



(86) Date de dépôt PCT/PCT Filing Date: 2009/02/17

(87) Date publication PCT/PCT Publication Date: 2009/09/03

(85) Entrée phase nationale/National Entry: 2010/07/26

(86) N° demande PCT/PCT Application No.: GB 2009/050152

(87) N° publication PCT/PCT Publication No.: 2009/106871

(30) Priorité/Priority: 2008/02/29 (GB0803724.4)

(51) Cl.Int./Int.Cl. *B64C 23/04* (2006.01)

(71) Demandeur/Applicant:
AIRBUS UK LIMITED, GB

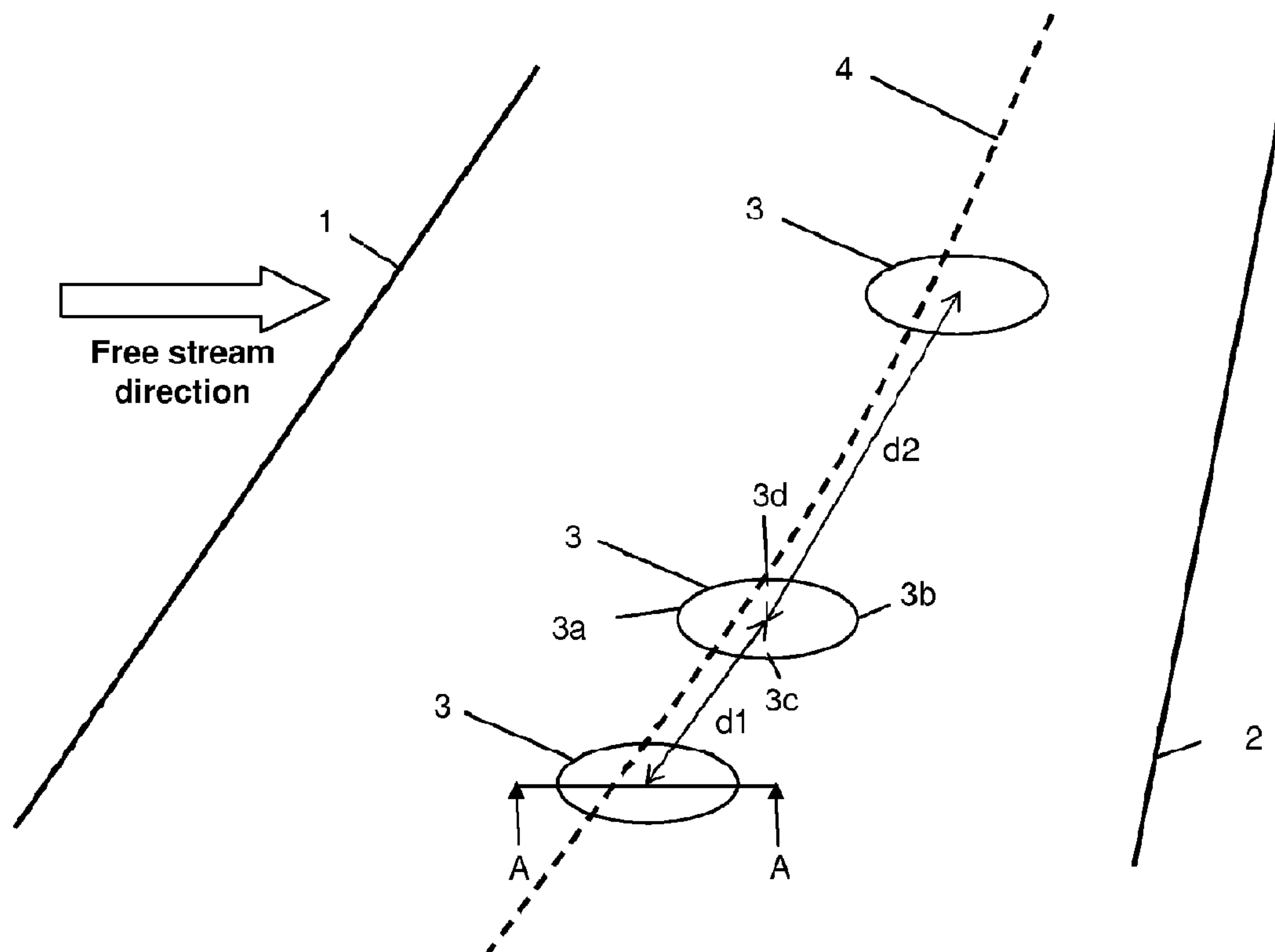
(72) Inventeur/Inventor:
WOOD, NORMAN, GB

(74) Agent: OYEN WIGGS GREEN & MUTALA LLP

(54) Titre : STRUCTURE AERODYNAMIQUE COMPORTANT DES BOSSES ANTICHOCS ESPACEES DE FACON NON UNIFORME

(54) Title: AERODYNAMIC STRUCTURE WITH NON-UNIFORMLY SPACED SHOCK BUMPS

Figure 1



(57) Abrégé/Abstract:

An aerodynamic structure comprising a series of shock bumps (3) extending from its surface. The shock bumps are distributed across the structure with a non-uniform spacing (d1, d2) between the centres and/or edges of adjacent bumps. The non-uniform



(57) **Abrégé(suite)/Abstract(continued):**

spacing between the bumps can be arranged to give maximum wave drag alleviation for the minimum number of bumps as a function of the shock strength across the span, leading to minimum wing weight penalties for a given amount of wave drag alleviation.

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau



(43) International Publication Date
3 September 2009 (03.09.2009)

(10) International Publication Number
WO 2009/106871 A3

(51) International Patent Classification:
B64C 23/04 (2006.01)

(21) International Application Number:
PCT/GB2009/050152

(22) International Filing Date:
17 February 2009 (17.02.2009)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
0803724.4 29 February 2008 (29.02.2008) GB

(71) Applicant (for all designated States except US): **AIRBUS UK LIMITED** [GB/GB]; New Filton House, Bristol BS99 7AR (GB).

(72) Inventor; and

(75) Inventor/Applicant (for US only): **WOOD, Norman** [GB/GB]; Airbus UK Limited, Filton, Bristol BS99 7AR (GB).

(74) Agent: **SCOTT, Alistair**; IP Dept, Building 09A, New Filton House, Filton, Bristol BS99 7AR (GB).

(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM,

AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

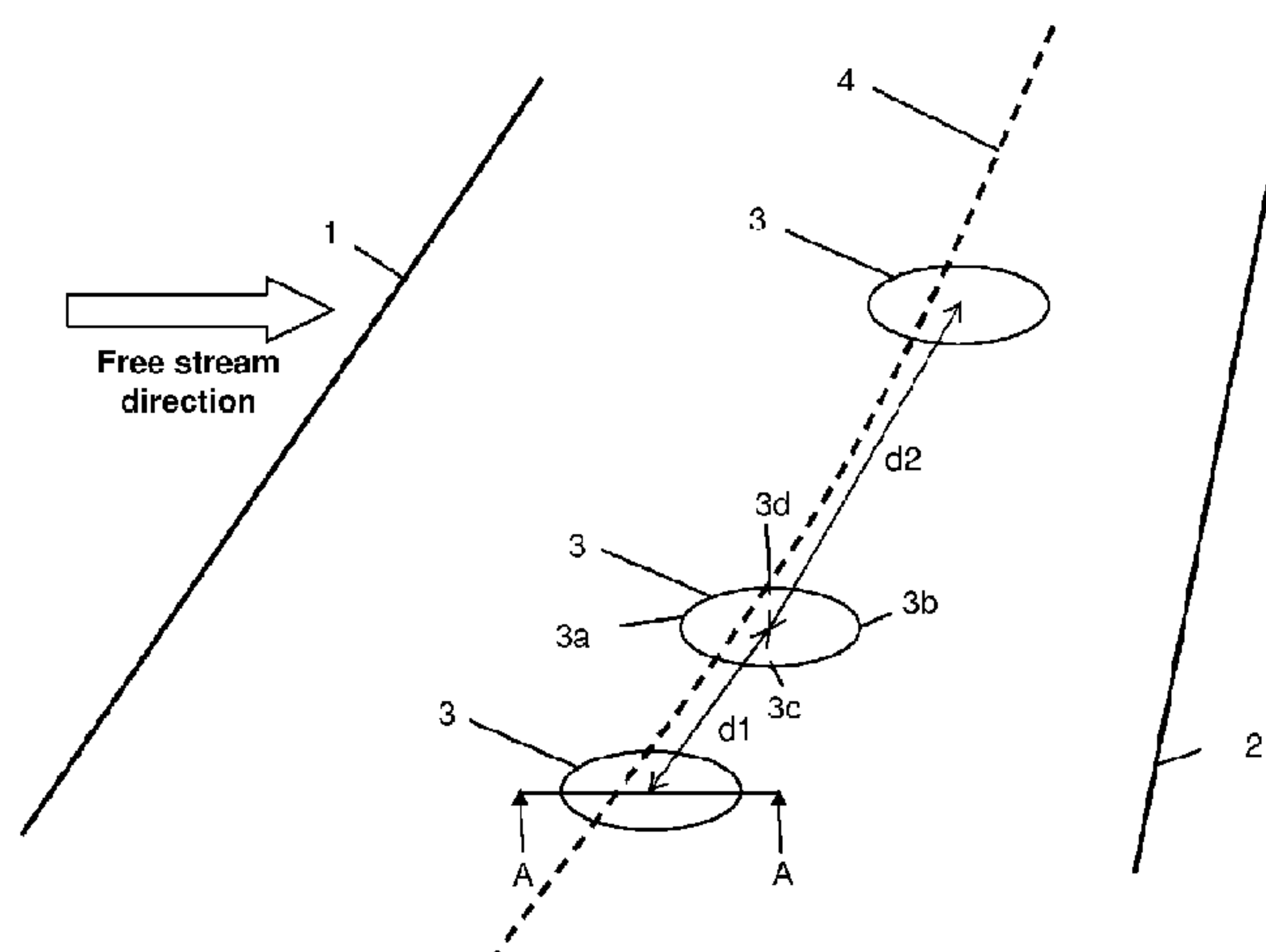
Published:

— with international search report (Art. 21(3))

(88) Date of publication of the international search report:
19 November 2009

(54) Title: AERODYNAMIC STRUCTURE WITH NON-UNIFORMLY SPACED SHOCK BUMPS

Figure 1



(57) Abstract: An aerodynamic structure comprising a series of shock bumps (3) extending from its surface. The shock bumps are distributed across the structure with a non-uniform spacing (d_1 , d_2) between the centres and/or edges of adjacent bumps. The non-uniform spacing between the bumps can be arranged to give maximum wave drag alleviation for the minimum number of bumps as a function of the shock strength across the span, leading to minimum wing weight penalties for a given amount of wave drag alleviation.

AERODYNAMIC STRUCTURE WITH NON-UNIFORMLY SPACED SHOCK BUMPS

5 FIELD OF THE INVENTION

The present invention relates to an aerodynamic structure comprising a series of shock bumps extending from its surface, and a method of operating such a structure.

BACKGROUND OF THE INVENTION

As described in Holden, H.A. and Babinsky, H. (2003) *Shock/boundary layer*
10 *interaction control using 3D devices* In: 41st Aerospace Sciences Meeting and Exhibit, January 6-9, 2003, Reno, Nevada, USA, Paper no. AIAA 2003-447, as a transonic flow passes over a 3-D shock bump the supersonic local conditions induce a smeared shock foot with a lambda-like wave pattern.

Conventionally a series of such bumps is distributed across the structure with a
15 uniform spacing.

US 2006/0060720 uses a shock control protrusion to generate a shock extending away from the lower surface of a wing.

SUMMARY OF THE INVENTION

A first aspect of the invention provides an aerodynamic structure comprising a series
20 of shock bumps extending from its surface, wherein the shock bumps are distributed across the structure with a non-uniform spacing between adjacent bumps.

Typically each bump has a leading edge, a trailing edge, an inboard edge and an outboard edge. The bumps may merge gradually into the surface at its edges or there may be an abrupt concave discontinuity at one or more of its edges.

25 Typically each bump has substantially no sharp convex edges or points.

Typically the shock bumps are shaped and positioned so as to modify the structure of a shock which would form adjacent to the surface of the structure in the absence of the

shock bumps when the structure is moved at transonic speed. This can be contrasted with US 2006/0060720 which uses a shock control protrusion to generate a shock which would not otherwise exist in the absence of the shock control protrusion.

5 A second aspect of the invention provides a method of operating the structure of the first aspect of the invention, the method comprising moving the structure at a transonic speed; forming a shock adjacent to the series of shock bumps; and modifying the structure of the shock with the shock bumps.

The shock bumps may be distributed with a non-uniform spacing between adjacent bump centres and/or between adjacent bump edges.

10 The structure may comprise an aerofoil such as an aircraft wing, horizontal tail plane or control surface; an aircraft structure such as a nacelle, pylon or fin; or any other kind of aerodynamic structure such as a turbine blade.

In the case of an aerofoil the shock bumps may be located on a high pressure surface of the aerofoil (that is, the lower surface in the case of an aircraft wing) but more
15 preferably the surface is a low pressure surface of the aerofoil (that is, the upper surface in the case of an aircraft wing). Also each bump typically has an apex which is positioned towards the trailing edge of the aerofoil, in other words it is positioned aft of 50% chord. The apex of each bump may be a single point, or a plateau. In the
20 case of a plateau then the leading edge of the plateau is positioned towards the trailing edge of the aerofoil.

Various preferred aspects of the invention are set out in the dependent claims.

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments of the invention will now be described with reference to the accompanying drawings, in which:

25 Figure 1 is a plan view of the top of an aircraft wing carrying a series of shock bumps according to a first embodiment of the invention;

Figure 2 is a cross-sectional view through the centre of one of the bumps taken along a line A-A;

Figure 3 is a plan view of the top of an aircraft wing carrying a series of shock bumps according to a second embodiment of the invention;

- 5 Figure 4 is a plan view of the top of an aircraft wing carrying a series of shock bumps according to a third embodiment of the invention; and

Figure 5 is a plan view of the top of an aircraft wing carrying a series of shock bumps according to a fourth embodiment of the invention.

DETAILED DESCRIPTION OF EMBODIMENT(S)

- 10 Figure 1 is a plan view of the upper surface of an aircraft wing. The wing has a leading edge 1 and a trailing edge 2, each swept to the rear relative to the free stream direction.

The footprints of a series of shock bumps are indicated at 3 in Figure 1. Figure 2 is a longitudinal cross-sectional view through the centre of one of the bumps taken along a
15 line A-A which is parallel with the free stream direction.

Each bump protrudes from a nominal surface of the wing, and meets the nominal surface 8 at a leading edge 3a; a trailing edge 3b; an inboard edge 3c; and an outboard edge 3d. The lower portions of the sides of bumps are concave and merge gradually into the nominal surface 8. For example in Figure 2 the lower portion 9 of the front
20 side of the bump merges gradually into the nominal surface 8 at leading edge 3a. Alternatively there may be an abrupt discontinuity at one or more of the edges of the bump. For instance the lower portion of the front side of the bump may be planar as illustrated by dashed line 9a. In this case the front side 9a of the shock bump meets the nominal surface 8 with an abrupt discontinuity at the leading edge 3a.

- 25 The apex point 7 of the fore/aft cross-section A-A is offset aft of the centre 6 of the bump. The apex 7 of each bump 3 is positioned aft of 50% chord, typically between 60% and 65% chord.

At transonic speeds a swept shock 4 forms normal to the upper surface of the wing, and the shock bumps 3 are positioned so as to modify the structure of the shock by inducing a smeared shock foot 5 with a lambda like wave pattern shown in Figure 2. When the shock bumps 3 are operated at their optimum with the shock 4 just ahead of the apex 7 of the bump as shown in Figure 2, the smeared foot 5 has a lambda-like wave pattern with a single forward shock 5a towards the leading edge of the bump and a single rear shock 5b positioned slightly forward of the apex 7. Alternatively, instead of having only a single forward shock 5a, the smeared foot may have a lambda-like wave pattern with a fan-like series of forward shocks. Note that, unlike vortex generators, the bumps have no sharp convex edges or points so the flow remains attached over the bumps when they are operated at their optimum (i.e. when the shock is positioned on the bump just ahead of its apex).

As shown in Figure 1, the centres of the shock bumps 3 are distributed across the wing along a line which is swept with respect to the free stream direction, and positioned slightly aft of the shock 4.

The shock bumps 3 have a non-uniform spacing between adjacent bump centres. That is, the distance d1 between centres of the inboard pair of bumps is greater than the distance d2 between centres of the outboard pair of bumps. Each bump has the same size and shape so there is also a non-uniform spacing between adjacent bump edges.

Figure 3 shows a longer series of bumps 3, also distributed across the wing with a non-uniform spacing d1-d6 between adjacent bump centres. The distances d1-d6 satisfy the following relationship:

$$d1 > d2 > d3 > d4 < d5 < d6$$

That is, the spacing between the bump centres reaches a minimum (d4) at an intermediate position in the series. Each bump has the same size and shape so the same spacing relationship exists for the distances between adjacent bump edges.

Figure 4 shows a series of bumps 3a-3c which are distributed across the wing with a uniform spacing between adjacent bump centres. However the bumps have different

widths transverse to the free stream direction, so the minimum distances s_1 - s_5 between adjacent bump edges satisfy the following relationship:

$$s_1 > s_2 > s_3 > s_4 < s_5$$

That is, the spacing between the bump edges reaches a minimum (s_4) at an intermediate position in the series.

Figure 5 shows a series of bumps 3a-3c which are distributed across the wing with a non-uniform spacing between adjacent bump centres, and with different widths w_1 - w_3 transverse to the free stream direction. The spacing between the bumps reaches a minimum between the bumps 3c, and the widths satisfy the following relationship:

$$w_1 < w_2 < w_3$$

The strength of the shock 4 varies across the span of the wing according to the load distribution and surface geometry. For each individual shock bump, the resulting flow perturbation, in the form of a lambda like shock foot, will spread laterally, more or less normal to the free stream direction and symmetrically about the bump.

The exact geometry of the bump can range from an angular surface with the minimum number of shock waves to a smoothly varying surface (as shown in Figure 2) with an infinite number of waves with a similar result. The perturbation caused by the bump spreads laterally since the Mach numbers are close to unity. The lateral decay of the wave pattern induced by the bump is slow and hence its effect may be felt many bump heights away in a span-wise direction. How those perturbations affect the performance of subsequent bumps can be ascertained and hence the optimum spacing and geometry can be defined.

The non-uniform width and/or centre spacing between the bumps can be arranged to give maximum wave drag alleviation for the minimum number of bumps as a function of the shock strength across the span, leading to minimum wing weight penalties for a given amount of wave drag alleviation. It may be that a revised load distribution can be defined to provide still further overall drag reduction.

For instance the size and spacing between the bumps in the embodiments of Figures 3-5 may be selected so that the bump spacing reaches a minimum at a position approximately 70% of the distance along the span of the wing. This is typically the position of maximum Mach number and maximum local lift coefficient, so it is
5 expected that a higher density of shock bumps may be more beneficial in this region than at the wing root or wing tip.

Although the invention has been described above with reference to one or more preferred embodiments, it will be appreciated that various changes or modifications may be made without departing from the scope of the invention as defined in the
10 appended claims.

Claims

1. An aerodynamic structure comprising a series of shock bumps extending from its surface, wherein the shock bumps are distributed across the structure with a non-uniform spacing between adjacent bumps.
5
2. The structure of any preceding claim wherein the shock bumps are distributed across the structure with a non-uniform spacing between adjacent bump centres.
3. The structure of any preceding claim wherein the shock bumps are distributed across the structure with a non-uniform spacing between adjacent bump edges.
- 10 4. The structure of any preceding claim wherein the spacing reaches a minimum at an intermediate position in the series.
5. The structure of any preceding claim wherein at least two of the shock bumps have different widths transverse to a free stream direction.
6. The structure of any preceding claim wherein the centres of the shock bumps are
15 distributed along a line which is swept with respect to a free stream direction.
7. The structure of any preceding claim wherein each bump has a leading edge, a trailing edge, an inboard edge and an outboard edge.
8. The structure of claim 7 wherein each bump meets the surface at the leading edge, trailing edge, inboard edge and outboard edge.
- 20 9. The structure of any preceding claim wherein each bump has substantially no sharp convex edges or points.
10. The structure of any preceding claim wherein the shock bumps are shaped and positioned so as to modify the structure of a shock which would form adjacent to the surface of the structure in the absence of the shock bumps when the structure is
25 moved at transonic speed.

11. The structure of claim 10 wherein the shock bumps are shaped and positioned so as to induce a smeared foot in the shock with a lambda like wave pattern when it is moved at transonic speed.
12. The structure of any preceding claim wherein the aerodynamic structure is an
5 aerofoil and the surface is a low pressure surface of the aerofoil.
13. The structure of any preceding claim wherein the aerodynamic structure is an aerofoil having a leading edge and a trailing edge, and wherein each bump has an apex which is positioned towards the trailing edge of the aerofoil.
14. A method of operating the structure of any preceding claim, the method comprising
10 moving the structure at a transonic speed; forming a shock adjacent to the series of shock bumps; and modifying the structure of the shock with the shock bumps.
15. The method of claim 14 wherein the flow over at least one of the shock bumps is substantially fully attached when the shock is formed on the bump just ahead of its apex.
- 15 16. The method of claims 14 or 15 wherein the shock bumps induce a smeared foot in the shock with a lambda like wave pattern when it is moved at transonic speed.

Figure 1

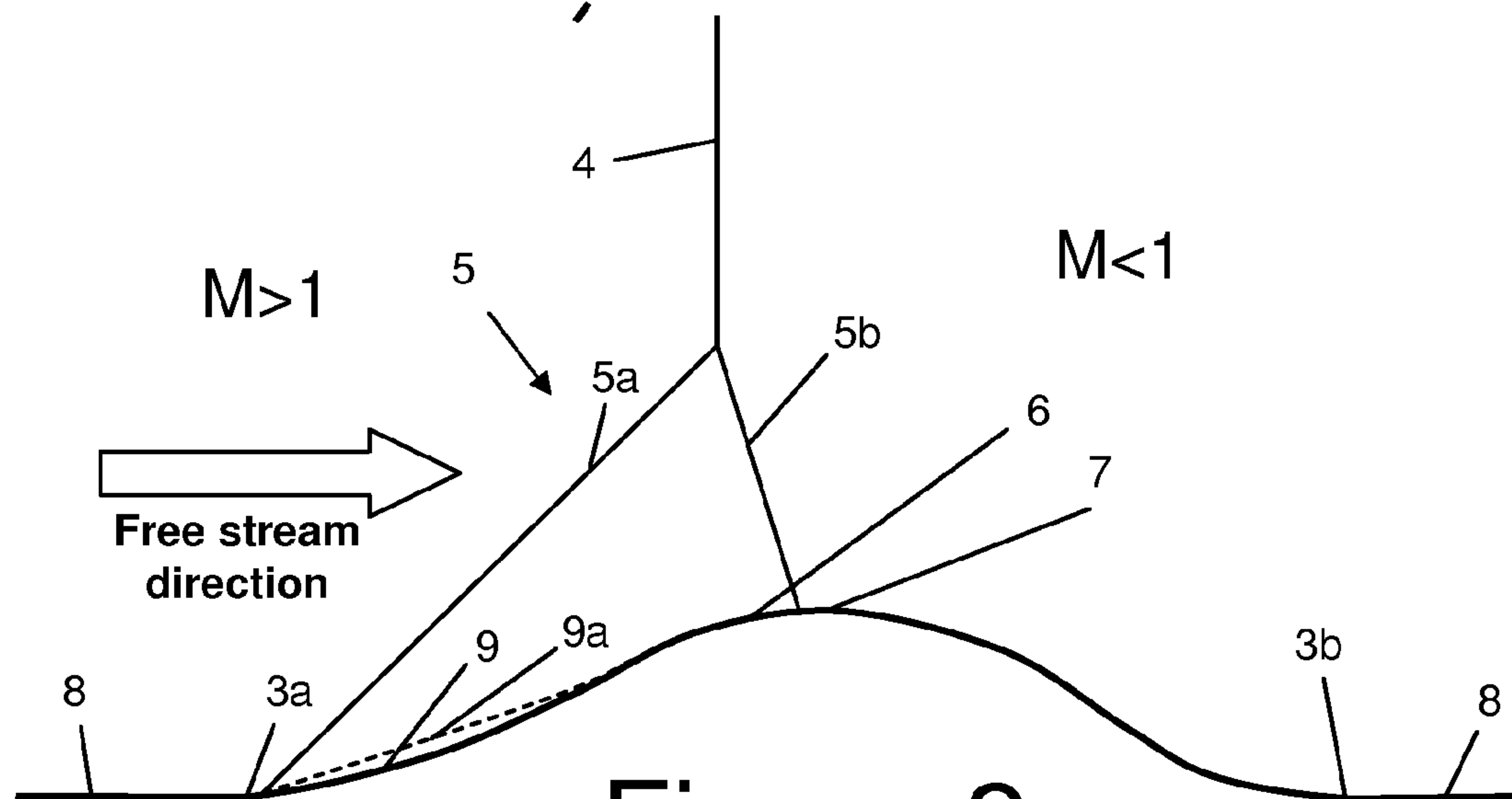
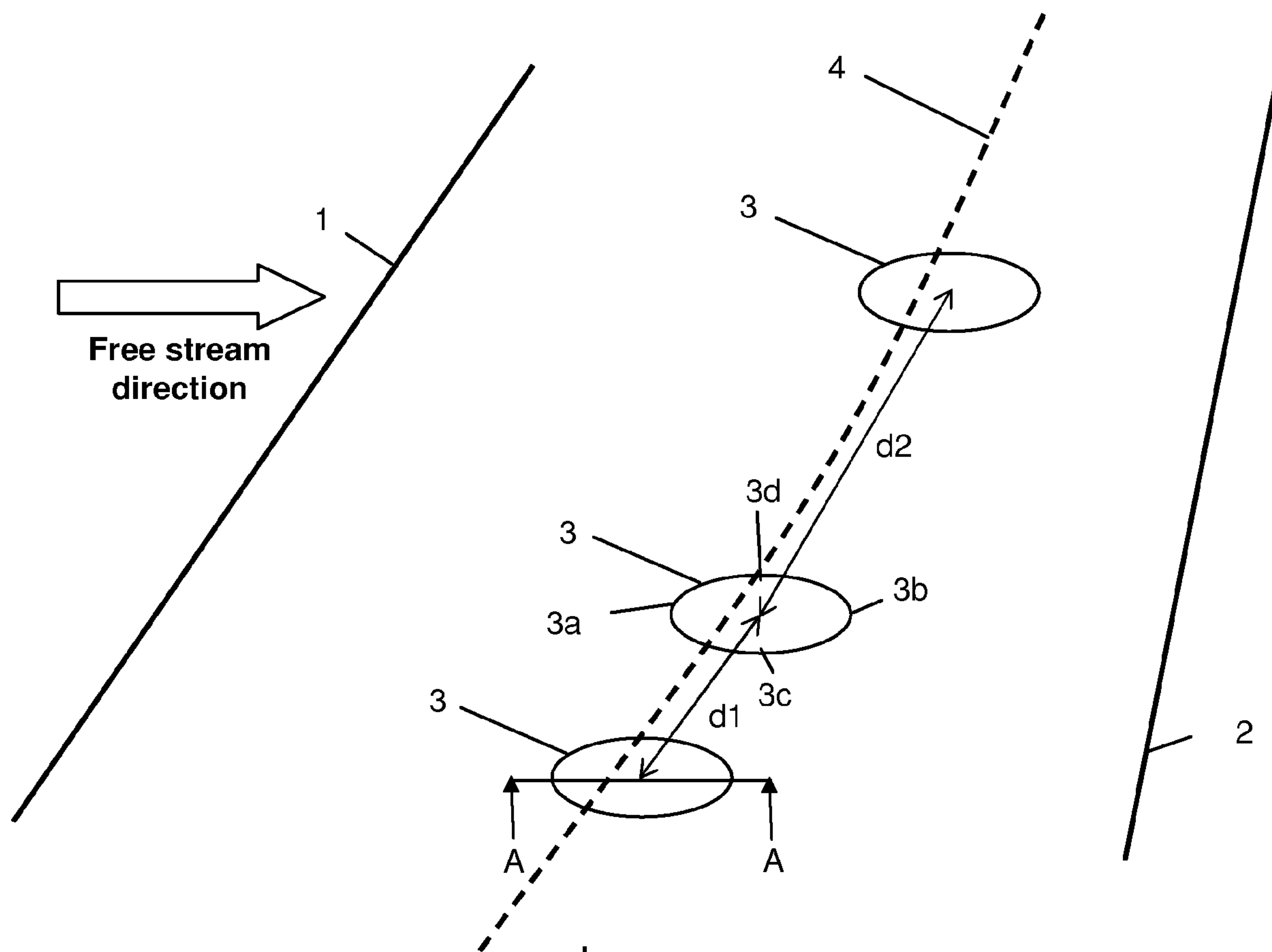


Figure 2

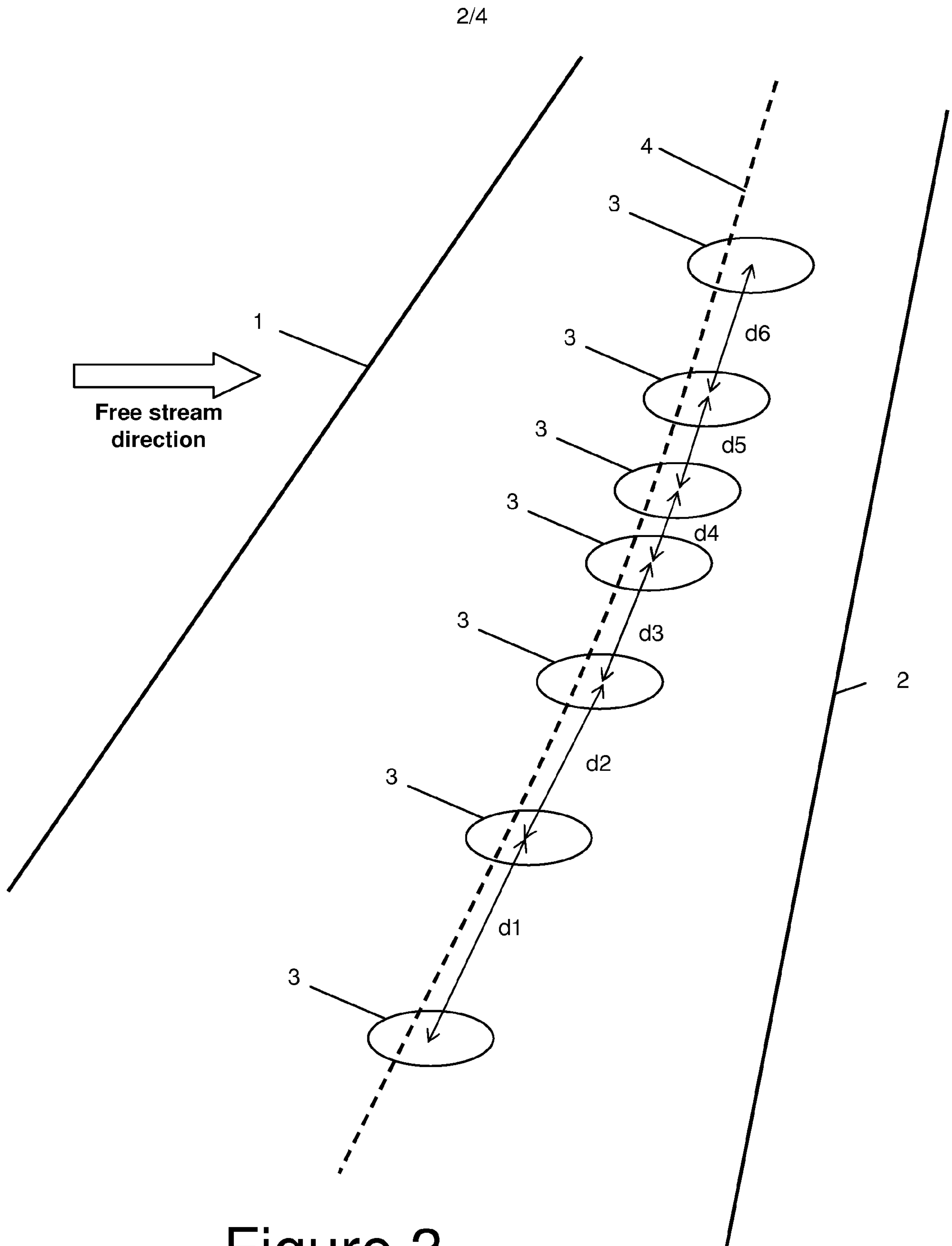


Figure 3

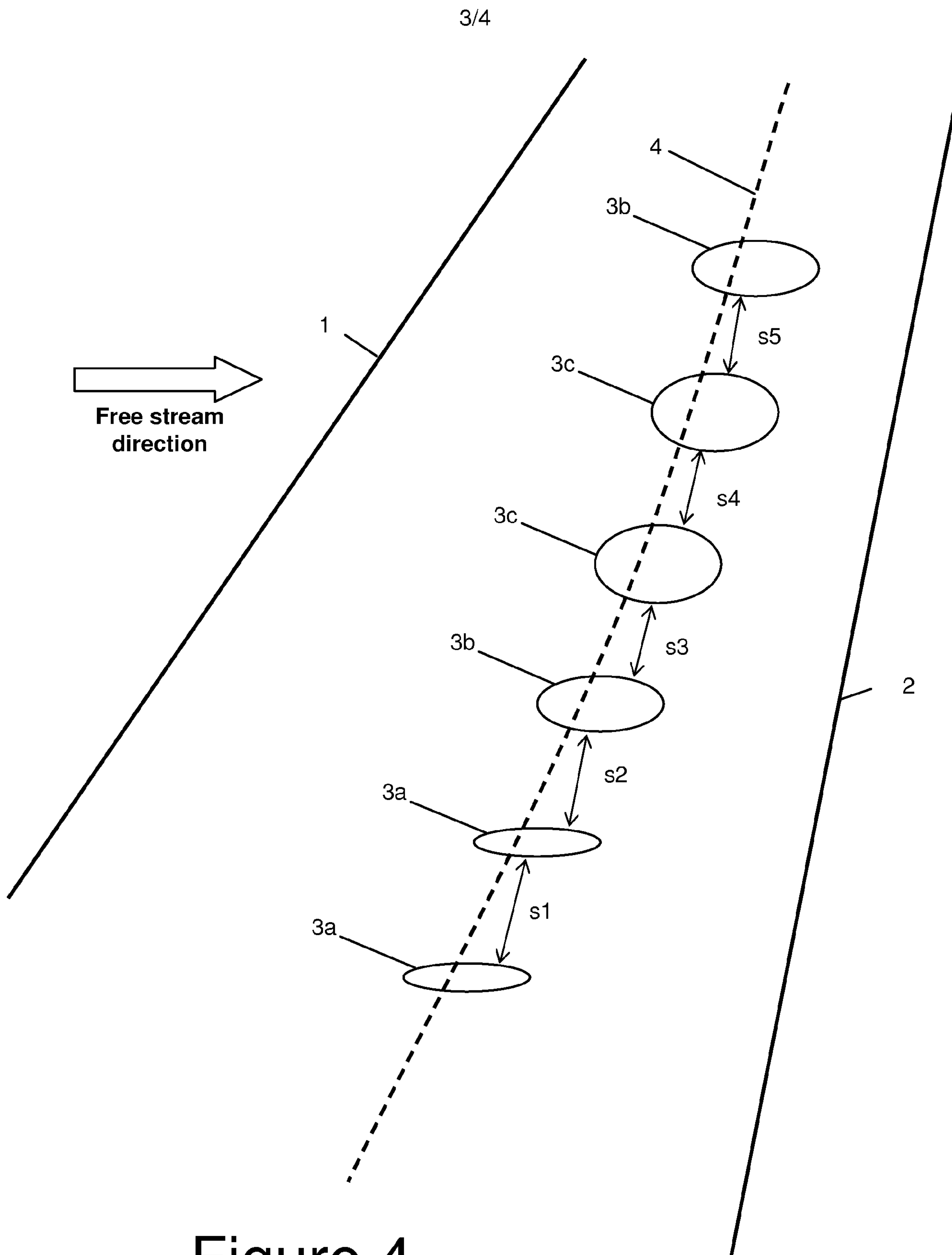


Figure 4

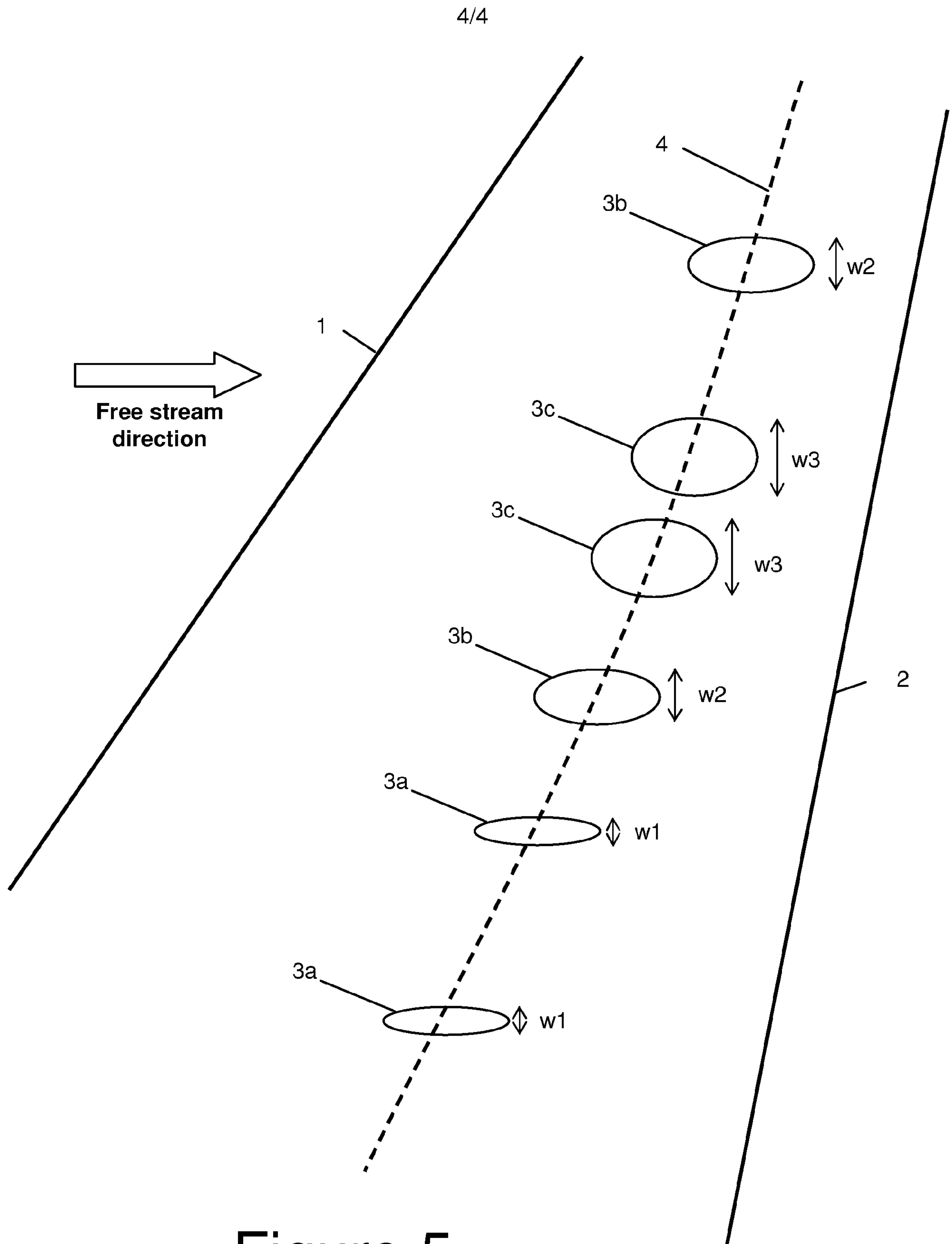
**Figure 5**

Figure 1

