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SETHI

(54) SMOOTH BORE NOZZLE

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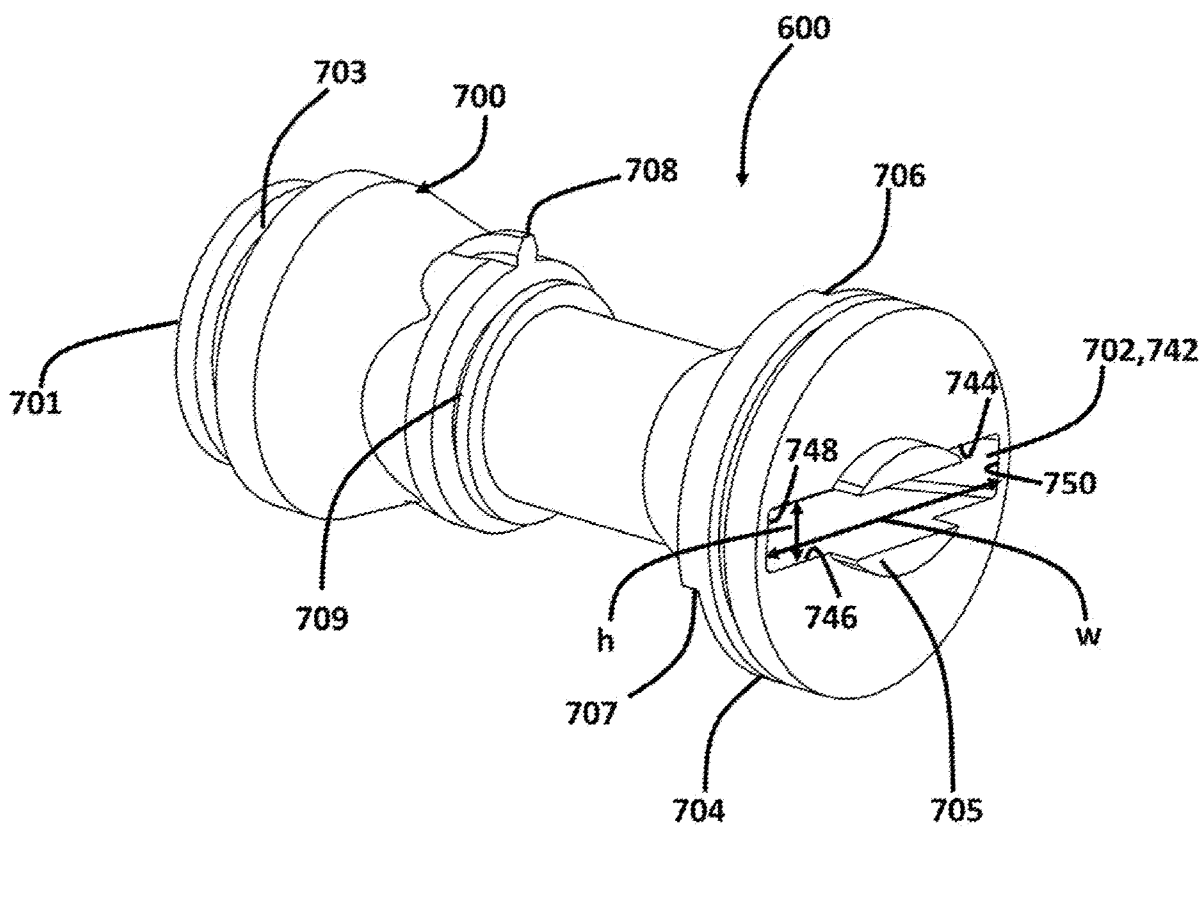
(57) **ABSTRACT**

A smooth bore nozzle includes an inlet section having planar converging inlet side walls and top and bottom walls forming an unobstructed rectangular inlet section fluid passageway; a straight section having planar side walls and top and bottom walls contiguous with the inlet side walls and top and bottom walls forming an unobstructed rectangular straight section fluid passageway; and an outlet section having planar converging outlet top and bottom walls and diverging outlet side walls contiguous with the straight section side walls and top and bottom walls, and an unobstructed rectangular outlet section fluid passageway; wherein the cross-sectional area of the fluid passageway remains constant or decreases in a downstream direction, and a perimeter of the cross section increases along a length of the inlet section, and a perimeter of a cross section of the rectangular outlet section fluid passageway decreases along a length of the outlet section.



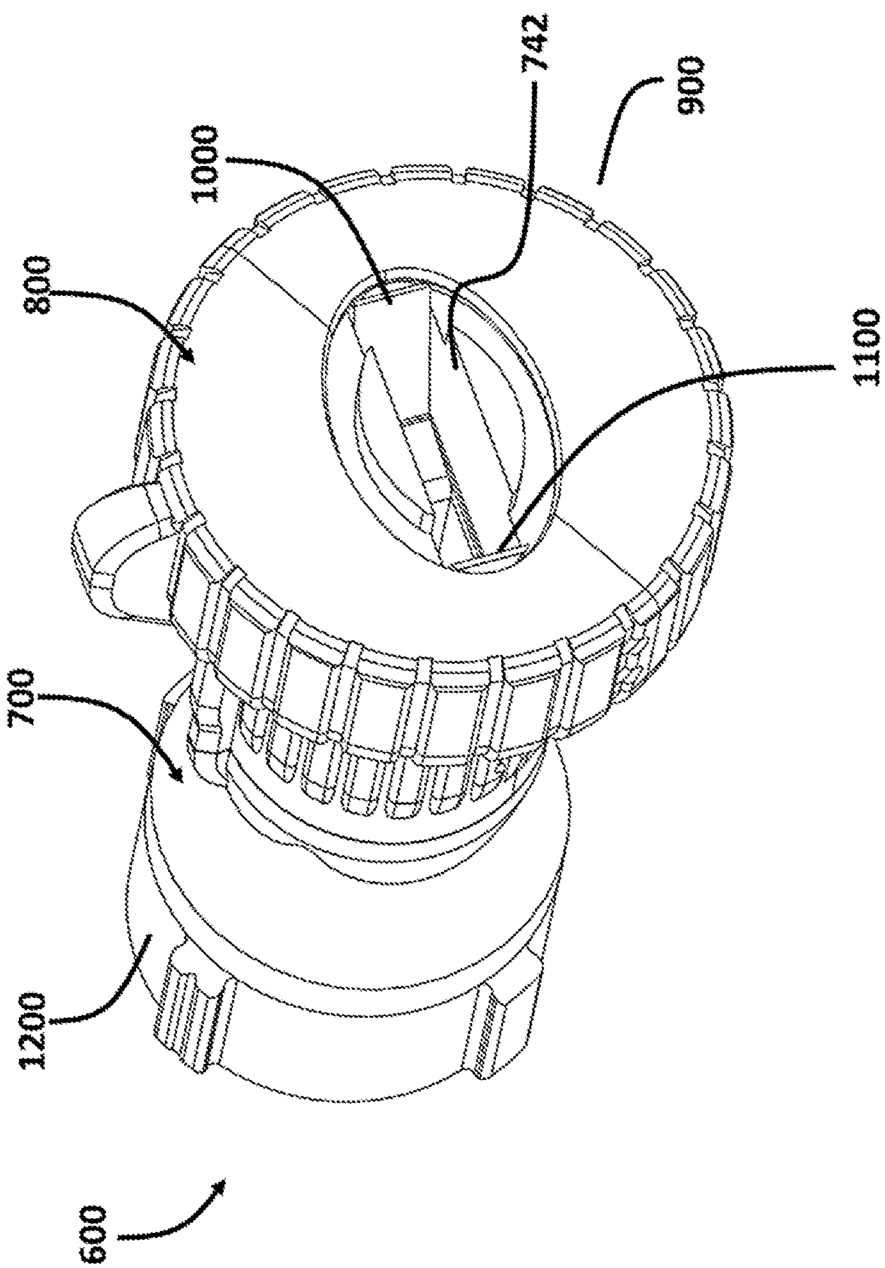
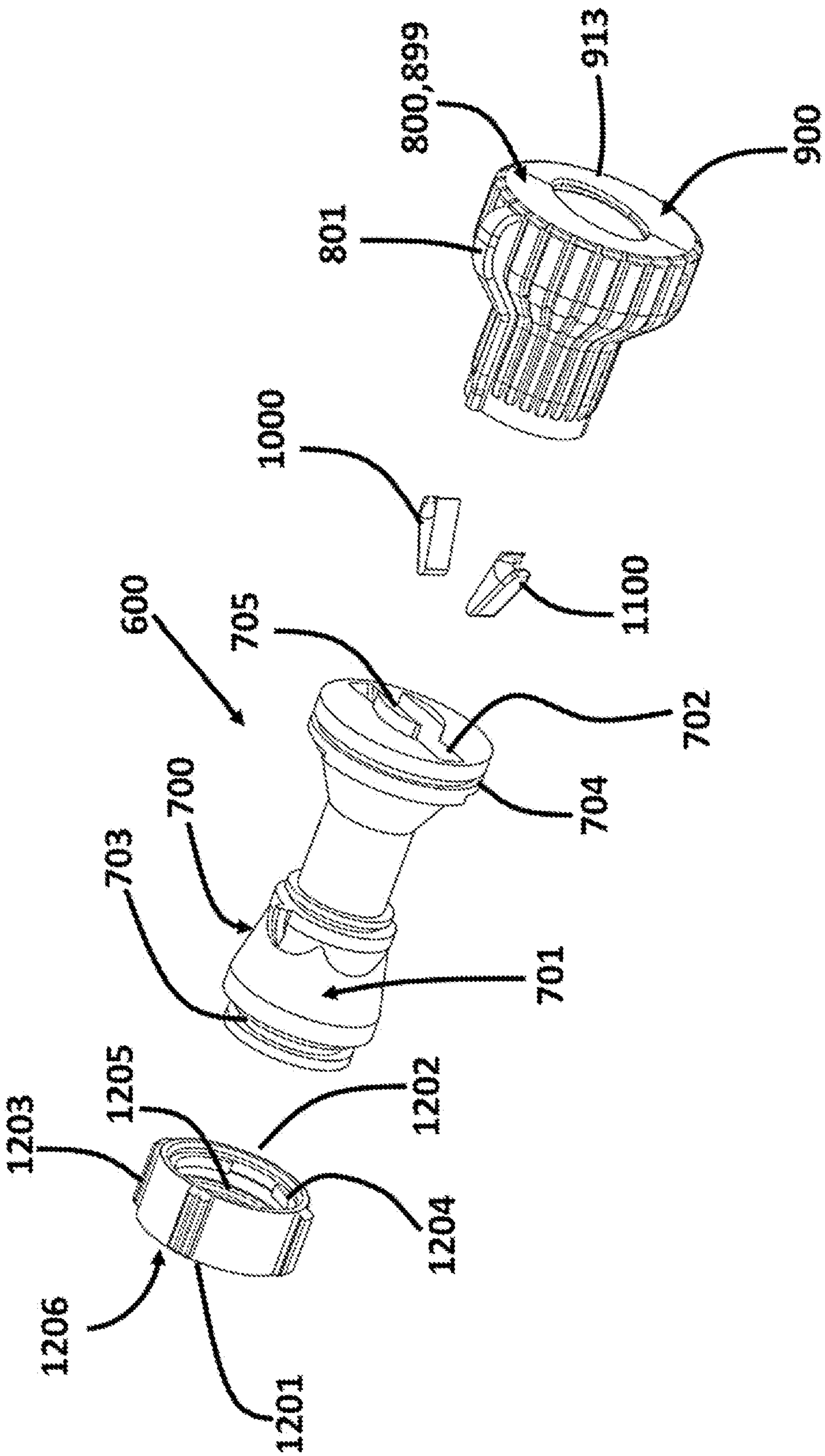


Fig. 1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913
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801
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1100
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702
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700
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701
1203
1205
1202
1204
1206
1201

Fig. 2

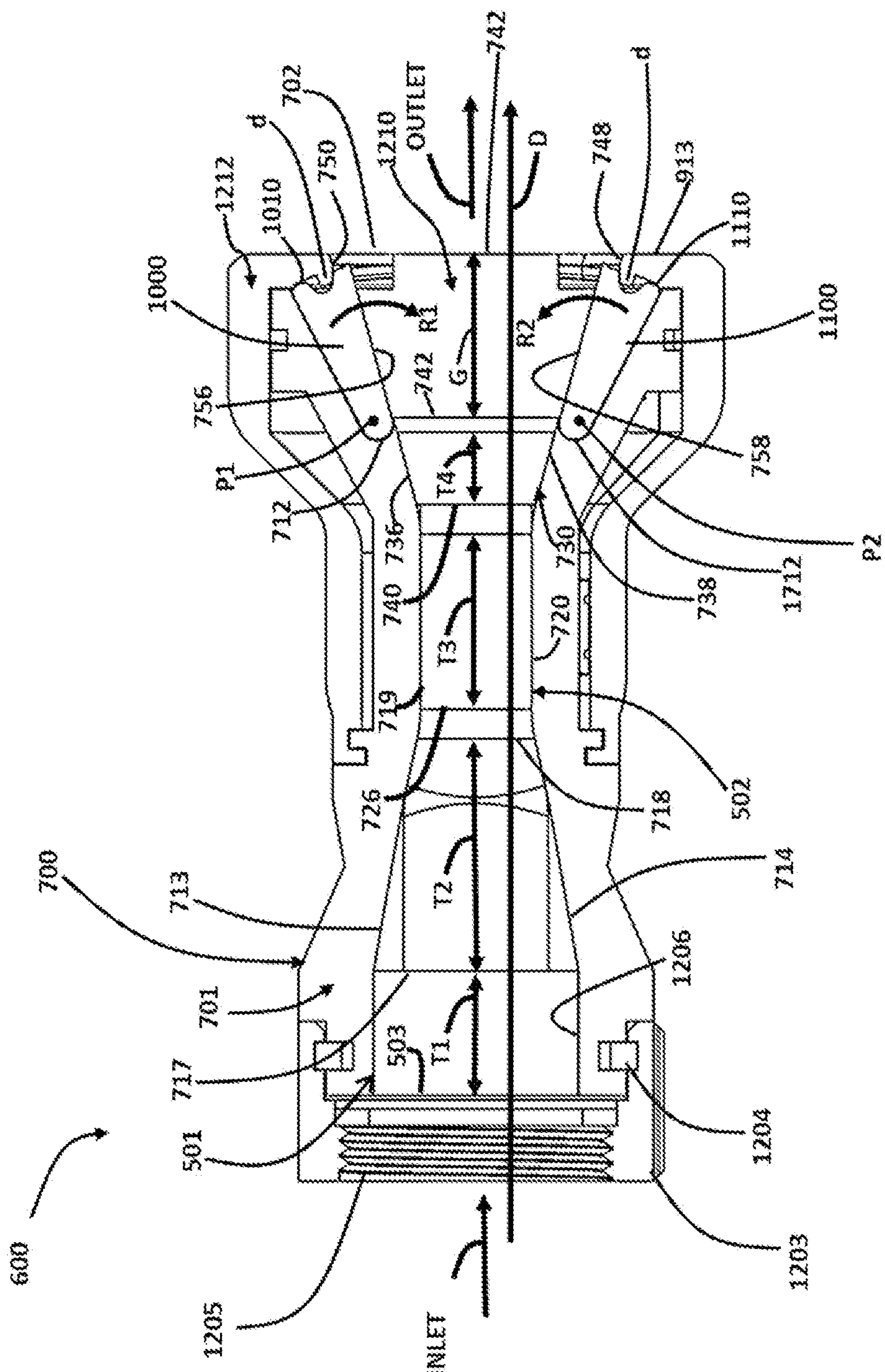
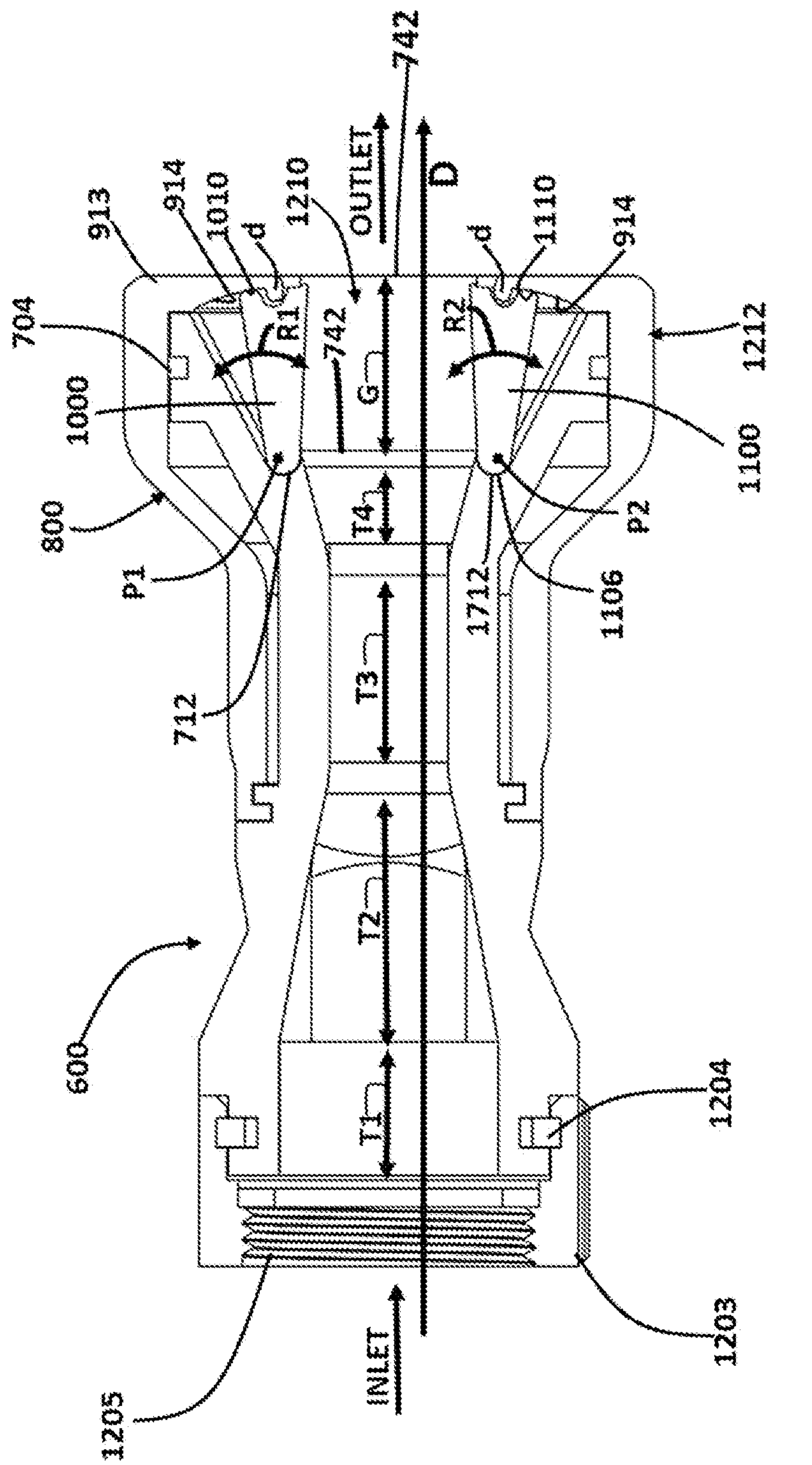

OUTLET
INLET
742
702
d
750
1010
1212
1210
D
748
913
1110
1000
R1
R2
1100
G
756
742
758
P1
T4
712
736
730
P2
740
738
1712
720
T3
719
502
726
718
700
713
T2
714
1206
701
717
503
T1
501
1204
600
1203
1205

Fig. 3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OUTLET
D
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914
1010
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d
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704
R1
742
R2
1212
1000
G
1100
800
T4
P2
P1
1712
1106
T3
712
T2
600
T1
1204
INLET
1203
1205

Fig. 4

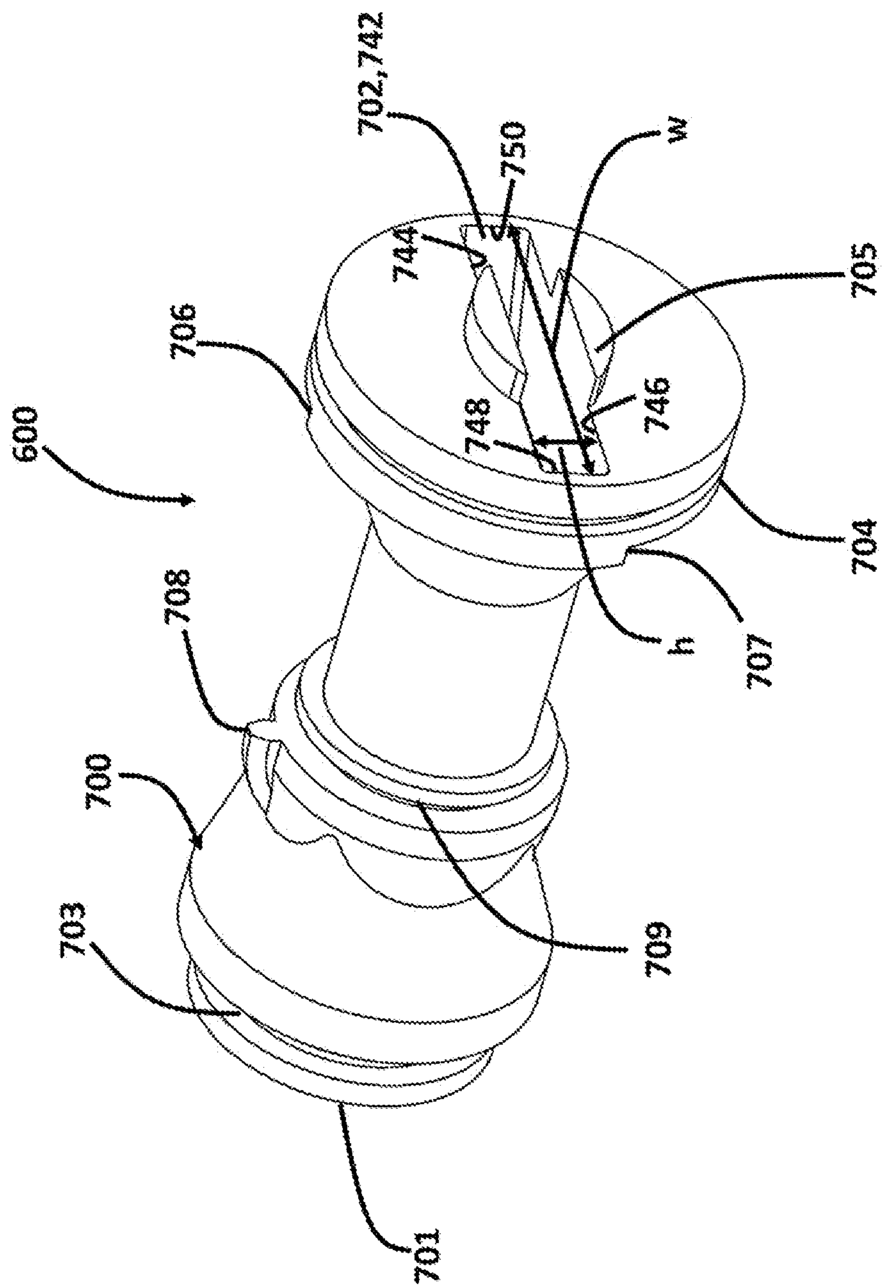

600
702,742
750
w
744
705
706
746
748
704
707
h
708
700
703
709
701

Fig. 5

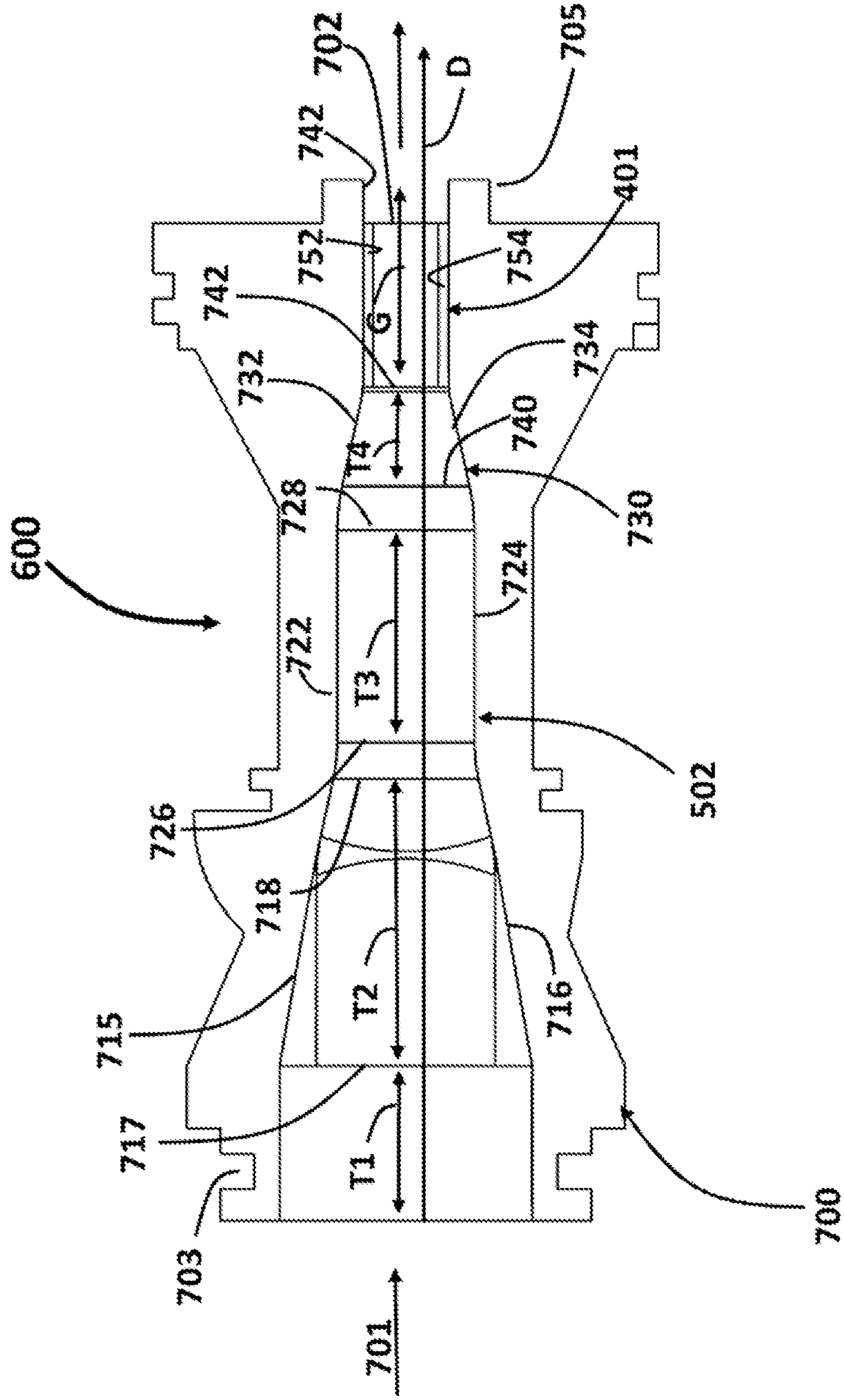

600
700
701
702
703
705
715
716
717
718
722
724
726
728
730
732
734
740
742
742
752
754
401
502
T1
T2
T3
T4
G
D

Fig. 6

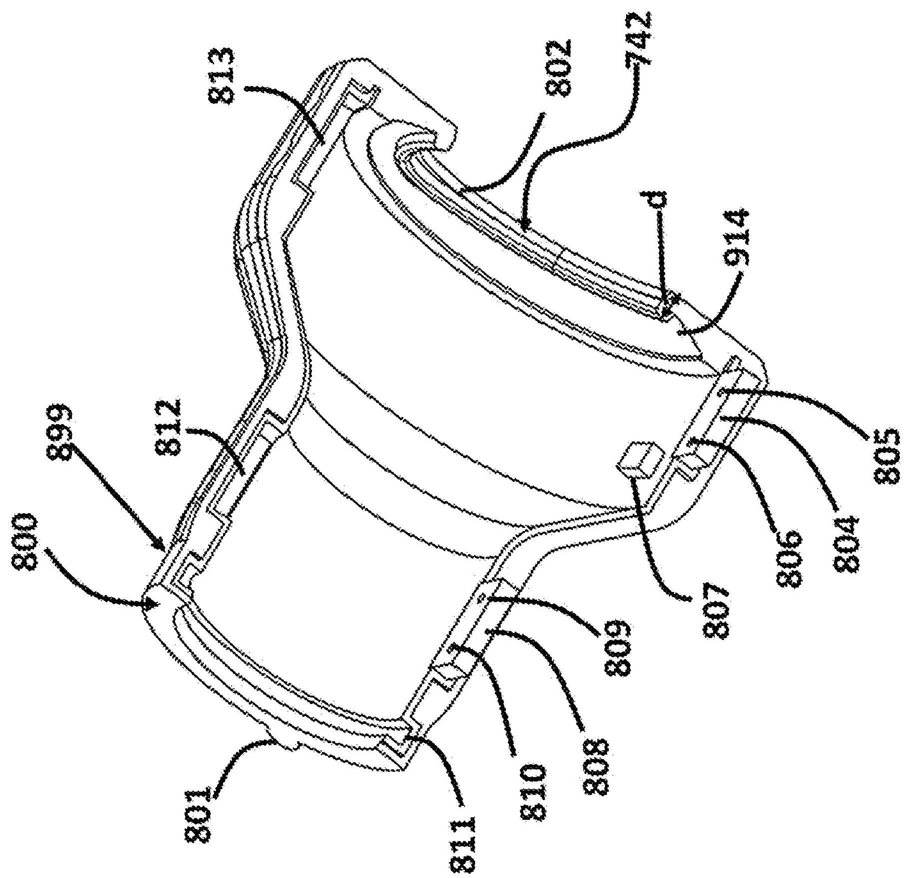


Fig. 7

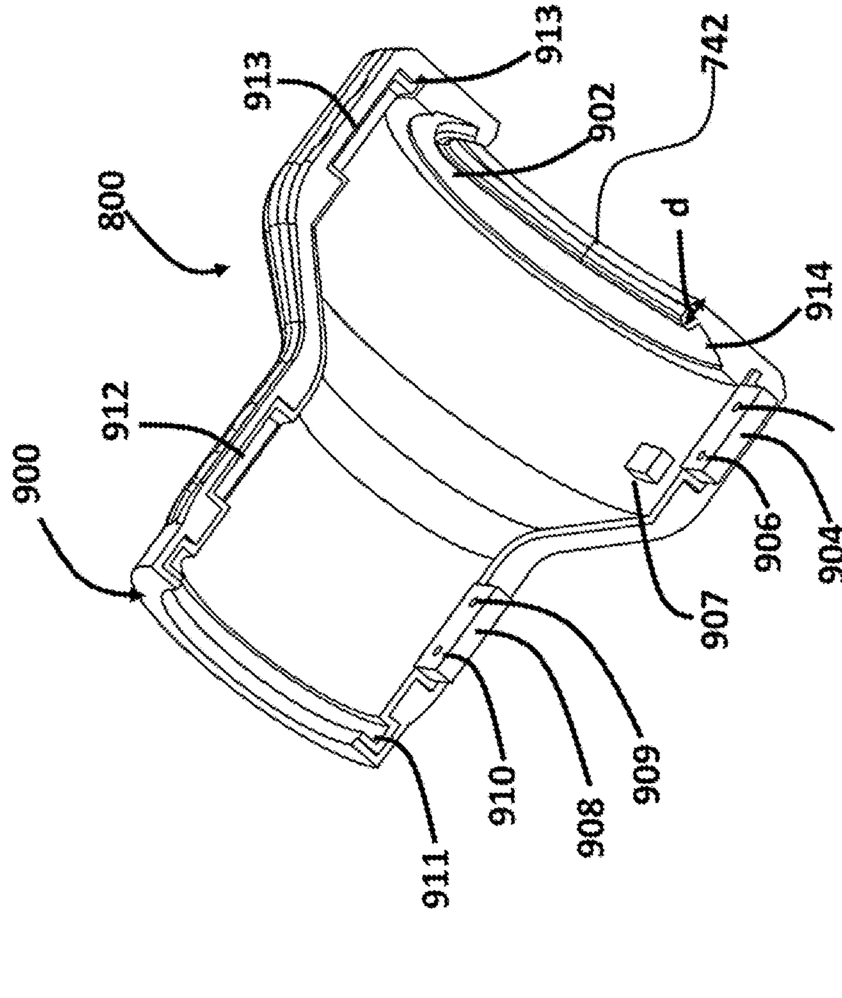


Fig. 8

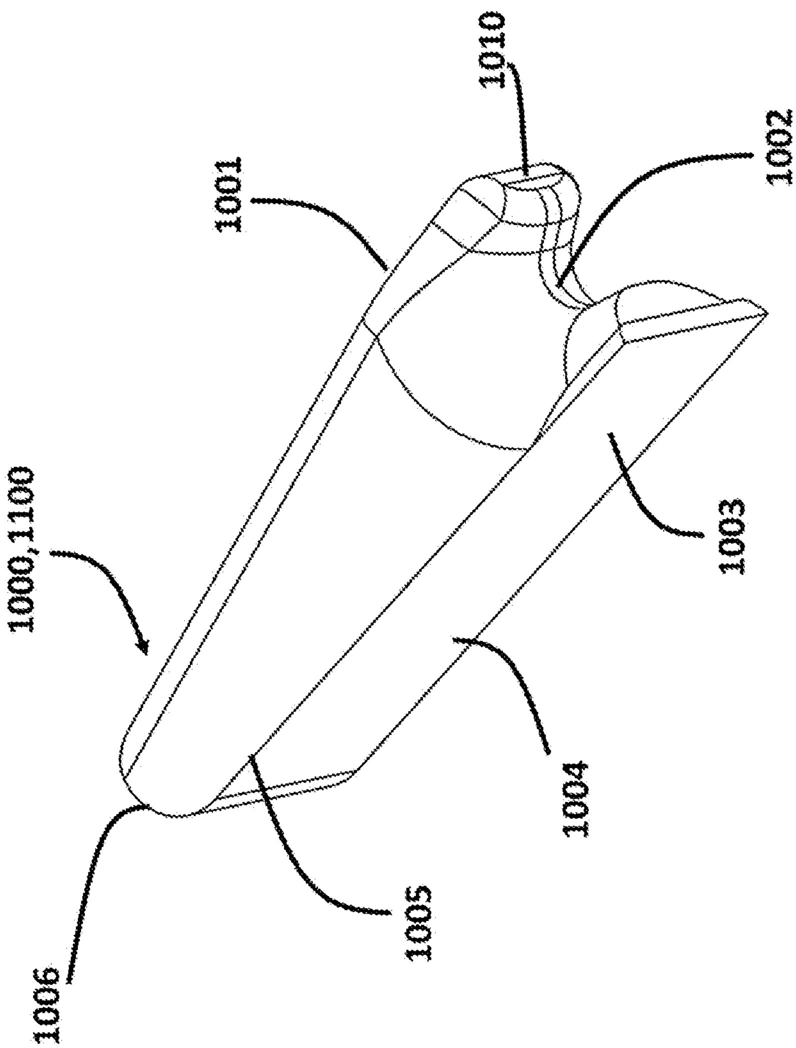


Fig. 9

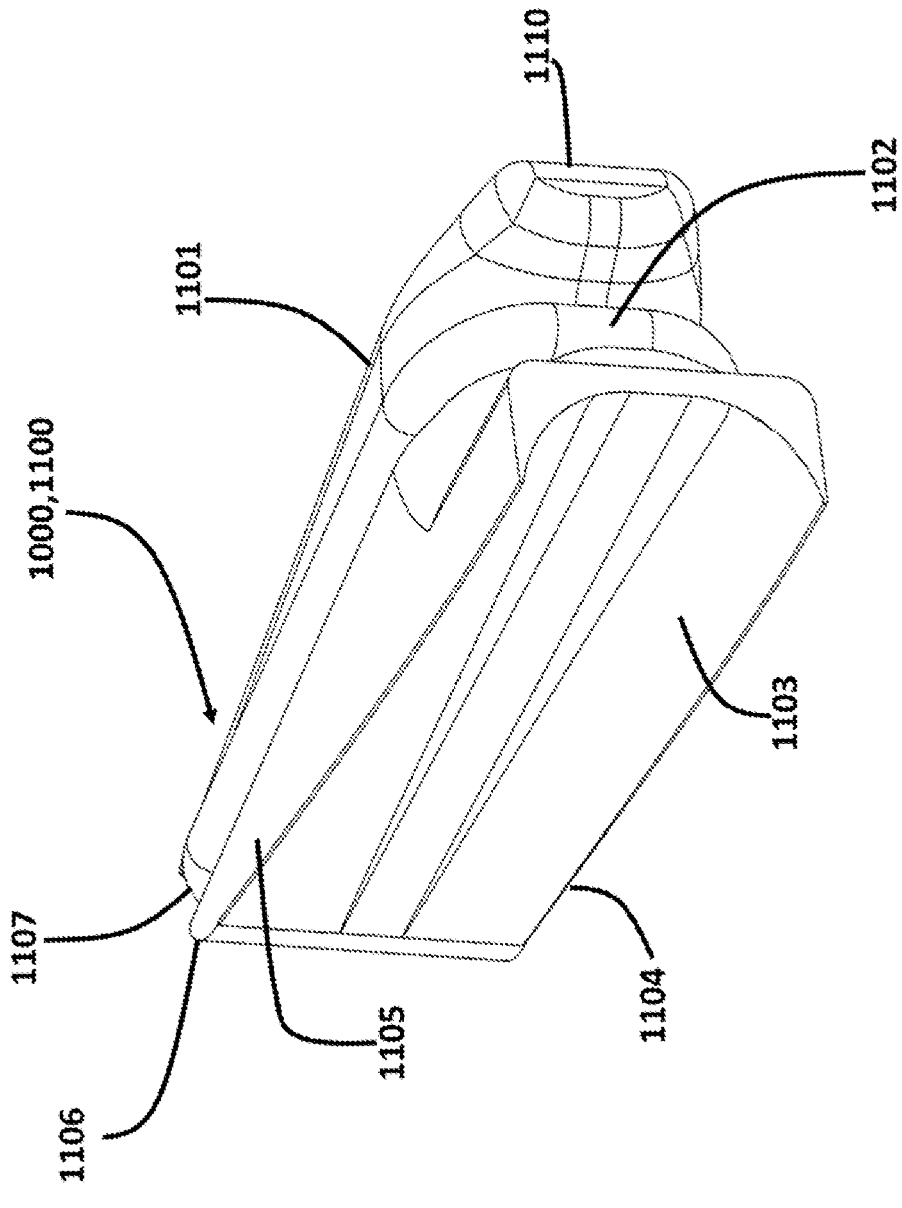
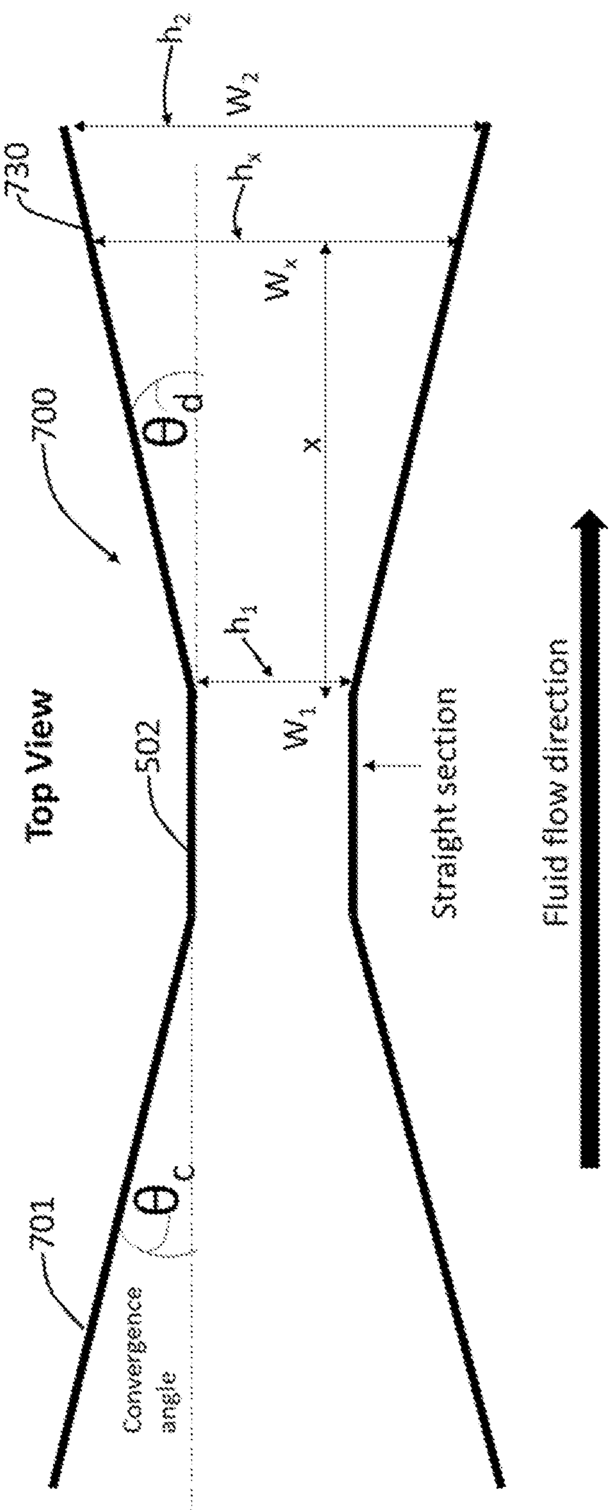


Fig. 10



Top View
700
730
502
701
h_2
W_2
h_x
W_x
θ_d
x
h_1
W_1
Straight section
θ_c
Convergence angle
Fluid flow direction

Fig. 11

SMOOTH BORE NOZZLE

GOVERNMENT LICENSE RIGHTS

[0001] This invention was made with government support under Contract No. 2127461 awarded by The National Science Foundation. The government has certain rights in the invention.

TECHNICAL FIELD

[0002] The present invention relates to nozzles for spraying fluids, and more particularly to nozzles for spraying liquids under pressure.

BACKGROUND

[0003] Nozzles are used to receive a fluid under pressure and control the shape and other characteristics of the stream of the fluid as it exits the nozzle. Such nozzles typically have an inlet opening, an exit opening that may take the form of a single orifice or multiple orifices, and a fluid flow path extending between the inlet opening and the exit opening. The inlet opening may include a fitting, which may be circular in cross section, for connecting the nozzle to a complementary fitting on a tank, flexible hose, or pipe.

[0004] Nozzles frequently are designed to increase the velocity of the fluid entering the nozzle to project the fluid stream exiting the nozzle in a long trajectory. This is achieved by providing the nozzle with a constriction in the fluid flow path. The constriction may take the form of a decrease in cross-sectional area from the nozzle inlet opening to the exit opening and/or an orifice or other restriction in the fluid flow path that effectively reduces the cross-sectional area of fluid flow. Providing such a constriction to fluid flow under constant pressure and constant volume flow rate results in the increase in fluid flow velocity. In some nozzles, the nozzle outlet orifice itself is reduced in cross-sectional area relative to the nozzle inlet and provides the constriction to increase velocity of fluid flow.

[0005] Fluid conduits having a flow path defined by smooth continuous nozzle walls and an absence of internal obstructions provide laminar flow of the fluid flowing through them. Laminar fluid flow is desirable over turbulent fluid flow because it optimizes fluid flow through the nozzle and provides a uniform spray from the exit opening. A disadvantage with some nozzle designs is that obstructions, sharp corners, and abrupt changes in fluid flow direction in the fluid flow path of a nozzle create obstructions in the flow of fluid through the nozzle that create turbulence in the flow of fluid through the nozzle. Turbulence in fluid flow through nozzles is undesirable in applications where spray from the exit opening that is uniform across the width of the nozzle exit opening is desired. The reach or throw distance of the fluid exiting a nozzle is the distance the fluid travels before the stream loses its momentum and/or integrity. Turbulence of the fluid in the nozzle also reduces the fluid velocity and negatively impacts the reach and penetration of the fluid. Accordingly, there is a need for a nozzle that adjusts the effective cross-sectional area of the exit opening to vary the shape of the fluid stream from the exit opening but that does not present inclusions, obstructions, or sharp corners in the fluid flow path through the nozzle that create turbulence in the fluid. There is also a need for a compact nozzle that is rugged and yet provides optimal laminar fluid flow.

SUMMARY

[0006] The present disclosure describes a nozzle and the method of its operation that optimizes fluid flow through the nozzle and consequently the throw distance and coverage of the fluid stream exiting the nozzle. The nozzle can be used to project a uniform stream a distance greater than current nozzle designs for a given fluid flow rate. The fluid flow pathway of the nozzle is smooth and free of obstructions, which promotes laminar fluid flow resulting in a fluid flow stream that is uniform along its width and along its length. The fluid flow path in the nozzle includes a constriction that is designed to increase fluid flow velocity while minimizing turbulence to provide maximum exit stream distance.

[0007] In an exemplary embodiment, a nozzle includes an inlet section having a first and a second smooth, planar opposing converging inlet side walls contiguous with smooth, planar opposing converging inlet top and bottom walls. The first and the second inlet side walls and the inlet top and bottom walls form an inlet section opening, an inlet section outlet opening, and an unobstructed oblong inlet section fluid passageway from the inlet section opening to the inlet section outlet opening.

[0008] The inlet section transitions to a straight section having first and second smooth, planar opposing parallel side walls contiguous with the first and the second inlet side walls, respectively, and contiguous with smooth, planar opposing parallel top and bottom walls that are contiguous with the inlet top and bottom walls, respectively. The first and the second opposing parallel side walls and the opposing parallel top and bottom walls form a straight section inlet opening attached to receive the fluid from the inlet section outlet opening, a straight section outlet opening, and an unobstructed rectangular straight section fluid passageway from the straight section inlet opening to the straight section outlet opening.

[0009] The straight section transitions to an outlet section having smooth, planar opposing converging outlet top and bottom walls contiguous with the parallel top and bottom walls, respectively, and contiguous with first and second opposing diverging outlet side walls that are contiguous with the opposing parallel side walls. The outlet top and bottom walls are contiguous with the first and the second outlet side walls to form an outlet section inlet opening attached to receive the fluid from the straight section outlet opening and a frustum-shaped, unobstructed rectangular outlet section fluid passageway from the outlet section inlet opening to terminate in an oblong outlet opening.

[0010] A cross-sectional area of the rectangular inlet fluid passageway and a cross-sectional area of the rectangular outlet section fluid passageway remain constant or decrease in a downstream direction, and a perimeter of a cross section of the rectangular inlet section remains constant along a length of the inlet section and a perimeter of a cross section of the rectangular outlet section fluid passageway increases along a length of the outlet section.

[0011] In another embodiment, a nozzle includes an inlet section having a first and a second smooth, planar opposing inlet side walls and smooth, planar opposing inlet top and bottom walls. The first and the second inlet side walls and the inlet top and bottom walls are contiguous and form an inlet opening, an inlet section outlet opening, and an unobstructed rectangular frustum-shaped inlet section fluid passageway from the inlet section inlet opening to the inlet section outlet opening At least one pair of the first and second opposing inlet side walls and the inlet top and bottom walls converge such that a cross sectional area of the inlet section fluid passageway decreases continuously from the inlet section inlet opening to the outlet section outlet opening.

[0012] A straight section has first and second smooth, planar opposing parallel side walls contiguous with the first and the second inlet side walls, respectively, and having smooth, planar opposing parallel top and bottom walls that are contiguous with the inlet top and bottom walls, respectively, wherein the first and the second opposing parallel side walls and the opposing parallel top and bottom walls form a straight section inlet opening attached to receive the fluid from the inlet section outlet opening, a straight section outlet opening, and an unobstructed rectangular straight section fluid passageway from the straight section inlet opening to the straight section outlet opening. The straight section creates a smooth transition between the converging inlet section and diverging outlet section.

[0013] An outlet section has smooth, planar opposing converging outlet top and bottom walls contiguous with the parallel top and bottom walls, respectively, and contiguous with first and second opposing diverging outlet side walls that are contiguous with the opposing parallel side walls. The outlet top and bottom walls are contiguous with the first and the second outlet side walls to form an outlet section inlet opening attached to receive the fluid from the straight section outlet opening and an unobstructed rectangular outlet section fluid passageway from the outlet section inlet opening to terminate in an oblong outlet opening.

[0014] At least one pair of the first and second opposing outlet side walls and the outlet top and bottom walls diverge such that a cross sectional area of the outlet section fluid passageway decreases continuously from the outlet section inlet opening to the oblong outlet opening. As the cross-sectional area of the rectangular inlet fluid passageway and a cross-sectional area of the rectangular outlet section fluid passageway decrease in a downstream direction, a perimeter of a cross section of the rectangular inlet section decreases along a length of the inlet section and a perimeter of a cross section of the rectangular outlet section fluid passageway increases along a length of the outlet section The rectangular inlet fluid passageway, the straight section fluid passageway, and the outlet section fluid passageway together define a continuous nozzle fluid passageway that is bilaterally symmetrical about a central axis of the nozzle extending in a fluid flow direction.

[0015] In yet another embodiment, a method of making a nozzle includes forming an inlet section having a first and a second smooth, planar opposing converging inlet side walls and smooth, planar opposing converging inlet top and bottom walls; attaching the first and the second inlet side walls to the inlet top and bottom walls to form an inlet opening, an inlet section outlet opening, and an unobstructed rectangular inlet section fluid passageway from the inlet opening to the inlet section outlet opening. A straight section having first and second smooth, planar opposing parallel side walls and smooth, planar opposing parallel top and bottom walls is formed such that the first and the second parallel side walls are attached to the parallel top and bottom walls to form a straight section inlet opening, a straight section outlet opening, and an unobstructed rectangular straight section fluid passageway from the straight section inlet opening to the straight section outlet opening.

[0016] The first and the second parallel side walls are attached to the first and the second inlet side walls, respectively, and the parallel top and bottom walls are attached to the converging inlet top and bottom walls to receive the fluid from the inlet section outlet opening. An outlet section having smooth, planar opposing converging outlet top and bottom walls and first and second smooth, planar opposing diverging outlet side walls that are contiguous with the opposing converging outlet top and bottom walls is formed to form an outlet section inlet opening attached that receives fluid from the straight section outlet opening and an unobstructed rectangular outlet section fluid passageway from the outlet section inlet opening to terminate in an oblong outlet opening.

[0017] The outlet top and bottom walls are attached to the parallel top and bottom walls and attaching the first and second opposing diverging outlet side walls to the first and the second parallel side walls. A cross-sectional area of the rectangular inlet section fluid passageway and a cross-sectional area of the rectangular outlet section fluid passageway decrease in a downstream direction, and a perimeter of a cross section of the rectangular inlet section remains constant along a length of the inlet section and a perimeter of a cross section of the rectangular outlet section fluid passageway decreases along a length of the outlet section. The rectangular inlet fluid passageway, the straight section fluid passageway, and the outlet section fluid passageway together define a continuous nozzle fluid passageway symmetrical about a bilateral axis of symmetry of the nozzle extending in a fluid flow direction.

[0018] Other objects and advantages of the disclosed smooth bore nozzle will be apparent from the following description, the accompanying drawings, and the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0019] FIG. **1** is a perspective view of an exemplary embodiment of the disclosed smooth bore nozzle;

[0020] FIG. **2** is an exploded perspective view of the smooth bore nozzle of FIG. **1**;

[0021] FIG. **3** is a top view in section of the smooth bore nozzle of FIG. **1** showing the fluid flow path, in which adjustable pivot arms for modulating spray width are actuated to provide a relatively wide exit stream;

[0022] FIG. **4** is a top view in section of the smooth bore nozzle of FIG. **1** showing the fluid flow path, in which the adjustable pivot arms are pivoted to provide a relatively narrow exit stream;

[0023] FIG. **5** is a perspective view of the smooth bore nozzle of FIG. **1** in which the adjustment collar is removed;

[0024] FIG. **6** is a side elevation in section of the smooth bore nozzle of FIG. **1** showing the fluid flow path;

[0025] FIG. **7** is a perspective view of the interior of a first adjustment collar element of the embodiment of FIG. **1**;

[0026] FIG. **8** is a perspective view of the interior of a second adjustment collar element of the embodiment of FIG. **1**;

[0027] FIG. **9** is a perspective view of an embodiment of a pivot arm of the embodiment of FIG. **1**;

[0028] FIG. **10** is a perspective view of another embodiment of a pivot arm of the embodiment of FIG. **1**; and

[0029] FIG. **11** is a schematic diagram of an embodiment of the disclosed smooth bore nozzle.

DETAILED DESCRIPTION

[0030] As shown in FIGS. **1**, **2**, **3**, and **6**, in an exemplary embodiment, the smooth bore nozzle assembly, generally designated **600**, includes a nozzle body, generally designated **700**, having an inlet section **701** with first and a second smooth, planar opposing converging inlet side walls **713**, **714**, contiguous with smooth, planar opposing converging inlet top and bottom walls **715**, **716** that defines an inlet section flow path T**2**. The first and the second inlet side walls **713**, **714** and the inlet top and bottom walls **715**, **716** form an inlet section opening **717**, an inlet section outlet opening **718**, and an unobstructed rectangular inlet section **701** from the inlet section opening to the inlet section outlet opening.

[0031] In an embodiment, the nozzle body **700** includes a transition section **501** (also designated T**1**) upstream of the inlet section T**2**. The transition section **501** transitions from a round cross section to the rectangular cross section of the inlet section **701**. In an embodiment, the nozzle body **700** includes a fitting **1205** that takes the form of a threaded swivel adaptor **1205** that attaches the adjustable nozzle **600** to a source of fluid under pressure, such as a hose, and in embodiments, a firehose. The fitting **1205** is secured to the nozzle body **700** by a retaining ring **1204** that is seated in an annular recess **703**, which permits relative rotation of the fitting and the nozzle body **700**. In an embodiment, the transition section T**1** and the inlet section T**2** are unitary.

[0032] The nozzle body **700** includes a straight section **502** having first and second smooth, planar opposing parallel side walls **719**, **720** contiguous with the first and the second inlet side walls **713**, **714**, respectively, and contiguous with smooth, planar opposing parallel top and bottom walls **722**, **724**, respectively, that are contiguous with the inlet top and bottom walls **715**, **716**. The first and second parallel side walls **719**, **720** and opposing parallel top and bottom walls **722**, **724**, define a straight section flow path T**3**. The first and second parallel side walls **719**, **720** and the first and the second inlet side walls **713**, **714** are contiguous with the inlet top and bottom walls **715**, **716**, respectively. The first and the second opposing parallel side walls **719**, **720** and the opposing parallel top and bottom walls **722**, **724** form a straight section inlet opening **726** attached to receive the fluid from the inlet section outlet opening **718**, a straight section outlet opening **728**, which together form the unobstructed rectangular straight section **502**. The fluid passageway T**3** of straight section **502** is a fluid passageway from the straight section inlet opening **726** to the straight section outlet opening **728** and functions as a fluid relaxation section of the nozzle body **700**.

[0033] In embodiments, the nozzle body **700** includes an outlet section **730** having smooth, planar opposing converging outlet top and bottom walls **732**, **734**, respectively, contiguous with the parallel top and bottom walls **722**, **724**, respectively, and contiguous with first and second opposing diverging outlet side walls **736**, **738**, respectively, that are contiguous with the first and second parallel side walls **719**, **720**, forming an outlet flow passageway T**4**. The outlet top and bottom walls **732**, **734** are contiguous with the first and the second outlet extension side walls **736**, **738**, respectively, to form an outlet section inlet opening **740** attached to receive the fluid from the straight section outlet opening **728**. The outlet section **730** forms an unobstructed rectangular outlet section **730** from the outlet section inlet opening **740** to terminate in an oblong, fixed variable outlet opening **742**.

[0034] In an exemplary embodiment, the inlet section **701**, rectangular straight section **502**, and outlet section **730** together form a continuous, linear, unobstructed fluid flow path D, which in embodiments represents a bilateral axis of symmetry of the nozzle. In an embodiment, cross-sectional area of the rectangular inlet section **701** and the rectangular outlet section **730** (as well as rectangular straight section **502**) remain constant or decrease in a downstream direction of the fluid flow path D (i.e., the direction of arrow D), and a perimeter of a cross section of the rectangular inlet section **701** decreases along a length of the inlet section and a perimeter of a cross section of the rectangular outlet section **730** increases along a length of the outlet section. The fluid passageway T**3** of the straight section **502** reduces turbulence of the fluid flowing through the nozzle **600** as the fluid velocity direction changes from converging in the transition section T**1** and inlet section T**2** to diverging in the outlet flow passageway T**4**.

[0035] In an embodiment in which the fluid is water, as water flows from inlet section **701** to straight section **502** and from the straight section to outlet section **730**, in some nozzle geometries having converging inlet sections and diverging outlet sections the direction of the fluid flow D can change sharply. At such sharp transitions, turbulence is generated, causing fluid to move spirally. These spirally moving fluid are also known as eddies. These local eddies can persist downstream causing loss in water kinetic energy in the direction of fluid. This loss due to this sharp transition can be described by bend loss B that is given by the following equation:

$$B=(KV^2)/2g \tag{1}$$

[0036] where K is dependent on the total length of the bend and the ratio of the curvature of the bend and the cross-section height. For a circular pipe the cross-section height is equivalent to the pipe diameter and for a square pipe the value is equivalent to the side of the square. Vis the average velocity of fluid flowing through the nozzle **600**. However, by creating a transitional region (which in embodiments takes the form of straight section **502**) between the converging section (inlet section **701**) and diverging section (outlet section **730**) the impact of change in fluid direction is reduced. This transitional region **502** is achieved by providing the nozzle **600** with a straight section **502**. Straight section **502** minimizes the swirling motion of the local eddies to propagate in the fluid flow through the nozzle **600**.

[0037] As shown in FIG. **11**, to be effective in reducing eddies in the fluid flow path D, the length of the straight section **502** depends on the cross-section height h_t and the convergence and divergence angles. For convergence and divergence angles θ_c, θ_d, respectively, of less than 15° with the center C of the linear fluid flow path D, the straight section **502** is at least 2 times the cross-section height h_t at the transition region. For convergence and divergence angles θ_c, θ_d, respectively, of between 15° and 30° with the center C of the linear fluid flow path D, the straight section **502** is at least 4 times the cross-section height h_t at the transition region. For divergence angle θ_d of greater than 30°, a two-step transition to mitigate local eddies associated with sudden change in fluid direction is necessary. The second transition step is dictated by a transitional divergence angle.

[0038] As the fluid goes from inlet section **701** (converging) to straight section **502** (straight section) and finally to outlet section **730** (diverging section), the cross-sectional area is either kept constant or reduced in the downstream direction of fluid flow path D to allow maximizing fluid velocity at the exit. In the outlet section **730**, (the diverging section) the width dimension W of the fluid flow path D (see FIG. **5**) increases continuously. If the width of cross-section in the straight section is W_1, width of the cross-section at the nozzle exit is W_2 and the width anywhere in between is W_x, where x denotes the distance from the end of the straight section, then, as shown in FIG. **11**:

$$W_x=W_1+(2\times\tan\theta_d) \quad (2)$$

[0039] where θ_d is the divergence angle with respect to the straight section.

[0040] As the width W diverges, the height h (FIG. **6**) needs to converge or reduce to maintain or reduce the cross-sectional area (W×h) of the fluid flow path D. If the height h at the end of the straight section **502** is h_1 and height at the end of the diverging section is h_2, and the height at distance x from the end of the straight section is h_x, then:

$$W1h1\geq W_xh_x\geq W_2h_2 \quad (3)$$

$$W_1h_1\geq W_xh_x \quad (4)$$

$$W_1h_1\geq(W_1+(2\times\tan\theta_d))h_x \quad (5)$$

$$h_x=K[(W_1h_1)/(w_1+2\times\tan\theta_d)] \quad (6)$$

[0041] where K≤1 and depends on the ratio of cross-sectional area at the straight section and end of the diverging section.

[0042] In an embodiment, a rate of convergence (i.e., slope or angle made with the centerline C) of the opposing converging first and second inlet side walls **713**, **714** and/or the converging inlet top and bottom walls **715**, **716** is greater than a rate of divergence (i.e., slope or angle made with centerline D) of the first and the second opposing diverging outlet extension side walls **736**, **738**, such that a velocity of a fluid flowing through the nozzle **600** increases.

[0043] In an embodiment, the outlet section **730** terminates in a modulation segment **401** that defines a modulation flow passageway G (see, e.g., FIGS. **3**, **4**, and **6**). The modulation segment **401** terminates in a nozzle outlet **702**. The nozzle outlet **702** is defined by parallel opposing top and bottom outlet edges **744**, **746**, respectively, rectilinear along entire lengths thereof, and first and second opposing side edges **748**, **750**, respectively, wherein the opposing top and bottom outlet edges are parallel and contiguous with flat, parallel outlet top and bottom walls **752**, **754**, respectively, of the modulation segment **401**. In an embodiment, the modulation segment **401** includes first and second opposing side walls **756**, **758** that diverge and are a linear continuation of outlet extension side walls **736**, **738** of outlet section **730**.

[0044] In an embodiment, the side walls **756**, **758** and outlet extension side walls **736**, **738** are continuous, smooth, and the fluid pathway is unobstructed along its length. Similarly, the walls of the transition section **501** and the inlet section **701** are continuous, smooth, and provide an unobstructed fluid pathway. Accordingly, in an embodiment, the inlet opening **717** of the inlet section **701** is rectangular and a periphery of the inlet opening of the inlet section is contiguous with a periphery of the rectangular outlet of the transition section **501**.

[0045] In an embodiment, the outlet section **730** and modulation segment **401**, which define the modulation flow passageway G, provide a smooth fluid pathway to the nozzle outlet **702**. This is accomplished by the modulation segment **401** having first and second opposed diverging planar side walls **756**, **758** contiguous with the first and the second opposing diverging outlet extension side walls **736**, **738**, and parallel top and bottom walls **752**, **754** contiguous with the converging outlet top and bottom walls **732**, **734**. The first and the second side walls **756**, **758** are contiguous with the first and the second opposing outlet side walls **736**, **738** and terminate in the unobstructed rectangular modulation segment **401** from the outlet section inlet opening **740** to receive the fluid from the straight section outlet opening **728** and terminating in the oblong nozzle opening **702**. In embodiments, the shape of the cross section of the oblong nozzle outlet **702** is selected from a rhombus, a rectangle, and an ellipse. In embodiments, the shape of the outlet **702** would be cast or machined to have rounded corners to avoid stress concentrations.

[0046] In embodiments, a divergence angle of up to 30° made by the diverging first and the second opposing outlet side walls **736**, **738** (and extending to opposed planar side walls **756**, **758**) with the first and second parallel side walls **719**, **720**, a length of the straight section T**3** is at least 2 times a height h of the cross section of the straight section outlet opening **728**. In embodiments, a height hx between the outlet top and bottom walls at a distance x from the outlet section inlet opening is determined by equation (6).

[0047] In an embodiment, the diverging first and the second opposing outlet side walls **736**, **738** each have a first segment that diverges from a centerline of the outlet section, represented by linear flow pathway D, at a first angle and a second segment, downstream of the first segment, that diverges from a centerline of the outlet section fluid passageway at a second angle that is greater than the first angle. In an embodiment, the second segment takes the form of side walls **756**, **758** of modulation segment **401**. In an embodiment, the second segment is adjacent and is contiguous with the first segment. In an embodiment, the first segment and the second segment of the diverging first and the second opposing outlet side walls **736**, **738** are each smooth and planar in shape. In an embodiment, the second segments are contiguous with the first segments and make an angle with the first segments that does not exceed 30°.

[0048] In one exemplary embodiment, a nozzle **600** includes an inlet section **701** having a first and a second smooth, planar opposing inlet side walls **713**, **714** and smooth, planar opposing inlet top and bottom walls **715**, **716**. The first and the second inlet side walls **713**, **714** and the inlet top and bottom walls **715**, **716** are contiguous and form an inlet opening **717**, an inlet section outlet opening **718**, and an unobstructed rectangular inlet section fluid passageway T**2** from the inlet section inlet opening to the inlet section outlet opening. At least one pair of the first and second opposing inlet side walls **713**, **714** and the inlet top and bottom walls **715**, **716** are converging such that a cross sectional area of the inlet section fluid passageway decreases continuously from the inlet section inlet opening to the outlet section outlet opening.

[0049] The inlet section **701** is contiguous with a straight section **502** having first and second smooth, planar opposing parallel side walls **719**, **720** contiguous with the first and the second inlet side walls **713**, **714**, respectively, and having smooth, planar opposing parallel top and bottom walls **722**, **724** that are contiguous with the inlet top and bottom walls

715, **716**. The first and the second opposing parallel bottom walls **722**, **724** and the opposing parallel top and bottom walls **719**, **720** form a straight section inlet opening **726** attached to receive the fluid from the inlet section outlet opening **718**, a straight section outlet opening **728**, and an unobstructed rectangular straight section fluid passageway T**3** from the straight section inlet opening to the straight section outlet opening.

[0050] The outlet section **730** includes smooth, planar opposing converging outlet top and bottom walls **732**, **734** contiguous with the parallel top and bottom walls **722**, **724**, respectively, and is contiguous with first and second opposing diverging outlet side walls **736**, **738** that are contiguous with the first and second parallel side walls **719**,**720**. The outlet top and bottom walls **732**, **734** are contiguous with the first and the second outlet extension side walls **736**, **738** to form an outlet section inlet opening **740** attached to receive the fluid from the straight section outlet opening **728** and form an unobstructed rectangular outlet section fluid passageway T**4** from the outlet section inlet opening to terminate in an oblong variable outlet opening **742**. At least one pair of the first and second opposing outlet side walls **736**, **738** and the outlet top and bottom walls **732**,**734** are diverging such that a cross sectional area of the outlet section fluid passageway T**4** decreases continuously from the outlet section inlet opening **740** to the oblong variable outlet opening **742**.

[0051] As the cross-sectional area of the rectangular inlet fluid passageway T**2** and a cross-sectional area of the rectangular outlet section fluid passageway T**4** decrease in a downstream direction, a perimeter of a cross section of the rectangular inlet section decreases along a length of the inlet section **701** and a perimeter of a cross section of the rectangular outlet section fluid passageway T**4** increases along a length of the outlet section **730**. The rectangular inlet fluid passageway T**2**, the straight section fluid passageway T**3**, and the outlet section fluid passageway T**4** together define a continuous nozzle fluid passageway D symmetrical about central planes of the adjustable nozzle **600** extending in a fluid flow direction. In an embodiment, the nozzle **600** is bilaterally symmetric about the fluid passageway D, being symmetric as shown in FIGS. **3**, **4**, and **6**.

[0052] In an embodiment, the inlet section **701** includes a transition section **501** having a round inlet **503**, a rectangular outlet that coincides with inlet opening **717** of the inlet section **701**, and a continuous side wall **1206** that extends between the round inlet and the rectangular outlet and defines a fluid pathway T**1** attached to the inlet opening of the inlet section. The continuous side wall **1206** is defined by an entrance wall segment circular in cross section that transitions to an exit wall segment that is rectangular in cross section. In an embodiment, the transition section **501** is unitary and contiguous with the inlet section **701**.

[0053] In an embodiment, a method of making a nozzle **600** includes forming an inlet section **701** having a first and a second smooth, planar opposing converging inlet side walls **713**, **714** and smooth, planar opposing converging inlet top and bottom walls **715**, **716** and attaching the first and the second inlet side walls to the inlet top and bottom walls to form an inlet opening **717**, an inlet section outlet opening **718**, and an unobstructed rectangular inlet section fluid passageway T**2** from the inlet opening to the inlet section outlet opening. A straight section **502** is formed having first and second smooth, planar opposing parallel side walls **719**, **720** and smooth, planar opposing parallel top and bottom walls **722**, **724** such that the first and the second parallel side walls are attached to the parallel top and bottom walls to form a straight section inlet opening **726**, a straight section outlet opening **728**, and an unobstructed rectangular straight section fluid passageway T**3** from the straight section inlet opening to the straight section outlet opening.

[0054] The first and the second parallel side walls **719**, **720** are attached to the first and the second inlet side walls, **713**, **714**, respectively, and the parallel top and bottom walls **722**, **724** are attached to the converging inlet top and bottom walls to receive the fluid from the inlet section outlet opening **718**. An outlet section **730** is formed having smooth, planar opposing converging outlet top and bottom walls **732**, **734** and first and second smooth, planar opposing diverging outlet extension side walls **736**, **738** that are contiguous with the opposing converging outlet top and bottom walls to form an outlet section inlet opening **740** attached to receive the fluid from the straight section outlet opening **718** and a variable outlet opening **742**. The top and bottom walls **732**, **734** and outlet extension side walls **736**, **738** form an unobstructed rectangular outlet section fluid passageway T**4** from the outlet section inlet opening **740** to terminate in an oblong outlet opening.

[0055] The outlet top and bottom walls **732**, **734** are attached to the parallel top and bottom walls **722**, **724**, and the first and second opposing diverging outlet side walls **736**, **738** are attached to the first and the second parallel side walls **719**, **720**. A cross-sectional area of the rectangular inlet section fluid passageway T**2** and a cross-sectional area of the rectangular outlet section fluid passageway T**4** decrease in a downstream direction, and a perimeter of a cross section of the rectangular inlet section decreases along a length of the inlet section and a perimeter of a cross section of the rectangular outlet section fluid passageway increases along a length of the outlet section. The rectangular inlet fluid passageway T**2**, the straight section fluid passageway T**3**, and the outlet section fluid passageway T**4** together define a continuous nozzle fluid passageway D symmetrical about a the central planes of the nozzle extending in a fluid flow direction.

[0056] In an exemplary embodiment (see FIGS. **1**-**8**), the nozzle **600** takes the form of an adjustable nozzle. In the embodiment shown in the figures, the adjustable nozzle **600** is configured to vary a width of the fluid stream exiting the nozzle outlet **702** within a predetermined range. The adjustable nozzle **600** includes a nozzle body **700** having an inlet section **701** with an inlet section opening **717**, an outlet section **730** in which the nozzle outlet **702** of the modulation segment **401** takes the form of a variable outlet opening **742**, and the fluid flow path D extends from the inlet opening to the outlet opening. The modulation segment **401** takes the form of an adjustable spray restrictor segment **1210** in the outlet section **730**.

[0057] The adjustable nozzle **600** includes an actuator **1212** that displaces the adjustable spray restrictor segment **1210** toward and away from a center of the fluid flow path D, thereby varying an effective width W (see FIG. **5**) of the variable outlet opening **742** to vary a pattern of fluid flowing from the fluid flow path D through the variable outlet opening **742**. In an embodiment, the actuator **1212** includes a manually positionable adjustment collar **800** (see FIGS. **7** and **8**), which in embodiments is in the form of two complementary halves **899**, **900**, that is rotatably mounted on the nozzle body **700**. Manual rotation of the adjustment collar **800** relative to the nozzle body **700** displaces the adjustable spray restrictor segment **1210**.

[0058] Optionally, the adjustment collar **800** includes an indicator tab **801** that corresponds to a position of the adjustable spray restrictor segment **1210** and mating tabs **808**, **908** and grooves **812**, **912** that effect proper mating of the halves **899**, **900**. In an embodiment, the adjustment collar **800** includes a second set of mating tabs **804**, **904** and grooves **813**, **914** that facilitate proper mating of the complementary halves **899**, **900** during assembly. Optionally, the tabs include screw holes **810**, **910**, **809**, **909**, **806**, **906**, **805**, **905** to receive screws (not shown) to secure the complementary halves **899**, **900** together.

[0059] As shown in FIGS. **3**, **4**, and **9**, in an embodiment, the adjustable spray restrictor segment **1210** includes at least a first spray adjustment arm **1000** that is displaced by rotation of the adjustment collar **800** toward and away from the center of the fluid flow path D to vary the effective width W of the variable outlet opening **742**. In an embodiment, the first spray adjustment arm **1000** makes a pivotal engagement with the outlet section **730** and includes a downstream bearing surface **1010** that engages the adjustment collar **800**.

[0060] In an embodiment, the nozzle body **700** includes a first bearing recess **712** in the outlet section **730** (see FIGS. **3** and **4**). The first spray adjustment arm **1000** includes an upstream bearing surface **1006** (see FIG. **9**) that engages the first bearing recess **712** to make the pivotal engagement about a first pivot point P**1**. In an embodiment, the adjustment collar **800** includes an upstream end face **913** having an internal or upstream eccentric groove **914** extending about the variable outlet opening **742** that receives and engages the downstream bearing surface **1010**, such that rotation of the adjustment collar pivots the first spray adjustment arm toward and away from the center of the fluid flow path D (see FIGS. **3** and **4**). The radially inner boundary of the eccentric groove **914** is bounded and defined at an outer perimeter by an eccentric ridge d.

[0061] In an embodiment, the eccentric groove **914** is shaped to pivot the first spray adjustment arm **1000** between a first position, shown in FIG. **4**, resulting in a minimum spray width W and a second position, shown in FIG. **3**, resulting in a maximum spray width. In an embodiment, the eccentric groove **914** is in the form of a camming surface that engages the downstream bearing surface **1010** of the first spray adjustment arm **1000**, and the camming surface is curved, having a radius of curvature that corresponds to a radius of the first spray adjustment arm from the first pivot point P**1** to the camming surface of the eccentric groove **914**. In embodiments, the eccentric groove **914** is formed of groove segments **802**, **902** on the complementary halves **899**, **900**.

[0062] In an embodiment, the adjustable spray restrictor segment **1210** includes a second spray adjustment arm **1100** that is opposed to the first spray adjustment arm **1000**. The second spray adjustment arm **1100** is also displaced by rotation of the adjustment collar **800** toward and away from the center of the fluid flow path D to vary the effective width W of the variable outlet opening **742**. The nozzle body **700** includes a second bearing recess **1712** in the outlet section. As shown in FIG. **10**, the second spray adjustment arm **1100** includes an upstream bearing surface **1106** that engages the second bearing recess **1712** to make a pivotal engagement with the outlet section about a second pivot point P**2** and a downstream bearing surface **1110** that engages the camming surface of the eccentric groove **914** of the adjustment collar **800**.

[0063] In an embodiment, the outlet section **703** of the adjustable nozzle **600** includes the modulation segment **401** in the form of a terminal segment having opposed planar, parallel top and bottom walls **752**, **754** and first and second opposed planar side walls **756**, **758** contiguous with the top and bottom walls. The first and second spray adjustment arms **1000**, **1100** are mounted in the terminal segment to pivot toward and away from the first and second side walls **756**, **758**, respectively, when displaced by rotation of the adjustment collar **800**.

[0064] In an embodiment, the adjustment collar **800** is connected to the first and second spray adjustment arms **1000**, **1100** to pivot the first and second spray adjustment arms relative to the terminal segment of the modulation segment **401** toward and away from the first and second opposed planar side walls **756**, **758** to selectively vary the effective width W of the variable outlet opening **742**. In an embodiment, the first and second spray adjustment arms **1000**, **1100** are pivotally mounted at the upstream ends of the bearing surfaces **1006**, **1106**, respectively, thereof to the first and second bearing recesses **712**, **1712**, respectively, of the first and second side walls **756**, **758**.

[0065] In one embodiment shown in FIG. **9**, the first and second spray adjustment arms **1000**, **1100** (only one first spray adjustment arm **1000** is shown, it being understood that for this embodiment spray adjustment arm **1100** is identical thereto) include a guide surface **1003** that faces the center C (FIG. **11**) of the fluid flow path D. The upstream bearing surface **1006**, which is curved to match the curvature of the first bearing recess **712**, is connected to the downstream bearing surface **1010** by a spine **1001** that is opposite the guide surface **1003**.

[0066] In another embodiment shown in FIG. **10**, the first and second spray adjustment arms **1000**, **1100** (only one second spray adjustment arm **1100** is shown, it being understood that first spray adjustment arm **1000** is identical thereto) include a guide surface **1103** that faces the center C of the fluid flow path D. The upstream bearing surface **1106**, which is curved to match the curvature of the second bearing recess **1712**, is connected to the downstream bearing surface **1110** by a spine **1101**. The guide surfaces **1003**, **1103** are positioned in the terminal segment of the modulation or outlet section **730** to contact fluid flowing through the terminal segment of the modulating segment **401** and define the effective width W of the straight section variable outlet opening **728**.

[0067] In the embodiment of FIG. **9**, the guide surfaces **1003** of the first and second adjustment arms **1000**, **1100** are substantially flat and planar. In the embodiment of FIG. **10**, the guide surfaces **1103** of the first and second spray adjustment arms **1000**, **1100** are curved in a width direction (i.e., the "h" dimension in FIG. **5**). As shown in the embodiment of FIG. **10**, the guide surfaces **1103** of the first and second adjustment arms **1000**, **1100** are shaped to transition in a downstream direction from a flat contour to a curved contour in a width direction. In an embodiment, the first and second spray adjustment arms **1000**, **1100** include flat upper and lower surfaces **1004**, **1005** and **1104**, **1105**, respectively, that bear against, but pivot relative to, the top and bottom walls **752**, **754** of the modulation segment **401** to provide a fluid seal.

[0068] Also, in the embodiment shown in FIG. **10**, the first and second adjustment arms **1000**, **1100** (only second adjustment arm **1100** is shown in FIG. **10**, it being understood that spray adjustment arm **1000** is identical thereto in this embodiment) optionally include a gasket **1107** that extends about the adjustment arm in an annular, longitudinal recess between the spine **1101** and the face **1103**. This gasket prevents fluid leakage between the face **1103** and the top and bottom walls **752**, **754** of the modulation segment **401**. In embodiments, the gasket **1107** is made of rubber or an elastomer.

[0069] In both the embodiments shown in FIGS. **9** and **10**, the first and second spray adjustment arms **1000**, **1100** include notches or cutouts **1002**, **1102** that engage and are captured by the eccentric ridge d formed about the variable outlet opening **742**. As the adjustment collar **800** is rotated relative to the adjustable nozzle **600**, the first and second adjustment arms **1000**, **1100**, which pivot in response to the varying distance of the eccentric ridge d from the center of the fluid flow path D, vary the effective width W of the variable outlet opening **742**. In embodiments, the eccentric ridge d is in the form of an ellipse, but also can be in the form of other eccentric (i.e., non-circular) shapes to provide different responses in width of the spray pattern exiting the variable outlet opening **742** corresponding to a given rotation of the adjustment collar **800**.

[0070] As shown in FIGS. **7** and **8**, in an embodiment the adjustment collar **800** includes stops or bosses **807**, **907** positioned to engage cutouts **706**, **707** formed in the outer periphery of the nozzle body **700**. The stops **807**, **907** limit rotation of the adjustment collar **800** relative to the nozzle body **700** to a preselected amount. In an embodiment, the relative rotation is limited to a 90° clockwise and counterclockwise rotation. The eccentric groove **914** is sized and shaped such that such a 90° relative rotation of the adjustment collar **800** will cause the first and second spray adjustment arms **1000**, **1100** to pivot from their maximum separation shown in FIG. **3**, and hence maximum effective width W of the variable outlet opening **742** and fluid stream exiting the variable outlet opening, to their minimum separation shown in FIG. **4**, and hence minimum effective width W of the variable outlet opening and exiting fluid stream.

[0071] While the forms of apparatus and methods disclosed herein constitute preferred embodiments of the disclosed smooth bore nozzle, it is to be understood that the invention is not limited to these precise forms of apparatus and methods, and that changes may be made therein without departing from the scope of the invention.

What is claimed is:

1. A smooth bore nozzle, comprising:

an inlet section having a first and a second smooth, planar opposing converging inlet side walls contiguous with smooth, planar opposing converging inlet top and bottom walls, the first and the second inlet side walls and the inlet top and bottom walls forming an inlet section opening, an inlet section outlet opening, and an unobstructed rectangular inlet section fluid passageway from the inlet section opening to the inlet section outlet opening;

a straight section having first and second smooth, planar opposing parallel side walls contiguous with the first and the second inlet side walls, respectively, and contiguous with smooth, planar opposing parallel top and bottom walls that are contiguous with the inlet top and bottom walls, respectively, wherein the first and the second opposing parallel side walls and the opposing parallel top and bottom walls form a straight section inlet opening attached to receive the fluid from the inlet section outlet opening, a straight section outlet opening, and an unobstructed rectangular straight section fluid passageway from the straight section inlet opening to the straight section outlet opening; and

an outlet section having smooth, planar opposing converging outlet top and bottom walls contiguous with the parallel top and bottom walls, respectively, and contiguous with first and second opposing diverging outlet side walls that are contiguous with the opposing parallel side walls, wherein the outlet top and bottom walls are contiguous with the first and the second outlet side walls to form an outlet section inlet opening attached to receive the fluid from the straight section outlet opening and an unobstructed rectangular outlet section fluid passageway from the outlet section inlet opening to terminate in an oblong outlet opening;

wherein a cross-sectional area of the rectangular inlet fluid passageway and a cross-sectional area of the rectangular outlet section fluid passageway remain constant or decrease in a downstream direction, and a perimeter of a cross section of the rectangular inlet section decreases along a length of the inlet section and a perimeter of a cross section of the rectangular outlet section fluid passageway increases along a length of the outlet section.

2. The nozzle of claim **1**, wherein a rate of convergence of the opposing converging inlet side walls and/or the converging inlet top and bottom walls is greater than a rate of divergence of the first and the second opposing diverging outlet side walls, such that a velocity of a fluid flowing through the nozzle increases.

3. The nozzle of claim **1**, wherein the oblong outlet opening is defined by parallel opposing top and bottom outlet edges rectilinear along entire lengths thereof and first and second opposing side edges, wherein the opposing top and bottom outlet edges are parallel with the outlet top and bottom walls.

4. The nozzle of claim **1**, further comprising a modulation segment that extends from the outlet section and includes first and second opposing side edges that diverge and are a linear continuation of the diverging outlet side walls.

5. The nozzle of claim **1**, further comprising a transition section having a round inlet, a rectangular outlet contiguous with the inlet opening of the inlet section, and a continuous side wall that extends between the round inlet and the rectangular outlet and defines a transition fluid pathway attached to the inlet opening of the inlet section.

6. The nozzle of claim **5**, wherein the transition section and the inlet section are unitary.

7. The nozzle of claim **5**, wherein the continuous side wall is smooth, and the transition fluid pathway is unobstructed along its length.

8. The nozzle of claim **5**, wherein the inlet opening of the inlet section is rectangular and a periphery of the inlet opening of the inlet section is contiguous with a periphery of the rectangular outlet of the transition section.

9. The nozzle of claim **1**, wherein the outlet opening includes a modulation segment, the modulation segment having first and second parallel opposing extension side walls contiguous with the first and the second opposing diverging outlet section side walls, and parallel top and bottom extension walls contiguous with the converging outlet top and bottom walls, the first and the second extension side walls being contiguous with the first and the second opposing extension side walls to form an unobstructed rectangular outlet extension section fluid passageway from the outlet extension section inlet opening to receive the fluid from the straight section outlet opening and terminating in an oblong outlet opening.

10. The nozzle of claim **1**, wherein a shape of a cross section of the oblong outlet opening is selected from a rhombus, a rectangle, and an ellipse.

11. The nozzle of claim **1**, wherein for a divergence angle of up to 30° made by the first and the second opposing diverging outlet side walls with the opposing parallel side walls, a length of the straight section is at least 2 times a height of a cross section of the straight section outlet opening.

12. The nozzle of claim **7**, wherein a height h_x between the outlet top and bottom walls at a distance x from the outlet section inlet opening is determined by the equation $h_x = K[W_1 h_1/(W_1 + (2 \tan \theta))]$, where W_1 is a width of the outlet section inlet opening, h_1 is a height of the outlet section inlet opening, and $K \leq 1$.

13. The nozzle of claim **1**, wherein the outlet section first and second opposing diverging outlet side walls each have a first segment that diverges from a centerline of the outlet section fluid passageway at a first angle and a second segment downstream of the first segment that diverges from a centerline of the outlet section fluid passageway at a second angle that is greater than the first angle.

14. The nozzle of claim **13**, wherein the second section is adjacent and is contiguous with the first section.

15. The nozzle of claim **13**, wherein the first segment and the second segment of the outlet section first and second opposing diverging outlet side walls are each smooth and planar in shape.

16. The nozzle of claim **15**, wherein the second segments are contiguous with the first segments and make an angle with the first segments that does not exceed 30°.

17. A nozzle, comprising:

an inlet section having a first and a second smooth, planar opposing inlet side walls and smooth, planar opposing inlet top and bottom walls, the first and the second inlet side walls and the inlet top and bottom walls are contiguous and form an inlet opening, an inlet section outlet opening, and an unobstructed rectangular inlet section fluid passageway from the inlet section inlet opening to the inlet section outlet opening, wherein at least one pair of the first and second opposing inlet side walls and the inlet top and bottom walls being converging such that a cross sectional area of the inlet section fluid passageway decreases continuously from the inlet section inlet opening to the outlet section outlet opening;

a straight section having first and second smooth, planar opposing parallel side walls contiguous with the first and the second inlet side walls, respectively, and having smooth, planar opposing parallel top and bottom walls that are contiguous with the inlet top and bottom walls, respectively, wherein the first and the second opposing parallel side walls and the opposing parallel top and bottom walls form a straight section inlet opening attached to receive the fluid from the inlet section outlet opening, a straight section outlet opening, and an unobstructed rectangular straight section fluid passageway from the straight section inlet opening to the straight section outlet opening; and

an outlet section having smooth, planar opposing converging outlet top and bottom walls contiguous with the parallel top and bottom walls, respectively, and contiguous with first and second opposing diverging outlet side walls that are contiguous with the opposing parallel side walls, wherein the outlet top and bottom walls are contiguous with the first and the second outlet side walls to form an outlet section inlet opening attached to receive the fluid from the straight section outlet opening and an unobstructed rectangular outlet section fluid passageway from the outlet section inlet opening to terminate in an oblong outlet opening, wherein at least one pair of the first and second opposing outlet side walls and the outlet top and bottom walls being diverging such that a cross sectional area of the outlet section fluid passageway decreases continuously from the outlet section inlet opening to the oblong outlet opening;

wherein as the cross-sectional area of the rectangular inlet fluid passageway and a cross-sectional area of the rectangular outlet section fluid passageway decrease in a downstream direction, a perimeter of a cross section of the rectangular inlet section decreases along a length of the inlet section and a perimeter of a cross section of the rectangular outlet section fluid passageway increases along a length of the outlet section; and

wherein the rectangular inlet fluid passageway, the straight section fluid passageway, and the outlet section fluid passageway together define a continuous nozzle fluid passageway symmetrical about a central plane of the nozzle extending in a fluid flow direction.

18. The nozzle of claim **17**, wherein the inlet section includes a transition section having a round inlet, a rectangular outlet contiguous with the inlet opening of the inlet section, and a continuous side wall that extends between the round inlet and the rectangular outlet and defines a fluid pathway attached to the inlet opening of the inlet section that is defined by an entrance wall segment circular in cross section that transitions to an exit wall segment that is rectangular in cross section.

19. The nozzle of claim **18**, wherein the transition section is unitary and contiguous with the inlet section.

20. A method of making a nozzle, the method comprising:

forming an inlet section having a first and a second smooth, planar opposing converging inlet side walls and smooth, planar opposing converging inlet top and bottom walls;

attaching the first and the second inlet side walls to the inlet top and bottom walls to form an inlet opening, an inlet section outlet opening, and an unobstructed rectangular inlet section fluid passageway from the inlet opening to the inlet section outlet opening;

forming a straight section having first and second smooth, planar opposing parallel side walls and smooth, planar opposing parallel top and bottom walls such that the first and the second parallel side walls are attached to the parallel top and bottom walls to form a straight section inlet opening, a straight section outlet opening, and an unobstructed rectangular straight section fluid passageway from the straight section inlet opening to the straight section outlet opening;

attaching the first and the second parallel side walls to the first and the second inlet side walls, respectively, and attaching the parallel top and bottom walls to the converging inlet top and bottom walls to receive the fluid from the inlet section outlet opening;

forming an outlet section having smooth, planar opposing converging outlet top and bottom walls and first and second smooth, planar opposing diverging outlet side walls that are contiguous with the opposing converging outlet top and bottom walls to form an outlet section inlet opening attached to receive the fluid from the straight section outlet opening and an unobstructed rectangular outlet section fluid passageway from the outlet section inlet opening to terminate in an oblong outlet opening;

attaching the outlet top and bottom walls to the parallel top and bottom walls, and attaching the first and second opposing diverging outlet side walls to the first and the second parallel side walls;

wherein a cross-sectional area of the rectangular inlet section fluid passageway and a cross-sectional area of the rectangular outlet section fluid passageway decrease in a downstream direction, and a perimeter of a cross section of the rectangular inlet section remains constant along a length of the inlet section and a perimeter of a cross section of the rectangular outlet section fluid passageway remains constant along a length of the outlet section; and

wherein the rectangular inlet fluid passageway, the straight section fluid passageway, and the outlet section fluid passageway together define a continuous nozzle fluid passageway symmetrical about a central axis of the nozzle extending in a fluid flow direction.

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