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COMBUSTION SYSTEM

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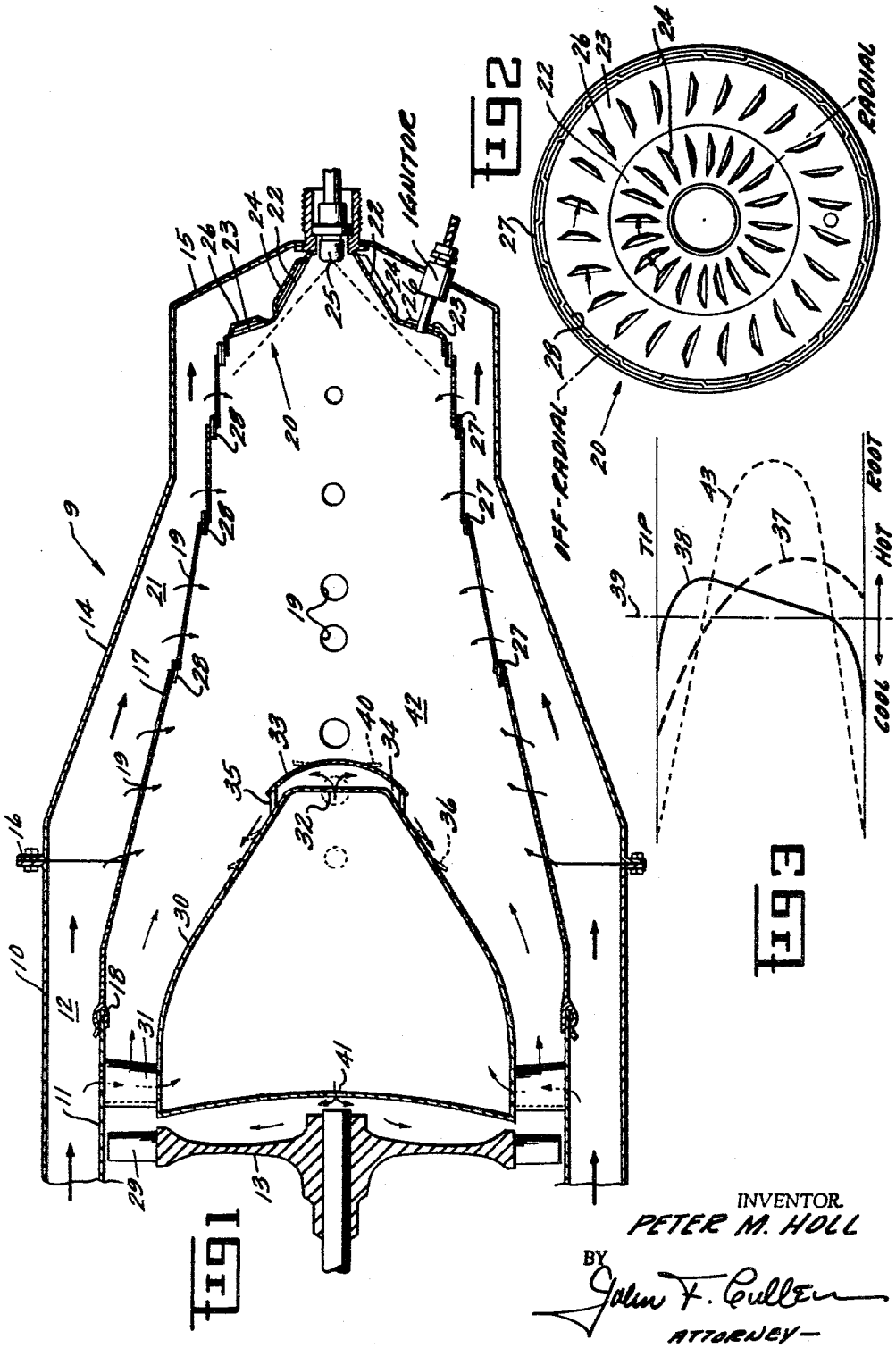


Fig 1

Fig 2

Fig 3

INVENTOR.
PETER M. HOLL
BY
John F. Cullen
ATTORNEY

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COMBUSTION SYSTEM

Peter M. Holl, Walnut Creek, Calif., assignor to General Electric Company, a corporation of New York

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The present invention relates to a combustion system and, more particularly, to a reverse flow combustion system adapted for use at the downstream or aft end of a gas turbine engine.

Small gas turbine powerplants are are compact and that use a single reverse flow combustor at the downstream end of the powerplant are known and a typical powerplant is shown in U.S. Patent 2,553,867. Such engines use a single combustion chamber at the aft end of the powerplant generally symmetrical about the longitudinal centerline of the engine. Because of the location at the aft end of the powerplant the single combustor is of the reverse flow type, and the combustor inlet from the upstream compressor and the combustor exit from the combustion zone to the turbine are concentric annular passages. Such engines are generally designed to be low cost, lightweight compact engines. In order to accomplish these objectives it is desirable to use low cost and easily formed materials as much as possible. In the combustion end of the engine it is necessary to have a predictable and uniform turbine inlet temperature distribution and highly advantageous to have a turbine inlet temperature profile which ensures that the turbine bucket roots are cool and the warmer temperatures occur at the tip of the turbine buckets. This temperature profile must be obtained of course at high combustion efficiency, with low pressure loss and easy ignition in the combustion zone. It is then possible to take advantage of such a desirable temperature profile in the turbine design. By keeping the roots of the turbine buckets relatively cool it is possible to withstand higher root stresses and thus minimize bucket mass and associated disk loads. This allows increased bucket life for a given inlet temperature, or a higher inlet temperature for a given life. Additionally, the turbine inlet temperature must be uniform about the complete circumference of the turbine inlet. Thus, such design objectives require specific combustion systems for a given engine.

The main object of the present invention is to provide a reverse flow combustion system that is low cost, lightweight and efficient, and that maintains a temperature profile at the turbine inlet for better cooling of the roots of the turbine buckets.

Another object is to provide such a combustion system which, by means of dome cap geometry and particularly oriented dome louvers takes advantage of the natural flow of air into the combustor to achieve better combustion performance including stabilizing the flame where desired.

A further object is to provide such a system which uses a centerbody member to direct exhaust to the turbine, to promote direct cooling of the turbine buckets, and provide better mixing of the hot combustion gases and the cooling air in the novel combustor.

Briefly stated, the invention provides a reverse flow combustion system including the combustor to be used on the aft end of a gas turbine engine next to the turbine which provides an annular air inlet circumferentially around the turbine and then funnels the air between a pair of conical-cylindrical members in an annular passage and directs a substantial percentage of the air into a combustion zone through particularly oriented louvers whereupon it is reversed and flows forward and out an annular passage concentric with the inlet annular passage and to a point of exhaust. A centerbody is disposed in the combustor chamber and is conical in shape, and the centerbody is provided with a dome cap at its cone end for directing airflow to achieve cooling of the turbine roots. An ignition means is provided at a specific location where there is a locally rich mixture of the fuel and air.

While the specification concludes with claims particularly pointing out and distinctly claiming the subject matter which is regarded as the invention, it is believed the invention will be better understood from the following description taken in connection with the accompanying drawing in which:

FIG. 1 is a diagrammatic cross-sectional view of the combustion system;

FIG. 2 is an end view of the dome closure; and

FIG. 3 is a graphic illustration of the temperature profile obtainable by the instant invention.

Referring first to FIG. 1, there is shown the reverse flow combustion system of the instant invention which system includes a combustor and may be hung on the downstream end of a small gas turbine powerplant of the type shown in the above-mentioned patent. Only so much of the combustion system as is necessary for its understanding is shown and it will be understood that it may be applicable to a number of powerplant arrangements of the type shown in the above-mentioned patent. Air from an upstream compressor source is funneled into the combustion system, and to the combustor generally indicated at 9 between a pair of concentric shells 10 and 11 to define an annular air passage 12 around the outer periphery of a turbine 13 which, in a powerplant of the type for which the instant combustion system is adapted, will generally be mounted as shown. In order to get the air into the combustion zone, an outer combination conical-cylindrical casing 14, which is closed at its cone end 15, is secured to outer shell 10 at flange 16 and an inner concentric combination conical-cylindrical liner 17 is secured to the inner shell 11 by any suitable means such as a sliding fit 18. The inner liner is perforated at 19 for a selected length by suitable openings such as slots, holes, etc. which are well known. Preferably, plain holes as shown are used. For purposes that will be apparent as the description proceeds, liner 17 is closed at its cylindrical end by a double conical dome closure generally indicated at 20. It will be noted that casing 14 and liner 17 are spaced aft in a symmetrical and axially aligned manner to form a coned and then cylindrical zone in a manner to provide a continuation 21 of annular air passage 12, and that such continuation decreases in cross-sectional area in the downstream direction to the cylindrical zone. It will be noted that the cone and cylinder shapes are low cost items to manufacture and provide straight passages for the flow of air to minimize area changes and reduce flow losses. Additionally, the use of the combined cone-cylindrical shape provides the desired volume for fuel-air mixing and required combustion intensity. Further, the decreasing area in the conical portion of annular passage 21 maintains the air velocity substantially constant as the incoming air is fed into the liner. The constant section area due to the cylinder shape provides a plenum chamber effect for maximum pressure drop across the liner wall to introduce the required mass of air with the required penetration into the primary combustion zone within the cylindrical part.

In order to obtain good mixing and fuel distribution in the combustor, the double conical dome closure is important. It includes an inner cone 22 and an outer cone 23. The outer cone is a continuation of the inner cone and opens out flatter and away from the inner cone. This arrangement provides completely separate zones of air introduction whose desirability will be apparent. For providing initial air to mix with and further atomize the incoming fuel, the inner cone 22 is provided with a series of substantially radial louvers 24 extending around the

inner cone and angled to introduce air tangentially to the inner surface of the cone as seen by the arrows in FIG. 2. This air tends to further break up the atomized fuel introduced by an injector **25** whose spray angle cone pattern is adjusted to come close to, but not impinge upon, the juncture of the inner and outer cones. Thus, the fuel spray is contained within the inner cone without striking it but filling it. In this way the formation of droplets is avoided while atomization is enhanced.

Because the air entering by louvers **24** tends to flow or spin outward along the liner walls carrying entrained fuel, it is important to control this centrifuging action. To this end, there is provided a second series of louvers **26** in the outer cone **23**. Control is obtained by orienting these more numerous louvers in an off radial direction as seen in FIG. 2. The air flow into louvers **26** is in generally the same direction as louvers **24** as seen by the arrows. Additionally the air is also introduced tangentially as in louvers **24**. However, because of the off radial orientation of louvers **26** located in cone **23**, the air flow also has a radial inward component of swirl to offset the centrifuging action of the inner louvers and confine and mix the flow into the cylindrical combustion zone in a core off the walls of the liner. Thus, the walls are protected from the high combustion reaction temperature, as well as the deposit and breakdown of fuel thereon.

Since the intersection of the louvered flows creates a good recirculation and rich fuel air mixture, it is at this juncture that good ignition will occur. An ignitor is disposed through the dome member **15** and outer cone **23** between the louvers therein to ignite in this preferred area.

The flatter outer cone **23** in conjunction with its off radial louvers **26** results in a strong flame stabilizer tending to hold or anchor the flame in the dome end of the cylindrical part of the combustor where it is desired.

Further cooling of the combustor liner is obtained by constructing the combination conical-cylindrical liner in a number of sections that are nested together as shown. These sections are joined by spacing means such as ribbon strips **27** which define air conduits **28** for the passage of air axially along the inner surface of the liner. These strips may be bent as shown at the junction of the cone and cylindrical parts of the liner. In addition to cooling the liner, the entering air furthers the combustion process in the cylindrical part of the liner and, with the air entering holes **19** in the conical portion, tends to quench the flame and reduce the temperature of the gases approaching turbine buckets **29**.

In order to direct the combustion gas smoothly into the turbine **13** and obtain the desired temperature profile across the turbine buckets **29**, a hollow cone-shaped centerbody **30** is provided. As shown, the centerbody is supported centrally of the combustion zone and extends axially into inner liner **17**. Support of the centerbody is obtained by connecting hollow turbine nozzles **31** with the liner concentric shell **11**. The hollow nozzles and hollow centerbody permit air in annular passage **12** to pass also to the interior of the centerbody due to the pressure differential between the combustion zone and the compressor air. In order to obtain the desired temperature profile across the turbine buckets, the centerbody is provided with an aperture means **32** in its cone. For guiding the cooling air, a dome cap **33** cups the end of the cone of centerbody **30** as shown and this provides an annular air metering duct **34** completely around the cap. Cap **33** is supported by any suitable means **35** from the centerbody and arranged so that the area of the annular duct **34** is equal to or smaller than the area of aperture **32** in order to prevent aperture **32** being a limiting factor in the flow of metered cooling air. It can be seen that the cupping or overlapping arrangement of cap **33** permits the air duct **34** to cool the cap and to direct air forwardly along the centerbody outer surface to cool the outer surface and to direct a cooling flow of air along the surface toward the root portions of turbine buckets **29**. If necessary, additional openings **36** can be provided in the centerbody.

Referring next to FIG. 3, the radial temperature profile across a typical turbine inlet annulus is indicated by the line **37** which shows a cool tip and hot root portion. In accordance with the invention, there is shown a radial temperature profile **38** across a turbine inlet annulus. The average temperature is shown by line **39**. By providing cooling air guided by the centerbody towards the root of the turbine buckets it is possible to, in effect, tilt the average temperature **39** to profile **38** providing a cooler root portion which is the highly stressed portion and a hotter tip portion which is the low stressed portion. Thus, the turbine design is improved enabling a given material to be used at higher turbine temperatures or, maintaining the same temperature, to minimize bucket weight and the associated disk loads. In either case an advantage is apparent.

If necessary or desirable, additional openings **40** may be provided in cap **33** to cool the outer surface of the cap and mix with the hot core in the combustion zone. The closed forward portion of the centerbody may also be provided with openings **41** for use of cooling air at additional points such as for turbine wheel cooling or for oil sump seal pressurization.

The use of the centerbody permits use of the cooling air flowing through annulus **34** in the thermodynamic cycle. In other words, the cooling air is returned to the combustion zone ahead of the turbine. Thus, there is no penalty in performance even when a large percentage of the total engine airflow is passed through the centerbody for cooling purposes. Additionally, the centerbody provides a convenient means for introducing cool air to mix with the hot central core of gas in liner **11** to promote uniformity of circumferential temperature pattern at the turbine inlet. It will be apparent that some of the air flowing along the outer surface of centerbody **30** mixes with the hot core combustion gas and therefore penetration of air through openings **19** need not be as deep because cool air is introduced from both sides—the centerbody side as well as the liner side. Thus, for mixing purposes, the penetration of the cool air may therefore be lower.

It is to be noted that perforations **19** of increasing area, in liner **17** extend substantially from the end **20** of the liner back to approximately the upstream end of dome cap **33** and that the remainder of the exit gas channel defined by the centerbody and liner is unperforated. This is deliberately provided in order to allow the temperature of the air at the walls to heat up sufficiently to maintain the proper bucket profile. In other words, excessive cooling air on the walls of the centerbody and the inner liner in the area **42**, would require much hotter air in the central portion in order to obtain the desired average temperature. This would produce a temperature profile across the buckets as shown by dotted line **43** in FIG. 3. Therefore it is desired to allow the exhaust gas in the area **42** to heat up the air along the walls to obtain the desired temperature profile **38**.

It can be seen that the conical-cylindrical shapes of the elements obtain the good air distribution and lightweight construction, and the particular louver orientation in the novel double dome closing permits the use of the natural inflow air pattern with good mixing and a prevention of carbon buildup. The centerbody with its dome cap permits control of the temperature profile across the turbine buckets with no penalty in performance because of the return of the air to the cycle and, in addition, provides uniform temperature at the turbine inlet as well as good mixing and lower required penetration of the cool liner air with the hot core of gas.

While I have hereinbefore described a preferred form of my invention, obviously many modifications and variations of the present invention are possible in the light of the above teachings. It is therefore to be understood

that within the scope of the appended claims, the invention may be practiced otherwise than as specifically described.

I claim:

1. A reverse flow combustion system adapted for use at the downstream end of a gas turbine engine adjacent the turbine, said system comprising:
a pair of concentric shells defining an annular air passage around the turbine,
an outer combination conical-cylindrical closed casing secured to the outer shell,
an inner concentric combination conical-cylindrical and open-ended perforated liner secured to the inner shell,
said casing and liner being symmetrically spaced to continue said annular air passage downstream,
a double conical dome member closing the open end of said liner including an inner cone and a continuing outer cone opening away from said inner cone,
a series of substantially radial louvers around said inner cone,
a second series of louvers in said outer cone oriented off radial to provide a component of flow radially inward of said liner,
a fuel injector through said dome member,
a hollow conical centerbody,
hollow turbine nozzles connecting said centerbody and inner shell to support said centerbody spaced centrally of said liner and to conduct air to said centerbody,
aperture means in the cone of the centerbody,
and a dome cap supported on and spaced from said centerbody over said aperture to provide an annular air metering duct to direct air forward along the centerbody surface.

2. Apparatus as described in claim 1 wherein the inner liner perforations extend from said open end to substantially the upstream end of said dome cap.

3. Apparatus as decribed in claim 1 wherein ignition means is disposed through said dome member outer cone between the louvers of said second series.

4. Apparatus as described in claim 1 wherein the area of said aperture is at least equal to the area of said annular air metering duct and said dome cap overlaps said centerbody to guide air flow along the outer surface thereof.

5. Apparatus as described in claim 1 wherein said inner conical-cylindrical liner consists of a plurality of nested sections spaced from one another by ribbon strips defining air conduits connecting said annular air passage with the interior of said liner.

6. A reverse flow combustion system adapted for use at the downstream end of a gas turbine engine adjacent the turbine, said system being symmetrical about the engine center line and comprising,
a pair of spaced concentric generally conical members with their cones directed aft including,
a first outer combination conical-cylindrical closed casing secured to the outer shell,
a second inner open-ended combination conical-cylindrical perforated liner connected to said inner shell,
said casing and liner being symmetrically spaced to continue said annular air passage downstream,
a third inner hollow centerbody having an aperture in its cone,
hollow nozzles connected to the inner shell and to said centerbody to support said centerbody spaced from and extending into the conical part of said inner liner and to conduct air to said centerbody,
a double conical dome member closing the open end of said inner liner in the cylindrical part thereof,
said dome member including an inner cone and a continuing outer cone opening away from said inner cone,

a series of substantially radial louvers around said inner cone,
a second series of louvers in said outer cone oriented off radial to provide components of flow tangentially and radially inward of said liner for spiral flow therein away from said liner walls,
a fuel injector through said dome member adapted to spray fuel in a pattern within said inner cone,
and a dome cap supported on and spaced from said centerbody over said aperture to provide an annular air metering duct to direct air forward along the centerbody surface.

7. Apparatus as described in claim 6 wherein the inner liner perforations extend with increasing area from said open end to substantially the upstream end of said dome cap.

8. Apparatus as described in claim 6 wherein ignition means is disposed through said dome member outer cone between the louvers of said second series.

9. Apparatus as described in claim 6 wherein the area of said aperture is at least equal to the area of said annular air metering duct and said dome cap overlaps said centerbody to guide air flow along the outer surface thereof.

10. Apparatus as described in claim 6 wherein said inner conical-cylindrical liner consists of a plurality of nested sections spaced from one another by ribbon strips defining air conduits connecting said annular air passage with the interior of said liner.

11. A combustor including an outer combination conical-cylindrical casing closed at one end,
an inner concentric combination conical-cylindrical and open-ended perforated liner,
said casing and liner being spaced apart to provide an annular air passage therebetween.
a double conical dome member closing an open end of said liner at said one end,
said dome member including an inner cone nad a continuing outer cone opening away from said inner cone,
a series of substantially radial louvers around said inner cone,
a second series of louvers in said outer cone oriented off radial,
and a fuel injector through said dome member,
whereby some air enters said liner through the radial louvers in said dome member for atomizing fuel and some air enters said liner from said off radial louvers in a tangential and radially inward direction to create swirl and keep fuel off the liner wall.

12. A combustor including an outer combination conical-cylindrical casing closed at one end,
an inner concentric combination conical-cylindrical and open-ended perforated liner,
said casing and liner being spaced apart and symmetrical to provide an annular air passage therebetween reducing in cross-sectional area in the conical part and substantially constant in the cylindrical part,
a double conical dome member closing an open end of said liner in the cylindrical part at said one end,
said dome member including an inner cone and a continuing outer cone opening away from said inner cone,
a series of substantially radial louvers around said inner cone,
a second series of louvers in said outer cone oriented off radial to provide components of flow tangentially and radially inward of said liner for spiral flow therein away from said liner walls,
a fuel injector through said dome member centrally thereof to spray a cone of fuel therein,
said inner and outer cones containing said fuel spray without impingement thereon.

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