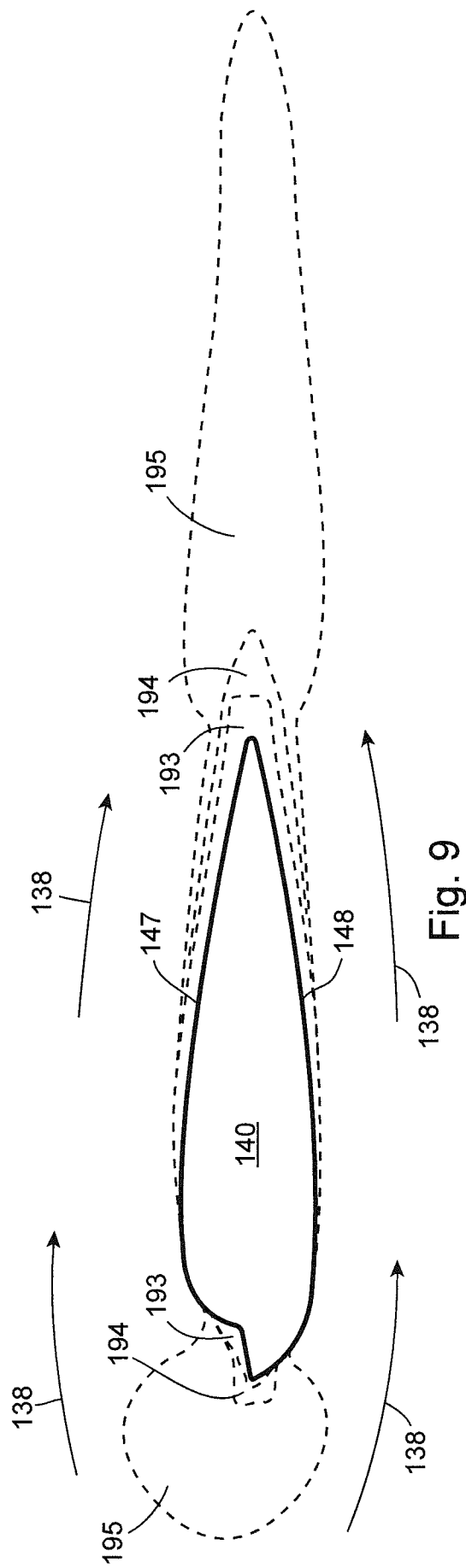


Fig. 8C



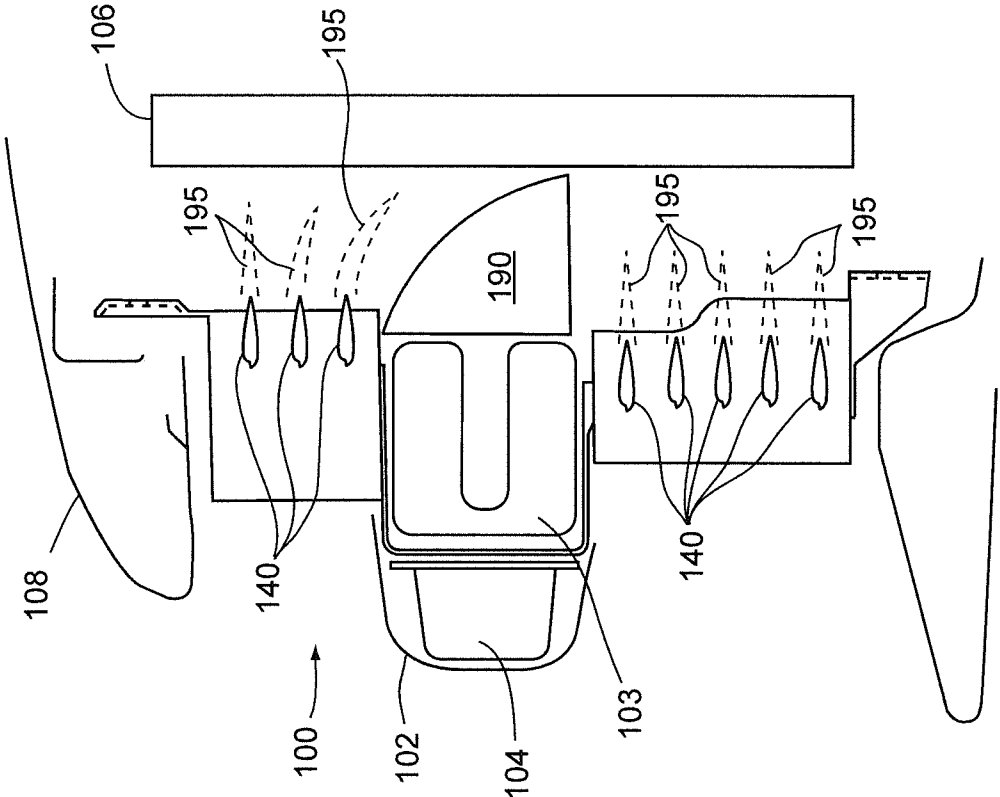


Fig. 12

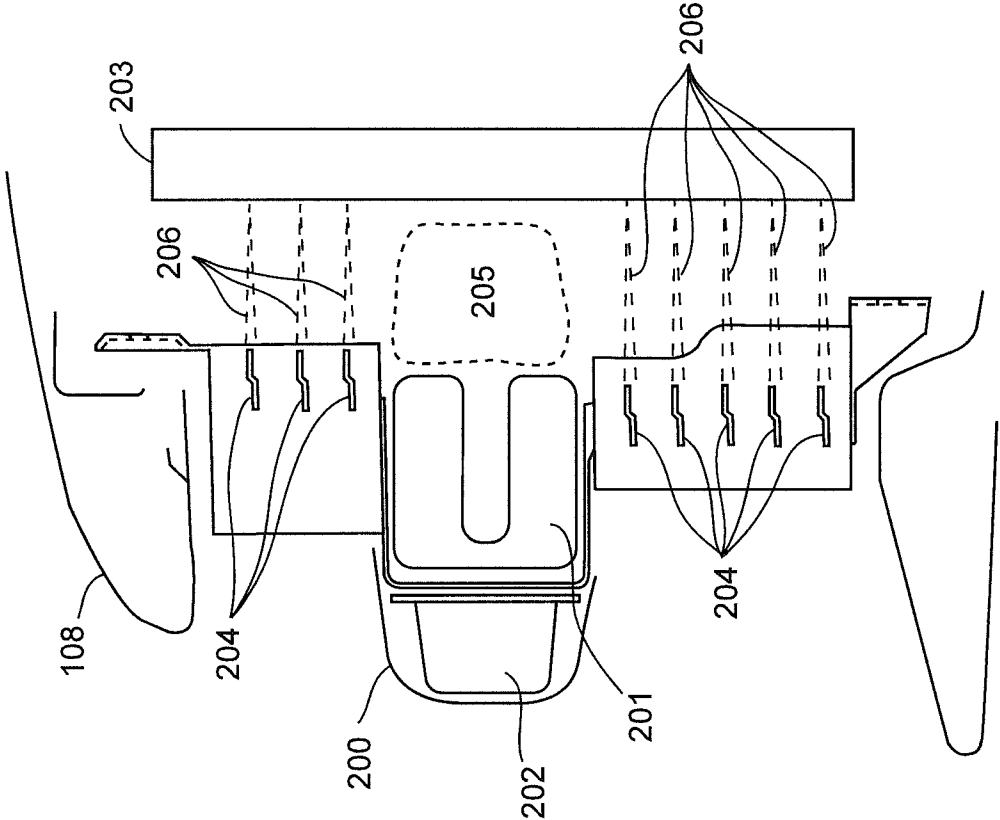


Fig. 11

A. CLASSIFICATION OF SUBJECT MATTER**B60K 11/08(2006.01)i, B60K 11/00(2006.01)i, F01P 11/00(2006.01)i, B62D 25/08(2006.01)i**

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

B60K 11/04; B60K 11/08; B60R 19/48; B60R 19/52; B62D 25/08; F01P 7/10; F01P 11/10

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Korean utility models and applications for utility models

Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

eKOMPASS(KIPO internal) & Keywords: bumper, grill, vane, and shutter

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP 2011-143913 A (HONDA MOTOR CO., LTD.) 28 July 2011 paragraphs [0028],[0034],[0035].[0039],[0073],[0074]; figures 1-5,11.	1-4,8-13,16-20
Y		5-7, 14, 15
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A	EP 2371602 A1 (AISIN SEIKI KABUSHIKI KAISHA) 05 October 2011 See paragraph [0020]; figure 1.	1-20
A	JP 2007-320527 A (TOYOTA MOTOR CORP.) 13 December 2007 See paragraphs [0018]-[0024]; figures 1,2.	1-20
A	JP 2007-001503 A (AISIN SEIKI CO., LTD.) 11 January 2007 See paragraphs [0017],[0018]; figure 1.	1-20



Further documents are listed in the continuation of Box C.



See patent family annex.

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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"&" document member of the same patent family

Date of the actual completion of the international search

17 June 2013 (17.06.2013)

Date of mailing of the international search report

18 June 2013 (18.06.2013)

Name and mailing address of the ISA/KR

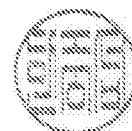
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HAN, Joong Sub

Telephone No. 82-42-481-5606



INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2013/027416

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