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Lohmann et al.

[11] **3,872,664**

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[54] **SWIRL COMBUSTOR WITH VORTEX BURNING AND MIXING**

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[73] Assignee: **United Aircraft Corporation,** East Hartford, Conn.

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[52] **U.S. Cl.** **60/39.65,** 60/DIG. 11, 431/9

[51] **Int. Cl.** **F02c 3/00**

[58] **Field of Search** ..... 60/39.65, 39.74 R, DIG. 11; 431/9

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Assistant Examiner—Robert E. Garrett
Attorney, Agent, or Firm—Jack N. McCarthy

[57] **ABSTRACT**

This disclosure sets forth an engine wherein the combustion section includes a combustor with a main combustion burner having a hot fluid injected thereinto from a pilot burner. A multiplicity of swirling jets of a cooler oxidizer fluid are directed into the combustor for engaging with the hot pilot fluid. The swirling jets are directed through tubes built into the combustor wall. Fuel is directed into the main combustion burner into the area of mixed pilot hot flow and cooler swirling jet flow. This fuel can be injected to flow in mixed with the hot flow from the pilot burner or mixed with the cooler oxidizer flow through the tubes.

27 Claims, 8 Drawing Figures

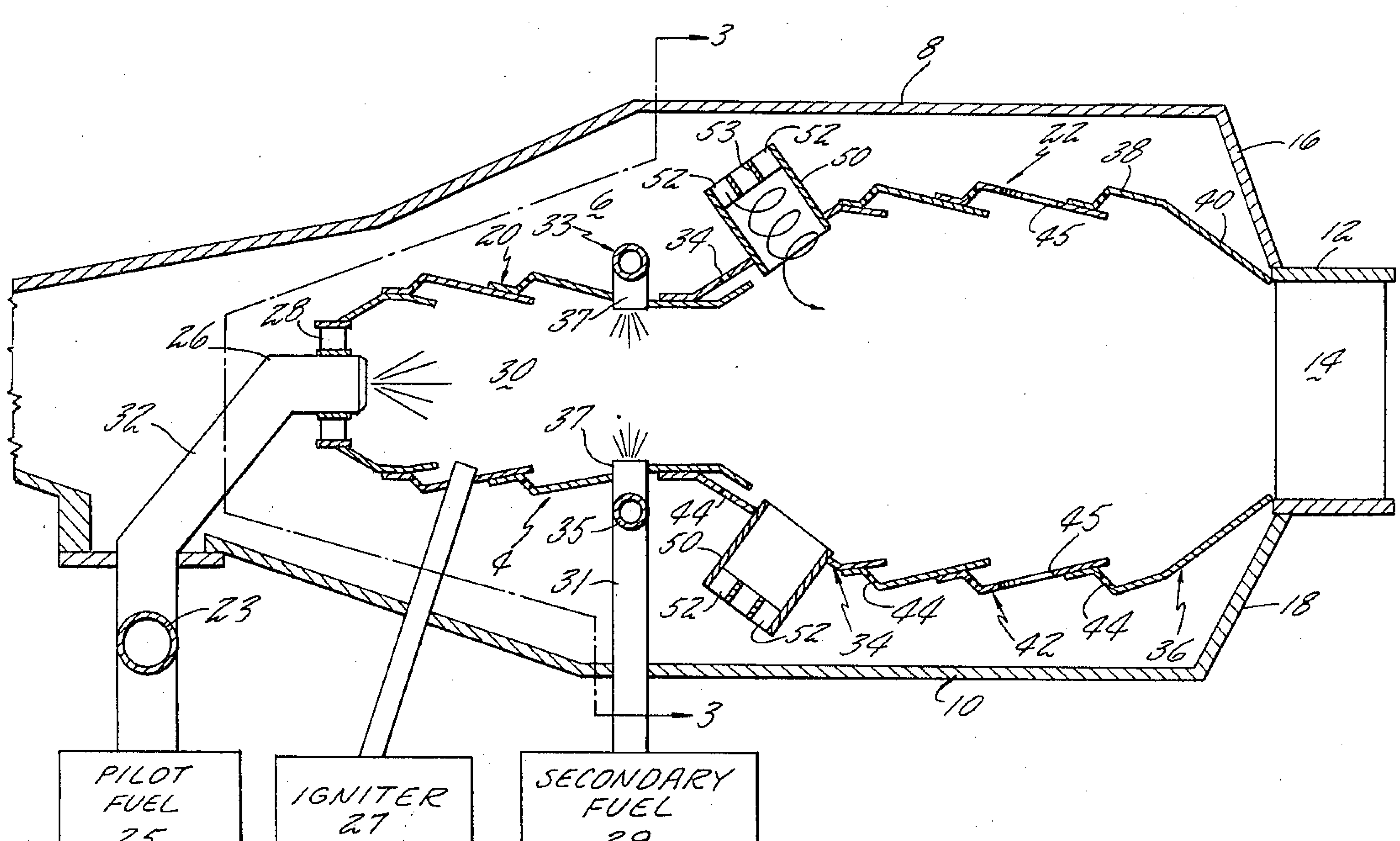
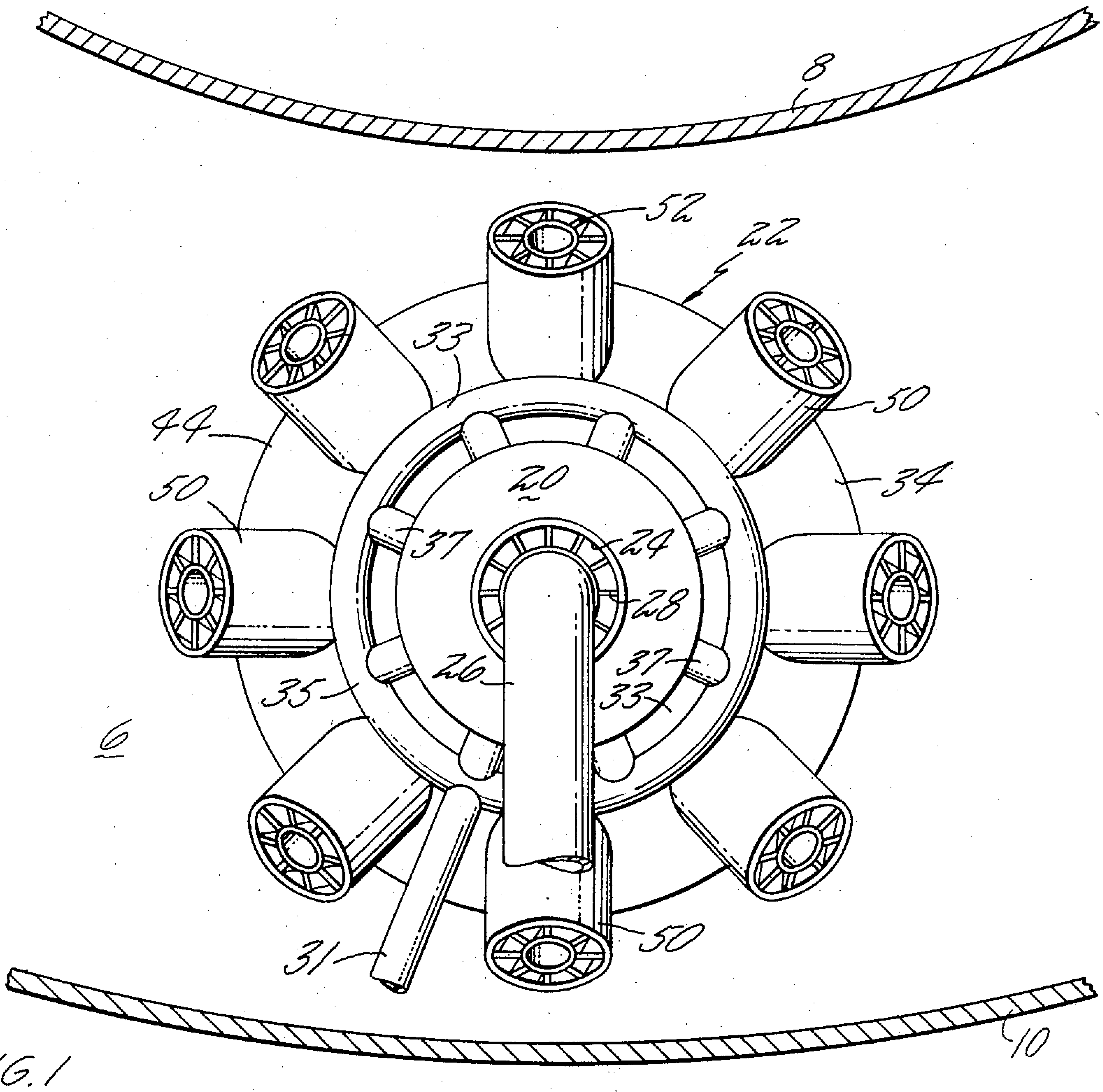


FIG. 3


8
52
22
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34
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37
24
28
26
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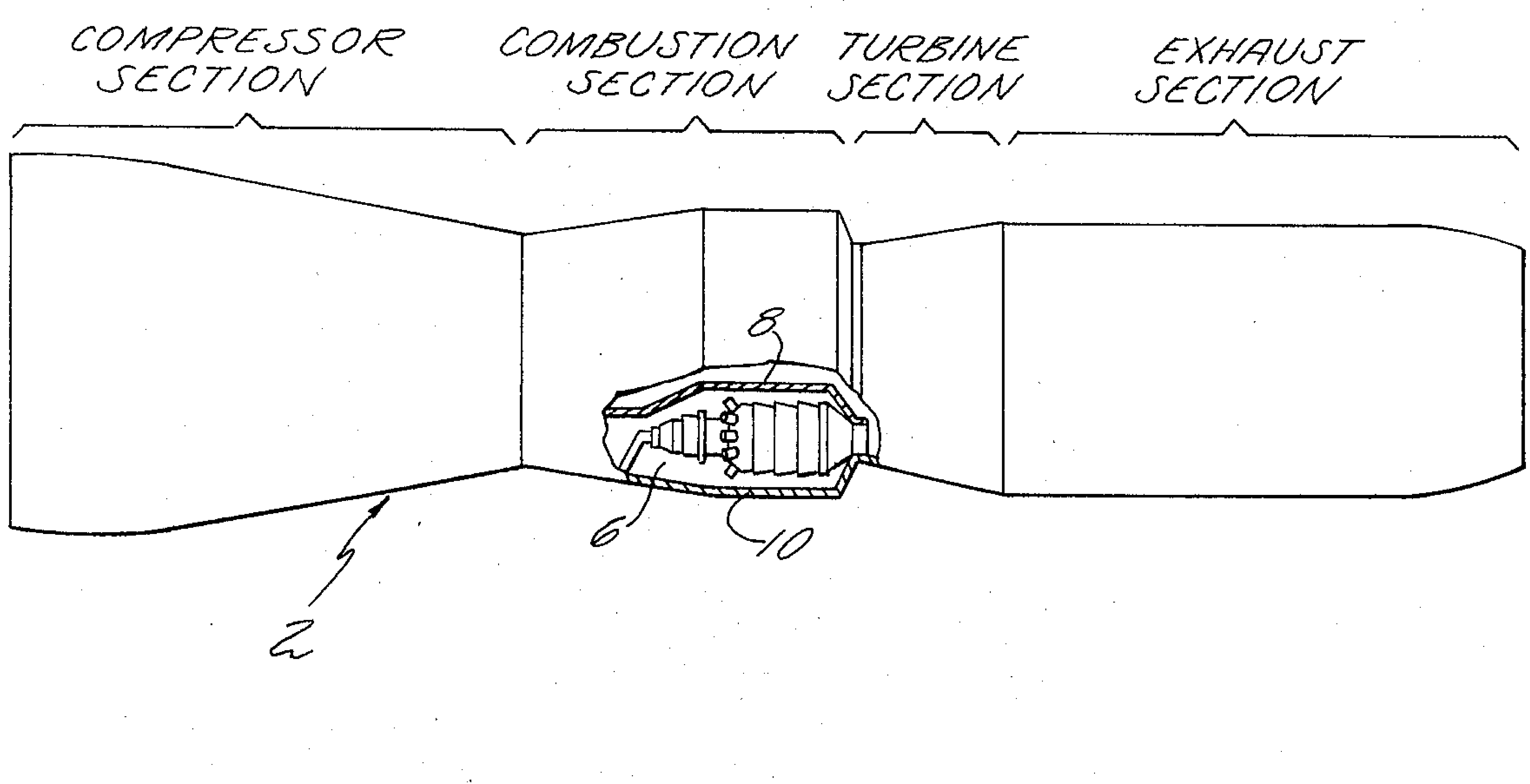
35
6
31
50
10

FIG. 1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COMBUSTION SECTION
TURBINE SECTION
EXHAUST SECTION
8
6
10
2

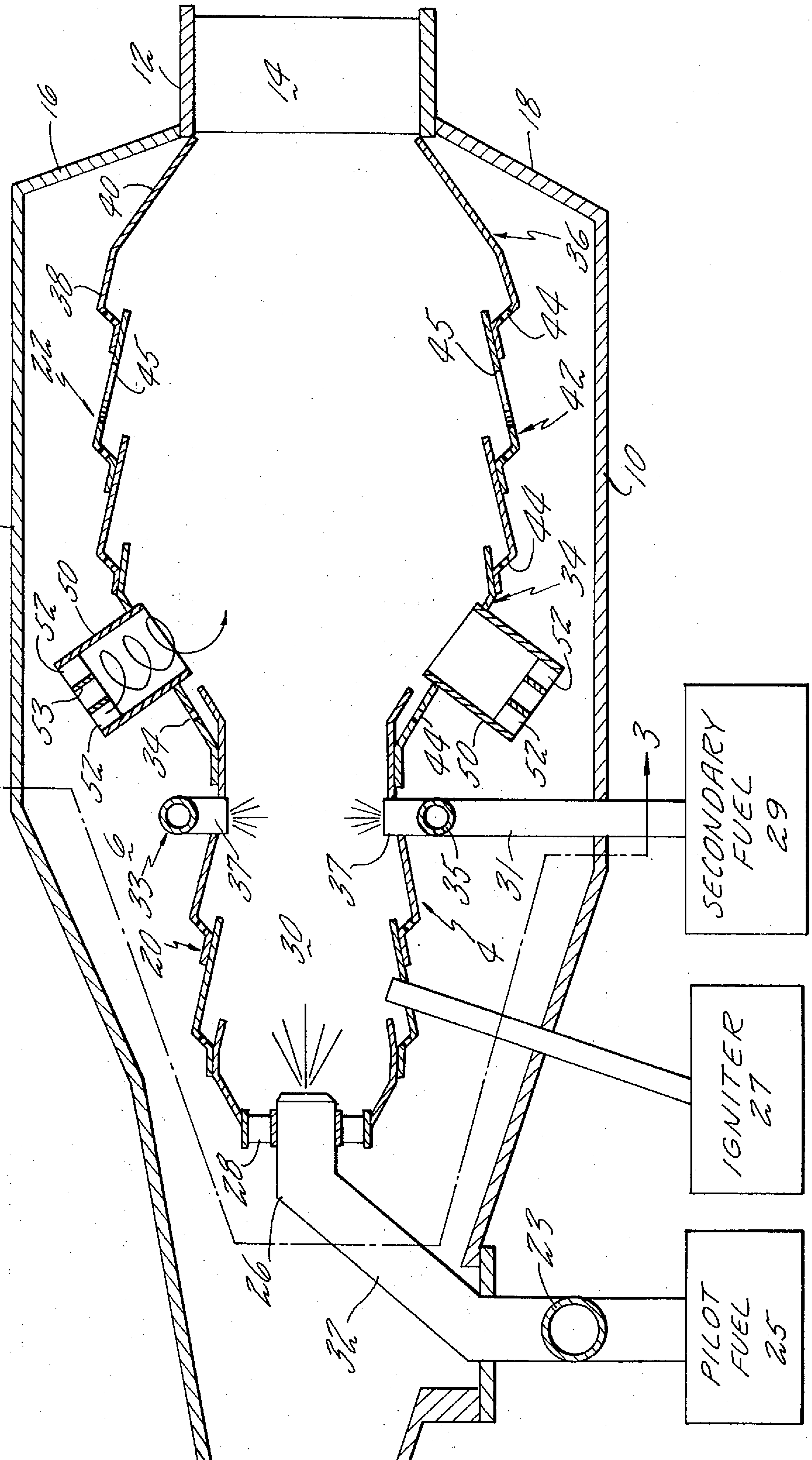
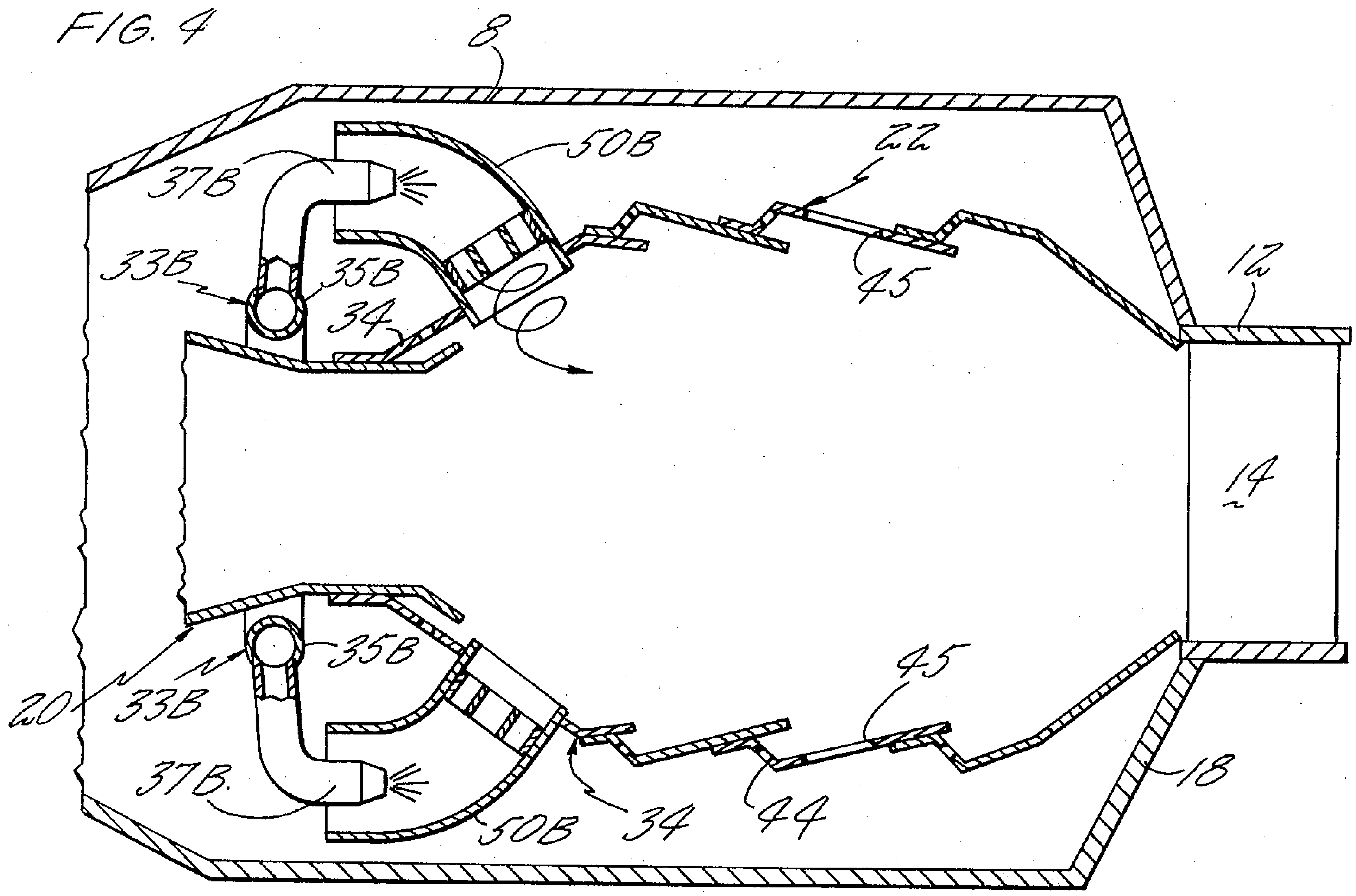


FIG. 2

FIG. 4


8
22
50B
37B
33B
35B
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12
14
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33B
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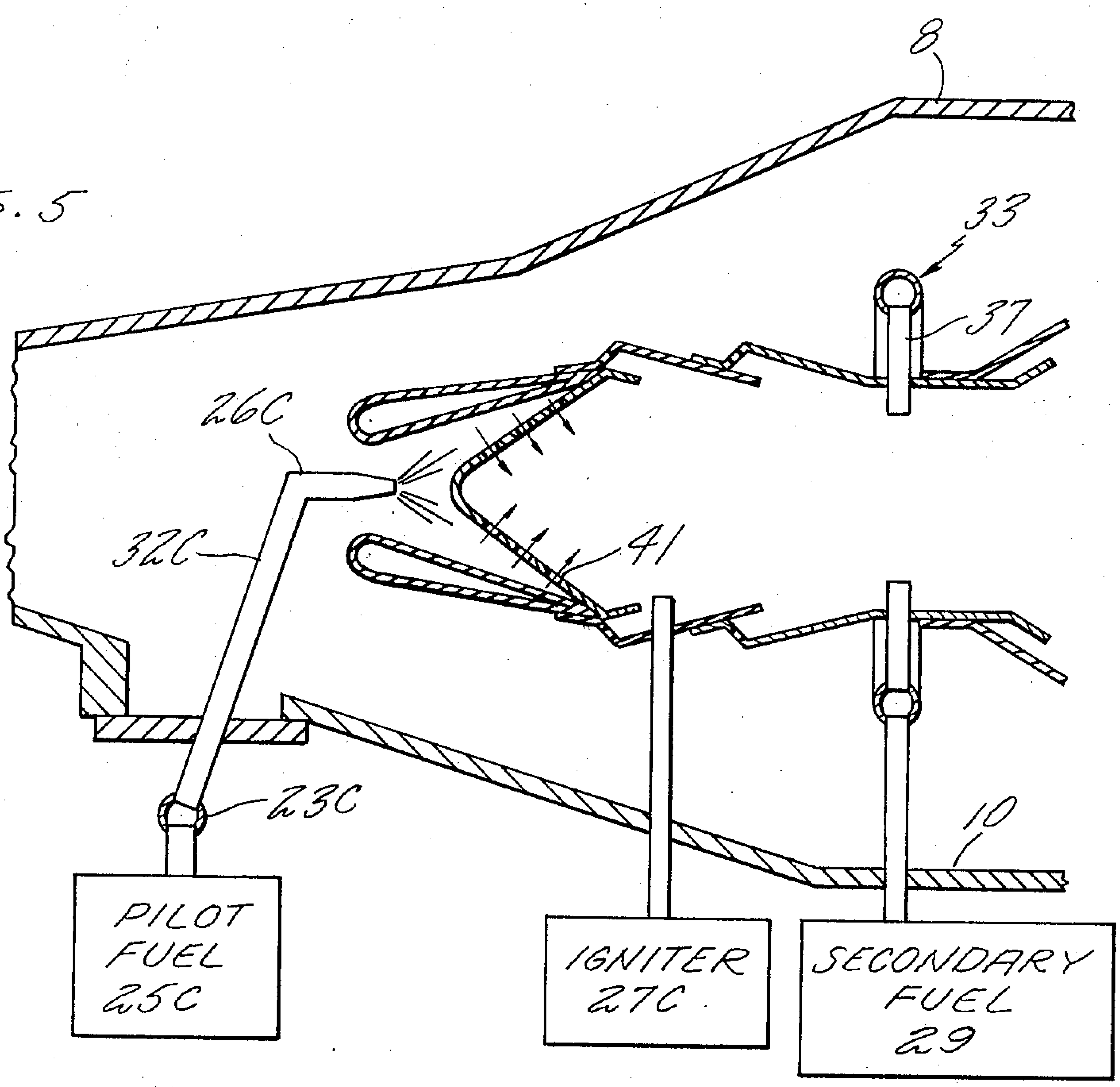
37B
50B
34
44
45
18

FIG. 5


8
33
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26C
32C
41
23C
10
PILOT
FUEL
25C
IGNITER
27C
SECONDARY
FUEL
29

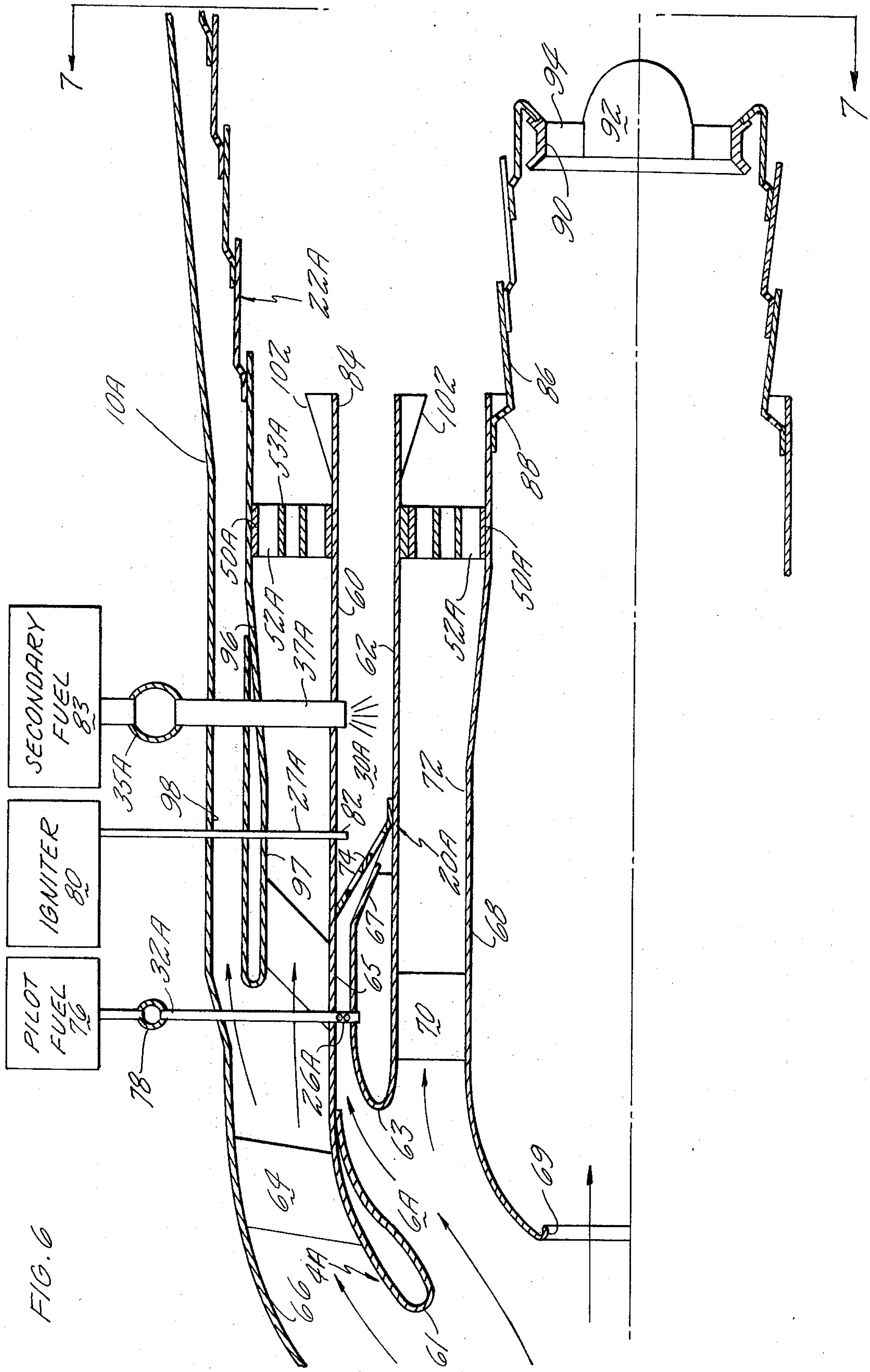

FIG. 6

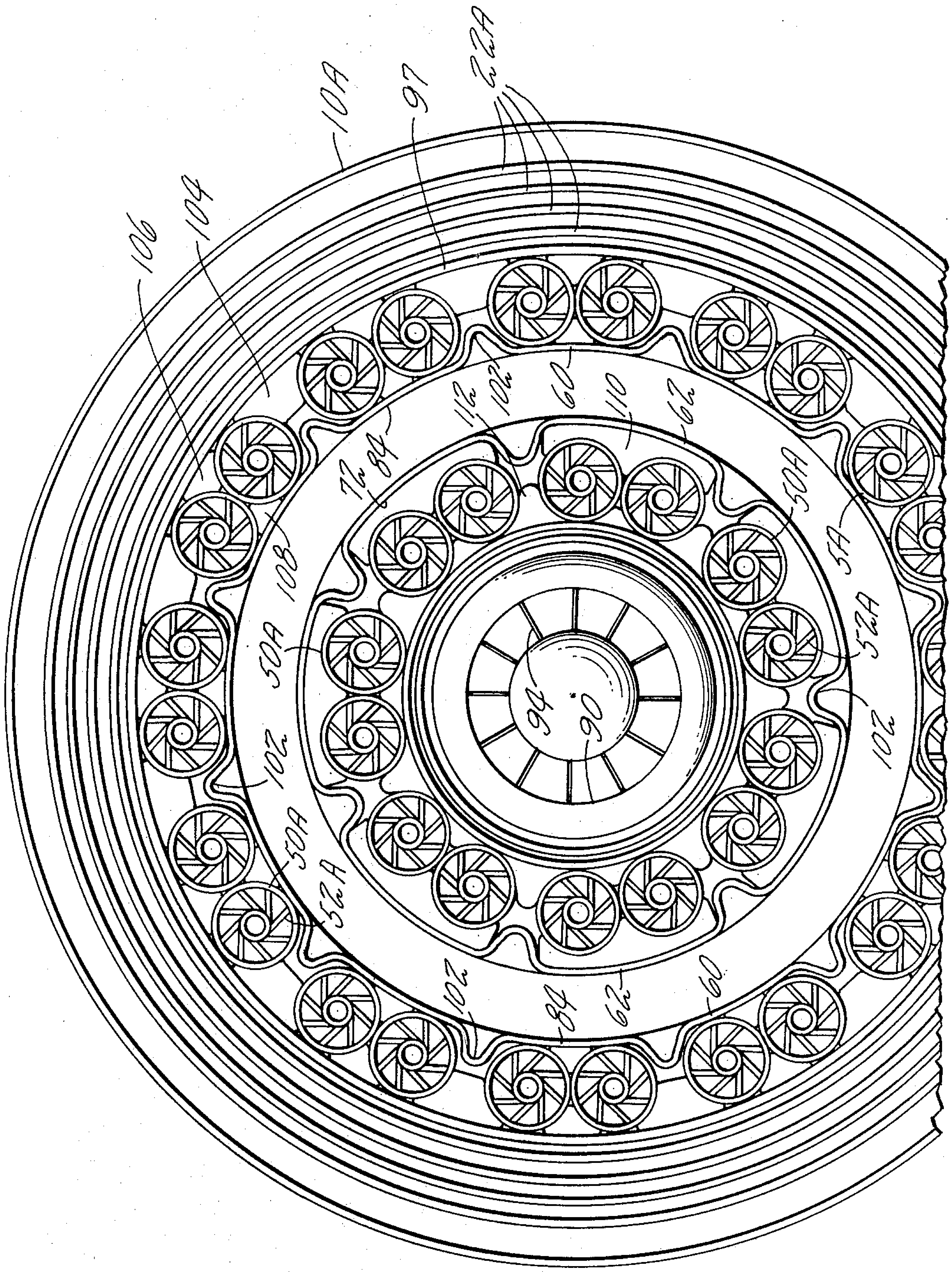

FIG. 7

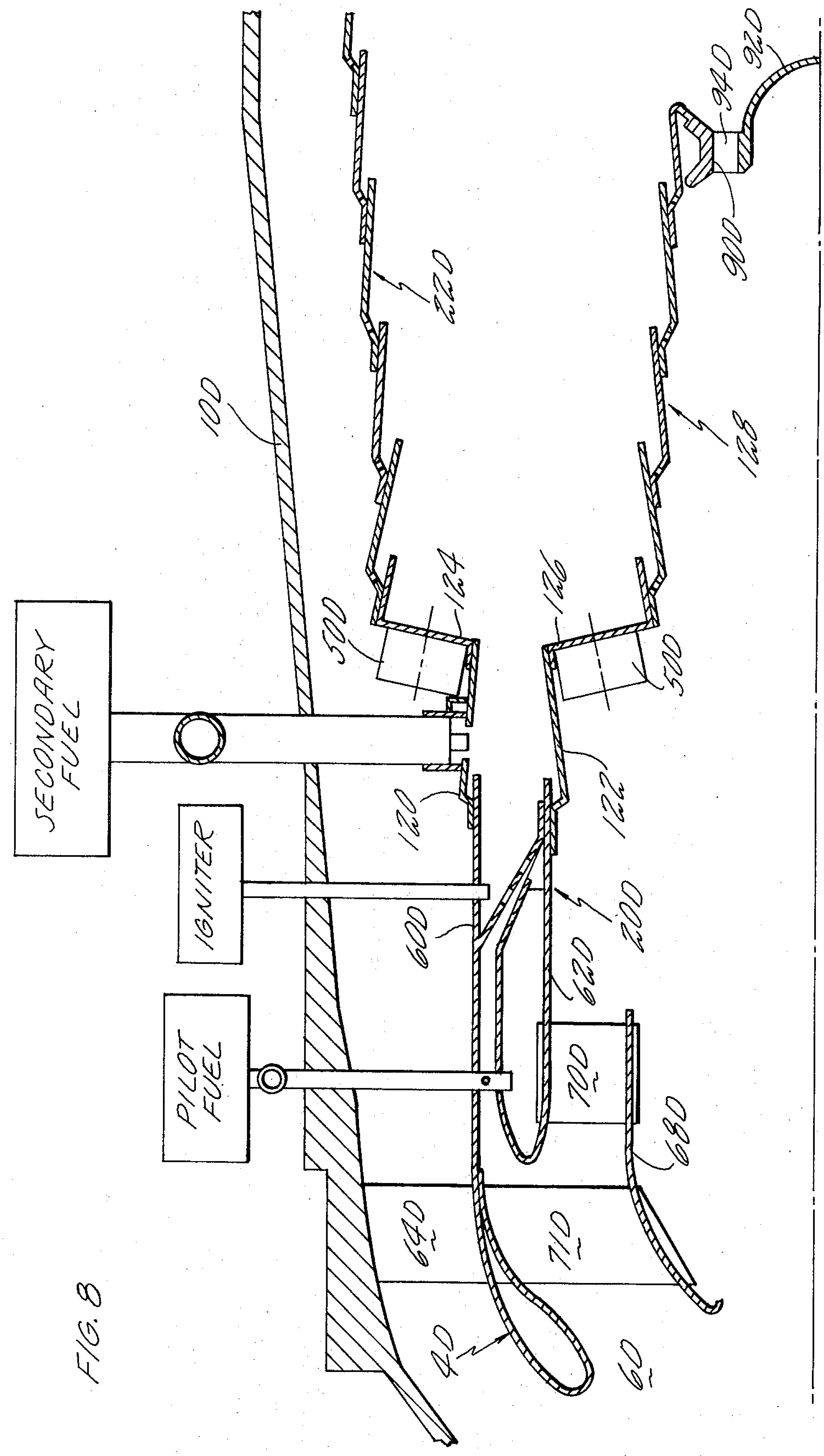
SECONDARY FUEL
IGNITER
PILOT FUEL
10D
22D
90D
94D
92D
128
124
126
50D
50D
120
122
60D
20D
62D
70D
68D
64D
71D
4D
6D

FIG. 8

SWIRL COMBUSTOR WITH VORTEX BURNING AND MIXING

BACKGROUND OF THE INVENTION

This concept is essentially an extension of the principle of the swirl burner discussed in detail in U.S. application Ser. No. 84,086, filed Oct. 26, 1970. A patent relating to the swirl burning is U.S. Pat. No. 3,701,255. Swirl burning is also discussed in U.S. Pat. No. 3,675,419.

As explained in the application Ser. No. 84,086 referred to above, mixing of two dissimilar fluids may be substantially augmented by making the interface between said fluids unstable to centrifugal forces. In that application it was shown that such an unstable interface may be produced by having the two fluids flow in a concentric swirling configuration with the aerodynamic properties of the streams selected so as to have the relation ρ Vt^2 outer $<\rho$ Vt^2 inner be satisfied. In this definition ρ is the density and Vt is the tangential velocity of the appropriate stream while the inner and outer refer to the radial position of the particular stream relative to the interface.

It is apparent that the condition for this augmentation of mixing through the use of centrifugal forces may also be satisfied if ρ Vt^2 of the outer stream were zero, that is, the configuration is a swirling jet surrounded by a stream of a dissimilar fluid.

It has also been shown in that application that by making one of the participating fluids a stream of hot gases and the other air, with suitable means of introducing fuel, the hot stream will act as a pilot stream providing an ignition source for combustion in the air stream. The ensuing combustion process is superimposed on the centrifugally driven mixing process so as to occur in an extremely rapid manner.

SUMMARY OF THE INVENTION

A combustor having a swirling flow therein has been formed employing a multiplicity of small swirling jets, rather than having a single interface of a larger characteristic radius, which increases substantially the rapidity of the mixing and the burning process since the centrifugal force, the driving force for a rapid mixing, is inversely proportional to the radius of the interface between the fluids.

A combustor having a hot fluid injected therein with a multiplicity of cooler jets having engagement therewith provides a combustion device which makes it readily adaptable for replacing a combustor of a more conventional design.

An object of this invention is to provide a combustion device which will optimize burning conditions to reduce NOx, permit all residual reactions to go to completion greatly reducing CO and unburned hydrocarbons, and greatly reduce any trace of smoke.

Another object of this invention is to provide a combustion device having a pilot burner for directing hot gases into a main burner wherein cooler swirling columns of an oxidizer can be mixed therewith, with fuel being directed into the mixture.

Another object of this invention is to provide a combustion device wherein the fuel can be carried into the main combustion chamber by the hot gases entering from the pilot burner.

A further object of this invention is to direct fuel into a column of swirling air thereby providing a vaporized,

premixed fuel-air mixture in one or more of the columns.

A further object of this invention is to provide a combustion device for a jet engine having two stages of in-line burning wherein one stage can be used for "idle" operation of the engine.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a view of a gas turbine engine showing the location of the combustion chamber;

FIG. **2** is an enlarged sectional view of the combustion section showing a combustion chamber therein;

FIG. **3** is a view taken along the line **3—3** of FIG. **2**;

FIG. **4** is a modification of the rear portion of the combustion chamber of FIG. **2**;

FIG. **5** is a modification of the front part of the combustion chamber of FIG. **2**;

FIG. **6** is a modification of the combustion chamber;

FIG. **7** is a view taken along the line **7—7** of FIG. **6**; and

FIG. **8** is another modification of the combustion chamber.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to FIG. **1** a turbojet engine **2** is shown comprising a compressor section, combustion section, turbine section and exhaust section. The engine **2** is of the conventional type described in greater particularity in U.S. Pat. No. 2,747,367.

Referring to FIG. **2** a combustor **4** is shown mounted in a chamber **6** formed between an inner casing **8** and outer casing **10**. This chamber **6** is annular and connected at its forward end between the forward portions of the inner and outer casing to the exit of the compressor section. The downstream end of the chamber **6** is connected to an annular exit duct **12** containing a plurality of turbine inlet vanes **14**. The inner casing **8** and outer casing **10** have annular flanges **16** and **18**, respectively, which extend outwardly and inwardly, respectively to the annular exit **12** to enclose the rear portion of the annular chamber **6**.

While in FIg. **1** the combustion section is formed as a plurality of individual cans between the inner and outer casings **8** and **10**, the combustor can be formed as a single annular combustor which is substantially symmetrical about the centerline of the engine and located within the inner and outer casings **8** and **10**. For simplicity the combustor will be described in terms of the can version. Although a plurality of these combustor cans are located around the annular chamber **6**, since they are alike only one of these cans will be described below: A combustor **4** comprises a pilot burner **20** and a main combustion burner **22**. The pilot burner **20** is shown as a conventional swirl stabilized burner employing an annular opening **24** around the end of a fuel nozzle **26** located in the forward end of the pilot burner, as in conventional combustor designs. Swril vanes **28** are located in the annular opening **24**. The swirling flow entering the pilot burner section **20** acts only to stabilize the recirculation region in the pilot combustion zone **30** and the tangential motion is essentially dissipated by the time the flow leaves the pilot burner **20** of the combustor **4**. The fuel nozzle **26** is of the conventional type and is connected by conduit **32** to a suitable external manifold **23** and fuel control means 25 not shown. Ignition means 27 provides for ignition of the mixture in the pilot burner section 20.

FIG. 3 shows the front view of one of the combustors 4 of the can type within the inner casing 8 and outer casing 10. The main combustion burner 22 is shown as an extension of the pilot burner 20 and has its rearward end exhausting into the annular exit duct 12 across the turbine inlet vanes 14. The forward end of the main combustion burner 22 is connected to the rearward end of the pilot burner 20. The forward part of the main combustion burner 22 includes an outwardly extending funnel-shaped transition member 34. The rearward part of the main combustion burner 22 includes a rearwardly extending transition member 36. Since this is the construction including a plurality of combustor cans the transition member 36 is formed of a plurality of circular projections 38 which blend into an annular rearward end 40 which is connected to the annular exit duct 12. An intermediate substantially circular section 42 of the main combustion burner 22 connects the rearward part of the member 34 to the forward part of the member 36. The members 34, 36 and section 42 are formed of a louvered construction to provide cooling of the combustor walls. Openings 44 direct cooling air into the louvers. It is noted that this same type construction is used for the wall of the pilot burner 20. Openings 45 direct dilution air into the main combustion sections.

A plurality of swirl tubes 50 each containing swirl vanes 52 at the forward end thereof are arranged around the periphery of the main combustion burner 22 in the funnel-shaped transition member 34. These tubes produce a multiplicity of small swirling jets discharging into the main combustion burner 22 and into engagement with the hot pilot stream. Fuel nozzle means 33 comprising a manifold 35 and nozzle 37 delivers fuel to the hot pilot stream entering the main combustion section 22. A fuel control 29 delivers fuel to manifold 35 by conduit 31. The pilot burner flow and swirling jet flow from tubes 50 have the flow split therethrough accomplished by the relative size of the pilot burner inlet passage 24 in relation to that of the swirl tubes 50. This split would be dictated by the amount of energy required to initiate the combustion process in the swirling jet flow and would generally involve having the jets flow about 70 to 80 percent of the total air that will be vitiated while the remainder passes through the pilot burner. The angular momentum of the individual jets dissipates by the time the bulk flow enters the turbine so there is no net rotation of the flow at this point either, and the swirling nature is restricted only to the immediate locality where it is employed to accelerate the combustion process.

In the modification of FIg. 2, approximately 20 percent of the fuel enters nozzle 26 while 80 percent enters through nozzle means 33. As for air flow, approximately 10 percent enters annular opening 24, approximately 30 percent enters tubes 50, approximately 30 percent enters dilution holes 45, and approximately 30 percent enters cooling holes 44.

An alternative construction is shown in FIG. 4 which would involve introducing the secondary fuel into the main combustion air prior to its passing through the swirlers. In this way the flow entering the main combustion burner is in the form of a swirling premixed fuel-air mixture. The instability arising at the outer boundary of these jets permits the surrounding pilot gases to act as a source of igniter for the ensuing main combustion process.

In FIG. 4 the changes from FIG. 2 are represented by the relationship between the swirl tubes 50B and the fuel nozzle means 33B. The swirl tubes 50B while being connected to the main combustion burner 22 in the same manner, have their forward ends curved to a point radially outwardly from, and just rearwardly of the manifold 35B of the fuel nozzle means 33. The fuel nozzles 37B extend into the curved forward ends of swirl tubes 50B and are connected at their forward ends to the manifold 35B. The fuel nozzles 37B need not be located in each swirl tube 50B. The amount of fuel desired can be placed through, for example, every other swirl tube 50B.

An alternative construction is shown in FIG. 5 where the forward part of the pilot burner is formed having the pilot fuel injected by fuel nozzles 26C into the air entering the pilot burner and where it then passes through a perforated plate flameholder 41C.

In a construction built the flameholder 41C acted to regulate the quantity of air entering the pilot combustion zone and also stabilized the flame in the pilot section. The function of the pilot burner is to generate a previtiated hot gas stream and to one skilled in the art there are other means of accomplishing this purpose within the content of this disclosure.

FIG. 6 shows a modification of the combustion section wherein a combustor 4A is shown mounted in a chamber 6A formed between an inner casing not shown and an outer casing 10A. This chamber 6A is annular and connected at its forward end to the exit of the compressor section. The downstream end of the chamber 6A is connected to an annular exit duct containing a plurality of turbine inlet vanes as shown in FIG. 2.

Here again, while in the construction shown, a plurality of combustors 4A formed as individual cans are used, a combustor can be formed equally as well as a single annular combustor. As before, although a plurality of these combustor cans are located around the annular chamber 6A, since they are alike, only one of these cans will be described below. The combustor 4A comprises a pilot burner 20A and a main combustion burner 22A. In this modification the pilot burner 20A is formed having an annular pilot combustion zone 30A formed between outer and inner wall members 60 and 62. The outer wall member 60 is connected to and spaced from the outer casing 10A by a plurality of struts 64. Inner wall 62 is connected to and spaced from a centerbody 68 by a plurality of struts 70, forming an annular passageway 72.

Outer wall member 60 extends forwardly in an annular passageway 66, approximately at the center thereof, formed by the wall of the centerbody 68 and outer casing 10A. The wall member 60 is bent rearwardly at its forward end 61 forming a streamline flow splitter for inlet air from the compressor section. The centerbody 68 has a forward opening 69 to permit the entry of inlet air from the compressor section.

Inner wall member 62 is spaced approximately halfway between the outer wall member 60 and the wall of the centerbody 68. The forward end of the wall member 62 is bent outwardly and rearwardly at 63 forming a smaller annular inlet passageway 65 which permits air in the annular passageway formed between the centerbody 68 and outer wall member 60 to enter the pilot combustion zone 30A. The rearward end of this bent back position is tapered inwardly at **67** forming an entry passage to the flameholder **74** which is placed between outer wall member **60** and inner wall member **62** to hold the flame at that point in the pilot burner. The pilot fuel is directed from a control **76** to a manifold **78**. The fuel is carried from manifold **78** by a plurality of conduits **32A** to fuel nozzles **26A**, said nozzles **26A** being located in the annular passage **65**. An igniter **80** provides ignition at **82**, just rearwardly of the flameholder **74**. Secondary fuel is delivered by control **83** to a manifold **35A**. This fuel is carried from manifold **35A** by a plurality of conduits to a plurality of fuel nozzles **37A** where it is directed into the pilot burner section so that it can be carried with the hot gases from the combustion zone, thereby forming a hot fuel rich mixture at the exit **84** located between the outer wall member **60** and inner wall member **62**.

The centerbody **68** extends downstream of the ends of the outer and inner wall members **60** and **62** and the portion extending rearwardly thereof comprises louvers **86** having cooling openings **88** and a rearward opening **90** for the exit of air therefrom. A center hub **92** is positioned in the opening **90** while swirl vanes **94** extend therearound. It is noted that a solid plate could be used in lieu of the hub **92** and swirl vanes **94**.

An intermediate wall member **96** is positioned between outer wall member **60** and outer casing **10A**, said wall **96** being spaced from outer wall **60** approximately the same distance as the wall of centerbody **68** is spaced from inner wall member **62** forming an annular passageway **97**. This construction also forms an annular passageway **98** between the wall member **96** and outer casing **10A** and this passageway permits cooling and dilution air to pass around the main combustion burner **22A**. Wall member **96** extends downstream, as referred to above, to an annular exit duct, such as shown in FIG. 2, with the wall formed as louver sections with cooling holes and dilution air holes.

Swirl tubes **50A** containing swirl vanes **52A** are located at the rear portion of the annular passageways **97** and **72**, a short distance from the rear end of the outer and inner wall members **60** and **62**. Each swirl tube **50A** has its swirl vanes **52A** fixed to the interior thereof and they extend inwardly to a smaller center tube **53A**. Each tube **50A** therefore emits a swirl column of air around a straight center column of air. This construction helps maintain the swirling column of air in its columnar form for a longer period of time. As seen in FIG. 7 the swirl tubes **50A** are located in pairs around the circumference of annular passageway **97** and annular passageway **72**. The pairs of swirl tubes **50A** are spaced apart to allow chutes **102** to be placed downstream thereof and not interfere in a detrimental way with flow from the tubes. The chutes are provided to divert part of the hot pilot gases into the void regions between the pairs of swirlers **50A**. The pairs of swirl tubes **50A** in both annular passageways **72** and **97** have their vanes **52A** directed so that fluid is swirled as it passes therethrough in opposite directions, that is air will be swirled in a clockwise direction through one swirl tube **50A** while it will be swirled in a counterclockwise direction in the adjacent swirl tube **50A** of the pair.

Blockage means are provided to prevent flow from passing around the swirl tubes **50A**. Blocking means are shown at **104, 106** and **108**. In annular passageway **72** blockage means are provided for the same purpose. They are shown at **110** and **112**.

In a construction built of the device shown in FIG. **6**, it was felt that approximately 4 percent of the air should enter the forward opening **69** of the centerbody **68**, approximately 17 percent should enter the annular passageway **72**, approximately 10 percent should enter the passageway **65**, approximately 17 percent should enter the annular passageway **97** and approximately 52 percent of the air should pass around the main combustion burner **22A** with approximately 30 percent entering dilution holes and approximately 22 percent entering through the louver cooling holes in operation. It was also felt that approximately 20 percent of the total fuel should be admitted through fuel nozzles **26A** while approximately 80 percent of the total fuel should enter through fuel nozzles **26A**. The construction was built substantially in the same proportion as FIG. **6** with there being **12** pairs of swirl tubes **50A**, each of approximately 1 inch diameter, around the annular passageway **97**, making a total of **24** swirl tubes, while **7** pairs of swirl tubes **50A**, of approximately the same diameter, were placed around passageway **72**, thereby providing a total of **14** swirl tubes. The swirl tubes **50A** in passageway **97** are located in the same transverse plane as swirl tubes **50A** in the annular passageway **72**.

FIG. **8** shows a modification of the construction of FIG. **6** wherein a combustor **4D** is shown mounted in chamber **6D** formed between an inner casing not shown and an outer casing **10D**. This chamber **6D** is annular and connected at its forward end to the exit of the compressor section. The downstream end of the chamber **6D** is connected to annular exit duct containing a plurality of turbine inlet vanes as shown in FIG. **2**.

Here again, while an individual can is shown, a single annular type can be used. One of these individual cans will be described belwo. A combustor **4D** comprises a pilot burner **20D** and a main combustor burner **22D**. In this modification the pilot burner **20D** is formed having an annular pilot combustion zone **30D** formed between outer and inner wall members **60D** and **62D**. The outer wall member **60D** is connected to and spaced from the outer casing **10D** by a plurality of struts **64D**. Inner wall **62D** is connected to and spaced from a short forward centerbody **68D** by a plurality of struts **70D**. Struts **71D** connect the short centerbody to wall member **60D**. The pilot burner is formed in the same manner as that in FIG. **6** with the pilot fuel, igniter and secondary fuel devices being substantially the same. At the rear end of the walls **60D** and **62D** two large louver extensions **120** and **122** complete the pilot burner. An annular flange member **124** extends outwardly and rearwardly from the rear end of member **120** and an annular flange member **126** extends inwardly and rearwardly from the end of **122**. Swirlers **50D** are mounted around each of the flanges **124** and **126** with the swirl tubes being directed inwardly at an angle towards each other. The swirl tubes **50D** are located around the flanges in much the same manner as in FIG. **7**. The main combustion burner **22D** extends rearwardly from the outer edge of the flange **124** and a short centerbody extends rearwardly from the inward end of the flange **128**. This centerbody **128** is formed as the rear section of the centerbody **68** in FIG. **6**.

If the annular can construction of FIGS. **6** and **8** were employed in a single annular combustor, the centerbody would not be truncated as shown but extended rearwardly to act as the inner wall of the annular inlet passage to the turbine while the outer wall of the main combustion chamber would become the outer wall of the annular inlet passage to the turbine.

I claim:

1. A method of carrying out a combustion process comprising the steps of:

1. directing hot gases into the upstream end of a confined volume,
2. forming a plurality of individual columns of an oxidizer, each swirling about its own axis,
3. directing said swirling columns of an oxidizer into said hot gases at the upstream end of the confined volume,
4. introducing a fuel in the mixed hot gases and oxidizer providing a combustible mixture,
5. igniting said combustible mixture,
6. directing exhaust gases from the downstream end of said confined volume.

2. A method as set forth in claim 1 wherein said oxidizer is air.

3. A method as set forth in claim 1 wherein the fuel is introduced in step 4 along with the hot gases of step 1.

4. A method as set forth in claim 1 wherein the fuel is introduced in step 4 along with the oxidizer of step 2.

5. A method as set forth in claim 1 wherein adjacent columns of an oxidizer in step 3 are formed having counter rotating swirling motions.

6. A method as set forth in claim 1 including the step of:

7. forming a combustion chamber as an annular chamber, wherein step 3 the swirling columns of an oxidizer are directed from both sides of said annular combustion chamber into said hot gases.

7. A method as set forth in claim 1 wherein step 5 the hot gases of step 1 have sufficient temperature to provide spontaneous ignition of the combustible mixture of step 4.

8. A method as set forth in claim 1 wherein step 2 an individual column of an oxidizer if formed by swirling an oxidizer around a straight jet of oxidizer.

9. A method as set forth in claim 8 wherein the fuel of step 4 is introduced into the swirling oxidizer and straight jet of oxidizer.

10. A method as set forth in claim 1 wherein step 1 the confined volume is a combustion chamber.

11. A method as set forth in claim 1 wherein steps 1 and 3 the oxidizer in the swirling columns and the hot gases provide all of the oxygen for combustion in the confined volume.

12. A combustor including a main combustion chamber, a pilot combustion chamber connected at the upstream end thereof for directing a hot gas flow thereinto, means for forming and directing a plurality of swirling jets of air each swirling individually about its own axis into the upstream end of said main combustion chamber and hot gas flow so as to establish intimate contact with the hot gas flow from said pilot combustion chamber, means for directing a fuel into said main combustion chamber for mixing with the hot gas flow and intermixing swirling jets of air.

13. A combination as set forth in claim 12 wherein said means for directing a fuel into said main combustion chamber includes means for directing a fuel into said pilot combustion chamber so as to enter said hot gas flow and be carried from the pilot combustion chamber into the main combustion chamber.

14. A combination as set forth in claim 12 wherein said means for directing a fuel into said main combustion chamber includes means for directing fuel into a plurality of each of the swirling jets of air prior to entering said main combustion chamber.

15. A combination as set forth in claim 12 wherein said means for forming and directing a plurality of swirling jets of air into said main combustion chamber comprises individual tubes fixed to said main combustion chamber adjacent its upstream end, said tubes having swirling means located therein to impart rotary motion to air passing therethrough.

16. A combination as set forth in claim 15 wherein said tubes have vanes located therein to swirl flow passing through the tube.

17. A combination as set forth in claim 12 wherein said main combustion chamber is annular.

18. A combination as set forth in claim 17 wherein said pilot combustion chamber has an annular discharge which is concentric with the annular main combustion chamber.

19. A combination as set forth in claim 21 wherein said main combustion chamber is formed having a diverging transition member at its forward end, said diverging transition member having a small forward opening and a larger rearward opening which is connected to the outer wall of the combustion chamber, said pilot combustion chamber being connected to the small forward opening of said diverging transition member, fixed to the diverging transition member a plurality of tubes of said main combustion chamber, said tubes having swirling means located therein.

20. A combination as set forth in claim 19 wherein said tubes are directed at an angle to the hot gas flow from said pilot combustion chamber as it enters into the main combustion chamber.

21. A combination as set forth in claim 20 wherein said tubes are placed in pairs, said areas between said pairs of tubes being blocked to prevent flow around said tubes.

22. A combination as set forth in claim 12 wherein the means for forming and directing a plurality of swirling jets of air provides all of the air added to the hot gases for combustion in the main combustion chamber.

23. A combination as set forth in claim 12 wherein said pilot combustion chamber forms its hot gas flow at a temperature which will provide spontaneous ignition when said hot gas, swirling jets of air and fuel mix within the combustion chamber.

24. A combination as set forth in claim 15 wherein said means for forming and directing a plurality of swirling jets of air into said main combustion chamber comprises smaller tubes positioned within said individual tubes for forming a straight jet of air at the center of said swirling jet.

25. A combination as set forth in claim 24 wherein said smaller tubes are positioned within said individual tubes by swirl vanes located therebetween.

26. A combination as set forth in claim 24 wherein said means for directing a fuel into said main combustion chamber includes means for directing fuel into air upstream of said swirling means.

27. A combination as set forth in claim 12 wherein said means for forming and directing a plurality of swirling jets of air into said main combustion chamber has means to direct said swirling jets at an angle to the hot gas flow from said pilot combustion chamber as it enters into the main combustion chamber.

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