United States Patent

Lewis

[15] 3,675,419

[45] July 11, 1972

[54] COMBUSTION CHAMBER HAVING SWIRLING FLOW

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

[22] Filed: **Oct. 26, 1970**

[21] Appl. No.: **84,088**

[52] **U.S. Cl.** ....**60/39.36**, 60/39.69, 60/39.72 R, 60/39.74 R, 431/173, 431/350

[51] **Int. Cl.** **F02c 3/24**

[58] **Field of Search** ....60/39.74 R, 39.36, 39.72 R, 60/39.69; 431/350, 173

[56] **References Cited**

UNITED STATES PATENTS

2,648,492	8/1953	Stalker	60/39.36
2,720,750	10/1955	Schelp	60/39.36
2,736,168	2/1956	Hanley	60/39.69
2,755,623	7/1956	Ferri	60/39.74 R
2,832,402	4/1958	Jurisich	60/39.74 R
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3,034,297	5/1962	Orchard	60/39.65
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FOREIGN PATENTS OR APPLICATIONS

164,359	7/1955	Australia	60/39.36

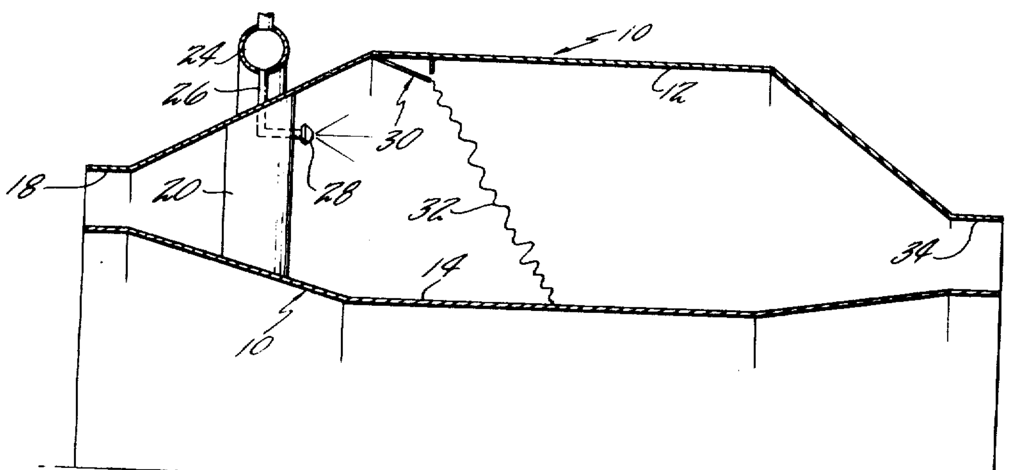
Primary Examiner—Douglas Hart

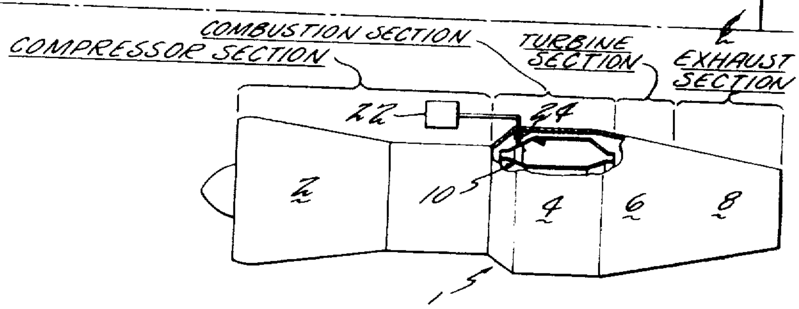
Attorney—Jack N. McCarthy

[57] **ABSTRACT**

A combustion chamber is arranged so that swirling flow is formed therein to improve the manner and rate of burning above that which is normally obtainable. Swirl inducing means are provided at the entrance to the burner and flameholding means are provided around the outer circumference of the burner. Fuel is injected rearwardly of the swirl inducing means.

9 Claims, 9 Drawing Figures





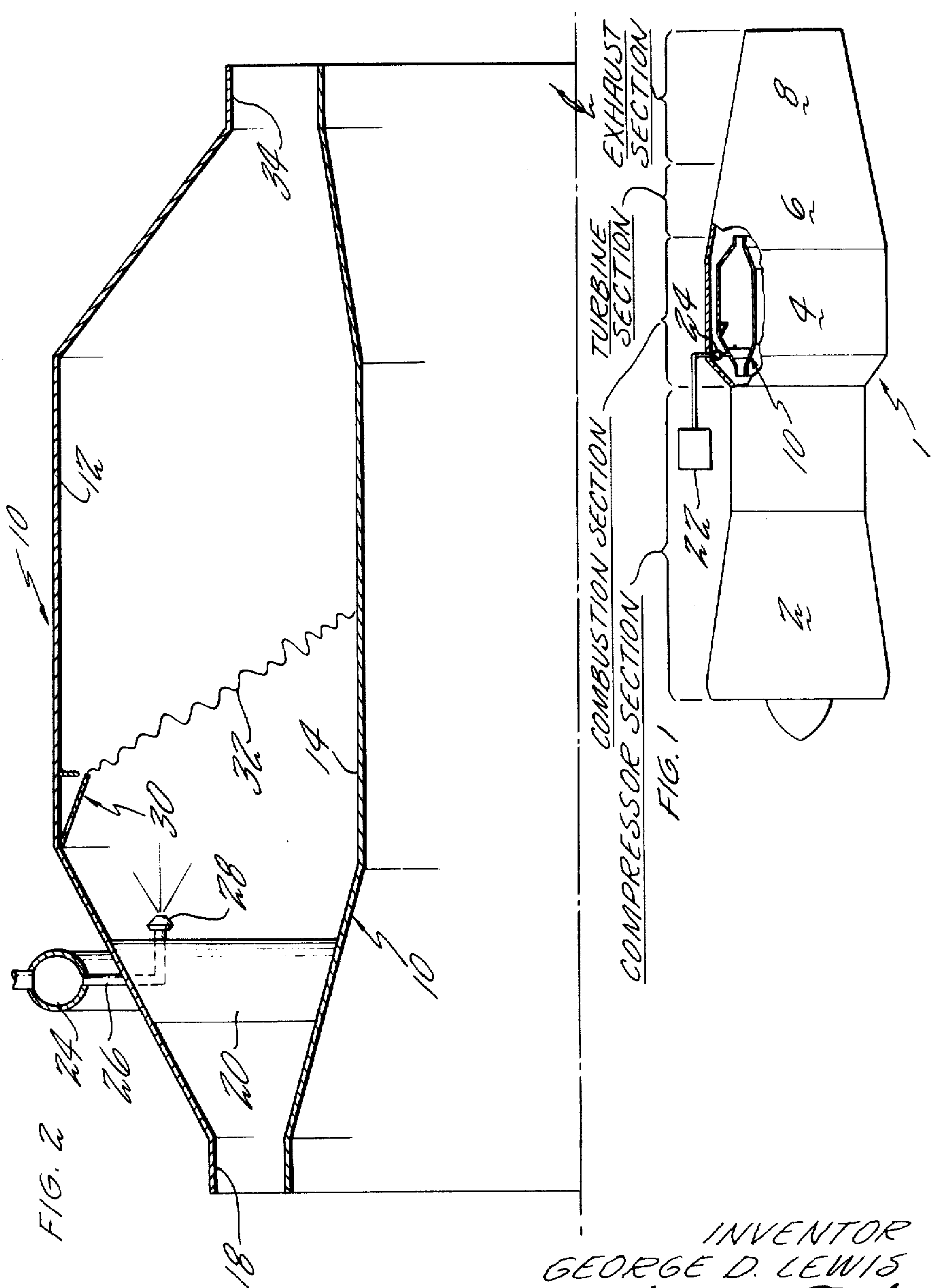


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FIG. 4

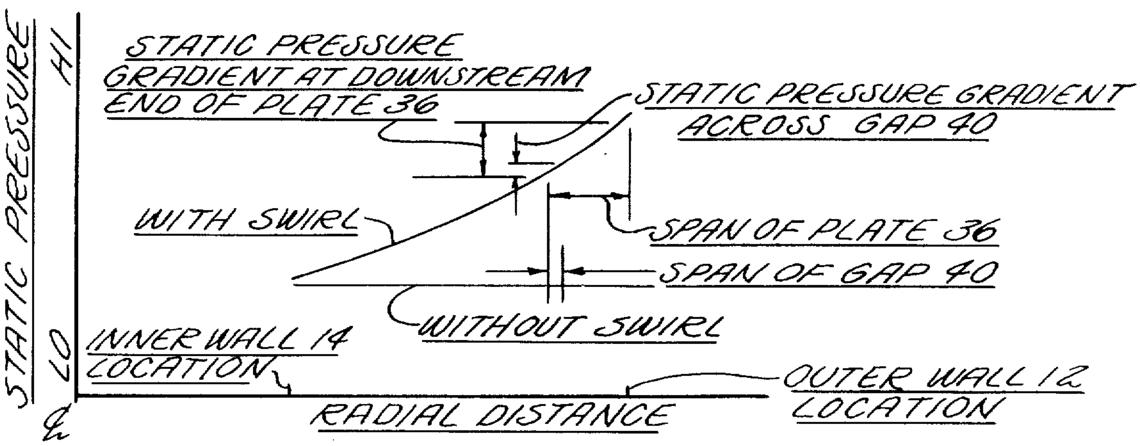
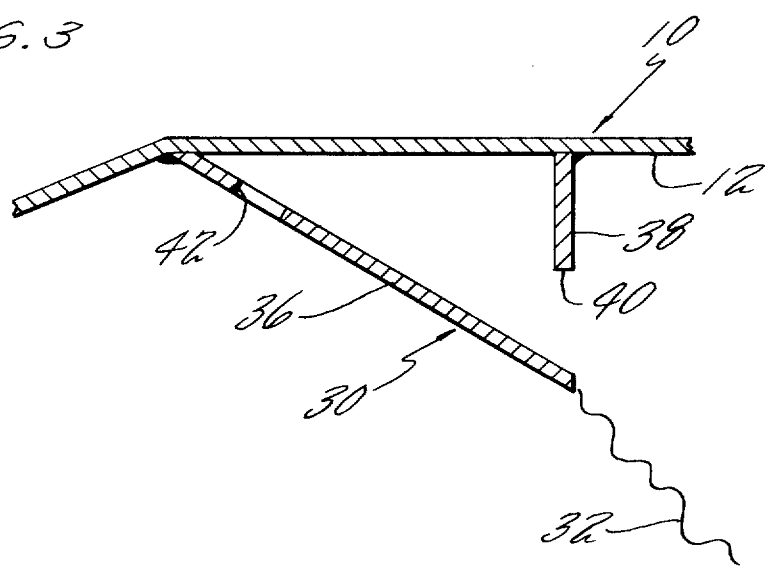

STATIC PRESSURE
HI
LO
STATIC PRESSURE GRADIENT AT DOWNSTREAM END OF PLATE 36
STATIC PRESSURE GRADIENT ACROSS GAP 40
WITH SWIRL
SPAN OF PLATE 36
SPAN OF GAP 40
WITHOUT SWIRL
INNER WALL 14 LOCATION
OUTER WALL 12 LOCATION
RADIAL DISTANCE

FIG. 3


10
12
38
40
42
36
30
32

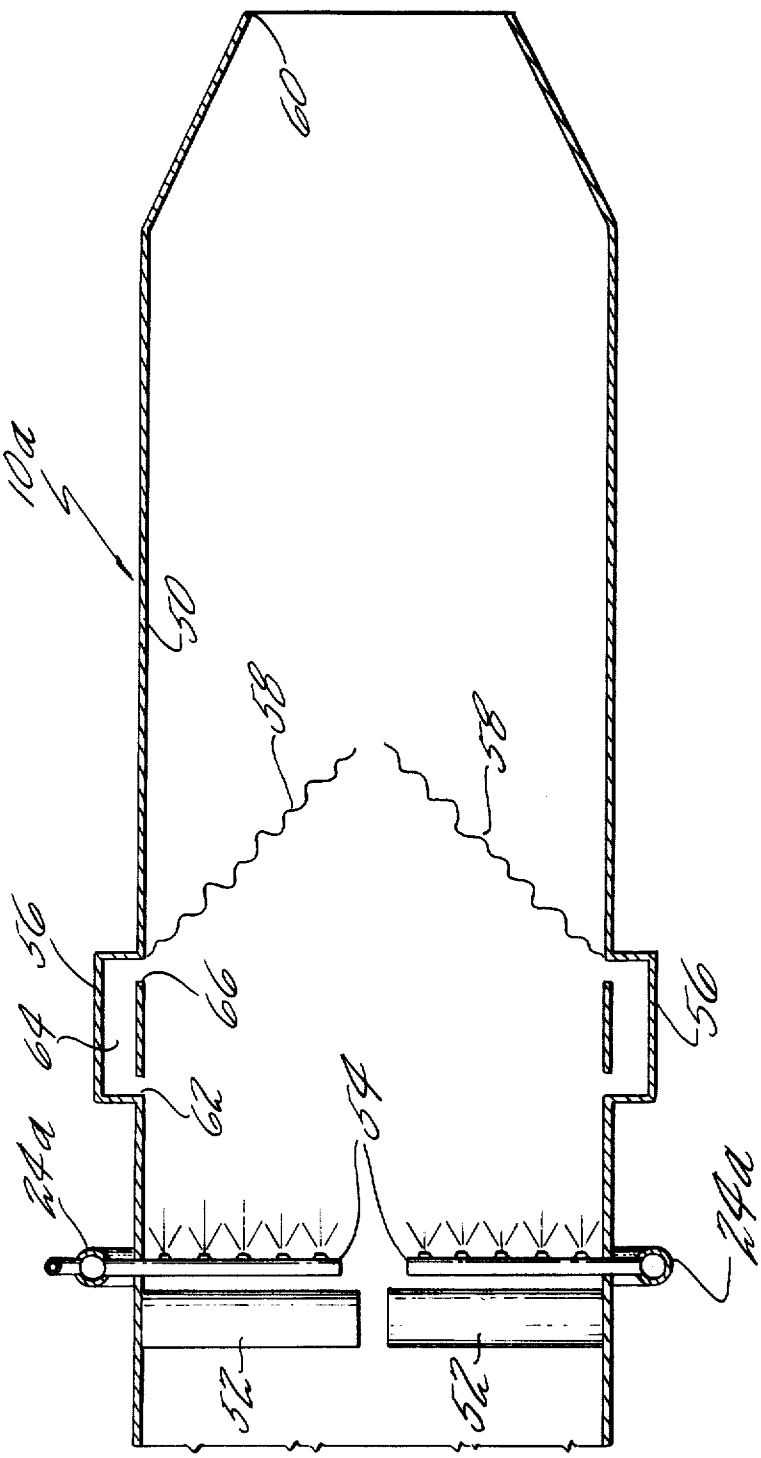


FIG. 5

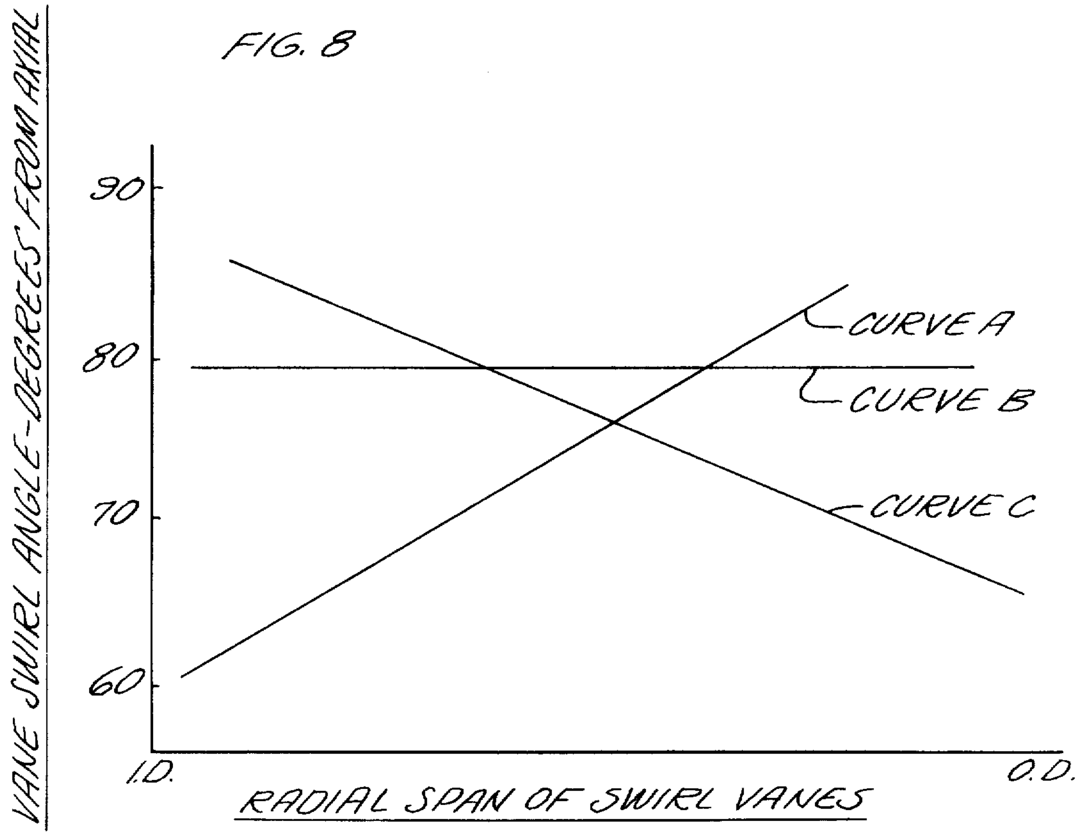


FIG. 8

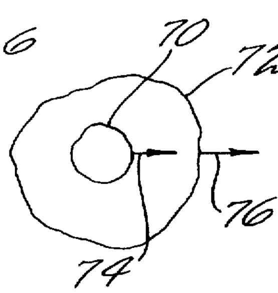


FIG. 6

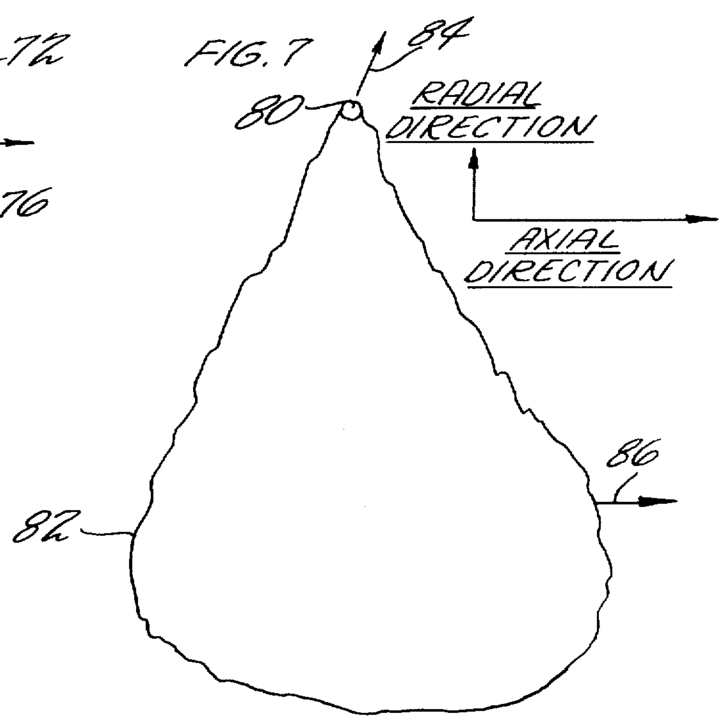
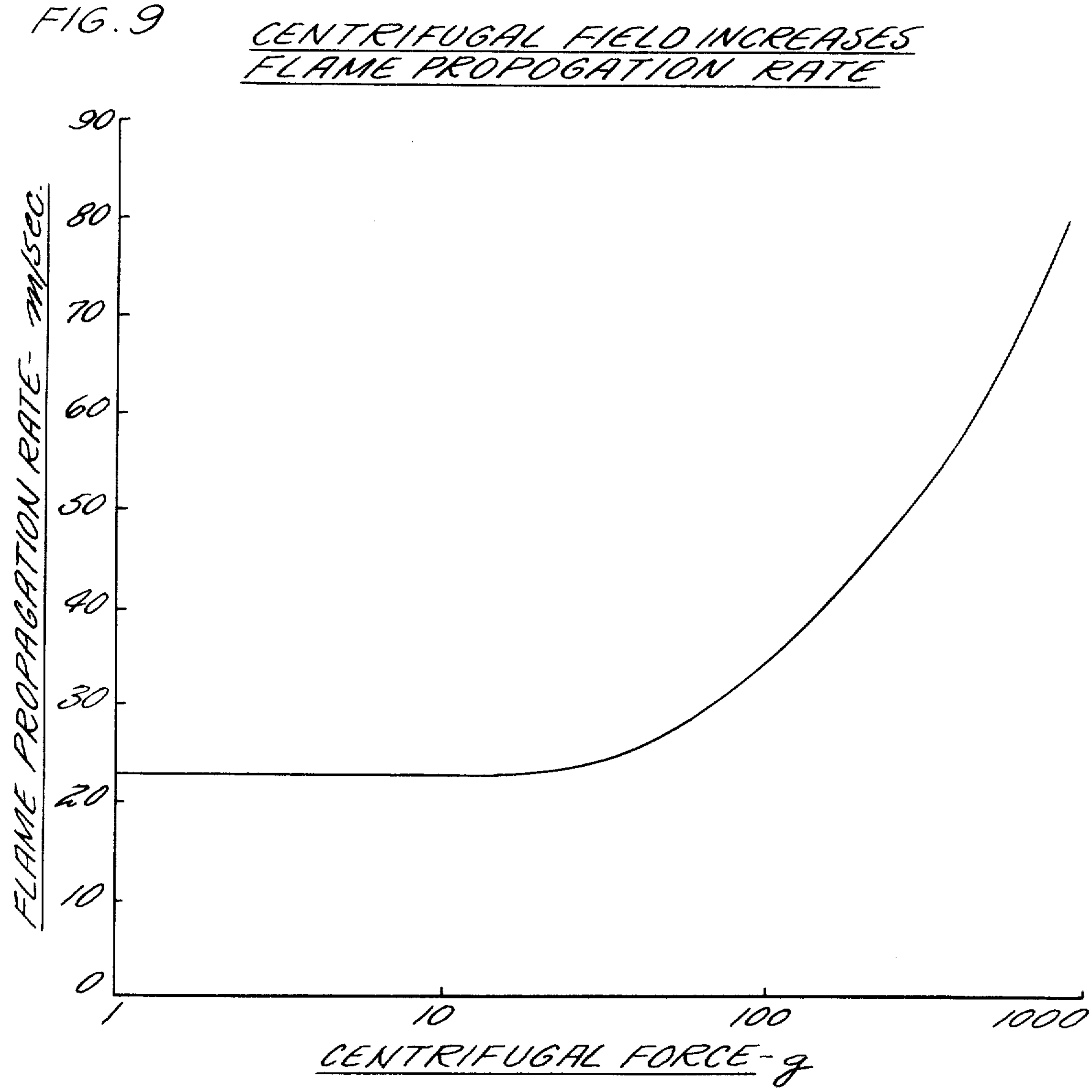


FIG. 7

FIG. 9


CENTRIFUGAL FIELD INCREASES FLAME PROPOGATION RATE
FLAME PROPAGATION RATE - m/sec.
0
10
20
30
40
50
60
70
80
90
1
10
100
1000
CENTRIFUGAL FORCE - g

COMBUSTION CHAMBER HAVING SWIRLING FLOW

CROSS-REFERENCES TO RELATED APPLICATIONS

This application contains subject matter related to the following two applications assigned to the same assignee: (1) application Ser, No. 84,086, filed concurrently herewith for "Annular Combustion Chamber for Dissimilar Fluids in Swirling Flow Relationship" and (2) application Ser. No. 84,087, filed concurrently herewith for "A Shortened Afterburner Construction for Turbine Engine".

BACKGROUND OF THE INVENTION

This invention relates to combustion in a centrifugal force field and is particularly concerned with burning in the combustion chamber of a turbojet engine. While swirl has been induced in a combustor before, such as shown in U.S. Pat. No. 2,755,623, the manner in which it is herein done is not heretofore known.

SUMMARY OF THE INVENTION

This invention relates to an improved method of burning fuels in propulsion devices and industrial furnaces. In detail, it relates to a method of using centrifugal force to improve the manner and rate of burning above that which is normally attainable. One object of this invention is to use centrifugal force to drive an igniting flame rapidly through a fuel-air mixture to greatly increase the rate of burning. In accordance with the present invention a combustion chamber uses centrifugal force to promote mixing of hot products of combustion with surrounding colder gases to provide a more uniform temperature at the combustor exit. This invention uses centrifugal force to increase the rate of fuel evaporation when liquid fuel is sprayed into an oxidizer stream, such as air.

In this arrangement a flameholder extends substantially around the combustion chamber at or near its outer periphery with the discharge area partially covered by a plate means to prevent recirculating flow. Means are included to provide a centrifugal acceleration of at least 3,000 feet per second per second.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a view of a turbojet engine showing the location of the combustion section.

FIG. 2 is an enlarged longitudinal section view of an annular combustion chamber of the main burner in a turbojet engine.

FIG. 3 is an enlarged view of the flameholder in FIG. 2.

FIG. 4 is a plot showing the static pressure distribution in the combustion chamber of FIG. 1.

FIG. 5 is a longitudinal sectional view of a cylindrical combustion chamber of a main burner or an afterburner in a turbojet engine.

FIG. 6 is an enlarged view of an individual fuel drop in a flowing air stream which does not have a strong centrifugal field.

FIG. 7 is an enlarged view of an individual fuel drop in a flowing air stream which does have a strong centrifugal field.

FIG. 8 is a plot of several possible variations in vane swirl angle with vane span.

FIG. 9 is a curve of experimental data showing the effect of centrifugal force on the flame propagation rate.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to FIG. 1 a gas turbine power plant is shown indicated generally by 1. The power plant has a compressor section 2, a combustion section 4, a turbine section 6, and an exhaust section 8. The combustion section 4 is comprised of an annular combustion chamber 10. As shown in FIG. 2, the annular combustion chamber 10 has an outer wall 12 and an inner wall 14. Air from the compressor section 2 is admitted to the annular combustion chamber through annular opening 18. If an arrangement is used other than a turbojet engine, air, or some other oxidizer, can be directed to opening 18 by some other external sources.

It is desired that the air entering the combustion area have a tangential swirl about the center line of the annular combustion chamber. This can be done by compressor design or by the use of swirl vanes 20 or a combination of both. If the air from the compressor section does not have adequate swirl, swirl vanes 20 are placed in the forward part of the annular combustion chamber to impart an additional tangential velocity to the air flow through them. In this device, it is desired that the air will rotate around the center line of the combustion chamber at a tangential velocity high enough to produce a centrifugal acceleration of at least 3,000 feet per second per second.

A conventional fuel supply and metering control 22 provides the desired overall fuel flow to an annular manifold 24. A separate pipe 26 extends inwardly to each fuel injection means 28 to produce a fuel spray therefrom into said combustion chamber. A plurality of fuel injection means 28 are located around the combustion chamber at a location just rearwardly of the swirl vanes 20.

A flameholder 30 is positioned adjacent the outer wall 12 to provide an ignition source around the entire periphery of the combustion chamber 10. Ignition means (not shown) are placed for cooperation with the flameholder 30. Line 32 represents a flamefront produced by combustion of the fuel-air mixture in the combustion chamber which has been observed in tests.

While flameholders in normal combustors not having any large tangential velocity component produce a flamefront having an angle between 6° and 10° from the axial direction, experimental burners having a large tangential velocity component have produced flamefronts having an angle of approximately 60° from the axial direction resulting in a greatly reduced burner length. After combustion is completed, the burned products leave the combustion chamber through annular opening 34.

The flameholder 30 comprises a plate 36 which extends rearwardly as a conical section forming an acute angle with the outer wall 12. This construction is generally similar to known annular V-shaped flameholders. An annular plate 38 is attached to and extends inwardly from the outer wall 12 in the same plane as the trailing edge of the plate 36, to a point adjacent said edge forming a small gap or opening 40. Plates 36 and 38 can be welded to outer wall 12 or attached by other suitable means. Openings 42 are provided in plate 36 to admit a small amount of fuel-air mixture to the sheltered zone under the flameholder as is common in jet engine practice. The total pressure of the gas discharging form the flameholder can be kept higher than the highest static pressure across the discharge gap to prevent cold gas circulation under the flameholder.

Without a large tangential velocity component to the gas flow the static pressure would be relatively constant at the downstream end of the flameholder and it would hold flame well as in conventional practice. With a large tangential velocity component in the fuel-air mixture, however, the static pressure is not constant across the downstream end of the flameholder. See FIG. 4 which is a plot of the static pressure in a radial direction across the combustion chamber of FIG. 2, it is apparent that the static pressure is higher at the outer wall 12 than it is at the downstream edge of plate 36. This static pressure gradient has been observed to cause a strong recirculating flow under the flameholder 30 without plate 38, thus eliminating the sheltered low flow region necessary for effective flameholding.

While the flameholder 30 is shown as a continuous annular ring it can be formed of a plurality of flameholder sections around the periphery of the combustion chamber 10. Further, while plates 36 and 38 are shown as cantilevered, the flameholder can be constructed in other ways; for example, plate 38 could extend to the trailing edge of the plate 36 and be attached thereto with a plurality of openings being formed therearound to provide an area equal to the gap or opening 40.

As shown in FIG. 5, the cylindrical combustion chamber 10A has an outer wall 50. Here again, air is admitted in the same way as it is to the annular combustion chamber 10 shown in FIG. 2. If an adequate tangential velocity is not obtained from the compressor section design, swirl vanes 52 can be used. Fuel is provided to the annular manifold 24A and a plurality of spray bars 54 extend inwardly towards the center of said combustion chamber 10A from the annular manifold 24A. The resulting fuel-air mixture passes flameholder 56, which is shown in a different configuration from the flameholder of FIG. 3, where it is ignited to produce the flamefront 58. The resulting products of combustion discharge from the burner through the opening 60. It is noted that swirl vanes 20 and 52 can be mounted for rotation so that their angular position with respect to the longitudinal axis of the combustion chamber can be varied either separately or all together.

A small amount of fuel-air mixture passes through a plurality of holes 62 to the sheltered flameholding volume 63 where it is ignited by an ignition means (not shown) and burns to produce a pilot flame which issues through slot 66 to ignite the main fuel-air mixture stream. This configuration increases engine thrust by eliminating the aerodynamic drag associated with flameholders which are normally immersed in the high velocity gas stream in the combustion chamber.

FIG. 8 shows three typical ways the angle of the vanes 20 in FIG. 2 or vanes 52 in FIG. 5 may vary along their radial span. Curve B represents vanes having a constant angle along their radial span in relation to the axial direction of said combustion chamber. Fluid leaving these vanes would have a relatively constant tangential velocity along the radial direction in the combustion chamber. The figure shown a typical value of 80° which was found to be a reasonable value but it does not mean that other values are not suitable. Curve A shows a typical variation of increasing vane swirl angle along the radial span of the vane. This configuration causes the radially outward portion of the flow to move circumferentially around the combustion chamber faster than the inner portion and thus increases the circumferential mixing to produce more nearly uniform combustion chamber exit temperatures. Similarly, curve C shows another typical variation of decreasing vane swirl angle with radial span. This configuration produces the same mixing effect as the one represented by curve A but in the opposite manner, i.e., by causing the radially outward portion of the flowing gas to move around the combustion chamber more slowly than the inner portion.

In a flowing air stream which does not have a strong centrifugal field, the aerodynamic drag of the air stream on a fuel drop 70 (see FIG. 6) rapidly accelerates the drop to nearly the same velocity as the air and the heat transferred from the air to the drop 70 causes the drop to evaporate until it becomes surrounded by a cloud 72 of saturated fuel vapor. Arrow 74 and 76, respectively, show the direction of motion of the drop 70 and vapor cloud 72. Thereafter, evaporation of the fuel drop is slowed and can proceed only as fast as the saturated vapor cloud is depleted through diffusion and turbulence.

In a flowing air stream which does have a strong centrifugal field, with a high tangential velocity component a fuel drop 80 (see FIG. 7) evaporates under its influence. The aerodynamic drag of the air stream on fuel drop 80 rapidly accelerates it to, or near, the air velocity but at the same time, centrifugal force acts more strongly on the dense fuel drop 80 than it does on the surrounding less dense air and fuel vapor cloud 82 thereby causing the drop 80 to move rapidly in a radially outward direction across the flowing air stream. This resulting motion moves the dense fuel drop 80 away from the vapor cloud 82 as fast as it forms, greatly accelerating the evaporation rate. Arrows 84 and 86, respectively, show the direction of motion of the drop 80 and vapor cloud 82.

In most combustion chambers, the rate at which flame spreads through a mixture of fuel and air is controlled by heat transfer, turbulence, and diffusion processes. As previously stated, one object of this invention is to use the centrifugal force field generated by swirling the air in a combustion chamber in a spiraling manner around the center of the chamber. To understand how this is accomplished, it is instructive to look at the following equation which analytically expresses the force driving the hot ignition flame through a colder mixture of fuel and air in a combustion chamber designed according to the principles of this invention.

$$F = \rho g (1 - Tc/Th)$$

Listed below are the symbols set forth in the formula above together with their meaning:

F = force driving the hot flame or products of combustion through the colder surrounding fuel-air mixture (pounds per cubic foot)

ρ = density of the surrounding colder fuel-air mixture (pounds per cubic foot)

g = acceleration due to gravity or centrifugal force in multiples of the earth's gravitational acceleration (dimensionless)

Th = temperature of the hot flame or products of combustion (degrees rankine)

Tc = temperature of the colder surrounding fuel air mixture (degrees rankine)

Values for the symbols in the above formula applied to a typical turbojet engine combustion chamber in which the air flow does not have a high tangential velocity component are $\rho = 0.4$, $g = 1.0$, $Tc = 1{,}000$, $Th = 3{,}000$ and $F = 0.267$. However, when the principles of this invention are applied, g in the formula above changes from 1 to a typical value of 4,000 and F changes for 0.267 to 1068. This strong increase in force driving the hot flame through the cold fuel air mixture produces a large increase in the rate of flame spreading and burning. The increased Force increases the flame propagation rate as shown in FIG. 9 which curve is the result of testing in this field.

Although only two embodiments of the invention are illustrated and described herein, it will be apparent that various changes and modifications may be made in the construction and arrangement of the various parts without departing from the scope of this novel concept.

I claim:

1. A combustion chamber having an outer wall and means for directing air into said combustion chamber at one end thereof, means for causing the air to rotate around the center line of the combustion chamber at a tangential velocity to produce a large centrifugal acceleration, means for introducing fuel into said air, a flameholder located adjacent the outer wall, said flameholder having an inlet area and a discharge area, said inlet area permitting fuel-air mixture within said flameholder, said discharge area being sized to prevent recirculating flow therein due to the rotating air, means for igniting the fuel-air mixture.

2. A combination as set forth in claim 1 wherein said fuel is introduced by being sprayed into the air after it has obtained its centrifugal acceleration.

3. A combination as set forth in claim 1 wherein the flameholder comprises a plurality of individual sections.

4. A combination as set forth in claim 1 wherein said combination chamber has an inner wall thereby forming an annular combustion chamber.

5. A combination as set forth in claim 1 wherein the flameholder is formed against the outer wall of said combustion chamber by a first plate extending radially inwardly and rearwardly, a second plate extending radially inwardly from said outer wall, said discharge area being formed between said first and second plates.

6. A combination as set forth in claim 1 wherein the flameholder is formed against the outer wall by chamber means located around said wall, said inlet area being located at the upstream end of said chamber means, and said sized discharge area being located downstream of said inlet area.

7. A combination as set forth in claim 1 wherein said means for causing the air to rotate includes a plurality of swirl vanes located just upstream of the means for introducing fuel into said air.

8. A combination as set forth in claim 7 wherein at least some of said vanes have a varying vane swirl angle along the radial span of the vane to rotate the air at a velocity which is different at different radial positions in the chamber.

9. A combination as set forth in claim 1 wherein said large centrifugal acceleration is at least 3,000 feet per second per second.

* * * * *

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,675,419 Dated July 11, 1972

Inventor(s) George D. Lewis

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Claim 4, Column 4, lines 61 and 62, "combination" should read -- combustion --.

Signed and sealed this 31st day of October 1972.

(SEAL)
Attest:

EDWARD M.FLETCHER,JR.
Attesting Officer

ROBERT GOTTSCHALK
Commissioner of Patents