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### Cooling a vehicle heat exchanger

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#### Abstract

A vehicle comprising: a wheel arch; an occupant door rearward of the wheel arch; a heat exchanger rearward of the occupant door; and an airflow passage configured such that, when the vehicle is in forward motion, the airflow passage directs a first rearward airflow from the wheel arch to the heat exchanger, the airflow passage comprising: a channel delimited by at least one surface of the occupant door and being at least partially open to a running surface of the vehicle; and a first inlet duct to the heat exchanger.

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## **Background/Summary**

### **CROSS-REFERENCE TO RELATED APPLICATIONS**

(1) This application claims priority to GB Patent Application Serial No. 2102164.7. filed on Feb. 16, 2021, the entire contents of which are hereby incorporated by reference.

### **BACKGROUND**

(2) This invention relates to cooling a vehicle heat exchanger. In particular, this invention relates to cooling a heat exchanger in a mid- or rear-engined vehicle.

(3) In a mid-engined vehicle, the engine is typically located rearward of the front axle by which the front wheels rotate, but forward of the rear axle by which the rear wheels rotate. If any portion of the engine is located rearward of the rear axle by which the rear wheels rotate, the vehicle may be termed a rear-engined vehicle.

(4) A heat exchanger can be used to cool the engine, and/or other operational parts of the vehicle. A radiator is an example of a heat exchanger used for this purpose. Typically, heat energy generated by the engine is transferred to a fluid circulating through the engine and the heat exchanger. The fluid is often water. In turn, the heat exchanger transfers heat energy from the fluid to its surroundings. A heat exchanger typically has a large surface area, relative to its volume, to facilitate the transfer of heat energy from the fluid to its surroundings. The transfer of heat energy from a heat exchanger to its surroundings can be increased by causing air, in particular low temperature air, to flow through (i.e. over the various surfaces of) that heat exchanger.

(5) Positioning a heat exchanger in close proximity to the engine is advantageous, as the length of tubing used to carry the circulating fluid to/from engine can be minimised. Thus, in a mid- or rear-engined vehicle, it is often desirable to position the heat exchanger rearward of the front axle by which the front wheels rotate. That said, relative to front-engined vehicles in which the heat exchanger(s) are typically positioned in the front of the vehicle and so receive an ample flow of air when the vehicle is in forward motion, the natural flow of air to a heat exchanger positioned rearward of the front axle may be reduced.

(6) It would be desirable if there was an improved way of cooling a heat exchanger in a mid- or rear-engined vehicle.

### **SUMMARY OF THE INVENTION**

(7) According to a first aspect of the present invention there is provided a vehicle comprising: a wheel arch; an occupant door rearward of the wheel arch; a heat exchanger rearward of the occupant door; and an airflow passage configured such that, when the vehicle is in forward motion, the airflow passage directs a first rearward airflow from the wheel arch to the heat exchanger, the airflow passage comprising: a channel delimited by at least one surface of the occupant door and being at least partially open to a running surface of the vehicle; and a first inlet duct to the heat exchanger.

(8) The airflow passage may be configured such that, when the vehicle is in forward motion, the

- airflow passage directs the first rearward airflow from an outlet of the wheel arch, via the channel delimited by at least one surface of the occupant door, to the first inlet duct to the heat exchanger.
- (9) A second rearward airflow may be directed between the underside of the vehicle and the running surface of the vehicle when the vehicle is in forward motion such that an airflow boundary forms between the first and second rearward airflows that reduces the amount of air of the first rearward airflow that escapes from the channel delimited by at least one surface of the occupant door and being at least partially open to the running surface of the vehicle.
- (10) The vehicle may further comprise an airflow splitter forward of the wheel arch, the airflow splitter being configured such that, when the vehicle is in forward motion, the airflow splitter directs the second rearward airflow between the underside of the vehicle and the running surface of the vehicle.
- (11) The vehicle may further comprise an airflow diverter forward of the wheel arch, the airflow diverter being configured such that, when the vehicle is in forward motion, the airflow diverter directs a primary rearward airflow to the channel.
- (12) The vehicle may further comprise a wheel positioned in the wheel arch, and the airflow diverter may be configured such that, when the vehicle is in forward motion, the airflow diverter directs the primary rearward airflow inboard of the wheel.
- (13) The interior of the wheel arch may comprise one or more gradually curved faces.
- (14) The vehicle may further comprise: a second inlet duct to the heat exchanger; and a wheel arch duct configured such that, when the vehicle is in forward motion, the wheel arch duct directs a third rearward airflow from the wheel arch to a position below the second inlet duct to the heat exchanger.
- (15) The second inlet duct to the heat exchanger may be above the first inlet duct to the heat exchanger and the wheel arch duct may be above the channel.
- (16) The first and second inlet ducts to the heat exchanger may converge.
- (17) The wheel arch duct may be configured to direct the third rearward airflow to remain substantially attached to the vehicle.
- (18) The vehicle may further comprise a secondary heat exchanger forward of the wheel arch, and the wheel arch duct may be configured to receive air that has passed through the secondary heat exchanger.
- (19) The vehicle may further comprise a projection on the occupant door, the projection being configured such that, when the vehicle is in forward motion, the third rearward airflow impinges on the projection such that the projection assists the wheel arch duct in directing the third rearward airflow from the wheel arch to the position below the second inlet duct to the heat exchanger.
- (20) The projection may be a wing mirror or a component of a wing mirror.
- (21) The second inlet duct to the heat exchanger may be configured to receive a fourth rearward airflow composed of ambient air from the surroundings of the vehicle when the vehicle is in forward motion.
- (22) The fourth rearward airflow may comprise more kinetic energy per volume than the third rearward airflow and/or the fourth rearward airflow may comprise less heat energy per volume than the third rearward airflow.
- (23) The occupant door may comprise a concave surface configured such that, when the vehicle is in forward motion, it directs the fourth rearward airflow into the second inlet duct to the heat exchanger.
- (24) The third rearward airflow may be directed so as to minimise impingement of the third rearward airflow on the fourth rearward airflow.
- (25) The vehicle may be a mid- or rear-engined vehicle.

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## Description

## BRIEF DESCRIPTION OF THE DRAWINGS

(1) The present invention will now be described by way of example with reference to the accompanying drawings. In the drawings:

(2) FIG. 1 shows a plan view of a vehicle.

(3) FIG. 2 shows a perspective view of a vehicle.

(4) FIG. 3 shows a side view of a vehicle.

(5) FIG. 4 shows a cross-sectional view of a vehicle.

(6) FIG. 5 shows a cross-sectional view of an occupant door of a vehicle.

(7) FIG. 6 shows a cross-sectional view of a wheel arch of a vehicle.

## DETAILED DESCRIPTION OF THE DRAWINGS

(8) The following description is presented to enable any person skilled in the art to make and use the invention, and is provided in the context of a particular application. Various modifications to the disclosed embodiments will be readily apparent to those skilled in the art.

(9) The general principles defined herein may be applied to other embodiments and applications without departing from the spirit and scope of the present invention. Thus, the present invention is not intended to be limited to the embodiments shown, but is to be accorded the widest scope consistent with the principles and features disclosed herein.

(10) FIGS. 1 to 3 show a vehicle **100**. FIG. 1 shows a plan view of the vehicle **100**. FIG. 2 shows a perspective view of the vehicle **100**. FIG. 3 shows a side view of the vehicle **100**.

(11) The vehicle **100** may be an automobile. The vehicle **100** may be a car. The front of the vehicle **100** is defined with reference to the primary motion direction of the vehicle **100**. The front of the vehicle **100** points in the primary motion direction of the vehicle. Generally, a vehicle has a primary motion direction that is the forward direction **104**. The vehicle **100** can be said to have a longitudinal axis **102**. The forward direction **104** may be colinear with, or parallel to, the longitudinal axis **102** of the vehicle **100**. When the vehicle is moving in the forward direction **104**, it can be said to be in forward motion.

(12) The vehicle **100** comprises a vehicle body **112**. The vehicle body **112** comprises a chassis and/or tub, and a plurality of body panels. A tub is a structural component of a vehicle. A tub may be made of a composite material such as a carbon fibre/resin composite. A tub may form part of a chassis. The body panels may be attached to the chassis and/or tub. The body panels may include bonnet panels, wing panels, occupant door panels, roof panels and rear deck panels. Each of these listed example areas of body panels may be formed of one or more body panels. Each body panel may be a sheet element whose outer surface defines part of the exterior surface of the vehicle. The body panels may conveniently be made of a composite material such as a carbon fibre/resin composite, or of a metal such as aluminium or steel.

(13) The vehicle **100** comprises front wheels **106a** and **106b**, and rear wheels **106c** and **106d**. The vehicle **100** comprises a plurality of wheel arches. The vehicle **100** comprises a wheel arch per wheel **106a-d**. The vehicle **100** comprises four wheel arches: two front wheel arches and two rear wheel arches. FIGS. 2 and 3 show front wheel arch **204a** and rear wheel arch **204c**. FIGS. 2 and 3 primarily show the left side of the vehicle. The right side can be a mirror image. That is, it will be understood that for each component described with reference to left side of vehicle **100** shown in FIGS. 2 and 3, an identical component may also be present on the right side of vehicle **100**. Front wheel **106a** is positioned in the front wheel arch **204a**. Rear wheel **106c** is positioned in rear wheel arch **204c**. The wheel arches each form an opening in the underside of the vehicle body **112** through which the respective wheel extends. The openings permit each wheel to contact a running surface **314** on which the wheels can support the vehicle **100**. The running surface **314** may be, for example, a road, a racing track, or an off-road surface.

(14) The vehicle body **112** also has an underside. The underside of the vehicle body **112** may face the running surface **314**. The underside of the vehicle body **112** may comprise any portion of the

vehicle body that faces the running surface **314**. The underside of the vehicle body **112** may be formed of the tub and/or a plurality of panels that together form the underside of the vehicle body **112**.

(15) The vehicle **100** comprises an occupant compartment **108**. The occupant compartment **108** may comprise one or more seats for occupants of the vehicle to sit in. The occupant compartment **108** may accommodate a driver. The occupant compartment **108** may accommodate one or more passengers. The vehicle **100** may comprise controls located within the occupant compartment **108** to enable an occupant to control the motion of the vehicle. The vehicle comprises one or more occupant doors **110** that enable an occupant to access the occupant compartment **108**.

(16) The vehicle shown in FIGS. **1** to **3** comprises two occupant doors **110a** and **110b** that enable occupants to access the occupant compartment **108** from opposite sides of the vehicle. Occupant door **110a** is rearward of wheel arch **204a**. The term “rearward” is defined relative to, or with reference to, the forward direction **104**. In other words, occupant door **110a** is generally a greater distance from the front of the vehicle **100** than the wheel arch **204a**. It will be understood that the occupant door may delimit part of the wheel arch and so it is to be understood that the occupant door **110a** runs to a position on the vehicle that is a greater distance from the front of the vehicle **100** than the wheel arch **204a**. In other examples (not shown), the vehicle may comprise more than one occupant door on each side of the vehicle. In these examples, each occupant door would be rearward of the front wheel arch.

(17) The vehicle **100** may be a mid- or rear-engined vehicle. In a mid-engined vehicle, the engine is typically located rearward of the front axle by which the front wheels rotate, but forward of the rear axle by which the rear wheels rotate. The terms “rearward” and “forward” are defined relative to, or with reference to, the forward direction **104**. If any portion of the engine is located rearward of the rear axle by which the rear wheels rotate, the vehicle may be termed a rear-engined vehicle. In both a mid- or rear-engine vehicle the engine is generally located behind the occupant compartment **108**.

(18) Vehicle **100** comprises a heat exchanger **310**. Heat exchanger **310** is covered by a body panel, and so is not visible from the exterior of the vehicle **100**. The position of heat exchanger **310** is shown using hatching in FIG. **3**. Heat exchanger **310** is positioned rearward of the occupant door **110a**. The term “rearward” is defined relative to, or with reference to, the forward direction **104**. In other words, heat exchanger **310** is a greater distance from the front of the vehicle **100** than the occupant door **110a**.

(19) Heat exchanger **310** is used to cool the engine, and/or other operational parts of the vehicle. Heat exchanger **310** may be a radiator. For example, heat energy generated by the engine may be transferred to a fluid circulating through the engine and the heat exchanger **310**. The fluid may be water. In turn, the heat exchanger **310** transfers heat energy from the fluid to its surroundings. Heat exchanger **310** may have a large surface area, relative to its volume, to facilitate the transfer of heat energy from the fluid to its surroundings. The transfer of heat energy from the heat exchanger **310** to its surroundings can be increased by causing air, in particular low temperature air, to flow through (i.e. over the various surfaces of) the heat exchanger.

(20) Positioning heat exchanger **310** rearward of the occupant door **110a** is advantageous when the vehicle **100** is a mid- or rear-engined vehicle. This is because heat exchanger **310** is in close proximity to the engine—and so the length of tubing used to carry the circulating fluid to/from engine can be minimised. That said, relative to front-engined vehicles in which the heat exchanger(s) are typically positioned in the front of the vehicle and so receive an ample flow of air when the vehicle is in forward motion, the natural flow of air to heat exchanger **310** positioned rearward of the occupant door **110a** may be reduced. The principles described herein are intended to address this.

(21) FIG. **4** shows a cross-sectional view of vehicle **100**. For simplicity, the wheels are not shown. Vehicle **100** comprises an airflow passage **400** configured such that, when the vehicle is in forward

motion, the airflow passage **400** directs a first rearward airflow **410** from the wheel arch **204a** to the heat exchanger **310**. The airflow passage **400** comprises a channel **404** delimited by at least one surface of the occupant door **110a** and being at least partially open to a running surface **314** of the vehicle **100**, and a first inlet duct **406** to the heat exchanger **310**. The airflow passage **400** may be configured such that, when the vehicle **100** is in forward motion, it directs a first rearward airflow **410** from an outlet **402** of the wheel arch **204a**, via the channel **404** delimited by at least one surface of the occupant door **110a**, to the first inlet duct **406** to the heat exchanger **310**. In this way, the first rearward airflow **204** is conveyed to heat exchanger **310** in order to aid its cooling.

(22) Channel **404** directs air from the wheel arch **204a** to the first inlet duct **406**. The interior surfaces of the channel **404** may be smooth. This is because flowing air loses kinetic energy, and therefore velocity, when it encounters resistance (e.g. air resistance). It is preferable for the first rearward airflow **410** to maintain a higher kinetic energy per volume, and therefore a higher velocity, as a higher velocity airflow means that more air flows through (i.e. over the various surfaces of) the heat exchanger **310** per unit time and so enables more heat energy to be transferred away from the heat exchanger **310**. The smooth interior surfaces of the channel **404** can minimise the loss of kinetic energy of the first rearward airflow by reducing the resistance (e.g. air resistance) experienced by the first rearward airflow **410** as it flows through the channel **404**. The interior surfaces of the channel **404** may comprise one or more gradually curved faces to direct the first rearward airflow in the desired direction. This is in contrast to having a two or more faces meeting at an abrupt angle in the path of the first rearward airflow—which would provide significant resistance to the first rearward airflow. The channel **404** may comprise one or more vanes, or other projections, in order to aid in directing the first rearward airflow **410** in the desired direction. The channel **404** may run substantially the full length of the occupant door **110a**. The channel **404** may run along the bottom of the occupant door **110a**.

(23) Channel **404** may direct air from an outlet **402** of the wheel arch **204a** to the first inlet duct **406**. In an example, the outlet **402** may be an opening in the interior of the wheel arch **204a**, such as a cut through in a rearward interior surface of the wheel arch. In a preferred example, the interior of the wheel arch **204a** may be shaped so as to define the outlet **402**. For example, a rearward portion of the interior of the wheel arch **204a** may comprise one or more gradually curved faces arranged to form an opening that funnels airflow towards the channel **404**. This rearward portion of the interior of the wheel arch **204a** may be termed the outlet **404**. The forward edge of occupant door **108** may delimit part of the wheel arch **204a** (e.g. as can be seen in FIGS. **1** to **3**). Thus, one or more gradually curved faces of a rearward portion of the interior of the wheel arch **204a** and at least part of the forward edge of occupant door **108** may together define the outlet **402**. The outlet **402** is positioned in the rearward half of the wheel arch **204a**. The outlet **402** may be positioned in the bottom half of the wheel arch **204a**. That is, the outlet **402** may be positioned in the bottom-rearward quarter of the wheel arch **204a**.

(24) In other examples (not shown in the Figures), the forward edge of the occupant door may not delimit part of the wheel arch, and may instead be positioned rearward of the wheel arch. For example, a body panel and/or portion of the tub may separate the wheel arch and the forward edge of the occupant door. In these examples, the outlet may further comprise a wheel arch duct to direct air from an opening in the wheel arch to the channel. Said wheel arch duct may pass through the vehicle body **112**. Said wheel arch duct may be at least partially open to the running surface of the vehicle, or may be enclosed between the opening in the wheel arch and the entry to the channel.

(25) Channel **404** is described in further detail with reference to FIG. **5**, which shows a cross-sectional view of the bottom of occupant door **110a**. Channel **404** can be formed between an extended section **502** of the occupant door **110a** and the chassis or tub **504** of the vehicle, and/or between an extended section **502** of the occupant door **110a** and one or more body panel(s) attached to the chassis or tub **504** of the vehicle (e.g. such as protective door opening panel **506**, shown in hatching in FIG. **5**). One or more panel(s) (e.g. protective panels) could also be attached

to the inside surface of extended section **502**. In each of these examples, channel **404** can be said to be delimited by at least one surface of the occupant door **110a**. As shown in FIG. 5, the channel is at least partially open to the running surface **314** of the vehicle **100**. In examples, the channel **404** may be at least 5%, at least 10%, or at least 20% open to the running surface **314** of the vehicle. For example, the channel may have a substantially rectangular cross-section, where one side of that rectangle is open to the running surface **314** of the vehicle. The channel **404** may be open to the running surface **314** of the vehicle **100** along the full extent of the occupant door **110a** between the outlet **402** in the wheel arch **204a** and the first inlet duct **406**. In other examples, the channel **404** may be open to the running surface **314** of the vehicle **100** along less than the full extent of the occupant door **110a** between the outlet **402** in the wheel arch **204a** and the first inlet duct **406**.

(26) It is possible to form a closed channel through the occupant door **110a**. However, providing a channel that is at least partially open to the running surface **314** of the vehicle **100** is desirable as it reduces the complexity of the manufacture of the occupant door **110a**, as well as reducing the weight of the occupant door **110a**.

(27) In other examples (not shown), the vehicle may comprise multiple occupant doors on the same side. In these examples, the channel **404** may be delimited by at least one surface of each of those occupant doors.

(28) Returning to FIG. 4, the first inlet duct **406** directs air from the channel **404** to the heat exchanger **310**. The first inlet duct **406** may run through the vehicle body **112**. For example, the first inlet duct **406** may run through the tub, may be delimited by a surface of the tub and an interior surface of a body panel attached to the tub, and/or may be delimited by a plurality of panels forming an enclosed duct. Said plurality of panels forming an enclosed duct may be attached to the tub, a housing for the heat exchanger **310** and/or a body panel of vehicle **100**. The first inlet duct **406** may comprise an exit to the housing for the heat exchanger **310**. The cross-section of the first inlet duct **406** may gradually increase in area in the rearward direction so as to enable the first rearward airflow **410** to expand over the heat exchanger **310**. For example, the cross-sectional area of the exit of the first inlet duct **406** may be greater than the cross-sectional area of the entrance to the first inlet duct **406**. The interior surfaces of the first inlet duct **406** may be smooth. The interior surface of the first inlet duct **406** may comprise one or more gradually curved faces to direct the first rearward airflow in the desired direction. The first inlet duct **406** may comprise one or more vanes, or other projections, in order to aid in directing the first rearward airflow **410** in the desired direction.

(29) When the vehicle **100** is in forward motion, a second rearward airflow **304** may be directed between the underside of the vehicle **100** and the running surface **314** of the vehicle such that an airflow boundary forms between the first and second rearward airflows that reduces the amount of air of the first rearward airflow that escapes from the channel **404**. The difference in velocity and/or pressure between the first rearward airflow **410** and second rearward airflow **304** may cause the formation of the airflow boundary.

(30) The vehicle may be configured so as to increase the amount of kinetic energy, and therefore velocity, maintained by the second rearward airflow when it is directed between the underside of the vehicle **100** and the running surface **314** of the vehicle. This can aid in forming a better airflow boundary. For example, the vehicle may comprise an airflow splitter **202** forward of the wheel arch **204a** to aid in directing the second rearward airflow **304** between the underside of the vehicle **100** and the running surface **314** of the vehicle. The term “forward” is defined relative to, or with reference to, the forward direction **104**. In other words, airflow splitter **202** is a lesser distance from the front of the vehicle **100** than the wheel arch **204a**. An airflow splitter **202** may be a portion that protrudes forward of other portions of a front bumper panel of the vehicle.

(31) The airflow splitter **202** may cause a high pressure area over the top of the airflow splitter **202** and a low pressure area under the airflow splitter **202**. The high pressure area is created by the air above the airflow splitter **202** being brought to stagnation, for example by an air dam. The low



pressure area is created by the air under the airflow splitter **202** being accelerated due to its the proximity to the running surface **314** which thus reduces the pressure of this air—thus directing the second rearward airflow **304** between the underside of the vehicle **100** and the running surface **314**. (32) It is to be understood that the vehicle **100** need not comprise an airflow splitter **202**, and that other features such as a smooth underside of the vehicle, a rear diffuser and/or other vanes or projections attached to the front or underside of the vehicle can alternatively or additionally be used to increase the amount of kinetic energy maintained by the second rearward airflow when it is directed between the underside of the vehicle **100** and the running surface **314** of the vehicle.

(33) FIG. **6** shows a cross-sectional view of wheel arch **204a**. As shown in FIG. **6**, the vehicle **100** may also comprise an airflow diverter **602** forward of the wheel arch **204a**. The term “forward” is defined relative to, or with reference to, the forward direction **104**. In other words, airflow diverter **602** is a lesser distance from the front of the vehicle **100** than the wheel arch **204a**. The airflow diverter **602** may be configured such that, when the vehicle is in forward motion, it directs a primary rearward airflow **604** to the channel **404**. The airflow diverter **602** may comprise one or more vanes, or other projections, in order to aid in directing the primary rearward airflow **604** in the desired direction. The airflow diverter **602** may be formed in, attached to, or run through, a body panel of the underside of the vehicle body **112**.

(34) The airflow diverter **602** may be configured such that, when the vehicle is in forward motion, it directs the primary rearward airflow **604** inboard of the wheel **106a**. One way of achieving this is to position the airflow diverter **602** inboard of the wheel **106a**. The term “inboard” is defined relative to, or with reference to, the longitudinal axis **102** (shown in FIG. **1**). That is, airflow diverter **602** is considered to be positioned inboard of the wheel **106a** because the shortest distance between the airflow diverter **602** and the longitudinal axis **102** is lesser than the shortest distance between the wheel **106a** and the longitudinal axis **102**.

(35) Using the airflow diverter **602** to direct the primary rearward airflow **604** inboard of the wheel **106a** to the channel **404** is advantageous because this reduces the impingement of the primary rearward airflow **604** on the wheel **106a**—which would provide significant resistance to the primary rearward airflow **604**. Avoiding impingement on the wheel **106a** reduces the losses in kinetic energy per unit volume, and therefore velocity, experienced by the primary rearward airflow **604**. In this way, the airflow received at the channel **404** has a higher kinetic energy per volume, and therefore higher velocity, than if the channel **404** were to be fed primarily by air circulating within the wheel arch **204a** and impinging on the wheel **106a**. This in turn increases the kinetic energy per volume, and therefore velocity, of the first rearward airflow **410**.

(36) For the same reason, the interior surface of the wheel arch **204a** may comprise one or more gradually curved faces to direct the primary rearward airflow **604** in the desired direction. This is in contrast to having a two or more faces meeting at an abrupt angle in the path of the primary rearward airflow—which would provide significant resistance to the primary rearward airflow.

(37) The vehicle **100** may comprise a secondary heat exchanger **316**. Secondary heat exchanger **316** is covered by a body panel, and so is not visible from the exterior of the vehicle **100**. The position of secondary heat exchanger **316** is shown using hatching in FIG. **3**. Secondary heat exchanger **316** is positioned forward of the wheel arch **204a**. Secondary heat exchanger **316** may be used to cool operational parts of the vehicle **100** other than the engine. In an example, the secondary heat exchanger **316** may be responsible for cooling the charge air of the engine (e.g. air that has passed through a turbocharger, before it enters the engine). In another example, the secondary heat exchanger **316** may be used for cooling a condenser of a refrigerant circuit for cooling of the occupant compartment **108**. In examples where the vehicle is a hybrid vehicle, the secondary heat exchanger **316** may be responsible for cooling the hybrid powertrain components, such as one or more e-motors, motor control units (power electronics for the e-motor), and/or a high voltage battery. Air flow used to cool the secondary heat exchanger **316** may be vented or exhausted into the wheel arch **204a**. Air that flows through (i.e. over the various surfaces of) a heat

exchanger is heated (i.e. its heat energy per unit volume, and thus its temperature, increases), as well as losing significant amounts of kinetic energy owing to resistance (e.g. air resistance) caused by impinging on the heat exchanger. Higher temperature air (i.e. air with a greater heat energy per volume) is less effective at cooling a heat exchanger—because the temperature gradient between the air and the heat exchanger is lesser.

(38) Returning to FIG. 6, the airflow diverter **602** may be configured such that, when the vehicle is in forward motion, it receives air that forms the primary rearward airflow **604** from the underside of the vehicle in a position rearward of any secondary heat exchangers positioned in the front of the vehicle (e.g. secondary heat exchanger **316** shown in FIG. 3). That is, the primary rearward airflow **604** may be composed primarily of ambient air from the surroundings of the vehicle, that has not passed through (i.e. over the various surfaces of) a secondary heat exchanger of the vehicle. For example, the airflow diverter **602** may lift the primary rearward airflow **604** from between the underside of the vehicle and the running surface **314** upwards to the channel **404**.

(39) This is advantageous because the airflow received at the channel **404** has a higher kinetic energy and lower temperature, than if the channel **404** were to be fed primarily by air circulating within the wheel arch **204a**—which may have already flowed through (i.e. over the various surfaces of) a secondary heat exchanger positioned in the front of the vehicle, and subsequently impinged on the wheel. In this way, the kinetic energy of the first rearward airflow **410** is maximised whilst its temperature is minimised—such that it can cool heat exchanger **310** more effectively.

(40) FIG. 6 primarily shows the front-left side of the vehicle. The front-right side of the vehicle can be a mirror image. That is, with reference to FIG. 1, there may be an airflow diverter **602** for each front wheel arch **106a** and **106b**. The airflow diverter **602** for each front wheel arch **106a** and **106b** may be positioned either side of the longitudinal axis **102** of vehicle **100**. Each airflow diverter **602** may direct a respective primary rearward airflow, as described herein, to its respective channel.

(41) Returning to FIGS. 2 and 3, the vehicle **100** may also comprise a second inlet duct **214** to the heat exchanger. The second inlet duct **214** may be above the first inlet duct **406** (shown in FIG. 4). That is, the second inlet duct **214** may be a greater distance from the running surface **314** than the first inlet duct **214**. The second inlet duct **214** may pass through the vehicle body. The second inlet duct **214** may enter the vehicle body at an opening in a body panel. The second inlet duct **214** may comprise an exit to a housing for the heat exchanger **310**. The cross-section of the second inlet duct **214** may gradually increase in area in the rearward direction. For example, the cross-sectional area of the exit of the second inlet duct **214** may be greater than the cross-sectional area of the entrance to second inlet duct **214**. As shown in cross-section in FIG. 4, the first inlet duct **406** and the second inlet duct **214** may converge forward of the heat exchanger **310**.

(42) The vehicle **100** may comprise a wheel arch duct **206**. The wheel arch duct **206** may be above the channel **404**. That is, the wheel arch duct **206** may be a greater distance from the running surface **314** than the channel **404**. The channel **404** and the wheel arch duct **206** may both originate in wheel arch **204a**. The wheel arch duct **206** may run through the vehicle body **112**. For example, the wheel arch duct **206** may run through a body panel. The wheel arch duct **206** may enter the vehicle body via an opening in the interior of the wheel arch **204a**. The opening to the wheel arch duct **206** may be positioned in the rearward half of the wheel arch **204a**. The opening to the wheel arch duct **206** may be positioned in the upper half of the wheel arch **204a**. That is, the opening to the wheel arch duct **206** may be positioned in the rearward-upper quarter of the wheel arch **204a**. The interior surfaces of the wheel arch duct **206** may be smooth. The interior surface of the wheel arch duct **206** may comprise one or more gradually curved faces. The wheel arch duct **206** may comprise one or more vanes, or other projections, in order to aid in directing airflow in the desired direction. The wheel arch duct **206** may exit the vehicle body **112** via an exterior body panel, such as a front wing panel. The exit of the wheel arch duct **206** may be visible on the exterior of the vehicle **100**.

(43) The wheel arch duct **206** may be configured such that, when the vehicle **100** is in forward motion, it directs a third rearward airflow **302** from the wheel arch **204a** to a position below the second inlet duct **214** to the heat exchanger **310**. That is, the wheel arch duct **206** may direct the third rearward airflow **302** to not enter the second inlet duct **214** to the heat exchanger **310**.

(44) As described herein, air circulating within the wheel arch **204a** may have already flowed through a secondary heat exchanger **316** positioned in the front of the vehicle **100**. This means that the air circulating within the wheel arch typically has both a relatively low kinetic energy per unit volume—e.g. owing to air resistance provided by the heat exchanger **316** and impingement on the wheel **106a**—and a relatively high temperature (compared to ambient air). Were the wheel arch **204a** not to comprise the wheel arch duct **206**, air circulating within the wheel arch **204a** would likely escape the wheel arch **204a** in a disordered manner in a direction substantially perpendicular to the forward direction **104**. Some or all of the air escaping from the wheel arch **204a** in that manner would likely enter the second inlet duct **214**. As this air has a relatively low kinetic energy per unit volume, and a relatively high temperature (compared to ambient air) its cooling effect on the heat exchanger **310** would be limited if it were allowed to escape in this way.

(45) Instead, this is the air that is received by the wheel arch duct **206** and forms the third rearward airflow **302**. This means that the third rearward airflow **302** has a relatively low kinetic energy per unit volume, and a relatively high temperature (compared to airflows formed of ambient air)—meaning that its cooling effect on the heat exchanger **310** would be limited. By directing the third rearward airflow **302** to a position below the second inlet duct **214** to the heat exchanger **310**, the wheel arch duct **206** enables the second inlet duct **214** to receive a fourth rearward airflow **306** when the vehicle is in forward motion. That is, the third rearward airflow **302** may be directed so as to minimise its impingement on the fourth rearward airflow **306**. The fourth rearward airflow **306** may comprise ambient air from the surroundings of the vehicle **100**. Thus, the fourth rearward airflow **306** may comprise more kinetic energy per volume than the third rearward airflow **302** and/or less heat energy per volume than the third rearward airflow **302**—such that it can cool heat exchanger **310** more effectively than the third rearward airflow **302**.

(46) It is to be understood that not all of the air circulating within the wheel arch **204a** need have flowed through a secondary heat exchanger. For example, the vehicle may not comprise secondary heat exchanger **316**, or secondary heat exchanger **316** may primarily vent or exhaust air elsewhere and not into the wheel arch. That is, some or all of the circulating air may have entered the wheel arch **204a** from the ambient air surrounding the vehicle. In these examples, the air circulating within the wheel arch **204a** may still have a relatively low kinetic energy per unit volume (compared to ambient air) owing to impingement of that air on the wheel **106a**—meaning that its cooling effect on the heat exchanger **310** would be limited. Thus, wheel arch duct **206** as described herein is also advantageous in these examples.

(47) The vehicle may comprise other features to aid the wheel arch duct **206** in directing the third rearward airflow **302**. For example, the vehicle **100** may comprise a projection **210** on the occupant door **110a**. The projection **210** may be configured such that, when the vehicle **100** is in forward motion, the third rearward airflow **302** impinges on the projection **210** such that the projection **210** assists the wheel arch duct **206** in directing the third rearward airflow **302** from the wheel arch **204a** to the position below the second inlet duct **214** to the heat exchanger. The projection may be wing mirror **208**, or a component of a wing mirror **208** such as a wing mirror arm stem **210**.

(48) The vehicle may comprise other features to aid the second inlet duct **214** in receiving the fourth rearward airflow **306** when the vehicle is in forward motion. For example, the occupant door **110a** may comprise a concave surface **212** configured such that, when the vehicle **100** is in forward motion, it directs the fourth rearward airflow **306** into the second inlet duct **214** to the heat exchanger **310**. The concave surface **212** may be smooth so as to reduce the air resistance experienced by the fourth rearward airflow **306**. The concave surface **212** may be formed in an occupant door panel.

(49) The wheel arch duct **206** may also be configured to direct the third rearward airflow **302** to remain substantially attached to the vehicle **100**. As described herein, were the wheel arch **204a** not to comprise the wheel arch duct **206**, air circulating within the wheel arch **204a** would likely escape the wheel arch **204a** in a disordered manner in a direction substantially perpendicular to the forward direction **104**. Airflow escaping in that manner would increase the wake of the vehicle **100**, and so increase its drag. By enabling air circulating within the wheel arch **204a** to escape the wheel arch **204a** via the wheel arch duct **206** in a rearward direction substantially parallel with the forward direction **104**, the third rearward airflow **302** is able to remain substantially attached to the exterior of the vehicle **100**. This reduces the vehicles wake and drag. Thus, the wheel arch duct **206** also reduces the drag of the vehicle, in addition to improving the cooling of heat exchanger **310**.

(50) The applicant hereby discloses in isolation each individual feature described herein and any combination of two or more such features, to the extent that such features or combinations are capable of being carried out based on the present specification as a whole in the light of the common general knowledge of a person skilled in the art, irrespective of whether such features or combinations of features solve any problems disclosed herein, and without limitation to the scope of the claims. The applicant indicates that aspects of the present invention may consist of any such individual feature or combination of features. In view of the foregoing description it will be evident to a person skilled in the art that various modifications may be made within the scope of the invention.

## Claims

1. A vehicle comprising: a wheel arch; an occupant door rearward of the wheel arch; a heat exchanger rearward of the occupant door; an airflow passage comprising: a channel running along a bottom of the occupant door, being inboard of an exterior surface of the occupant door along a length of the channel, being delimited by at least one surface of the occupant door, and being at least partially open to a running surface of the vehicle; and a first inlet duct to the heat exchanger; a wheel positioned in the wheel arch; and an airflow diverter forward of the wheel arch, wherein the airflow passage and the airflow diverter are configured such that, when the vehicle is in forward motion, the airflow passage and the airflow diverter direct a first rearward airflow from a surrounding of the vehicle, inboard of the wheel, through an outlet of the wheel arch, through the channel delimited by the at least one surface of the occupant door, and through the first inlet duct to the heat exchanger for cooling the heat exchanger.
2. The vehicle as claimed in claim 1, wherein a second rearward airflow is directed between an underside of the vehicle and the running surface of the vehicle when the vehicle is in forward motion such that an airflow boundary forms between the first and second rearward airflows that reduces an amount of air of the first rearward airflow that escapes from the channel delimited by at least one surface of the occupant door and being at least partially open to the running surface of the vehicle.
3. The vehicle as claimed in claim 2, the vehicle further comprising an airflow splitter forward of the wheel arch, the airflow splitter being configured such that, when the vehicle is in forward motion, the airflow splitter directs the second rearward airflow between the underside of the vehicle and the running surface of the vehicle.
4. The vehicle as claimed in claim 1, the vehicle further comprising a second inlet duct to the heat exchanger, wherein the second inlet duct to the heat exchanger is above the first inlet duct to the heat exchanger.
5. The vehicle as claimed in claim 4, the vehicle further comprising a wheel arch duct configured such that, when the vehicle is in forward motion, the wheel arch duct directs a third rearward airflow from the wheel arch to a position below the second inlet duct to the heat exchanger so as to direct the third rearward airflow to not enter the second inlet duct to the heat exchanger, wherein

the third rearward airflow has a higher temperature and/or lower kinetic energy than an airflow formed of ambient air surrounding the vehicle.

6. The vehicle as claimed in claim 1, wherein the outlet of the wheel arch is an opening in an interior of the wheel arch, the outlet of the wheel arch is positioned in a bottom half of the wheel arch, the interior of the wheel arch is shaped so as to define the outlet of the wheel arch, and the interior of the wheel arch comprises one or more gradually curved faces.

7. The vehicle as claimed in claim 1, wherein the vehicle is a mid-or rear-engined vehicle.

8. A vehicle comprising: a wheel arch; an occupant door rearward of the wheel arch; a heat exchanger rearward of the occupant door; an airflow passage configured such that, when the vehicle is in forward motion, the airflow passage directs a first rearward airflow from an outlet of the wheel arch to the heat exchanger for cooling the heat exchanger, the airflow passage comprising: a channel running along a bottom of the occupant door, being inboard of an exterior surface of the occupant door along a length of the channel, being delimited by at least one surface of the occupant door, and being at least partially open to a running surface of the vehicle; a first inlet duct to the heat exchanger; a second inlet duct to the heat exchanger; and a wheel arch duct above the outlet of the wheel arch, the wheel arch duct configured to direct airflow downward when the vehicle is in forward motion such that, when the vehicle is in forward motion, the wheel arch duct directs a third rearward airflow from the wheel arch to a position below the second inlet duct to the heat exchanger so as to direct the third rearward airflow to not enter the second inlet duct to the heat exchanger, wherein the third rearward airflow has a higher temperature and/or lower kinetic energy than an airflow formed of ambient air surrounding the vehicle; wherein the wheel arch duct comprises one or more vanes or first projections which to direct the third rearward airflow from the wheel arch to the position below the second inlet duct to the heat exchanger.

9. The vehicle as claimed in claim 8, the vehicle further comprising a secondary heat exchanger forward of the wheel arch, wherein the wheel arch duct is configured to (i) receive air that has passed through the secondary heat exchanger and (ii) direct the third rearward airflow to remain attached to the vehicle.

10. The vehicle as claimed in claim 8, the vehicle further comprising a second projection on the occupant door, the second projection being configured such that, when the vehicle is in forward motion, the third rearward airflow impinges on the second projection such that the second projection assists the wheel arch duct in directing the third rearward airflow from the wheel arch to the position below the second inlet duct to the heat exchanger.

11. The vehicle as claimed in claim 10, wherein the second projection is a wing mirror or a component of the wing mirror.

12. The vehicle as claimed in claim 8, wherein the second inlet duct to the heat exchanger is (i) above the first inlet duct to the heat exchanger, and (ii) configured to receive a fourth rearward airflow composed of ambient air from a surroundings of the vehicle when the vehicle is in forward motion.

13. The vehicle as claimed in claim 12, wherein the fourth rearward airflow comprises more kinetic energy per volume than the third rearward airflow and/or the fourth rearward airflow comprises less heat energy per volume than the third rearward airflow.

14. The vehicle as claimed in claim 12, wherein the occupant door comprises a concave surface configured such that, when the vehicle is in forward motion, the concave surface directs the fourth rearward airflow into the second inlet duct to the heat exchanger for cooling the heat exchanger.

15. The vehicle as claimed in claim 8, wherein a longitudinal axis of the vehicle separates a left side of the vehicle from a right side of the vehicle, the first and second inlet ducts to the heat exchanger are both located on the left or right side of the vehicle.

16. The vehicle as claimed in claim 15, comprising third and fourth inlet ducts to the heat exchanger that are both located on the other of the left or right side of the vehicle.

17. A vehicle comprising: a wheel arch; an occupant door rearward of the wheel arch; a heat

exchanger rearward of the occupant door; an airflow passage configured such that, when the vehicle is in forward motion, the airflow passage directs a first rearward airflow from an outlet of the wheel arch to the heat exchanger for cooling the heat exchanger, the airflow passage comprising: a channel delimited by at least one interior surface of the occupant door, and being at least partially open to a running surface of the vehicle; and a first inlet duct to the heat exchanger; a second inlet duct to the heat exchanger, wherein the second inlet duct to the heat exchanger is above the first inlet duct to the heat exchanger and wherein the first and second inlet ducts to the heat exchanger converge forward of the heat exchanger; and a wheel arch duct configured such that, when the vehicle is in forward motion, the wheel arch duct directs a third rearward airflow of air from the wheel arch to a position below the second inlet duct to the heat exchanger, wherein the wheel arch duct is above the channel delimited by at least one surface of the occupant door.

18. The vehicle as claimed in claim 17, wherein the channel runs along a bottom of the occupant door and is inboard of an exterior surface of the occupant door along a length of the channel.

19. The vehicle as claimed in claim 17, wherein the wheel arch duct is configured such that, when the vehicle is in forward motion, the wheel arch duct directs the third rearward airflow from the wheel arch to the position below the second inlet duct to the heat exchanger so as to direct the third rearward airflow to not enter the second inlet duct to the heat exchanger, wherein the third rearward airflow has a higher temperature and/or lower kinetic energy than an airflow formed of ambient air surrounding the vehicle.

20. The vehicle as claimed in claim 17, the vehicle further comprising an airflow diverter forward of the wheel arch, wherein the airflow passage and the airflow diverter are configured such that, when the vehicle is in forward motion, the airflow passage and the airflow diverter direct the first rearward airflow from a surroundings of the vehicle, inboard of a wheel within the wheel arch, through the outlet of the wheel arch, through the channel, and through the first inlet duct to the heat exchanger for cooling the heat exchanger.

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