Abstract: For establishment of a laminar attachment line flow, the invention proposes an aircraft wing (10) comprising: a leading edge (12), the leading edge (12) including an attachment line (14), being a region where air impinging on the region flows in a boundary layer spanwise along the leading edge (12), a first slat (22) and a second slat (24), wherein the leading edge (12) and the attachment line (14) are at least partially formed at the first and second slats (22, 24), the second slat (24) is located adjacent to the first slat (22) in the downstream direction of the attachment line flow, so that the leading edge (12) includes a slat-to-slat junction (26), and a slat cavity (30) is formed at the slat-to-slat junction (26) beneath a skin area (36) of at least one of the first and the second slats (22, 24), and a duct (38) having a duct entrance (40) at the slat-to-slat junction (26) for receiving spanwise flow along the leading edge (12) of the wing (10), the duct (38) being at least partly formed by said slat cavity (30), wherein the duct entrance (40) extends around the leading edge (12) and over the range of positions of the attachment line (14) at the slat-to-slat junction (26).
Aircraft wing with system establishing a laminar boundary layer flow

The invention relates to an aircraft wing. Especially the invention relates to an aircraft wing having a system or device for establishment of laminar boundary layer flow on said wing.

The wing of a conventional aircraft has movable devices called slats positioned along the leading edge of the wing to improve high lift performance. The slats are retracted in the cruise phase of the flight. At the leading edge of an aft swept wing - which is typical for transonic aircraft - there is a spanwise flow from wing root to tip above which the air flows over the upper surface and below which the air flows over the lower surface. This flow is known as the attachment line flow. The presence of the leading edge slats or other types of movable high lift devices, e.g. droop nose devices, introduces surface discontinuities (steps and gaps) on the leading edge in the spanwise direction. The presence of these discontinuities means that the spanwise attachment line flow will be turbulent (rather than laminar) in the cruise flight phase.

Up to now, aircraft slats are designed so that in a slat-to-slat junction these surface discontinuities are as low as possible and that a smooth leading edge is provided. For example, slat seals are used in a junction area between adjacent slats.

It is known in the art that turbulences at the attachment line flow can disturb a boundary layer flow over an airfoil. It is especially referred to US 3,288,399 describing an arrangement in which a shaped "bump", having a bluff front end and an inclined rearward surface, is fitted to the leading edge. The bluff front creates a stagnation region whereby a laminar boundary layer is established on the rearward surface. Successful relaminarisation of a turbulent attachment line flow has been demonstrated using such known "bump" device in both wind-tunnel and flight experiments. However, such a bump only works provided the attachment line position on the leading edge is fixed during the cruise. This is the case for a fin, which has been shown in a laminar flow flight test using
Airbus A320, but not for a wing, as the attachment line position changes with aircraft lift and aircraft weight.

Laminarisation of a turbulent leading edge flow can also be achieved by surface suction to a porous skin. However, porous surfaces are expensive to manufacture, have complications relating to cleaning and icing, and may have a weight penalty due to the required pipe-work. Examples for such active suction systems can be found in US 6,216,982 B1 and EP 1 744 952 B1. Such suction systems normally are active systems that need a further pump or suction mechanism.

EP 2 091 814 B1 is considered to disclose the closest prior art. This document relates to an easy system for establishment of laminar boundary layer flow on an airfoil body which system is a passive system without use of additional pump means. This prior art proposes a kind of "bleeding slot". It is proposed to mount a plate to the leading edge. This plate forms - together with the airfoil leading edge region - a duct having a duct entrance for receiving spanwise flow along the leading edge of the airfoil body; a duct entrance extends around the leading edge and over the range of positions of the attachment line. Along the spanwise edges of this plate, duct exits are formed. Hence, this plate functions in flight such that attachment line flow air is drawn through the duct entrance and led upwards or downwards. Hence, a turbulent attachment line flow can be relaminarized.

Such a kind of plate as known from EP 2 091 814 B1 has been successfully tested; however, there are concerns about the integration of this plate onto the leading edge, its tolerance to damage, and the impact of the device on ice growth.

It is an object of the invention to provide an aircraft wing having a plurality of slats and being configured to enable a relaminarization of turbulent attachment line flow in a safe, cost-effective and simple manner.

This object is achieved by the subject-matter of the independent claim.
Advantageous embodiments of the invention are given in the dependent claims.

According to a preferred aspect of the invention, it is proposed to modify the slat geometry locally in the slat-to-slat junction to enable a laminar attachment line to be created and/or maintained in the spanwise direction.

Especially, the invention provides according to one aspect thereof an aircraft wing comprising:

- a leading edge, the leading edge including an attachment line being a region where air impinging on the region flows in a boundary layer spanwise along the leading edge,

- a first slat and a second slat, wherein the leading edge and the attachment line are at least partially formed at the first and second slats, wherein the second slat is located adjacent to the first slat in the downstream direction of the attachment line flow, so that the leading edge includes a slat-to-slat junction, wherein a slat cavity is formed at the slat-to-slat junction beneath a skin area of at least one of the first and the second slats forming a part of the leading edge, and

- a duct having a duct entrance at the slat-to-slat junction for receiving spanwise flow along the leading edge of the wing, the duct being at least partly formed by said slat cavity, wherein the duct entrance extends around the leading edge and over the range of positions of the attachment line at the slat-to-slat junction.

Preferably, a slat lip of the second slat, which slat lip extends at the slat-to-slat junction transverse to the leading edge, protrudes in the chordwise direction over an adjacent slat lip area of the first slat so that a step is formed between the first and second slats wherein said duct entrance comprises an orifice in said step.

Preferably, said skin area defining the slat cavity comprises said slat lips of at least one of the slats or is constituted by such slat lips. The slat lip area of the first slat may comprise an indentation for forming said step, said orifice being formed between said indentation and said slat lip of the second slat.
Preferably, the leading edge lines of the first and the second slats are offset to each other in a chordwise direction when seen in thickness direction of the wing for forming said step in the slat-to-slat-junction.

Preferably, said first and second slats are movable relatively to each other wherein the slat lip of the second slat is movable relatively to the adjacent lip area of the first slat in chordwise direction in order to change the entrance area of said orifice.

Preferably, said duct comprises a duct exit formed at a slat lower surface trailing edge, and said duct entrance comprises a slot in a leading edge skin surface of the second slat at the slat-to-slat junction wherein the slot communicates with the slat cavity and extends in the wing thickness direction.

The duct may be configured as passive boundary layer flow influencing device such that, during flight, an air pressure lower than the air pressure at the leading edge is established within the duct so that air is drawn through the duct entrance without the use of a pump mechanism.

Preferably, the aircraft wing is an aft swept wing with an inboard slat as first slat and an outboard slat as second slat, but it may also be a forward swept wing with an outboard slat as the first slat and an inboard slat as the second slat.

According to some embodiments, the outboard edge of the inboard slat has a depression that exposes the inboard edge of the outboard slat. This inboard edge of the outboard slat is shaped to allow a laminar attachment line flow to form.

When compared to conventional designs of slat-to-slat junctions of a conventional air-wing, slat seals can be repositioned or modified to allow for some air to flow under the inboard edge of the outboard slat, which air can be exhausted onto the wing lower surface along the slat lower surface trailing edge, for example.
Rather than having a depression, a further embodiment proposes to slightly rotate the slats about a vertical axis (axis directed in a thickness direction of the aircraft wing) to expose the inboard edge of the outboard slat.

According to still another embodiment, an alternative concept is to incorporate a slot into at least one of the slats to allow for air flow to create a laminar attachment line.

The drag (and therefore fuel consumption) of the aircraft can be reduced by ensuring that the attachment line flow is laminar. The drag benefit or drag reduction may be in the order of 0.5-1.5% of the total aircraft drag without the device.

The proposed embodiments exploit the existing features of the slat structure without having to add an additional plate as required by EP 2 091 814 B1. By having an integrated design, there is no issue of managing the discontinuity of the plate with the leading edge surface. The integrated design is more tolerant to damage. Ice growth can be avoided using the existing slat thermal ice protection system.

Especially, the invention relates to a new slat design for laminar flow.

Embodiments of the invention will be described, by way of example only, with reference to the accompanying drawings, wherein

- Fig. 1 is a perspective view of a leading edge region of an aircraft wing having a first slat and a second slat and showing a first embodiment of the invention;
- Fig. 2 shows a sectional view through a slat-to-slat junction region of the aircraft wing of Fig. 2, taken along an attachment line plane extending in the spanwise and chordwise directions;
- Fig. 3 is a top plan view of a conventional aircraft wing having several slats with a conventional slat rigging;
- Fig. 4 shows a sectional view of the detail D of Fig. 3 illustrating the slat-to-slat junction area in the conventional slat design;
Fig. 5 is a top plan view of an aircraft wing according to a further embodiment of the invention having slats which are re-rigged by rotation (exaggerated for illustration purposes);

Fig. 6 shows the view similar as in Fig. 4 of the detail D of Fig. 5 illustrating the slat-to-slat junction in the aircraft wing according to the embodiment of the invention; and

Fig. 7 is a perspective view similar to Fig. 1 showing an aircraft wing according to still another embodiment of the invention.

Fig. 1, 2, 5, 6 and 7 show embodiments of aircraft wings 10 according to the invention. The aircraft wings 10 are swept aircraft wings of an aircraft having a leading edge 12 including an attachment line 14. The attachment line 14 is a region where air impinging on the region flows in a boundary layer spanwise along the leading edge 12.

Above the attachment line 14, air 15 flows over the upper surface 16 of the aircraft wing 10. Below the attachment line 14, air 17 flows over the lower surface 18 of the aircraft wing 10. Along the leading edge 12, the aircraft wing 10 has an arrangement 20 of a plurality of slats which are configured to improve highlift performance.

The slat arrangement 20 has at least a first slat 22 and a second slat 24 with a slat-to-slat junction 26 therebetween.

As indicated in Fig. 5, the slat arrangement 20 may have more than two slats, such as three, four, five or more slats.

When looking to the attachment line flow that flows along the leading edge 12 from the wing root 28 in a spanwise direction to the tip 29 of the aircraft wing 10, a first slat 22 which is located more inboard, nearer to the wing root 28, can also be referred to as "inboard slat" or as "upstream slat", while the second slat 24, which is located adjacent to the first slat 22 downstream in the direction of the attachment line flow, can be referred to as the or an "outboard slat" or "downstream slat".
In Fig. 2, a sectional view of the area around the slat-to-slat junction 26 is shown. As shown there, the first and second slats 22, 24 have lips 32, 34 extending to each other with the transition line between the slats 22, 24 therebetween wherein a slat cavity 30 is formed beneath these slat lips 32, 34.

The slat lips 32, 34 form a skin area 36 which forms a part of the leading edge 12 of the aircraft wing 10 at the slat-to-slat junction 26.

According to the embodiments of the invention, the slat geometry is modified in the slat-to-slat junction 26 to enable a laminar attachment line to be created or maintained in the spanwise direction.

The slat geometry is configured such that a duct 38 is formed which duct 38 is at least partly formed using the slat cavity 30 and having a duct entrance 40 at or near the slat-to-slat junction 26. The duct entrance 40 extends around the leading edge 12 and over the range of positions of the attachment line 14, as this is in principle explained for another construction in EP 2 091 814 B1.

However, according to the embodiments of the invention, the slat-to-slat junction 26 between a first slat 22 and a second slat 24 is used for forming the duct entrance 40.

A first embodiment is shown in Fig. 1 and 2. As shown therein, the slat lip 34 of the second slat 24 is protruding in the chordwise direction at the leading edge over an adjacent area of the slat lip 32 of the first slat 22. Hence, a step 42 is formed between the slat lip 34 of the second slat 24 and the slat lip 32 of the first slat 22. The duct entrance 40 comprises an orifice 44 which is formed within this step 42. In the embodiments shown, this orifice 44 is formed between the slat lip 34 of the second slat 24 and the slat lip 32 of the first slat 22 which is depressed or indented in chordwise direction.

As shown in Fig. 1 and 2, an outboard edge 46 of the inboard slat 22 has a depression 48 or indentation 50 that exposes the inboard edge 52 of the outboard slat 24. This inboard edge 52, formed by the slat lip 34, is configured and shaped to allow a laminar attachment line to form.
Slat seals (not shown) are arranged and positioned such that the orifice 44 is formed to allow for some air to flow under the inboard edge 52 into the duct 38 at least partly formed by the slat cavity 30. This air can be exhausted onto the lower surface 18 along the lower surface trailing edge 58 of at least one of the slats 22, 24.

Figs. 5 and 6 show a further embodiment of the aircraft wing 10 according to the invention, wherein the step 52 with the orifice 44 is used as well. However, rather than having a depression 48, the slats 22, 24 (and a third slat 60 in this embodiment) are slightly rotated about vertical axes 62.

Fig. 3 and 4 show a conventional slat rigging wherein the slats 22, 24, 60 are rigged such that their leading edges are in line. Fig. 4 shows a slat-to-slat junction 26 of this conventional slat rigging, it is shown that there is a smooth transition between the slats.

When compared with this conventional slat design, the slats 22, 24, 60 of the embodiment of Fig. 5 and 6 are rotated about the vertical axes 62 so that the leading edges of the slats 22, 24, 60 are offset to each other in the chordwise direction. Hence, the inboard edges 52 of the outboard slats 24, 60 are protruding in chordwise direction more to the front over the outboard edges 46 of the adjacent inboard slats 22, 24. Hence, the step 42 with the orifice 44 is formed, and the slat cavity 30 functions as duct 38 for establishing a laminar attachment line flow.

According to a special embodiment, the rotation which is illustrated in Fig. 5 can be controlled or initiated by actors (not shown). Hence, the relaminarization of the attachment line can be switched on or off or can be controlled by changing the step 42 and changing the entrance area of the orifice 44.

Fig. 7 shows a third embodiment of the aircraft wing 10. In this embodiment, the duct entrance 40 comprises a slot 64 extending in the thickness direction of the aircraft wing 10 at the slat-to-slat junction 26 in fluid communication with the slat cavity 30. For example, the slot 64 is formed in the second slat 24 (i.e. the
outboard slat) so that disturbances caused by the transition between the slats 22, 24 are handled immediately by drawing air through the slot 64.

The slot 64 is a suction slot at the attachment line 14. The suction is driven by natural pressure difference in the slat cavity 30. Hence, a passive relaminarization system is formed thereby without need for additional suction means.

Further, there is shown in Fig. 7 an exhaust slot 66 functioning as a duct exit 68 of the duct 38. The exhaust slot 66 can be inboard or outboard from the suction slot 64.

Alternatively, seals may be arranged to allow the air to exhaust at 58.

Preferably, duct exits 68 are formed such that air drawn into the slat cavity 30 is exhausted onto the lower surface 18.
### List of Reference Signs

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<th>Sign</th>
<th>Description</th>
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<td>10</td>
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<tr>
<td>12</td>
<td>Leading edge</td>
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<td>14</td>
<td>Attachment line</td>
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<td>Upper surface</td>
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<td>22</td>
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<tr>
<td>24</td>
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<td>Slat-to-slat junction</td>
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<tr>
<td>28</td>
<td>Wing root</td>
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<tr>
<td>29</td>
<td>Wing tip</td>
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<tr>
<td>30</td>
<td>Slat cavity</td>
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<td>32</td>
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<td>34</td>
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<td>36</td>
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<td>44</td>
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<td>48</td>
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<td>60</td>
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<td>62</td>
<td>Vertical axis</td>
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<tr>
<td>64</td>
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<td>66</td>
<td>Exhaust slot</td>
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<tr>
<td>68</td>
<td>Duct exit</td>
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Claims

1. An aircraft wing (10) comprising:
a leading edge (12), the leading edge (12) including an attachment line (14)
being a region where air impinging on the region flows in a boundary layer
spanwise along the leading edge (12),
a first slat (22) and a second slat (24) wherein the leading edge (12) and
the attachment line (14) are at least partially formed at the first and second
slats (22, 24), wherein the second slat (24) is located adjacent to the first
slat (22) in the downstream direction of the attachment line flow, so that the
leading edge (12) includes a slat-to-slat junction (26), wherein a slat
cavity (30) is formed at the slat-to-slat junction (26) beneath a skin
area (36) of at least one of the first and the second slats (22, 24), and
a duct (38) having a duct entrance (40) at the slat-to-slat junction (26) for
receiving spanwise flow along the leading edge (12) of the wing (10), the
duct (38) being at least partly formed by said slat cavity (30), wherein the
duct entrance (40) extends around the leading edge (12) and over the
range of positions of the attachment line (14) at the slat-to-slat junction (26).

2. An aircraft wing (10) according to claim 1,
characterized in that a slat lip (34) of the second slat (24) which slat lip (34)
extends at the slat-to-slat junction (26) transverse to the leading edge (12)
is protruding in the chordwise direction over an adjacent slat lip area of the
first slat (22) so that a step (42) is formed between the first and second
slats (22, 24) wherein said duct entrance (40) comprises an orifice (44) in
said said step (42).

3. An aircraft wing (10) according to claim 2,
characterized in that said slat lip area of the first slat (22) comprises an
indentation (50) for forming said step (42) and that said orifice (44) is
formed between said indentation (50) and said slat lip (34) of the second
slat (24).
4. An aircraft wing (10) according to claim 2 or 3,
   characterized in that said leading edge lines of the first and second slats
   (22, 24) are offset to each other in a chordwise direction when seen in
   thickness direction of the wing (10) for forming said step (42) in the slat-to-
   slat-junction (26).

5. An aircraft wing (10) according to any of the claims 2 or 4,
   characterized in that said first and second slats (22, 24) are movable
   relatively to each other, wherein the slat lip (34) of the second slat (24) is
   movable relatively to the adjacent lip area of the first slat (22) in the
   chordwise direction in order to change the entrance area of said orifice (44).

6. An aircraft wing (10) according to any of the preceding claims,
   characterized in that said duct comprises a duct exit formed at a slat lower
   surface trailing edge.

7. An aircraft wing according to any of the preceding claims,
   wherein said duct entrance (40) comprises a slot (64) in a leading edge skin
   surface of the second slat (24) at the slat-to-slat junction (26) wherein the
   slot (64) communicates with the slat cavity (30) and extends in the wing
   thickness direction.

8. An aircraft wing (10) according to any of the preceding claims,
   wherein the duct (38) is configured as passive boundary layer flow
   influencing device such that, during flight, an air pressure lower than the air
   pressure at the leading edge (12) is established within the duct (38) so that
   air is drawn through the duct entrance (40) without use of an additional
   suction or pump mechanism.
INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER
INV. B64C21/02 B64C21/06 B64C9/24

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)
B64C

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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<td>wo 2008/075106 AI (GASTER CONSULTANTS LTD [GB]; GASTER MICHAEL [GB]) 26 June 2008 (2008-06-26) cited in the application on the whole document</td>
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Further documents are listed in the continuation of Box C.

X See patent family annex.

* Special categories of cited documents:
  "A" document defining the general state of the art which is not considered to be of particular relevance
  "E" earlier application or patent not published on or after the international filing date
  "L" document on which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
  "O" document referring to an oral disclosure, use, exhibition or other means
  "P" document published prior to the international filing date but later than the priority date claimed
  "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
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  "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
  "Z" document member of the same patent family

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12 November 2013

Date of mailing of the international search report
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Authorized officer
Sal entny, Gerard
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