



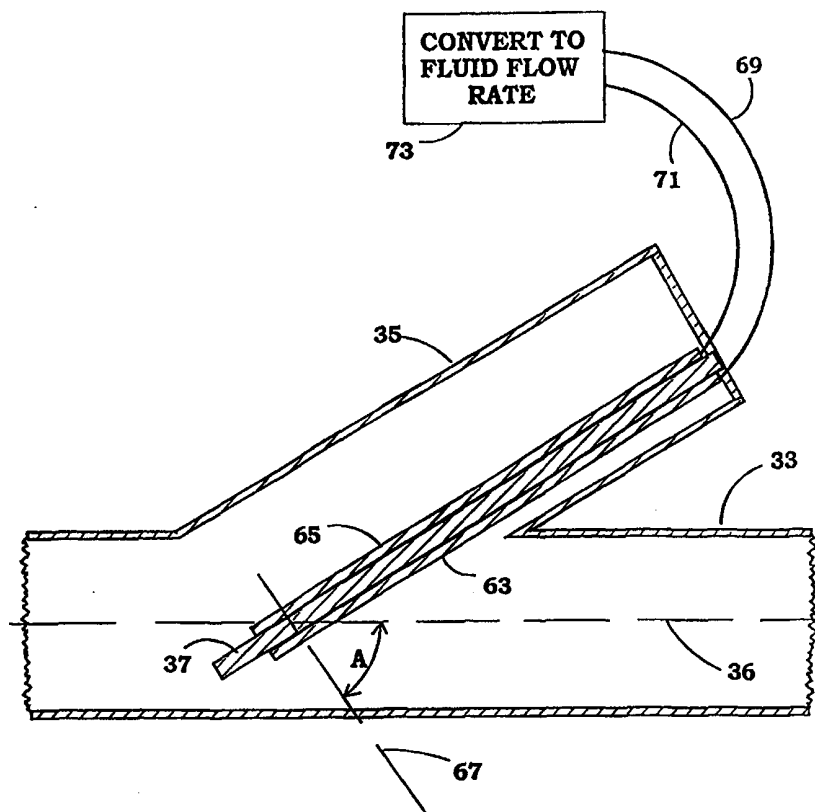
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<p>(21) International Application Number: PCT/US99/23960</p> <p>(22) International Filing Date: 14 October 1999 (14.10.99)</p> <p>(30) Priority Data: 09/172,447 14 October 1998 (14.10.98) US</p> <p>(71) Applicant: ALLIEDSIGNAL INC. [US/US]; 101 Columbia Road, P.O. Box 2245, Morristown, NJ 07962-2245 (US).</p> <p>(72) Inventors: PIASCIK, James; 10 Sandra Lane, Randolph, NJ 07869 (US). OBOODI, Reza; 27 Meadow Bluff Road, Morris Plains, NJ 07950 (US). GUALTIERI, Devlin, M.; 12 Moore Street, Ledgewood, NJ 07852 (US).</p> <p>(74) Agents: CRISS, Roger, H. et al.; AlliedSignal Inc., Law Dept., (A. Olinger), 101 Columbia Road, P.O. Box 2245, Morristown, NJ 07962-2245 (US).</p>		<p>(81) Designated States: JP, European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).</p> <p>Published With international search report. Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.</p>

(54) Title: FLOW SENSOR WITH WIDE DYNAMIC RANGE

(57) Abstract

An improved fluid flow measuring device having more nearly linear response characteristics over a wide range of fluid flow rates measures the force exerted on a fluid flow sensing element (21, 37, 41, 47, 55, 61) located in the fluid flow. The effective area of the sensing element subjected to the fluid force decreases as the flow rate increases and increases as the flow rate decreases thereby compensating for the non-linear relationship between fluid flow rate and the force exerted thereby. The sensing element may retract somewhat into a calm or minimal flow region (27, 35) in response to increased flow rate. The sensing element may include resilient vanes (45, 51, 52, 53, 57, 59) which bend thereby reducing their effective area in response to increased flow. The sensing element may include one or more flow passing apertures (43, 49) the size of which varies with flow rates.



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FLOW SENSOR WITH WIDE DYNAMIC RANGE

BACKGROUND OF THE INVENTION

The present invention relates generally to methods and apparatus for measuring fluid flow in a conduit and more especially to such methods and apparatus requiring operation over a wide range of flow rates.

Current flow sensors for fuel measurement in aircraft engines are both expensive and require frequent replacement. These flow sensors are required to operate on fluid flows varying from no flow, to a few hundred pounds per hour (pph), to 5000 pph or more.

Cantilevered beam flow meters are known and provide adequate measures of fluid flow in many applications, however, the prior art designs are often inadequate for applications having a wide range of fluid flow rates. The force applied on the cantilever beam is governed by: the area of the beam exposed to the flow; the drag coefficient which is determined by the sensor and the pipe geometries as well and the flow characteristics; specific gravity of the fluid being measured; and the square of the flow velocity. Because of this square relationship, the drag force on the beam is far greater at high flows compared to low flows. As noted earlier, in typical aircraft applications the operating fluid flow can vary from a few tens of pounds per hour (pph), for example, during descent or idle operation to thousands pph or more, for example, during take-off. The cantilever beam, therefore, has to be designed to operate and survive the high flow which results in a very large drag force. Moreover, the sensitivity of the device is as important at the low flows (very small drag force) as well as high flows (unproportionately large drag force).

It is desirable to provide a flow sensor exhibiting a reduced likelihood of damage at high flow rates and enhanced sensitivity at low flow rates. It is also desirable to provide a highly reliable flow sensor at low cost.

The present invention provides solutions to the above problems by providing a cantilever beam sensor in which the drag area of the beam decreases as the flow increases. This allows the flow meter to operate accurately both at low and high flows (high turndown ratio). The present

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invention further provides a flow sensor based on thick film technology with a wide dynamic range.

In accordance with one form the invention, the dynamic range of a fluid flow sensing device of the type that provides a measure of fluid flow based on the force the flowing fluid exerts on a surface of a sensor member exposed to that fluid flow, is enhanced by reducing the effective area of the sensor member surface which is exposed to the fluid flow as the fluid flow rate increases, and increasing the effective area of the sensor member surface which is exposed to the fluid flow as the fluid flow rate decreases. The effective area may be increased and decreased by changing the angle between the surface and the direction of fluid flow, or it may be increased by inserting an additional portion of the sensor member into the fluid flow, and decreased by withdrawing a portion of the sensor member from the fluid flow. Both techniques are utilized in a preferred embodiment. In accordance with another aspect of the invention, a fluid flow measuring device includes a conduit through which fluid may flow and a cantilevered beam having a free end portion thereof extending obliquely into the conduit to be deflected by the flow of fluid in the conduit. There is an arrangement which provides an indication of the amount of beam deflection and converts the indicated amount of beam deflection into a measure of the fluid flow rate. There may be a recess in the conduit forming a region of substantially reduced fluid flow and an end of the cantilevered beam which is opposite the free end is fixed within the recess. As beam deflection increases in response to increasing fluid flow, the portion of the beam within the recess increases and the portion of the beam exposed to the fluid flow decreases thereby providing enhanced flow sensitivity at lower flow rates and a measuring device of enhanced dynamic range. The present invention comprises a fluid flow measuring device comprising a conduit through which fluid may flow; a cantilevered beam having a free end portion thereof extending obliquely into the conduit to be deflected by the flow of fluid in the conduit; means responsive to beam deflection for providing an indication of the amount of beam deflection; and

means for converting the indicated amount of beam deflection into a measure of the fluid flow rate.

BRIEF DESCRIPTION OF THE DRAWINGS

- 5 Figures 1a-1d are schematic illustrations of a flow meter at various flow rates exhibiting nonlinear response characteristics;
- Figures 2a-2d are schematic illustrations of a flow meter according to the present invention at various flow rates exhibiting substantially linear response characteristics;
- 10 Figure 3a is a schematic sectional side view along lines a-a of Figure 3c illustrating a cantilevered beam sensor flow meter according to the present invention;
- Figure 3b is a schematic sectional side view along lines b-b of Figure 3d of the cantilevered beam flow sensor under nearly full flow conditions;
- 15 Figure 3c is a right side view of the sensor of Figure 3a;
- Figure 3d is a right side view of the sensor of Figure 3b;
- Figure 3e is a cross-sectional view similar to Figure 3a, but illustrating the cantilevered beam flow meter in greater detail;
- Figures 4a and 4b are plan views of an apertured flow meter sensor;
- 20 Figures 5a and 5b are plan views of another apertured flow meter sensor;
- Figure 6a is an isometric view of a flow meter sensor having cantilevered resilient vanes under no flow conditions;
- Figure 6b is a top view of the sensor of Figure 6a;
- 25 Figure 6c is an isometric view of the flow meter sensor of Figure 6a with the vanes responding to fluid flow;
- Figure 6d is a top view of the sensor of Figure 6b; and
- Figure 7 is an isometric view of a flow meter sensor having multiple cantilevered resilient vanes under no flow conditions.
- 30 Corresponding reference characters indicate corresponding parts throughout the several views of the drawing.

DETAILED DESCRIPTION OF THE INVENTION

In Figure 1, a sensor element 11 is pivotally connected at 13 to conduit 15. As fluid flows through the conduit 15 from right to left, the fluid exerts a force on the sensor element 11 causing it to pivot clockwise against a spiral spring or other bias (not shown). The sensor element 11 rigidly supports a cursor 17 which points to the current rate of fluid flow on dial 19. The dial is calibrated generically from no-flow as in Figure 1a to full-flow as in Figure 1d. Recall, the force on the element 11 is proportional to the square of the fluid velocity. Thus, at 1/4 flow rate, the cursor has moved only 1/16 of the way from zero to full-flow as shown in Figure 1b. For 1/8 of full flow, the cursor would have moved only 1/64 of the distance from zero to full-flow which would be almost imperceptible. The fluid flow metering device of Figure 1 exhibits very poor sensitivity at low flow rates.

Figure 2 illustrates a modification to enhance low flow rate sensitivity. The sensor element 21 pivots at 23 and is rigidly connected to cursor 29. Fluid flow is again from right to left through the conduit 25. There are two important differences between Figures 1 and 2. The sensor element 21 is initially inclined at an oblique angle to the direction of fluid flow. The pivot location for the sensor element 21 is located a significant distance away from the fluid flow in a pocket or recess 27. The advantages of this configuration are two-fold. As the flow increases, the angle at which the sensor element 21 faces the flow increases. This reduces the effective area of the sensor element--the area of the sensor element perpendicular to the direction of flow thus reducing the overall force exerted on the element by the flowing fluid. This reduction changes the nonlinear (approximately second degree polynomial) response characteristics of Figure 1 to the more nearly linear response characteristics of Figure 2.

In Figure 3, fluid flow is through the conduit 33 from right to left along the axis 36. A cantilevered beam sensor 37 is fixed at 39 and extends into the flow at an oblique angle A to the direction of fluid flow. Note, the angle between the beam surface and a vertical line (Figure 3a) is the same as the angle between a normal to the surface of the beam and the direction of fluid

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flow (Figure 3e). As fluid flow increases, the beam 37 experiences increasing deflection as illustrated in Figures 3b and 3d. The effects of this deflection are two-fold. A portion of the beam surface area moves out of the main flow of fluid and retreats into the low flow region of the pocket or recess 35. Thus, 5 the beam area which is subjected to the force of the fluid flow is reduced. Moreover, the angle between the beam and the direction of fluid flow increases by the angle B. Since the force on the beam 37 is proportional to the projected or normal component of surface area, the force is proportional to $\cos (A+B)$ times the actual surface area exposed to the flow. The 10 projected or effective surface area of beam 37 at no flow is seen within the circular conduit 33 in Figure 3c while the effective or projected surface area of beam 37 at a significant flow rate is seen within the circular conduit 33 in Figure 3d. For this particular illustration, the area is reduced to about 1/3 of its no flow value. Beam deflection may be translated electronically into an 15 indication of flow rate as indicated in Figure 3e.

In Figure 3e, strain responsive coatings 63 and 65 are disposed on opposite sides of the beam 37. These coatings may, for example, be variable resistance ceramic coatings as disclosed in U.S. Patents 4,794,048 and 4,997,698 and provide an indication of the amount of beam deflection. These 20 variable resistance coatings 63 and 65 are connected by twin conductor leads 69 and 71 to a conversion circuit, for example, a resistance bridge circuit 73 with the layers comprising two legs of the bridge. Circuit 73 provides a measure or indication of the fluid flow rate. Piezoelectric or variable capacitance layers may also be used.

25 The sensor portion exposed to the flow to be measured may be the simple beam as thus far discussed, or may be a somewhat larger beam supported paddle. Since the response of a paddle type flow sensor is proportional to the area of the paddle, the sensitivity of such a sensor to low flow rates can be enhanced if the paddle area is larger at low flow rates than 30 at high flow rates. Figure 4a shows a paddle section 41 which is to be acted upon by fluid flow. A series of radial slots such as 43 define therebetween a series of pie-shaped segments such as 45. As the fluid flow (which is normal

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to the plane of the drawing) increases, these pie-shaped segments bend outwardly with the flow opening a central aperture as shown in Figure 4b thereby reducing the effective area of the paddle. The number of pie-shaped segments as well as the number of whole pies on a paddle are determined by
5 the particular application.

Figure 5a similarly illustrates a paddle section 47 which is to be acted upon by fluid flow. Again, a series of radial slots such as 49 define therebetween a series of pie-shaped segments such as 51. While the pie-shaped segments of Figures 4a and 4b were fixed to the paddle along their
10 outer edges (the pie crust), the segments of Figures 5a and 5b are joined and supported at the center. As the fluid flow (again normal to the plane of the drawing) increases, these pie-shaped segments bend outwardly with the flow opening an annulus as shown in Figure 5b thereby reducing the effective area of the paddle.

15 As shown in Figures 6a-d, making the effective sensor area larger at low flow rates than at high flow rates can be accomplished with paddle sections or vanes 52 and 53 which elastically bend back at high flow rates. These vanes are supported on a beam 55 which may flex with that flexure monitored by some type of strain gauge, or the beam may be relatively inflexible and its
20 pivotal motion in response to fluid flow monitored. As the flow indicated by the arrows in Figure 6c increases, the vanes yield as best seen in Figure 6d reducing the flow responsive effective area. The effective area of this bendable section is proportional to the product of its area and the cosine of the bend angle C.

25 Figure 7 illustrates a variation on the concept of Figures 6a-6d having a multitude of separate vanes such as 57 and 59 supported on a common beam 61. The vanes 57 and 59 yield to increasing flow in a manner similar to the vanes 52 and 53 of Figure 6c.

WHAT IS CLAIMED IS:

1. A method of extending the dynamic range of a fluid flow sensing device of the type that provides a measure of fluid flow based on the force flowing fluid exerts on a surface of a sensor member (21, 37, 41, 47; 52, 53, 55) exposed to the fluid flow, comprising reducing the effective area of the sensor member surface which is exposed to the fluid flow as the fluid flow rate increases, and increasing the effective area of the sensor member surface which is exposed to the fluid flow as the fluid flow rate decreases.
2. The method of Claim 1, wherein the effective area is increased and decreased by changing the angle (A, C) between the surface and the direction of fluid flow.
3. The method of Claim 1, wherein the effective area is increased by inserting an additional portion of the sensor member (21, 37) into the fluid flow and decreased by withdrawing a portion of the sensor member from the fluid flow.
4. The method of Claim 1, wherein the sensor member (21, 37) comprises a cantilevered beam (21, 37) having a free end within and deflected by the fluid flow, the surface comprising a relatively planar surface area of the beam and disposed at a substantial oblique angle (A) to a direction of fluid flow when the fluid is static.
5. The method of Claim 4, wherein as the flow increases, the beam (21, 37) deflects withdrawing a portion of the free end from the fluid flow.
6. The method of Claim 4, wherein as the flow increases, the beam (21, 37) deflects increasing the oblique angle between the direction of fluid flow and the surface.
7. The method of Claim 4, wherein the beam (21, 37) is supported at a location (23, 39) substantially removed from the fluid flow and is inclined at an oblique angle (A) to the direction of fluid flow, whereby as the flow increases the beam (21, 37) deflects to withdraw a portion of

the free end from the fluid flow thereby reducing the beam surface area which is subjected to flowing fluid and increasing the oblique angle between the direction of fluid flow and the reduced beam surface area by an angle (B) thereby further reducing the effective area of the reduced
5 beam surface area.

8. A fluid flow measuring device comprising:
a conduit (33) through which fluid may flow;
a sensing element (21, 37, 41, 47, 55, 61) having a portion thereof
extending into the conduit to be subjected to the force of the flow of fluid
10 in the conduit, the sensing element portion including a resiliently yieldable region (21, 37, 45, 51, 52, 53, 57, 59) which progressively yields as the fluid flow rate increases to progressively diminish the effective sensing element area subjected to the force of the flowing fluid;
means (63, 65) for providing a measure of the force exerted on the
15 sensing element; and
means (73) for converting the force measure into a measure of the fluid flow rate.

9. The fluid flow measuring device of Claim 8, wherein the resiliently yieldable region comprises a variable size aperture (43, 45; 49,
20 51) in the sensing element portion.

10. The fluid flow measuring device of Claim 8, wherein the resiliently yieldable region comprises at least one cantilevered vane (52, 53; 57, 59) extending from the sensing element portion (55, 61) generally orthogonal to a direction of fluid flow.

25 11. The fluid flow measuring device of Claim 8, wherein the resiliently yieldable region (21, 37) comprises the entire sensing element.

12. The fluid flow measuring device of Claim 8, wherein the conduit includes a recessed region (27, 35) having significantly reduced fluid flow into which part of the sensing element portion retracts as the
30 fluid flow increases thereby diminishing an area of the sensing element portion affected by fluid flow as the flow increases and increasing the

area of the sensing element portion effected by fluid flow as the flow decreases.

13. The fluid flow measuring device of Claim 8, wherein the force measure means comprises layers (63, 65) of variable resistance ceramic material, one layer on each of two opposed beam surfaces and the means for converting (73) comprises a wheatstone bridge circuit with the layers (63, 65) comprising two legs of the bridge.

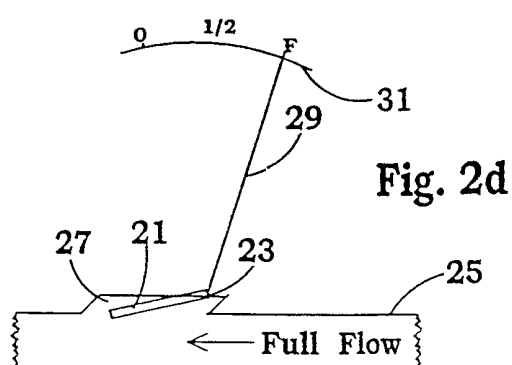
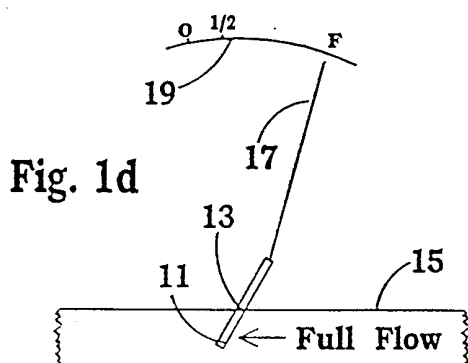
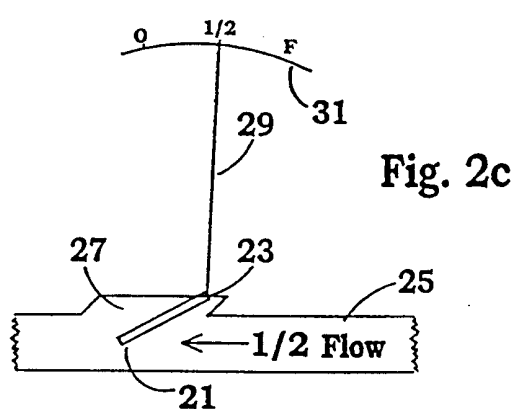
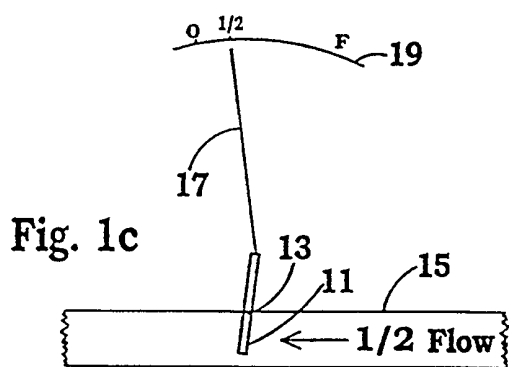
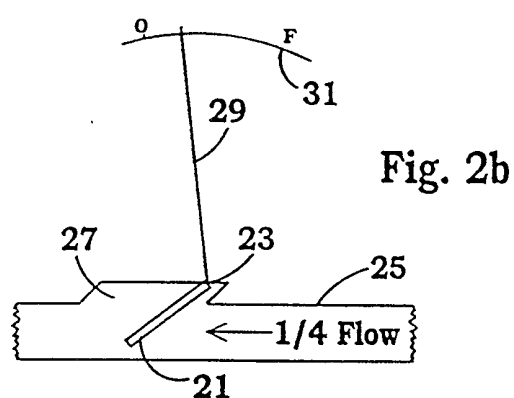
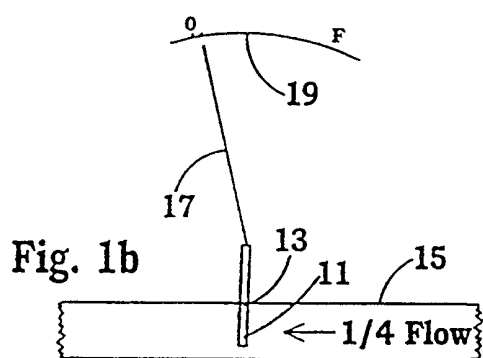
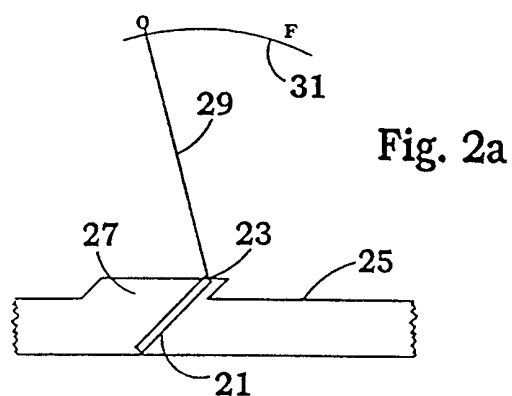
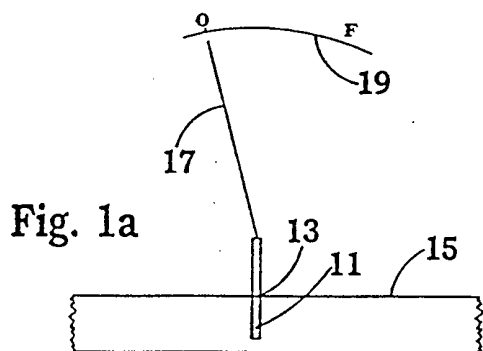
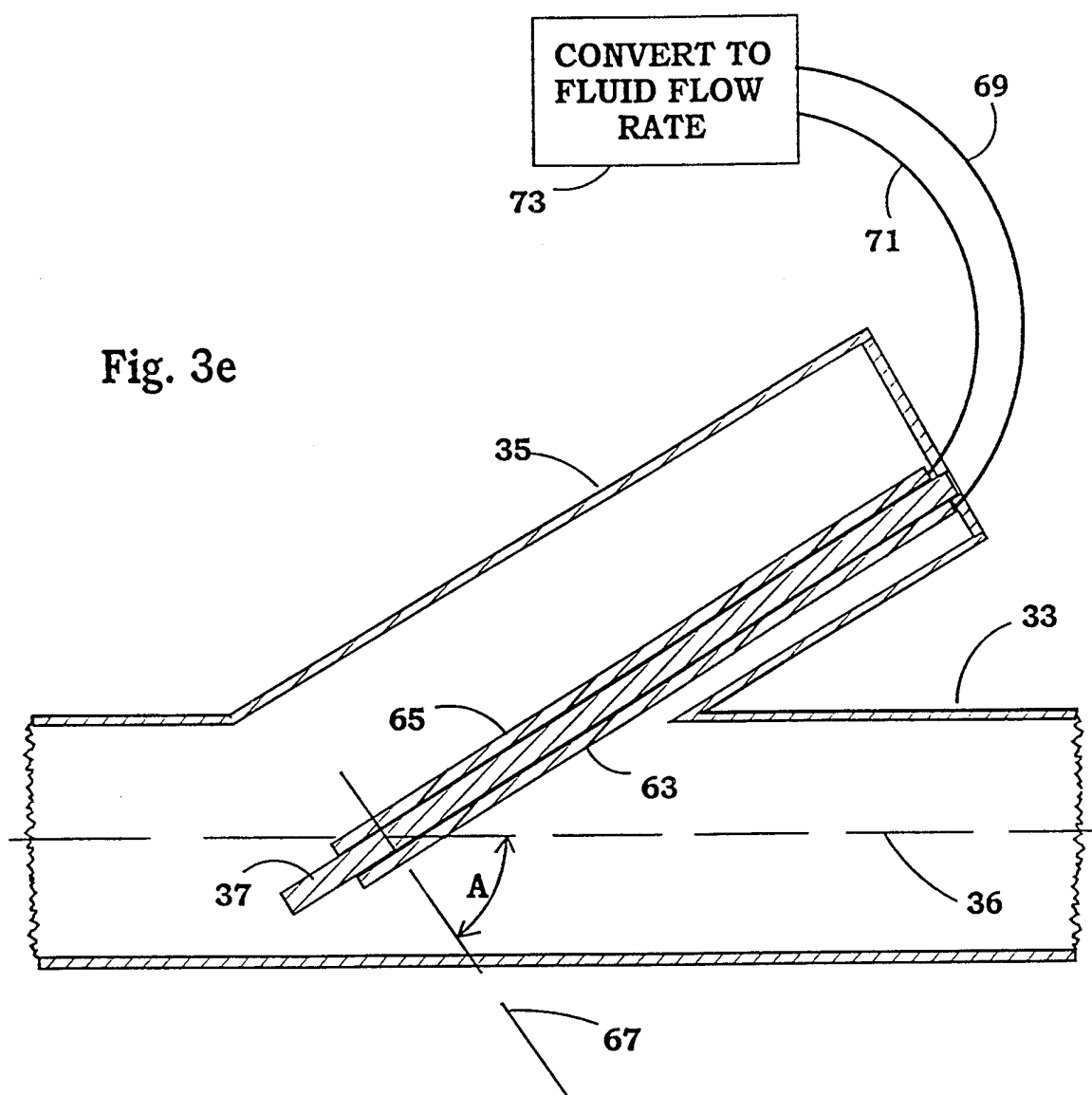


Fig. 3e



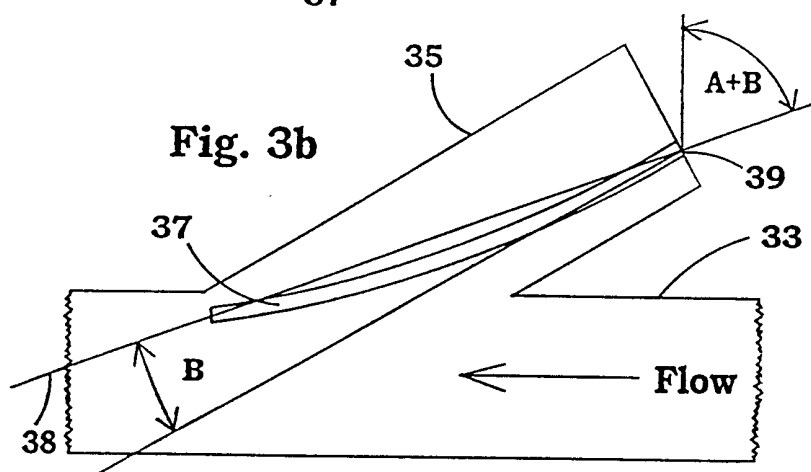
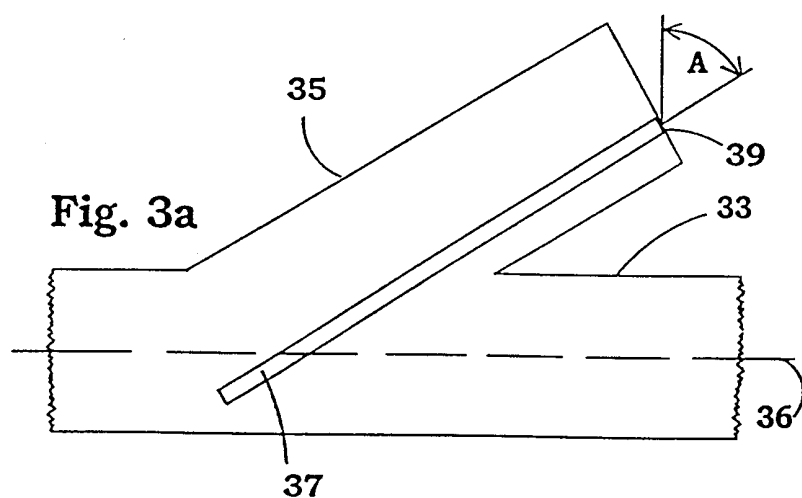
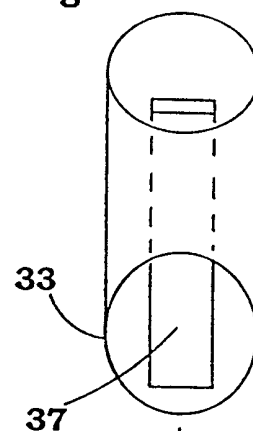


Fig. 3c $\rightarrow a$



$\rightarrow a$

$\rightarrow b$

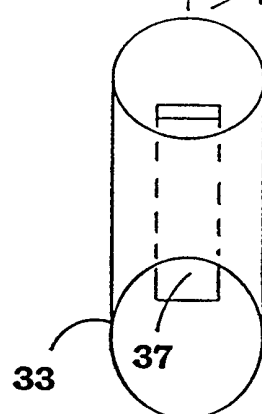


Fig. 3d $\rightarrow b$

Fig. 4a

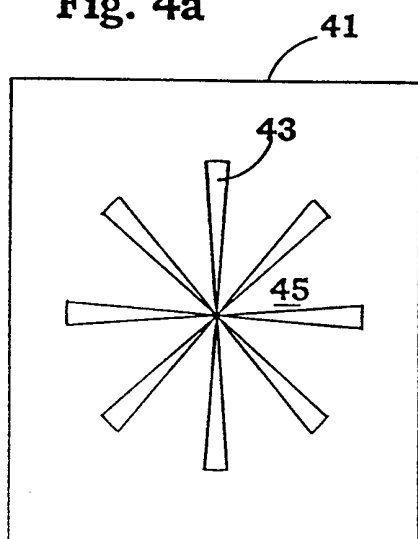
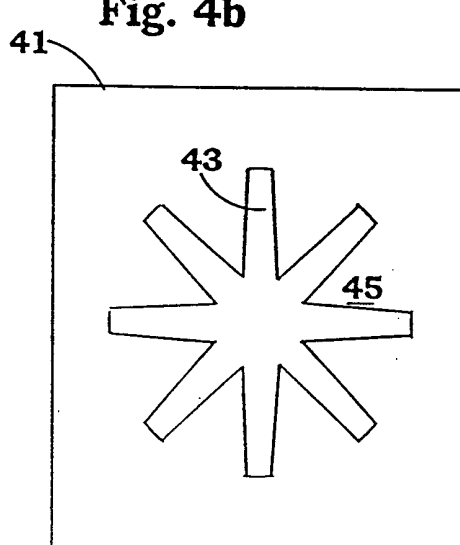


Fig. 4b



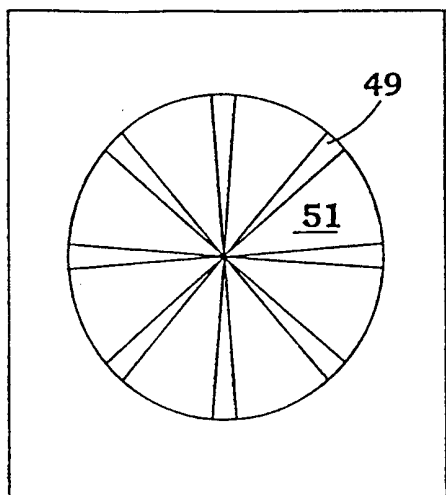


Fig. 5a

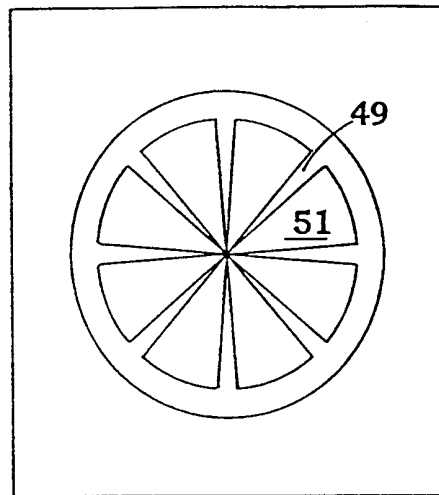


Fig. 5b

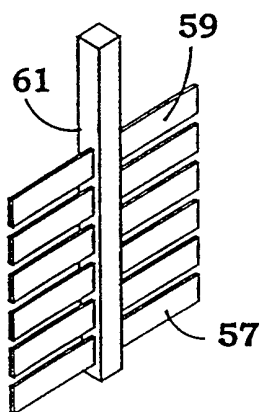


Fig. 7

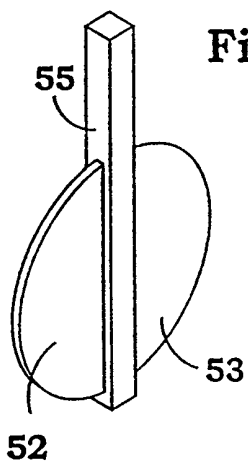


Fig. 6a

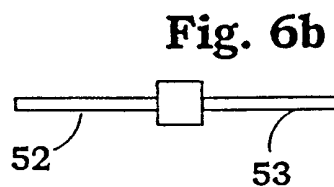


Fig. 6b

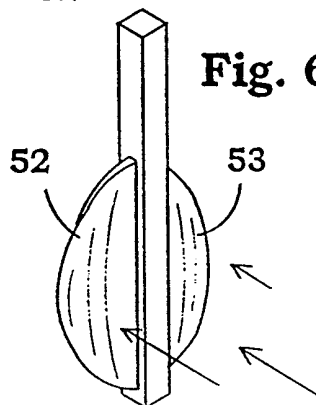


Fig. 6c

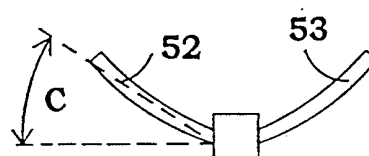


Fig. 6d

INTERNATIONAL SEARCH REPORT

Int. Application No

PCT/US 99/23960

A. CLASSIFICATION OF SUBJECT MATTER

IPC 7 G01F1/28

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)

IPC 7 G01F

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C. DOCUMENTS CONSIDERED TO BE RELEVANT

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Y	---	13
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X	US 3 147 620 A (STAPLER WILLIAM M) 8 September 1964 (1964-09-08) column 4, line 26 - line 47; figures 4,5 -/--	1,8

☒ Further documents are listed in the continuation of box C.☒ Patent family members are listed in annex.

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Date of the actual completion of the international search

17 February 2000

Date of mailing of the international search report

23/02/2000

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INTERNATIONAL SEARCH REPORT

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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

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