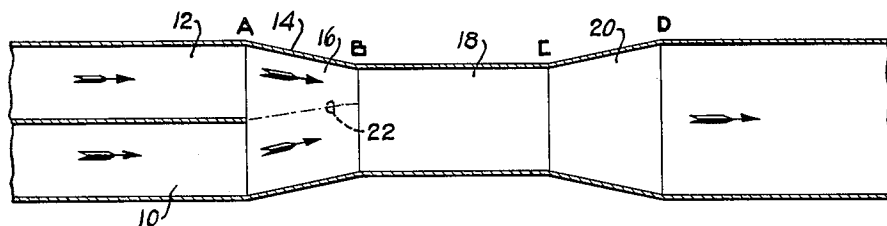


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Filed April 9, 1958

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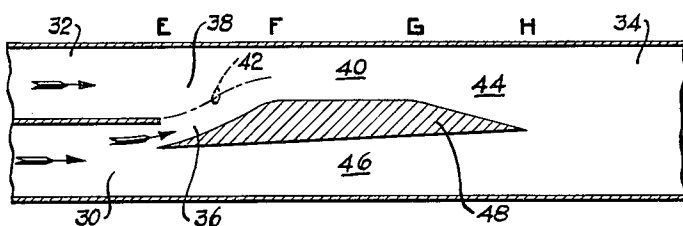
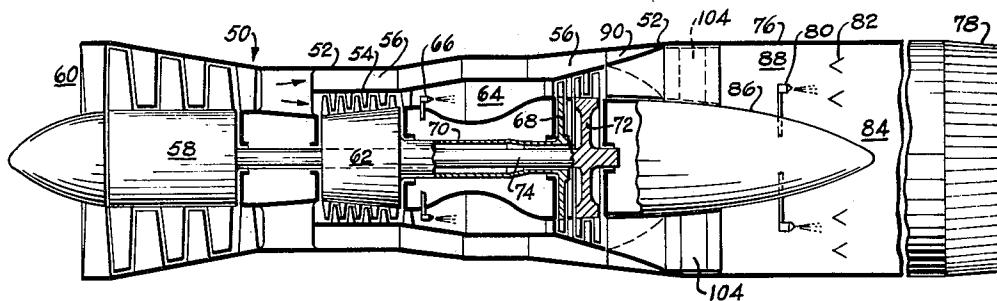
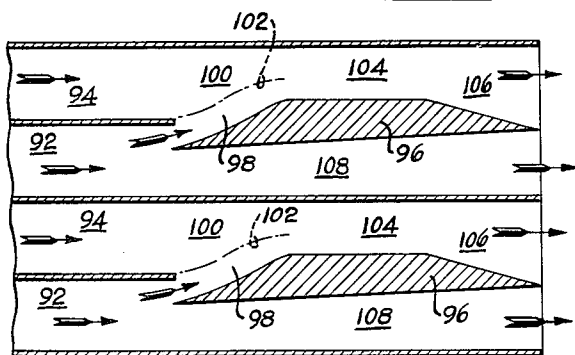


FIG. 2



19-3



19.6

INVENTOR.
DANIEL L. HARSHMAN

BY

Victor D. Behn

ATTORNEY

Sept. 12, 1961

D. L. HARSHMAN

2,999,672

FLUID MIXING APPARATUS

Filed April 9, 1958

2 Sheets-Sheet 2

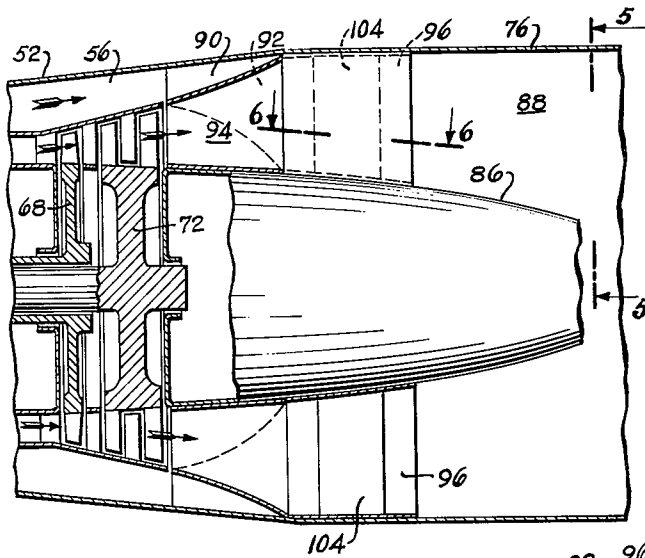


FIG. 4

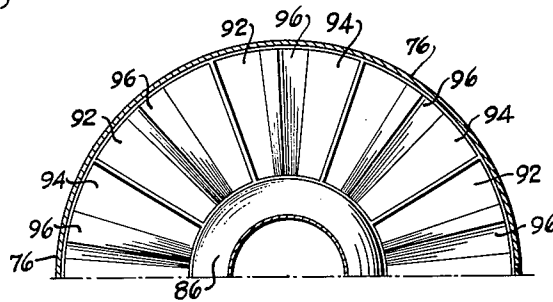


FIG. 5

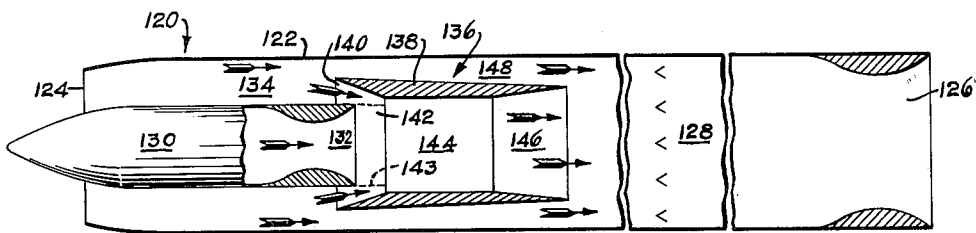


FIG. 7

INVENTOR.
DANIEL L. HARSHMAN

BY *Victor D. Behn*
ATTORNEY

1

2,999,672

FLUID MIXING APPARATUS

Daniel L. Harshman, Cedar Grove, N.J., assignor to
Curtiss-Wright Corporation, a corporation of Delaware

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6 Claims. (Cl. 259-4)

This invention relates to fluid mixing apparatus and is particularly directed to apparatus for mixing two fluid streams of different velocity and/or temperature in stages.

The mixing of two fluid streams of different velocity produces turbulence with an accompanying pressure loss. The magnitude of this pressure loss increases with increase in the velocity difference of the two streams.

It can be shown that if two streams are brought together in a common convergent passage in which the convergence is fairly abrupt that very little mixing will take place in the convergent region. Instead both streams will contract in the common convergent passage with the low velocity stream contracting to the greater extent. As a result of this unequal contraction of the two streams the velocity difference between the two streams is minimized so that the resulting pressure loss when the two streams subsequently mix is likewise minimized.

An object of this invention comprises the provision of fluid mixing apparatus in which two streams to be mixed are first brought together in a common convergent passage and then mixed.

A further object of the invention comprises the provision of such a fluid mixing apparatus in which the mixing takes place in stages.

Other objects of the invention will become apparent upon reading the annexed detailed description in connection with the drawing in which:

FIG. 1 is a schematic view showing an arrangement for mixing two streams in accordance with the invention;

FIG. 2 is a schematic view similar to FIG. 1 but showing an improved arrangement in which the mixing of the stream occurs in stages or steps;

FIG. 3 is an axial sectional view of a turbo fan engine embodying the fluid mixing arrangement of FIG. 2;

FIG. 4 is an enlarged view of the fluid mixing portion of FIG. 3;

FIG. 5 is a view taken along line 5-5 of FIG. 4;

FIG. 6 is a sectional view along line 6-6 of FIGS. 4 and 5; and

FIG. 7 is an axial sectional view illustrating a ram-jet engine embodying the invention.

Referring first to FIG. 1 of the drawing, two side-by-side fluid passageways are shown at 10 and 12. The fluid streams of passages 10 and 12 are supplied to a third passageway 14. At station A in FIG. 1 the two passageways 10 and 12 open into the third passageway 14. From station A to a station B the cross-sectional area of the passage 14 progressively decreases so that the region 16 between said stations is one of convergence. From station B to a more downstream station C the cross-sectional area of the third passageway is substantially constant. From station C the cross-section of the third passageway may again increase in area to the downstream station D. Thus the region 18 between the stations B and C is a throat area region having substantially constant area throughout its length while the region 20 between stations C and D is a region of divergence for recovering pressure from the stream velocity.

If two fluid streams of substantially different velocity are simply dumped into a common third passage this velocity difference will result in considerable turbulence and pressure loss. If, however, as in FIG. 1, the third pas-

2

sageway converges rather abruptly at the point the two streams are brought together then the two streams will adjust their individual stream areas in this converging region to maintain equal static pressures and will only mix slightly in this region. It can be shown that the stream with the lower initial velocity will show a greater percentage decrease in area in said converging region than the higher velocity stream. Hence the velocity difference between the two streams will be minimized in such an converging region. Thus in FIG. 1 if the stream velocity of the passage 10 is substantially higher than that of the passage 12 the two streams will converge so that the percentage convergence of the stream of passage 10 is much less than that of the stream of the passage 12. The boundary line between the two streams is indicated by the dot and dash line 22 in FIG. 1, this line generally being termed a slip line.

Mixing of the two fluid streams takes place in the constant area throat region 18. However because their velocity difference has been minimized by convergence of two streams in a common passage, the resulting turbulence upon mixing of the two streams, with its accompanying pressure loss, is minimized.

The convergence in the region 16 should be fairly abrupt to avoid any substantial mixing of the two streams in this region. The throat or minimum area region 18 in which the mixing takes place should have a length of at least equal to the diameter of a circle having an area equal to the cross-sectional area of this throat region and preferably has a length at least equal to three times this dimension for substantially complete mixing of the two streams.

At the station C the passage 14 may again diverge, for example to that of the combined original area of the passages 10 and 12, to provide a recovery of static pressure from the velocity increase resulting from the convergence in the region 16.

Because of the length required for substantially complete mixing in the region 18 the arrangement of FIG. 1 may not be feasible from a weight and space standpoint for certain applications for example in the case of aircraft. For such applications the stepped or stage arrangement of FIG. 2 is preferred.

Referring now to FIG. 2, two side-by-side parallel fluid passageways are shown at 30 and 32. The fluid streams of these two passageways are to be supplied to a third passageway 34. In FIG. 2 a portion only of one of the streams, preferably the high velocity stream, is first mixed with the other stream. Thus in FIG. 2 the passage 30 is assumed to have the high velocity stream and a portion of this stream is initially mixed with the stream of the passage 32. For this purpose a passageway 36 is provided for diverting a portion of the stream of the passage 30 into the passage 32. As illustrated, the flow diverting passageway 36 has its entrance opening directed substantially upstream into the passageway 30 and has its outlet arranged to discharge in a substantially downstream direction into the passageway 32, the station E indicating the upstream point of discharge of the diverted fluid into the passageway 32. In the region 38 from the station E to the more downstream station F, the cross-sectional area of the passage 32 is one of convergence such that the fluid stream of the passage 32 and the portion of the fluid stream of the passage 30 diverted into the passage 32 both converge in this region. Between the station F and a more downstream station G the passage 32 has a substantially constant area throat region 40.

As stated, the diverted portion of the stream of passage 30 and the stream of passage 32 both converge in the region 38. However, as in FIG. 1, the percentage decrease in cross-sectional area of the slower moving stream of the

3

passage 32 will be greater than the percentage decrease of the diverted stream portion of the passage 30. Hence these two streams will mix in the throat region 40 with relatively little turbulence and pressure loss. As in FIG. 1 the length of the throat or mixing region 40 is at least equal to the diameter of a circle having an area equal to the cross-sectional area of this throat region and preferably is at least equal to three times this dimension for substantially complete mixing. The slip or dividing line between the stream of passage 32 and said diverted stream portion of the passage 30 is indicated by a dot and dash line at 42.

The mixed stream of the passage 32 expands in area in the diverging region 44 between the stations G and H. The undiverted portion of the stream of passage 30 diverges in the region 46 from the station E to the station H. The relative amounts of divergence of these two passages is such that at the station H both streams have substantially the desired static pressure. Also because of the initial mixing of a portion of one stream with the other the velocity difference between the two streams is substantially less at station H than it was at station E. Accordingly the two streams will mix in the passage 34 with relatively little turbulence and resulting pressure loss.

As illustrated in FIG. 2 the passageway 36 with the associated converging region 38, the throat region 40 and the diverging regions 44 and 46 are formed by the shape of the separating partition 48 between the two passageways 30 and 32.

If desired the step of diverting another portion of the stream 30 and mixing it with the now mixed stream in the passage 32 may be repeated at the station H. In fact this partial mixing step obviously may be repeated several times before the two streams 30 and 32 are completely brought together.

As described in connection with FIG. 2, a portion of the high velocity stream, rather than the low velocity stream, is initially mixed with the other stream. This arrangement is preferred because less pre-mixing takes place then in the converging region.

One application requiring the mixing of two fluid streams occurs in a turbo fan engine. FIG. 3 discloses a turbo fan engine 50. This engine comprises an outer annular shell or housing 52 and an inner shell 54 concentrically supported within the shell 52 so as to leave an annular path 56 therebetween. A low pressure axial flow compressor 58 is journaled within the shell 52 forwardly of the inner shell 54. The compressor 58 receives air through the forwardly directed inlet 60 formed at the forward end of the shell 52. The compressor 58 delivers a portion of its air to the annular path 56 and the remaining portion to a high pressure axial flow compressor 62 journaled within the inner shell 54.

The high pressure compressor 62 supplies its air to an annular combustion chamber 64 where heat is added to said air by burning fuel therein, said fuel being supplied by burner apparatus schematically indicated at 66. From the combustion chamber 64 the hot gases co-act with the blades of a high pressure turbine 68 for driving said turbine. A shaft 70 drivably connects the high pressure turbine 68 with the high pressure compressor 62. The hot gases exhausting from the high pressure turbine 68 co-act with the blades of a low pressure turbine 72 for driving said latter turbine. The low pressure turbine 72 is drivably connected to the low pressure compressor 58 by a shaft 74 extending coaxially through the shaft 70. The high pressure compressor 62, combustion chamber 64 and turbines 68 and 72 provide an annular fluid path co-axial with and surrounded by the annular fluid path 56. From the low pressure turbine 72 the hot gases discharge into an exhaust duct 76 formed by a rearward extension of the outer shell 52 beyond the turbine assembly 68 and 72. The air supplied through the annular fluid path 56 by the compressor 58 also dis-

4

charges into the duct 76. The exhaust duct 76 has a rearwardly directed exhaust nozzle 78 at its rear end through which the air from the fluid path 56 and the hot gases from the turbine assembly discharge into the surrounding atmosphere whereby the engine 50 is provided with forward propulsive thrust.

For increasing the thrust output of the engine 50 provision is made for afterburning in the exhaust duct 76. For this purpose fuel nozzles 80 are provided for introducing fuel into the exhaust duct 76 upstream of flameholder apparatus 82 for combustion in the duct 76 downstream of said flameholder apparatus. Thus the portion 74 of the space inside the duct 76 downstream of the flameholder apparatus 82 forms the afterburner combustion chamber 84.

As stated, the air in the annular by-pass path 56 and the exhaust gases from the turbine 72 both discharge into the exhaust duct 76. A centerbody 86 extends downstream from the turbine 72 so that the upstream portion 88 of the passage formed by the duct 76 is annular. For efficient combustion in the afterburner combustion chamber 84 these gases should be substantially completely mixed upstream of the flameholder apparatus 82. The apparatus for mixing these fluids is indicated by reference numeral 90. The fluid mixing apparatus portion of the engine 90 is best seen in FIGS. 4-6.

The upstream portion of the apparatus 90 divides the by-pass air into a plurality of circumferentially-spaced passageways 92 which extend radially across the annular space 88 and similarly divides the turbine exhaust into a plurality of circumferentially-spaced passageways 94 which alternate with and are disposed between the passageways 92. Apparatus for splitting up these two fluid streams in this manner is more fully described and illustrated in copending application Serial No. 563,479, filed February 6, 1956.

Before the by-pass air and the turbine exhaust gases are discharged into the common exhaust duct 76 they are first partly mixed in a manner similar to the stepped mixing procedure of FIG. 2. For this purpose the partition between pairs of adjacent passages 92 and 94 has a portion 96 which is arranged as in FIG. 2 to divert a portion of the fluid stream from one of these passages into the other. Thus as seen in FIG. 6, each partition 96 is arranged to provide a passageway 98 for diverting a portion of the by-pass air from the adjacent passage 92 into the adjacent turbine exhaust passage 94.

Downstream from the point that a passageway 98 opens into a passageway 94, the cross-sectional area of said passage 94 is a converging region 100 such that the exhaust gas stream of said passage 94 and the portion of the air stream of the adjacent passage 92 diverted into said passage 94 both converge in this region. As in FIG. 2, with the by-pass air having the higher velocity the diverted by-pass air stream in the converging region 100 will undergo a smaller percentage decrease in area than the slower turbine exhaust. This is indicated by the dot-and-dash line 102 (FIG. 6) representing the slip line between each pair of such streams.

Again as in FIG. 2, each converging region 100 of a passage 94 ends in a throat region 104 which has a substantially constant cross-sectional area for a length which is at least equal to the smallest width dimension of the cross-sectional area and preferably has a length at least equal to three times this dimension for substantially complete mixing of the two streams. Following the throat region 104 the mixed stream of each passage 94 expands in a diverging region 106. The undiverted stream portion of each passage 92 preferably expands by providing said passage with a diverging portion 108. The two diverging regions 106 and 108 are designed so that their two streams will have substantially the desired static pressure at the discharge end at which they open into the common passage 76. It should now be apparent that the

5

mixing of the two streams of each pair of passages 92 and 94 for the turbo fan engine of FIGS. 3-6 is essentially the same as that described in connection with the schematic view of FIG. 2.

Another application of the invention is illustrated in the ramjet-rocket engine 120 of FIG. 7.

The engine 120 comprises a duct-like housing 122 having a forwardly directed air inlet opening 124 and a rearwardly directed exhaust nozzle 126. Within the duct 122 and between its ends is the ramjet combustion chamber 128.

A rocket unit 130 is co-axially mounted at the forward end of the duct 122. The rocket exhaust gases discharge rearwardly through the discharge nozzle 132 of the rocket unit 130 into the duct 122.

In order to facilitate mixing of the rocket exhaust gases with the air stream entering the duct 122 through the annular air passage 134 around said unit, mixing apparatus 136 similar to that of FIG. 2 is provided. The mixing apparatus 136 comprises an annular wall or partition member 138 co-axially with the rocket unit 130 and extending downstream of said unit. The annular wall 138 includes an opening 140 for diverting a portion of said air stream into the rocket exhaust gas stream.

Downstream from the opening 140 the inner surface of the annular wall 138 defines a converging region 142 in which the diverted air and exhaust gas streams both converge. The slip line between these two streams is indicated by the dot-and-dash line 143. The rocket exhaust gases have a higher velocity than that of the air stream and therefore said air stream shows a greater percentage decrease in area than that of said exhaust gases.

At this point it should be noted that in FIG. 7 a portion of the slower velocity stream (air stream) is initially diverted into the higher velocity stream (rocket exhaust) because of the extremely high temperature of said rocket exhaust.

The converging region 142 terminates in a throat region 144 which as in FIG. 2 has a length at least equal to the diameter of a circle having an area equal to the cross-sectional area of this throat region. Mixing of the diverted portion of the air stream and the rocket exhaust gases takes place in said throat region. Downstream of the throat region 144 the mixture of rocket gases and diverted air enter a region 146 of diverging area.

Externally, the annular wall 138 is formed to provide a region 148 of diverging area for the undiverted portion of the air stream. Downstream of the wall 138 the undiverted air stream and the mixture of rocket gases and diverted air are brought together to complete the mixing operation.

Except for its annular construction the mixing apparatus 136 is essentially like that of FIG. 2 and FIGS. 3-6. Accordingly no further description of the operation of FIG. 7 appears necessary.

While I have described my invention in detail in its present preferred embodiment, it will be obvious to those skilled in the art, after understanding my invention, that various changes and modifications may be made therein without departing from the spirit or scope thereof. I aim in the appended claims to cover all such modifications.

I claim as my invention:

1. Apparatus for mixing fluids; said apparatus comprising a first passageway for a first fluid; a second passageway for a second fluid having a velocity which in general is different from that of said first fluid; a third passageway into which said first and second passageways discharge; and a passageway having its entrance opening directed substantially upstream into the fluid flow of said second passageway and having its outlet opening arranged to discharge in a substantially downstream direction into the fluid flow of said first passageway for diverting a portion of said second passageway fluid into said

6

first passageway at a point upstream of the junction of said first and second passageways with said third passageway, downstream of said flow diverting passageway the cross-sectional area of said first passageway being such that the fluid of said first passageway and the diverted fluid of said second passageway converge to a throat region.

2. Apparatus as recited in claim 1 in which said throat region has a substantially constant cross-sectional area and has a length at least equal to the diameter of a circle having an area equal to said throat cross-sectional area.

3. Apparatus for mixing fluids of different velocity; said apparatus comprising a first passageway for a relatively low velocity first fluid; a second passageway for a relatively high velocity second fluid; a third passageway into which said first and second passageways discharge; and a passageway having its entrance opening directed substantially upstream into the fluid flow of said second passageway and having its outlet opening arranged to discharge in a substantially downstream direction into the fluid flow of said first passageway for diverting a portion of said second passageway fluid into said first passageway at a point upstream of the point of discharge of said first and second passageways into said third passageway, downstream of said flow diverting passageway the cross-sectional area of said first passageway being such that the fluid of said first passageway and the diverted fluid of said second passageway converge to a throat region.

4. Apparatus as recited in claim 3 in which said throat region has a substantially constant cross-sectional area and has a length at least equal to the diameter of a circle having an area equal to said throat cross-sectional area.

5. Apparatus for mixing fluids of different velocity; said apparatus comprising a first passageway for a first fluid; a second passageway for a second fluid having a velocity generally different from that of said first fluid; a third passageway into which said first and second passageways discharge; and a passageway having its entrance opening directed substantially upstream into the fluid flow of said second passageway and having its outlet opening arranged to discharge in a substantially downstream direction into the fluid flow of said first passageway for diverting a portion of said second passageway fluid into said first passageway at a point upstream of the point of discharge of said first and second passageways into said third passageway, downstream of the upstream point of discharge of fluid from said flow diverting passageway into said first passageway the cross-sectional area of said first passageway being such that the fluid of said first passageway and the diverted fluid of said second passageway converge to a throat region, said throat region having a substantially constant cross-sectional area and having a length at least equal to the diameter of a circle having an area equal to said throat cross-sectional area, the portion of said first passageway downstream of its said throat and the portion of said second passageway downstream of said flow diverting passageway both progressively increasing in cross-sectional area such that the static pressures in said passageways are substantially the same at their junction with said third passageway.

6. Apparatus for mixing fluids of different velocity; said apparatus comprising a first passageway for a relatively low velocity first fluid; a second passageway for a relatively high velocity second fluid; a third passageway into which said first and second passageways discharge, and a passageway having its entrance opening directed substantially upstream into the fluid flow of said second passageway and having its outlet opening arranged to discharge in a substantially downstream direction into the fluid flow of said first passageway for diverting a portion of said second passageway fluid into said first passageway at a point upstream of the point of discharge of said first and second passageways into said third pas-

7

sageway, downstream of the upstream point of discharge of fluid from said flow diverting passageway into said first passageway the cross-sectional area of said first passageway being such that the fluid of said first passageway and the diverted fluid of said second passageway converge to a throat region, said throat region having a substantially constant cross-sectional area and having a length at least equal to the diameter of a circle having an area equal to said throat cross-sectional area, said first passageway downstream of said throat region and said second passageway downstream of said flow diverting passageway both diverging in cross-sectional area to their junction with said third passageway.

8

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