AERODYNAMIC SYSTEM FOR A VEHICLE, VEHICLE EQUIPPED WITH SUCH AN AERODYNAMIC SYSTEM, AND METHOD FOR REDUCING A VEHICLE DRAG

An aerodynamic system designed to be arranged near at least one rear edge (2, 42, 43) of a box-shaped rear portion of a vehicle (3). The aerodynamic system (1) comprises, in the operative position: at least one gas jet generating system (12) able to generate jets of gas (17) at least one outer surface (45) along which air flow generated by at least the forward motion of the vehicle is flowing; at least one opening which opens onto the outer surface (45) and which is connected to said at least one gas jet generating system (12) in order to blow jets of gas (17) in the atmosphere and to influence said air flow. The opening (16) being designed and/or oriented to blow jets of gas (17) rearward. The outer surface (45) comprises at least a guiding surface (20) extending at least partially downstream from said opening (16) and oriented inwards from front to rear, in order to guide said influenced air flow downstream from the opening (16). The gas jet generating system (12) is designed to continuously generate jets of gas (17) at a frequency F that is higher than 100 Hz, that is preferably comprised between 200 Hz and 1000 Hz and more preferably between 200 Hz and 450 Hz.
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Field of the invention

The present invention relates to an aerodynamic system designed to be arranged near the top rear edge of a vehicle, especially a vehicle having a box-shaped rear portion such as a truck having a trailer. The invention also relates to a vehicle comprising at least one such aerodynamic system, as well as a method for reducing a vehicle drag using such an aerodynamic system.

Technological background

For many years, attempts have been made to improve vehicle efficiency. One factor in an efficient design is the aerodynamic characteristics of a vehicle. The air drag of a vehicle and especially of an industrial vehicle such as a truck is one of the factors that has a direct impact on fuel consumption and pollutant emissions. Therefore, in a general trend towards rare and expensive energy - whether fossil or not -, aerodynamics is one of the key issues in an efficient vehicle.

One problem with the current vehicles is that the path of air which has flowed upwardly along the windshield and passed longitudinally rearward above the roof of the vehicle is not favourable from an aerodynamics perspective. Indeed, said air path causes turbulence and, moreover, contributes to the creation of a low pressure area behind the vehicle. This increases the vehicle drag coefficient and, consequently, generates a high fuel consumption.

More specifically, in a vehicle having a box-shaped rear portion, such as the trailer of a truck, this rear portion is a part where a great potential of drag reduction could be obtained.

Indeed, the four right angles at the vehicle rear portion create a large flow separation area which is source of high drag. When the vehicle is moving forward, the natural air flow coming along the vehicle is separated at the rear portion edges. This flow separation creates an increase in drag.
Actually, this separation allows boundary layers to turn behind the vehicle into free shear layers that curve toward each other to form eddies of important size and which are closed to the rear portion of the vehicle in a given location called the free stagnation point. The area delimited by the vehicle rear portion and the shear layers is called the recirculation area and is an area where important total pressure losses occur. This results in a low pressure area behind the vehicle rear portion, dragging the vehicle rearward and therefore increasing the aerodynamic drag.

It is estimated that the aerodynamic drag of a long haul truck entails a consumption that may reach around 40%-60% of the engine power on a flat road at cruising speed.

However, due to its main function of load compartment, a trailer must be box-shaped and therefore cannot be aerodynamically streamlined.

It therefore appears that there is room for improvement in vehicles aerodynamics having a box shaped rear portion, especially but not exclusively in trailer aerodynamics.

Summary

It is an object of the invention to provide an improved vehicle which can overcome the drawbacks encountered in traditional vehicles, from the aerodynamics perspective.

More particularly, an object of the invention is to provide an aerodynamic system which can be arranged near the top and / or side rear edge(s) of a vehicle, to lower the vehicle aerodynamic drag.

According to a first aspect, the invention relates to an aerodynamic system designed to be arranged near at least one rear edge of a box-shaped rear portion of a vehicle, said aerodynamic system comprising, in the operative position:

- at least one gas jet generating system able to generate jets of gas;
- at least one outer surface along which incoming air flow generated by at least the forward motion of the vehicle is flowing;
at least one opening which opens onto the outer surface and which is connected to said at least one gas jet generating system in order to blow jets of gas in the atmosphere and to influence air flow flowing along the outer surface.

In the aerodynamic system, the opening is designed and/or oriented to blow jets of gas rearward, the outer surface comprises at least a guiding surface extending at least partially downstream from said opening and oriented inwards from front to rear, in order to guide, downstream from the opening, air flow which has been influenced by jets of gas. Said gas jet generating system is designed to discontinuously generate jets of gas at a frequency F that is higher than 100 Hz, that is preferably comprised between 200 Hz and 1000 Hz and more preferably between 200 Hz and 450 Hz.

In the operative position, i.e. when the aerodynamic system is mounted on the vehicle:

- the terms "rear", "front" and "rearward" are used with respect to the vehicle, front elements being closer to the cabin than rear elements;
- the terms "downstream" and "upstream" refer to the air flow coming along the vehicle when said vehicle is moving forward. In other words, "downstream" and "rearward" refer to the same direction;
- the terms "inwards" and "inwardly" are used for elements which are closer to the longitudinal axis of the vehicle or directed towards said axis, as opposed to the terms "outside", "outwards" and "outwardly".

Thus, the invention provides an aerodynamic system which comprises an active part, including means for generating jets of gas and blowing them into the atmosphere, and a passive part, which makes it possible to guide the air flow so as to improve the system efficiency.

In practice, for a given speed of the vehicle, the aerodynamic system generates at regular interval jets of gas which are changed into periodic vortex structures which influence the air flow, particularly by deflecting it, in order to prevent the air flow from deviating outward from the vehicle rear portion, and to reattach it onto the guiding surface until the downstream edge of said guiding surface.
As a result, the invention makes it possible to control the air flow downstream of the vehicle rear portion. More precisely, the incoming air flow is vectored inwards along the guiding surface, thereby decreasing the size of the recirculation area behind the vehicle and increasing the pressure in the wake by mitigating and delaying further downstream the vortex shedding. These two phenomena allow reducing the aerodynamic drag of the vehicle and therefore the fuel consumption and pollutant emissions.

Insofar as the gas is blown intermittently, the aerodynamic system according to the invention consumes less energy than a system that would provide a continuous jet of gas.

Another advantage of the invention is that actuation parameters, in particular the frequency at which jets of gas are generated, can be adapted to operating conditions, especially the vehicle speed, but also possibly the wind conditions, the acceleration / deceleration of the vehicle, etc. This allows improving the aerodynamic system efficiency since the jets of gas are generated at an optimized frequency depending on the operating conditions, in order to greatly improve the aerodynamics behind the vehicle without requiring too much energy for the aerodynamic system operation.

More specifically, when the aerodynamic system is arranged near at least one rear edge of a box-shaped rear portion of a vehicle, especially near the top edge of the box-shaped rear portion of the vehicle, it has been found that generating jets of gas at a frequency F that is higher than 100 Hz and that is preferably comprised between 200 Hz and 1000 Hz leads to an aerodynamic system which has a very satisfying efficiency.

Working with an actuation frequency F below 100 Hz doesn’t lead to optimized results. Indeed, the aerodynamic system would then generate a vortex structure that would interact with the incoming air flow in a way that it would not mitigate the development of eddies of important size – i.e. having a size that can be greater than quarter the vehicle height and that can reach half the vehicle height - in the wake region that is formed immediately behind the vehicle in motion. Therefore, the pressure in the recirculation area would not sufficiently increase and the aerodynamic drag would remain closed to the one obtained without any aerodynamic system.

On the contrary, generating jets of gas with a frequency F higher than 100 Hz proves to be particularly efficient for a vehicle having a box
shaped rear portion. Indeed, this makes the aerodynamic system generates a vortex structure which interacts with the incoming boundary layer in a way that their interaction provides small vortex series going towards the guiding surface. Said small vortex series delay the rolling-up of shear layer behind the vehicle and therefore prevent the formation of eddies in the wake region immediately behind the vehicle. As a result, the pressure behind the vehicle rear portion is increased and the drag is reduced.

A preferred embodiment is when the aerodynamic system is arranged near the top rear edge of the box-shaped rear portion because in this configuration, where the guiding surface is oriented downwards from the front to the rear, the aerodynamic system is more efficient with no or limited effects on the load capability of the vehicle, than a configuration wherein the aerodynamic system is arranged near the side rear edges of the box-shaped rear portion.

According to an advantageous embodiment of the invention, the gas jet velocity, at the opening, satisfies the following equation: $U_{\text{jet}} / U \geq 0.15$ and preferably $U_{\text{jet}} / U \geq 0.3$ wherein $U_{\text{jet}}$ is the gas jet velocity and $U$ is a parameter corresponding at least to the vehicle speed in the forward direction.

The parameter $U$, may correspond to a relative speed of the vehicle that takes into account the actual speed of the vehicle and also the wind speed thanks, for instance, to a speed and/or a pressure sensor located in a front part of the vehicle.

The gas jet velocity has a direct impact on the length of the jet of gas which should preferably be higher than the boundary layer thickness, so that the periodic vortex structures generated by the aerodynamic system can reach the high velocity regions of the boundary layer to sufficiently deflect the incoming air flow. The boundary layer thickness being dependent on the vehicle speed, the jet velocity is preferably set in function of said vehicle speed or relative speed with the above mentioned ratio, in order to optimize the aerodynamic system efficiency.

The opening is preferably formed as a slot extending in a transverse direction of the vehicle when the aerodynamic system is arranged on a vehicle and the opening has a thickness that ranges from 0.5 to 5 mm.

According to a particular embodiment of the invention, the opening is connected to the gas jet generating system through a duct having a first end.
connected to said gas jet generating system and a second end which extends rearward and outward to form the opening.

The outer surface of the aerodynamic system can further comprise a leading surface located upstream from the opening, said leading surface being arranged substantially horizontally or progressively sloping from rear to front with respect to the horizontal at a maximum angle of 90° or being inclined with respect to the horizontal with an angle inferior to 15°, in the operative position. Preferably, when the leading surface progressively slopes from rear to front, it slopes with a maximum rear angle α2 of 10° and preferably with a front angle α1 comprised between 45 and 90° with respect to the horizontal in the operative position of the aerodynamic system. The rear angle α2 corresponds to the angle α2 of the downstream portion of the leading surface.

Such a leading surface makes it possible to improve the system efficiency by reducing the boundary layer thickness to be controlled. Therefore, the gas jet length can be lower, which helps decrease the energy consumed by the aerodynamic system. As the shape of the leading surface influences the direction of the incoming air flow upstream or at opening, it has an impact on the way the generated gas jets are carried rearward by the incoming air flow. Preferably, if it is not horizontal, the leading surface can have a curved convex shape, for example similar to the profile of a wing.

In an implementation of the aerodynamic system, from front to rear, the guiding surface can make an angle α3 with the downstream portion of the leading surface which is comprised between 5 and 40°, preferably between 12 and 25°. In practice, angle α3 can be the angle between the guiding surface and the direction of air flow upstream from the opening.

On the one hand, if angle α3 is too low, the incoming airflow naturally stays attached to the guiding surface. In such a case, blowing jets of gas does not bring a significant advantage in terms of aerodynamics and the aerodynamic system would not be very efficient. On the other hand, if angle α3 is too high, the periodic vortex structures generated by the aerodynamic system are not able to deflect the airflow enough to reattach it on the guiding surface. Having α3 included in the above mentioned range, actuating the gas jet generating system allows the incoming air flow to be reattached to the guiding surface until its trailing edge – i.e. downstream edge – and thus vectoring it. Therefore, the wake is reduced and the drag decreased.
In an implementation, the central axis of the opening and/or the second end of the duct forming the opening can make an angle $\beta$ with the downstream portion of the leading surface which can be comprised between 90 and 170°, preferably between 120 and 150°, and for example around 135°.

According to an embodiment of the invention, the opening can be located substantially at the junction between the leading surface and the guiding surface.

According to another embodiment of the invention, the opening is located on the guiding surface at a distance $l$ from the junction between the leading surface and the guiding surface. The distance $l$ between the opening and said junction is inferior to 20 mm when measured along the longitudinal direction and in the operative position the aerodynamic system. The terms “measured along the longitudinal direction” mean the distance measured along the longitudinal axis of the vehicle.

In other words, the opening is located on the guiding surface and is also offset with respect to the junction between the leading surface and the guiding surface.

Preferably, the successive leading surface and guiding surface, form an airfoil substantially devoid of discontinuity, gap, or unevenness (except the opening).

For example, the guiding surface can substantially form a flat flap. Besides, the length of the guiding surface, along the longitudinal direction in the operative position, can be comprised between 5 and 150 cm, preferably between 20 and 70 cm, for example around 50 cm.

In an embodiment, the duct cross section area can progressively decrease from the first end towards the second end, the ratio $R = S1/S2$ being lower than 1,5, where $S1$ is the duct cross section area at its first end and $S2$ is the duct cross section area at its second end. In other words, $1 < R < 1.5$.

According to another embodiment, the duct cross section area is substantially constant from the first end towards the second end — i.e. $R = 1$.

In an implementation of the invention, the duct first end can be substantially circular — in order to adapt to the shape of an air supply conduit for example — and the duct second end can be substantially rectangular so that the opening forms a transverse slot. The transverse direction is the
direction which, in use, is substantially horizontal and orthogonal to the longitudinal direction.

The aerodynamic system can further comprise an electronic control unit coupled to at least one actuator of the gas jet generating system in order to control the gas jet generating system operation. The electronic control unit can also control the gas jet generating system operation according to at least one operating condition such as the vehicle speed, the vehicle acceleration or deceleration, the activation of braking or retarding devices of the vehicle.

In one embodiment, the aerodynamic system comprises an aerodynamic device which includes the opening, the guiding surface and the leading surface when present, said aerodynamic device being separated from the vehicle and being designed to be mounted onto a rear top surface or onto a rear side surface of the box-shaped rear portion of the vehicle, preferably near a rear edge thereof.

The aerodynamic device preferably comprises, opposite to the opening, the guiding surface and opposite to the leading surface, a mounting surface, substantially flat, and in that the aerodynamic device is mounted onto a rear top surface or onto a rear side surface of the box-shaped rear portion of the vehicle via said mounting surface.

The height $h_1$ of the aerodynamic device measured in a direction perpendicular to the mounting surface is comprised between 20 and 300 mm and preferably between 40 and 150 mm. The opening is preferably located at distance $h_2$ from said mounting surface when measured in a direction perpendicular to the mounting surface.

On the other hand, the gas jet generating system can belong to the vehicle. The aerodynamic device can also comprise the gas jet generating system or part of it and the duct connecting the opening to the gas jet generating system.

The aerodynamic device preferably assumes the form of an airfoil. It can protrude from a surface of the vehicle according to any of the following variants: it can be mounted on the top surface of the vehicle and extend beyond the vehicle rear face or not; it can be mounted on the rear surface of the vehicle, near the top rear edge; it can extend downwards with respect to the top rear edge or not, in order not to impair the rear door opening.
According to a second aspect, the invention relates to a vehicle having a box-shaped rear portion such as a trailer, which comprises at least one aerodynamic system as previously described. Said aerodynamic device is mounted onto a rear top surface of the box-shaped rear portion of the vehicle and/or is mounted onto a rear side surface of the box-shaped rear portion of the vehicle such that it projects outside from the box-shaped rear portion to and such that the opening is at distance h2, measured in a direction perpendicular to the mounting surface, from said rear side surface and/or said rear side surface.

In case the aerodynamic system comprises an aerodynamic device, said vehicle can comprise one or a plurality of aerodynamic devices mounted next to each other on the vehicle and near the top rear edge of the vehicle, so as to substantially cover the whole width of the vehicle rear portion. With this disposition, the invention provides a modular aerodynamic system which includes separates parts that can be mounted onto the vehicle, each aerodynamic device having its own gas jet generating system, or one single and common gas jet generating system being provided for all the aerodynamic devices.

In another embodiment, the top rear edge of the vehicle can be bevelled and form the guiding surface of the aerodynamic system while the portion of the vehicle top wall located upstream from the opening forms the leading surface. Thus, the aerodynamic system is partly formed by the rear portion of the vehicle itself. The bevelled part can be a static structure – i.e. created by the shape of the vehicle which cannot be modified – or a dynamic structure – for example including members that can pivot from an active position in which the top rear edge of the vehicle is bevelled and a passive position in which the top rear edge of the vehicle is at right angles.

In a further embodiment, the guiding surface extends totally or partially beyond the rear edge of the vehicle.

According to a third aspect, the invention relates to a method for reducing a vehicle drag, especially for a vehicle having a box-shaped rear portion, the method comprising:

- arranging an aerodynamic system near at least one rear edge of the vehicle, preferably near the top rear edge of the vehicle, said aerodynamic system comprising:
at least one gas jet generating system able to generate jets of gas;
at least one outer surface along which air flow generated by at least motion of the vehicle is flowing;
at least one opening which opens onto the outer surface and which is connected to said at least said one gas jet generating system in order to blow jets of gas in the atmosphere to influence air flow flowing along the outer surface;

wherein

the opening being designed and/or oriented to blow jets of gas rearward;
the outer surface comprises at least a guiding surface extending at least partially downstream from said opening and oriented inwards from front to rear, in order to guide, downstream from the opening, air flow which has been influenced by jets of gas;

— discontinuously generating jets of gas at a frequency F which is higher than 100 Hz, that is preferably comprised between 200 Hz and 1000 Hz and more preferably between 200 Hz and 450 Hz.

It may be envisaged that jets of gas are generated only when the vehicle speed U is higher than a determined threshold Uth, Uth being higher than 50 km/h, for example around 60 km/h. This is because, below Uth, the aerodynamic drag is not of major importance compared to other resisting forces, and because the driver generally often uses the braking system at such speeds. On the contrary, when the vehicle is moving more rapidly, for example on a highway at 90 km/h, aerodynamic drag becomes the most important resisting force applied to the vehicle, and the braking system is not intensively used, the operation of the aerodynamic system thus being very advantageous.

On the other hand, the method can comprise stopping the generation of jets of gas when the vehicle deceleration is higher than a threshold value, for instance 2 km/h/s, or when a braking or retarding device of the vehicle is activated.
Preferably the gas jet generating system generates jets of air or jets of gas having the same density than air.

These and other features and advantages will become apparent upon reading the following description in view of the drawing attached hereto representing, as non-limiting examples, embodiments of a vehicle according to the invention.
Brief description of the drawings

The following detailed description of several embodiments of the invention is better understood when read in conjunction with the appended drawings, it being however understood that the invention is not limited to the specific embodiments disclosed.

Figure 1 is a side view of a vehicle comprising an aerodynamic system according to a first embodiment of the invention;

Figure 2 is a detailed view of the rear portion of the vehicle of figure 1, showing the air path behind the vehicle with air jets generated according to the invention.

Figure 3 is a detailed view of an aerodynamic device belonging to the aerodynamic system of figure 1;

Figure 4 is a detailed view of the aerodynamic device of figure 3 showing a duct for blowing air jets into the atmosphere;

Figure 5 is a perspective view of the aerodynamic device of figure 3;

Figure 6 is a detailed but schematic view of the aerodynamic device of figure 3 showing the evolution of the duct cross-section;

Figure 7 shows in perspective the rear portion of the vehicle of figure 1;

Figure 8a is a graph showing the drag coefficient of a vehicle equipped with an aerodynamic system according to the invention as a function of the frequency F;

Figure 8b is a graph showing the drag coefficient of a vehicle equipped with an aerodynamic system according to the invention as a function of $U_{\text{jet}}/U$;

Figures 9 and 10 schematically show two operation phases of an air jet generating system of an aerodynamic system according to a possible embodiment of the invention;

Figure 11 is a detailed view of the rear portion of a vehicle equipped with an aerodynamic device according to a variant of figure 2;

Figure 12 is a detailed view of the rear portion of a vehicle equipped with an aerodynamic device according to another variant of figure 2;
Figure 13 is a detailed view of the rear portion of a vehicle comprising an aerodynamic system according to a second embodiment of the invention.

Figure 14 schematically shows a possible arrangement of the opening and the air jet generating system.
Detailed description of the invention

The invention relates to an aerodynamic system 1 which is designed to be arranged near one rear edge of a vehicle 3, in order to reduce the vehicle drag. In the following embodiments, the aerodynamic system 1 is designed to be arranged near the top rear edge 2 of the vehicle 3 but it can also be designed to be arranged near the side rear edges 42, 43 of the vehicle.

The invention is specifically for vehicles having a box-shaped rear portion. It can therefore be used with a vehicle for transporting goods, such as a truck having a trailer, a semi-trailer or a rigid, typically a long-haul truck, said vehicle comprising a cargo body having a box-shaped rear portion.

As this is illustrated in Figure 1, such a vehicle 3 can comprise a frame 4 supported by wheels 5 as well as a cab 6 and a cargo body 7. The cargo body 7 here comprises a container 8 having a top wall 9, a rear wall 13 which generally includes at least one door, and side walls 10. Preferably, the container 8 substantially has the shape of a parallelepiped. The vehicle 3 has a longitudinal axis 11.

More generally, the invention will be described for a vehicle 3 having a box-shaped rear portion comprising a substantially flat and horizontal top wall 9 – when the vehicle 3 is on a horizontal surface – and in the operative position, i.e. when the aerodynamic system 1 is mounted on near the top rear edge 2 of the vehicle 3. When the vehicle 3 is in motion in the forward direction, incoming air flows 47 passes longitudinally rearward above the top wall 9.

The aerodynamic system 1 is designed to discontinuously generate jets of gas at a frequency F, said jets of gas being oriented outwards and rearward, so as to influence, in the rearward direction, the incoming air flow in order to improve the path of air behind the vehicle 3.

Such as described in the following embodiments, jets of gas are preferably jets of air ("air jets"). This allows the use of simple systems to generate jets. Instead of air, the jets can be generated with a gas having the same density than air. The jets can also be generated with a different gas such as CO₂.
Such as illustrated in figure 2, the aerodynamic system 1 comprises an outer surface 45 along which incoming air generated by forward motions of the vehicle and by wind is flowing.

The aerodynamic system 1 also comprises an air jet generating system 12 and an opening 16 which opens onto the outer surface 45 and which is connected to the air jet generating system through a duct 14 having a first end 15 connected to said air jet generating system 12 and a second end which extends rearward and outward to form the opening 16. To be more precise, in the embodiments depicted in figures 2 to 6 and 11, it is the entire duct 14 that is oriented rearward and outwards from its first end 15 to its second end. Alternatively, only the second end 16 of the duct 14 is oriented rearward and outwards.

As a result, at a given moment, one air jet 17 is generated and sent from the duct 14 into the atmosphere in a rearward direction, as schematically shown in figures 1 and 2. This air jet 17 globally causes the formation of two vortex structures, a first one 18 which is directed downstream and which is carried rearward by the incoming air flow, while a second vortex structure 19 which is directed upstream is quickly destroyed by said incoming air flow. As a consequence, in the description, the term "air jet" will refer to the part of the air jet which causes the formation of the first vortex structure 18.

The outer surface 45 has at least a guiding surface 20 which extends at least partially downstream from the opening 16 and which is oriented downwards from the front to the rear, in order to guide incoming air flow. In the example of figures 2 to 5, the guiding surface 20 extends totally downstream from the opening 16. In the example of figure 11, the guiding surface extends partially downstream from the opening 16 and partially upstream from the opening 16.

According to an important aspect of the invention, the aerodynamic system 1 is designed so that air jets 17 are blown at a frequency F which is higher than 100 Hz.

Actuating the air jet generating system with a frequency F that is higher than 100 Hz and that is preferably comprised between 200 Hz and 1000 Hz makes the aerodynamic system 1 generate a first vortex structure 18 which interacts with the boundary layer of the incoming air flow 47 in a way that their interaction provides small vortex series 21 going down the guiding
surface 20. The small vortex series 21 causes the incoming air flow 47 to reattach on the guiding surface 20 so that, downstream the rear wall 13, the air flow is controlled and oriented downward in order to decrease the size of the recirculation area.

The small vortex series 21 persist after the guiding surface 20 following globally the same downward and rearward direction 50 given by the guiding surface 20. Downstream the guiding surface 20, the air boundary layer forms with the small vortex series 21 the shear layer 48.

Another positive effects resulting from the small vortex series 21 is that it is delayed the moment when the shear layer 48 is rolling-up. In other words, the zone where shear layer 48 is rolling-up and so the zone of formation of eddies 49 is now, thanks to the invention and by comparison with prior art, at distance from the rear wall 13 so that it is prevented the formation of eddies 49 in the wake region immedialy behind the vehicle.

An additional effect is that the size of eddies 49 is reduced compared to prior art. It is for instance possible to obtain eddies 21 having a size smaller than 1/5 the vehicle height.

Thanks to the preceding effects, by generating such air jets 17 at such a frequency F, the invention makes it possible to increase the static pressure in the wake, behind the vehicle rear portion, and to reduce the wake size. Therefore, a significant drag reduction is obtained.

When the aerodynamic system according to the invention is arranged near a rear edge 2, 42, 43 of a vehicle having a box-shaped rear portion, it has been highlighted (see figure 8a) by inventors that below 100 Hz the aerodynamic system is not efficient. When arranged near a rear edge of a vehicle having a box-shaped rear portion, the present aerodynamic system is efficient when frequency is higher than 100Hz, better results are obtained with frequency F between 200 Hz and 1000 Hz. A frequency limited to 450Hz is more cost effective and allows a limitation of noise emissions when the aerodynamic system is operated. Besides, gains are much more important between 200Hz and 450Hz than above 450 Hz, that's why a frequency F chosen in the range from 200 Hz to 450Hz is an optimized choice.

Another important parameter for the aerodynamic system efficiency is the air jet velocity \( U_{jet} \) at the duct second end 16, that is determined with respect to a parameter \( U \) corresponding at least to the vehicle
speed in the forward direction. According to a particular aspect of the invention, having Ujet / U ≥ 0.15, and preferably Ujet / U ≥ 0.3 leads to satisfactory results in terms of aerodynamics improvement (see figure 8b). It is also possible that U parameter corresponds to a relative speed of the vehicle that takes into account the wind speed in addition of the actual vehicle speed. To this aim at least one speed sensor 35 and/or a pressure sensor 36 can be provided and, for instance, located in a front part of the vehicle such as in front of the cab 6.

This ensures that the periodic vortex structures generated by the aerodynamic system reach the high velocity regions of the boundary layer of the incoming air flow 47 above the vehicle top wall 9, in order to sufficiently deflect the incoming air flow. Indeed, the air jet length depends on the jet velocity Ujet and the boundary layer thickness depends on the vehicle speed U.

As schematically depicted in figure 2, for example, the aerodynamic system 1 can further comprise an electronic control unit 22 coupled to at least one actuator 23, in order to efficiently operate the system and in particular to control the means for generating the air jets 17 at the appropriate frequency F, and preferably at an appropriate velocity Ujet. Such as explained hereinafter in detail, the actuator 23 can be a valve connected to a source providing compressed air or, according to a different implementation, it can be a synthetic jet actuator.

In order to further improve the aerodynamics, the aerodynamic system 1 can preferably comprise a leading surface 24 located upstream from the duct second end 16, said leading surface 24 being arranged substantially horizontally or progressively sloping from rear 242 to front 241 (see figure 3 or 5) with respect to the horizontal at a maximum angle of 90° or being inclined with respect to the horizontal with an angle inferior to 15°, in the operative position.

When the leading surface 24 is progressively sloping from rear 242 to front 241 (see figure 3), the maximum rear angle α2 is 10° and preferably the front angle α1 is comprised between 45 and 90° with respect to the horizontal in the operative position of the aerodynamic system. The rear angle α2 corresponds to the angle α2 of the downstream portion of the leading surface. In the example of figure 3 the downstream portion has, near the
opening 16, a tangent substantially horizontal and the front angle α1 is about 90°.

This leading surface 24, such as previously defined, influences the direction of the flow of ambient air due to the vehicle motion, upstream from the opening 16. This is of special importance at the downstream portion 25 of said leading surface. Indeed, said downstream portion 25 is located upstream — and possibly immediately upstream — the opening 16, and therefore greatly influences the way the generated air jets 17 are carried downstream by the incoming air flow 47.

Advantageously, as illustrated in figure 3, the above mentioned geometrical features of the aerodynamic system 1 can be set as follows:

- from front to rear, the guiding surface 20 can make an angle α3 with the downstream portion 25 of the leading surface 24 which is comprised between 5 and 40°, preferably between 12 and 25°;

- at least the second end of the the duct 14 can be oriented to make an angle β with the downstream portion 25 of the leading surface 24 which is comprised between 90 and 170°, preferably between 120 and 150°, and for example around 135°.

The aerodynamic system can also be designed without a duct 14 connecting the opening 16 to the air jet generating system 12. Instead of a duct and such as depicted in figure 14, a cavity 39 is formed to connect the opening 16 to the air jet generating system 12. In this case, it is the orientation of the opening 16, to be more precise the orientation of its central axis 44, that is chosen into the range between 90 and 170°, preferably between 120 and 150°, and for example around 135°.

These ranges have proved to have a better control of the size of the vortex structures 21, to obtain a better reattachment of the incoming airflow 47 onto the guiding surface 20 and so to lead to particularly satisfactory results from an aerodynamic perspective.

Reference is now made to figures 1-7 which illustrate a first embodiment of the invention.

According to this first embodiment, the aerodynamic system 1 comprises an aerodynamic device 30 which includes the opening 16, the duct 14, the guiding surface 20 and the leading surface 24, said aerodynamic device 30 being separate from the vehicle 3 and being designed to be
mounted onto the vehicle 3, near a rear edge 2, 42, 43 thereof preferably near the top rear edge 2. In figure 2, the air jet generating system 12 is depicted as belonging to the vehicle. Alternatively, the air jet generating system 12 can be partially or totally part of the aerodynamic device 30.

The aerodynamic device 30 comprises, opposite to the opening 16, opposite to the guiding surface 20 and opposite to the leading surface 24, a mounting surface 31 that is substantially flat. The Aerodynamic device 30 is mounted, via the mounting surface 31, onto a rear top surface 91 of the box-shaped rear portion of the vehicle and/or is mounted onto a rear side surface 101 of the box-shaped rear portion of the vehicle such that it projects from the top wall 9 and/or side wall 10 of the box-shaped rear portion to which it is mounted and such that the opening 16 is at distance h2, measured in a direction perpendicular to the mounting surface 31, from said top wall 9 or said side wall 10.

The height h1 of the aerodynamic device 30 measured in a direction perpendicular to the mounting surface 31 is comprised between 20 and 300 mm and preferably between 40 and 150 mm (see figures 3 and 11). The opening 16 is located on the outer surface 45 of the aerodynamic device 30 and at distance h2 from said mounting surface 31 when measured in a direction perpendicular to the mounting surface 31 (see figures 3 and 11). In the example of figure 3 h2 equals h1 and in the example of figure 11 h2 is inferior to h1.

The height h1 allows having a curved surface upstream the generated air jet 17, which reduces the boundary layer thickness to be controlled. Thanks to that and due to the fact that the opening 16 is located on the outer surface 45 of the aerodynamic device 30 at distance h2 from said mounting surface 31, the air jet stroke length can be reduced. As a consequence, the air jet velocity Ujet can be decreased, thereby reducing the energy consumed by the aerodynamic system 1.

Preferably, the outer surface 45 of the aerodynamic device 30 is similar in shape to a wing profile. It can for example assume the shape of a curved surface upstream the opening 16 while the guiding surface 20 can substantially form a flat flap ending at a sharp trailing edge 33. In the embodiment depicted in figures 1-7, the opening 16 is located substantially at the junction 29 between the leading surface 24 and the guiding surface 20.
Advantageously, the successive leading surface 24 and guiding surface 20 form a smooth shape substantially devoid of discontinuity, gap, or unevenness (except the opening 16) that might generate an extra flow separation.

The inward surface 31 of the aerodynamic device 30 can be flat in order to match the shape of the vehicle top wall 9. Furthermore, the aerodynamic device 30 can comprise flat lateral side walls 32 which, in the operative position, are substantially vertical and parallel to the longitudinal axis 11 of the vehicle 3.

Basically, the aerodynamic device 30 comprises:
- an active part, that comprises the opening 16 which is connected, through a duct 14, to the air jet generating system 12, in order to intermittently blowing air jets 17 towards the atmosphere;
- and a passive part, that comprises the leading surface 24 and the guiding surface 20, designed to optimize the air path upstream and downstream the opening 16 in order to improve the aerodynamic system efficiency.

The aerodynamic device 30 is designed to be connected, at the duct first end 15, to an air jet generating system 12 which can be partially or totally part of the vehicle 3 such as depicted on figure 2 or which can be totally part of the aerodynamic device 30 such as depicted on figures 9 and 10.

Advantageously, when a duct is used to connect the opening to the air jet generating system 12, the duct first end 15 is preferably substantially circular to adapt to a circular conduit. On the other hand, the duct second end 16 can be substantially rectangular so that the opening 16 forms a transverse slot, substantially orthogonal to the longitudinal axis 11 of the vehicle 3 in the operative position, as best shown in figure 5.

The thickness e of opening 16 can range from 0.5 to 5 mm (see figures 4 and 6), while its width d – along the transverse direction – can cover more than 80% of the total width of the aerodynamic device 30, and that is preferably about 95% of the total width of the aerodynamic device 30. One or several openings 16 can be formed on the total width of the aerodynamic device 30. When several openings 16 are formed, it is the sum of the widths d
of the openings 16 that covers more than 80% of the total width of the aerodynamic device 30.

According to an implementation, the duct cross section area can be substantially constant from the first end 15 towards the second end 16.

Alternatively, the duct cross section area can progressively decrease from the first end 15 towards the second end 6. It may be envisaged that the ratio between the duct cross section area S1 at its first end 15 and the duct cross section area S2 at its second end 16 – R=S1/S2 – be comprised between 1 and 1.5. Although a higher ratio can lead to higher pressure losses, having a ratio greater than one can be useful when high air jet velocities are needed to control the incoming flow 47 above the vehicle top wall 9.

The geometry of the duct 14, and in particular of its second end 16, has to be carefully designed. Indeed, it defines most of the properties of the unsteady vortex structure generated by the aerodynamic system 1 and blown in the atmosphere to influence the incoming air flow. In particular, the duct 14 is preferably designed to blow a homogeneous air jet along the second end width. Besides, the internal shape of the duct 14 can be especially designed to mitigate as much as possible the pressure losses from the first end 15 to the second end 16, by providing a smooth surface devoid of any angle. A possible shape of the internal surface of the duct 14, from a circular first end 15 to a rectangular second end 16, is illustrated in schematically figure 6.

In practice, as shown in figure 7, a plurality of aerodynamic devices 30 can be mounted next to each other on the vehicle 3, so as to substantially cover the whole width of the vehicle rear portion.

Each aerodynamic device 30 can be connected to its own and dedicated air jet generating system 12, or one single air jet generating system 12 may be provided for all aerodynamic devices.

The aerodynamic system 1 is thus a modular system that can be mounted near the top rear edge 2 of the vehicle 3. The second ends of the ducts 14 form a transversal dashed line of openings 16 that extends over substantially the whole width of the vehicle top rear edge 2.

In the embodiment illustrated in figures 2-7, the aerodynamic devices 30 are mounted onto the vehicle top wall 9, and extend beyond the vehicle rear wall 13. However, the aerodynamic devices 30 preferably do not
extend below the vehicle top rear edge 2, the inward surface 31 of the aerodynamic device 30 being substantially level with the vehicle top wall 9. Therefore, the aerodynamic devices 30 do not interfere with the rear door opening.

However in a different configuration, it is not excluded that the aerodynamic devices 30 is designed to extend below the vehicle top rear edge 2. In this case the part of the aerodynamic devices 30 that extends below the top rear edge can be pivotably mounted in order to allow the rear door opening.

The length L of the guiding surface 20, along the longitudinal direction in the operative position, can be comprised between 5 and 150 cm, preferably between 20 and 70 cm, for example around 50 cm. This makes it possible to have at least one generated vortex structure going down the guiding surface 20.

The guiding surface 20 can extend totally or partially beyond the vehicle rear wall 13 and therefore the length L can also correspond to the distance between the trailing edge 33 and the vehicle rear wall 13 as shown in figure 2.

Having a long guiding surface 20 and a tall aerodynamic device 30 leads to better aerodynamic performances of the system according to the invention. However, in practice, current or upcoming legislations state the maximum height and length of vehicles, in particular of long-haul trucks, and therefore limit the size and in particular the height h1 of the aerodynamic device 30 above the vehicle top wall 9. That’s why, depending on the national legislations, h1 is limited accordingly.

Figure 8a regards the minimum frequency F at which air jets are generated. It has to be noted that maximum frequency F is mainly set by the technology limitations, in particular in the air supply system. The maximum frequency F could be around 1000 Hz, bearing in mind that above a certain value, more precisely above 450 Hz, noise nuisance could become problematic.

This figure 8a shows the normalized drag coefficient Cd behind the vehicle 3 when Ujet/U= 0.4. This curve has been obtained experimentally for β = 135° and a transverse slot opening 16 having a width of 50 mm.
As can be seen, the drag coefficient $C_d$ significantly decreases when frequency is higher than 100 Hz.

Figure 8b shows the normalized drag coefficient $C_d$ behind the vehicle 3 when frequency is fixed at 200 Hz. As can be seen a value of $U_{jet}/U$ that is higher than 0.15 entails a larger reduction in the drag coefficient $C_d$.

For optimization purposes, the electronic control unit 22 can be capable of controlling the air jet generating system operation according to at least one operating condition in addition to the vehicle speed or relative vehicle speed $U$, such as the vehicle acceleration or deceleration, the activation of braking or retarding devices of the vehicle. Thus, air jets 17 can be generated only when the vehicle speed $U$ is higher than a determined threshold $U_{th}$, $U_{th}$ being higher than 50 km/h, for example around 60 km/h. Indeed, above said speed, the aerodynamic drag has a significant importance, and the untimely operation of the system in urban areas is prevented. Besides, the generation of air jets 17 can be stopped when the vehicle deceleration is higher than 2 km/h/s or when brakes are activated by the driver, insofar as, in these operative conditions, there is no need from the aerodynamic perspective to blow such air jets 17.

As regards the air jet generating system 12, at least two implementations can be envisaged.

One first implementation, schematically depicted in figure 2, consists in generating pulsed air jets 17 by means of a pulsed jet actuator 23 using compressed air from an external source. Said compressed air may be provided by an auxiliary air compressor situated within the vehicle 3. As an example, in long-haul trucks, the compressor system used for the braking system can be used for generating air jets, especially on highways where braking is not used and vehicle is heading at high speeds. The compressed air is carried to the actuator 23, which can consist of a solenoid valve that can control the frequency $F$ of the pulsed jets 17 blown into the atmosphere by the opening 16.

In order to optimize the system efficiency, air can preferably be pressurized around one bar. The compression value is of importance because it sets the jet velocity $U_{jet}$ and thus the air jet stroke length as previously explained. It has to be noted that one bar is a relatively low pressure, resulting in a very low energy consumption of the aerodynamic system 1 of the
invention. This advantage over bigger energy consuming aerodynamic systems of the prior art is not reached at the expense of the aerodynamics improvement.

Optimizing the internal shape of the duct 14, as previously described, further helps improving the system efficiency especially when pulsed jets are used. In particular, designing the duct internal shape so that it generates very low pressure losses makes it possible to use such a low pressure of compressed air.

Another implementation consists in using synthetic jets instead of pulsed jets. Figures 9, 10 and 14 show an air jet generating system 12 comprising a synthetic jet actuator 37 which comprises a diaphragm 38 moving between two positions for instance downward and upward within a cavity 39 which opens into the duct 14. In a first phase, when the diaphragm 38 is moving downward (figure 9), the volume of the cavity 39 increases, and thus the pressure inside the cavity 39 decreases. Hence, part of the external air included in the boundary layer is sucked into the cavity 39. In a second phase, when the diaphragm 38 is moving upward (figure 10), the volume of the cavity 39 decreases, and thus the pressure inside the cavity 39 increases, which generates air jets 17, similarly to jets obtained with a pulsed jet actuator. It is noticed, that in this implementation, that uses a synthetic jet actuator 37, the gas jets are necessary jets of air.

One advantage of this implementation is that there is no need for an external compressed air source, which facilitates the system implementation on a vehicle 3 and which, for instance, facilitates the integration of air jet generating system 12 in said system aerodynamic device 30 when the aerodynamic system is designed as a modular system. Another advantage is that, during the second phase, the aspiration makes it possible to decrease the pressure on the guiding surface 20. This results in an easier deflection of the incoming flow.

In the embodiment of figure 14, the duct 14 is cancelled and the opening 16 is directly connected to the cavity 39, in this case the opening 16 is oriented so that air jet is blown in the atmosphere in a rearward and outward direction.

This implementation, that uses a synthetic jet actuator 37, may be also used for passenger vehicles.
Variants of the first embodiment are illustrated in figures 11 and 12.

According to a first variant, shown in figure 11, the aerodynamic system 1 comprises an aerodynamic device 30 which is similar to the one of figure 3 with the following difference.

The opening 16 is located on the guiding surface 20 at a distance l from the junction 29 between the leading surface 24 and the guiding surface 20. The distance l between the opening 16 and said junction is preferably inferior to 20 mm.

In other words, the opening 16 is offset rearward with respect to the downstream edge 28 of the leading surface 24.

If l > 20 mm, the periodic vortex structures generated by the aerodynamic system 1 would not be efficient insofar as they would be injected in a recirculation region. Thus, the vortex structures would not reach the upper layers of the incoming airflow.

Preferably, the successive leading surface 24 and guiding surface 20, form a smooth shape substantially devoid of discontinuity, gap, or unevenness (except the opening 16) that might generate an extra flow separation.

As shown in figure 11, the aerodynamic device 30 – or the plurality of aerodynamic devices 30 forming adjacent modules – can be mounted on the vehicle top wall 9 so as not to extend beyond the vehicle rear wall 13. Thus, the trailing edge 33 of the guiding surface 20 can be located substantially in the same plane as the vehicle top wall 9, thereby reducing the overall length of the vehicle 3 equipped with the aerodynamic system 1 according to the invention.

Of course, alternatively, the aerodynamic device 30 of figure 11 could be mounted as shown in figure 2, and the aerodynamic device 30 of figures 2-7 could be mounted as shown in figure 11.

According to a second variant, shown in figure 12, the aerodynamic system 1 comprises an aerodynamic device 30 which can be similar to the one of figure 3 but does not include a leading surface 24.

In this case, the aerodynamic system 1 comprises a leading surface which is constituted by the portion of the vehicle top wall 9 located
upstream from the opening 16. The opening 16 can therefore be arranged very close to the vehicle top rear edge 2.

Therefore, preferably, the aerodynamic device 30 – or the plurality of aerodynamic devices 30 forming adjacent modules – is mounted on the upper portion of the vehicle rear wall 13, immediately below the vehicle top rear edge 2. As a result, there is no downward step between the downstream portion of the vehicle top wall 9, forming the leading surface 24, and the guiding surface 20, resulting in a smooth surface.

Means can be provided to allow the rear door opening despite the aerodynamic devices 30.

Reference is now made to figure 13 which illustrates a further embodiment of the invention.

According to this second embodiment, there is not provided an aerodynamic device separated from the vehicle. On the contrary, the top rear edge of the vehicle 3 is bevelled and forms the guiding surface 20 of the aerodynamic system 1, while the portion of the vehicle top wall 9 located upstream from the opening 16 forms the leading surface 24.

The bevelled portion of the vehicle 3 can be a movable part, in particular to ensure an unchanged cargo volume and to allow the rear door opening.

The invention allows a non negligible aerodynamic drag reduction and therefore significant fuel savings, especially for box-shaped ground vehicles equipped with said aerodynamic system.

With an aerodynamic system comprising a separate aerodynamic device, preferably designed as a modular kit, no main changes are required on the conventional box shape geometry. Modules can be assembled to cover the whole width of the vehicle as well as the sides if needed. Moreover, modules can preferably be mounted on the vehicle in such a way that they do not obstruct trailer rear base doors handling. Furthermore, regarding more specifically the long-haul truck application, the dimensions of the aerodynamic device allow staying in line with the new coming legislation dealing with maximum trucks dimensions.

The aerodynamic device 30 can, for example, be made of an plastic material by an injection moulding process and can be made into several parts.
The invention is of course not limited to the embodiments described above as examples, but encompasses all technical equivalents and alternatives of the means described as well as combinations thereof.
CLAIMS

1. An aerodynamic system designed to be arranged near at least one rear edge (2, 42, 43) of a box-shaped rear portion of a vehicle (3), said aerodynamic system (1) comprising, in the operative position:
   - at least one gas jet generating system (12) able to generate jets of gas (17);
   - at least one outer surface (45) along which air flow generated by at least the forward motion of the vehicle is flowing;
   - at least one opening which opens onto the outer surface (45) and which is connected to said at least one gas jet generating system (12) in order to blow jets of gas (17) in the atmosphere and to influence said air flow;

   wherein:
   - the opening (16) being designed and/or oriented to blow jets of gas (17) rearward;
   - the outer surface (45) comprising at least a guiding surface (20) extending at least partially downstream from said opening (16) and oriented inwards from front to rear, in order to guide said influenced air flow downstream from the opening (16);
   - said gas jet generating system (12) being designed to discontinuously generate jets of gas (17) at a frequency F that is higher than 100 Hz, that is preferably comprised between 200 Hz and 1000 Hz and more preferably between 200 Hz and 450 Hz.

2. The aerodynamic system according to claim 1, characterized in that it is designed to be arranged near the top edge (2) of the box-shaped rear portion of the vehicle (3).

3. The aerodynamic system according to claim 1 or 2, characterized in that the gas jet velocity (U.jet), at the opening (16), satisfies the following equation: U.jet / U ≥ 0.15, and preferably U.jet / U ≥ 0.3 wherein U.jet is the gas jet velocity and U is a parameter corresponding at least to the
vehicle speed in the forward direction, U is preferably a relative vehicle speed taking into account the wind speed.

4. The aerodynamic system according to any one of claim 1 to 3, characterized in that the opening (16) is formed as a slot extending in a transverse direction of the vehicle when it is arranged on a vehicle and the opening has a thickness (e) that ranges from 0.5 to 5 mm.

5. The aerodynamic system according to any one of claim 1 to 4, characterized in that said opening (16) is connected to the gas jet generating system (12) through a duct (14) having a first end (15) connected to said gas jet generating system and a second end which extends rearward and outward to form the opening (16).

6. The aerodynamic system according to any one of claim 1 to 5, characterized in that the outer surface (45) further comprises a leading surface (24) located upstream from the opening (16), said leading surface (24) being arranged substantially horizontally or progressively sloping from rear (242) to front (241) with respect to the horizontal at a maximum angle of 90° or being inclined with respect to the horizontal with an angle inferior to 15°, in the operative position.

7. The aerodynamic system according to claim 6, characterized in that said leading surface (24) progressively slopes from rear to front with a maximum rear angle (α2) of 10° and preferably with a front angle (α1) comprised between 45 and 90° with respect to the horizontal in the operative position of the aerodynamic system.

8. The aerodynamic system according to claim 6 or 7, characterized in that, from front to rear, the guiding surface (20) makes an angle (α3) with the downstream portion (25) of the leading surface (24) which is comprised between 5 and 40°, preferably between 12 and 25°.

9. The aerodynamic system according to claim 6, 7 or 8, characterized in that, the opening (16) is oriented so that its central axis (44) makes an angle (β) with the downstream portion (25) of the leading
surface (24) which is comprised between 90 and 170°, preferably between 120 and 150°, and for example around 135°.

10. The aerodynamic system according to any one of claims 6 to 9, characterized in that the opening (16) is located substantially at the junction (29) between the leading surface (24) and the guiding surface (20).

11. The aerodynamic system according to any one of claims 6 to 9, characterized in that the opening (16) is located on the guiding surface at a distance (l) from the junction (29) between the leading surface (24) and the guiding surface (20) with the distance (l) between the opening (16) and said junction being inferior to 20 mm.

12. The aerodynamic system according to any one of claims 1 to 11, characterized in that the guiding surface (20) substantially forms a flat flap.

13. The aerodynamic system according to any one of claims 1 to 12, characterized in that the length (L) of the guiding surface (20), along the longitudinal direction in the operative position, is comprised between 5 and 150 cm, preferably between 20 and 70 cm, for example around 50 cm.

14. The aerodynamic system according to any one of claims 1 to 13 in combination with claim 5, characterized in that the duct cross section area progressively decreases from the first end (15) towards the second end (16), the ratio R=S1/S2 being lower than 1,5, where S1 is the duct cross section area at its first end (15) and S2 is the duct cross section area at its second end (16).

15. The aerodynamic system according to any one of claims 1 to 14 in combination with claim 5, characterized in that the duct cross section area is substantially constant from the first end (15) towards the second end (16).

16. The aerodynamic system according to any one of claims 1 to 15 in combination with claim 5, characterized in that the duct first end (15) is
substantially circular and the duct second end (16) is substantially rectangular so that the opening forms a transverse slot.

17. The aerodynamic system according to any one of claims 1 to 16, characterized in that it further comprises an electronic control unit (22) coupled to at least one actuator (23) of the gas jet generating system (12) in order to control the gas jet generating system operation.

18. The aerodynamic system according to claim 17, characterized in that the electronic control unit (22) controls the gas jet generating system operation according to at least one operating condition, such as the vehicle speed, the vehicle acceleration or deceleration, the activation of braking or retarding devices of the vehicle.

19. The aerodynamic system according to any one of claims 1 to 18, characterized in that it comprises an aerodynamic device (30) which includes the opening (16), the guiding surface (20) and the leading surface (24) when present, said aerodynamic device (30) being separated from the vehicle (3) and being designed to be mounted onto a rear top surface (91) or onto a rear side surface (101) of the box-shaped rear portion of the vehicle (3), preferably near a rear edge (2, 42, 43) thereof.

20. The aerodynamic system according to the preceding claim, characterized in that the aerodynamic device comprises, opposite to the opening (16), the guiding surface (20) and opposite to the leading surface (24), a mounting surface (31), substantially flat, and in that the aerodynamic device is mounted onto a rear top surface or onto a rear side surface of the box-shaped rear portion of the vehicle via said mounting surface (31).

21. The aerodynamic system according to the preceding claim characterized in that the height (h1) of the aerodynamic device (30) measured in a direction perpendicular to the mounting surface (31) is comprised between 20 and 300 mm and preferably between 40 and 150 mm.

22. The aerodynamic system according to the preceding claim characterized in that the opening (16) is located at distance (h2) from said
mounting surface when measured in a direction perpendicular to the mounting surface (31).

23. The aerodynamic system according to any one of claims 19 to 22 characterized in that the jet generating system (12) is arranged in said aerodynamic device (30).

24. A vehicle having a box-shaped rear portion such as a trailer, characterized in that it comprises at least one aerodynamic system (1) according to any one of claims 19 to 23, wherein said aerodynamic device (30) is mounted onto a rear top surface (91) of the box-shaped rear portion of the vehicle and/or is mounted onto a rear side surface (101) of the box-shaped rear portion of the vehicle such that it projects outside from the box-shaped rear portion and such that the opening (16) is at distance (h2), measured in a direction perpendicular to the mounting surface (31), from said rear top surface (91) or said rear side surface (101).

25. The vehicle according to claim 24, characterized in that it comprises one or a plurality of aerodynamic devices (30) mounted next to each other on the vehicle (3) and near the top rear edge (2) of the vehicle, so as to substantially cover the whole width of the vehicle rear portion.

26. A method for reducing a vehicle drag, especially for a vehicle (3) having a box-shaped rear portion, the method comprising:

- arranging an aerodynamic system (1) near at least one rear edge (2) of the vehicle (3), preferably near the top rear edge of the vehicle, said aerodynamic system (1) comprising:
  - at least one gas jet generating system (12) able to generate jets of gas (17);
  - at least one outer surface (45) along which air flow generated by at least the forward motion of the vehicle is flowing;
  - at least one opening (16) which opens onto the outer surface (45) and which is connected to said at least one gas jet generating system (12) in order to blow jets of
gas (17) in the atmosphere to influence air flow flowing along the outer surface;

wherein:

- the opening (16) being designed and/or oriented to blow jets of gas rearward;
- the outer surface (45) comprises at least a guiding surface (20) extending at least partially downstream from said opening (16) and oriented inwards from front to rear, in order to guide said influenced air flow downstream from the opening (16);
- discontinuously generating jets of gas (17) at a frequency $F$ which is higher than 100 Hz, that is preferably comprised between 200 Hz and 1000 Hz and more preferably between 200 Hz and 450 Hz.

27. The method according to claim 26, characterized in that gas jets (17) are generated only when the vehicle speed $U$ is higher than a determined threshold $U_{th}$, $U_{th}$ being higher than 50 km/h, for example around 60 km/h.

28. The method according to claim 26 or claim 27, characterized in that it comprises stopping the generation of jets of gas (17) when the vehicle deceleration is higher than a threshold value, for instance 2 km/h/s, or when a braking or retarding device of the vehicle is activated.

29. The aerodynamic system according to any one of the preceding claims, characterized in that the gas jet generating system (12) generates jets of air or jets of gas having the same density than air.
Fig. 3

Fig. 4
\[ \Delta C_d \ [\cdot] \]

**Fig. 8a**

![Graph](image1)

\[ F \ (Hz) \]

- Positive
- Negative
- Zero

**Fig. 8b**

\[ \Delta C_d \ [\cdot] \]

- Positive
- Negative
- Zero

\[ U_{jet}/U \]

- 0
- 0.15
- 0.16
**INTERNATIONAL SEARCH REPORT**

**A. CLASSIFICATION OF SUBJECT MATTER**

INV. B62D35/00  B62D37/02

ADD.

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)

B62D

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

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

EPO-Internal, WPI Data

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

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Further documents are listed in the continuation of Box C. See patent family annex.

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**Date of the actual completion of the international search**

30 July 2014

**Date of mailing of the international search report**

06/08/2014

**Name and mailing address of the ISA/**

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**Authorized officer**

Tiedemann, Dirk

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</tbody>
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