Aug. 27, 1968 R. S. HALL ETAL 3,398,538

COMBUSTION APPARATUS

Filed Aug. 14, 1959 3 Sheets-Sheet 1

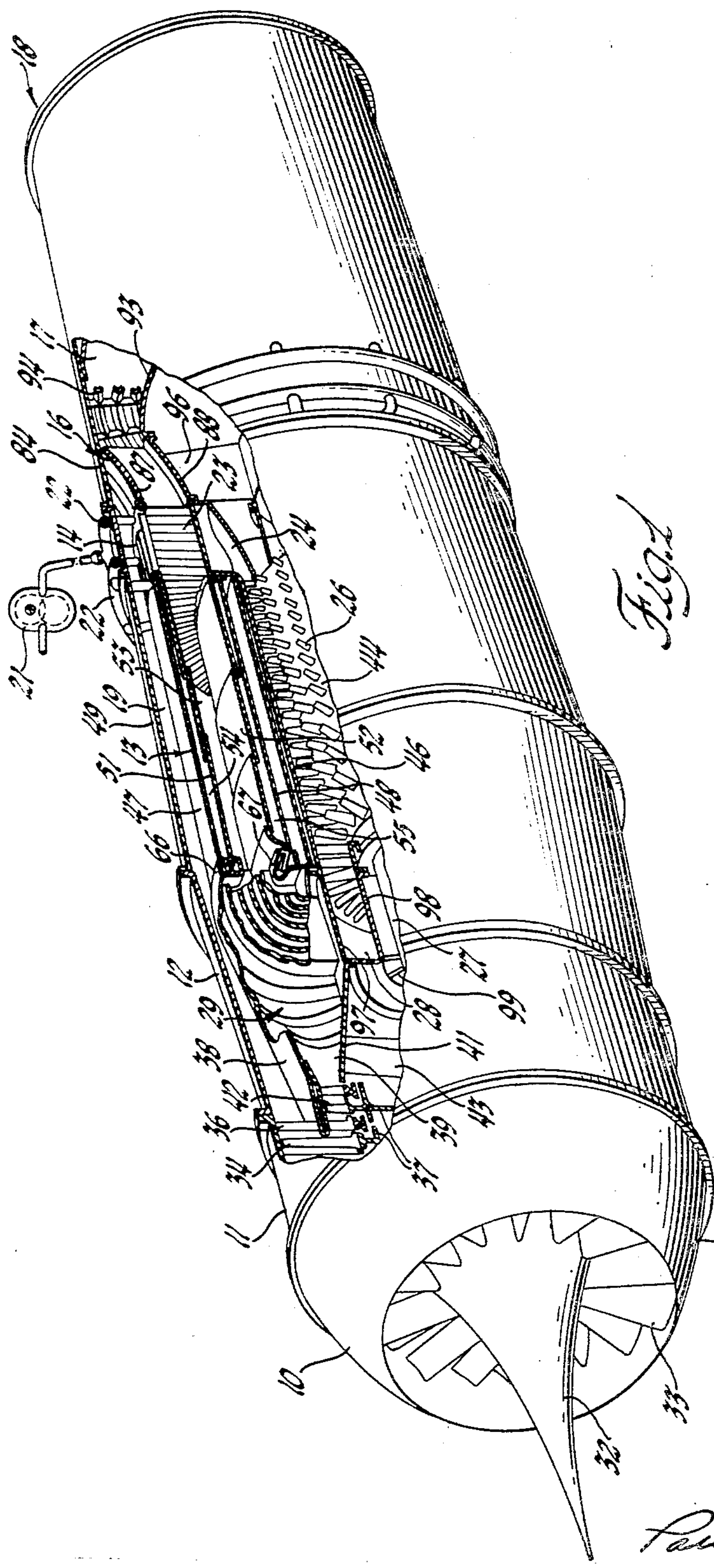

Fig. 1

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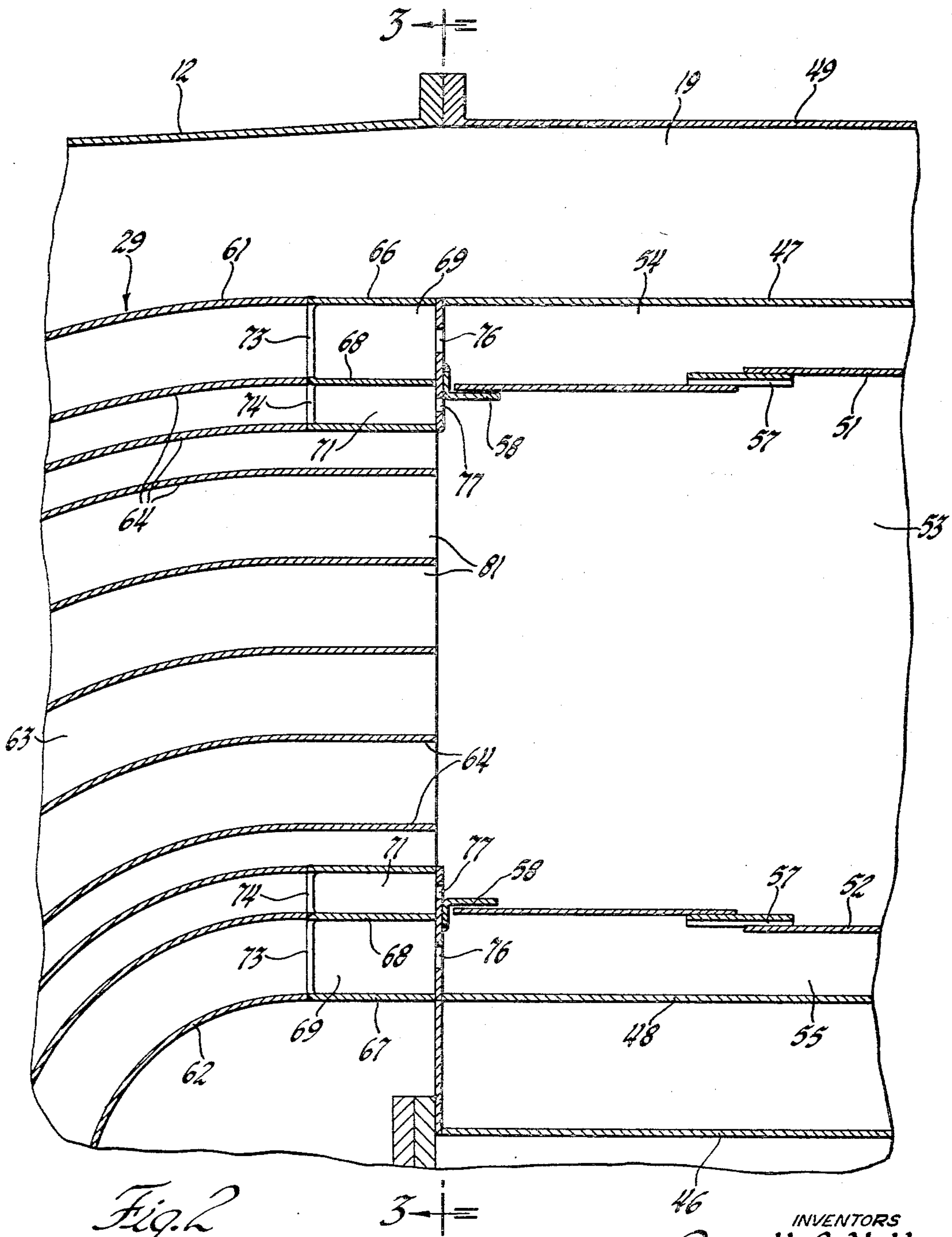

Fig. 2

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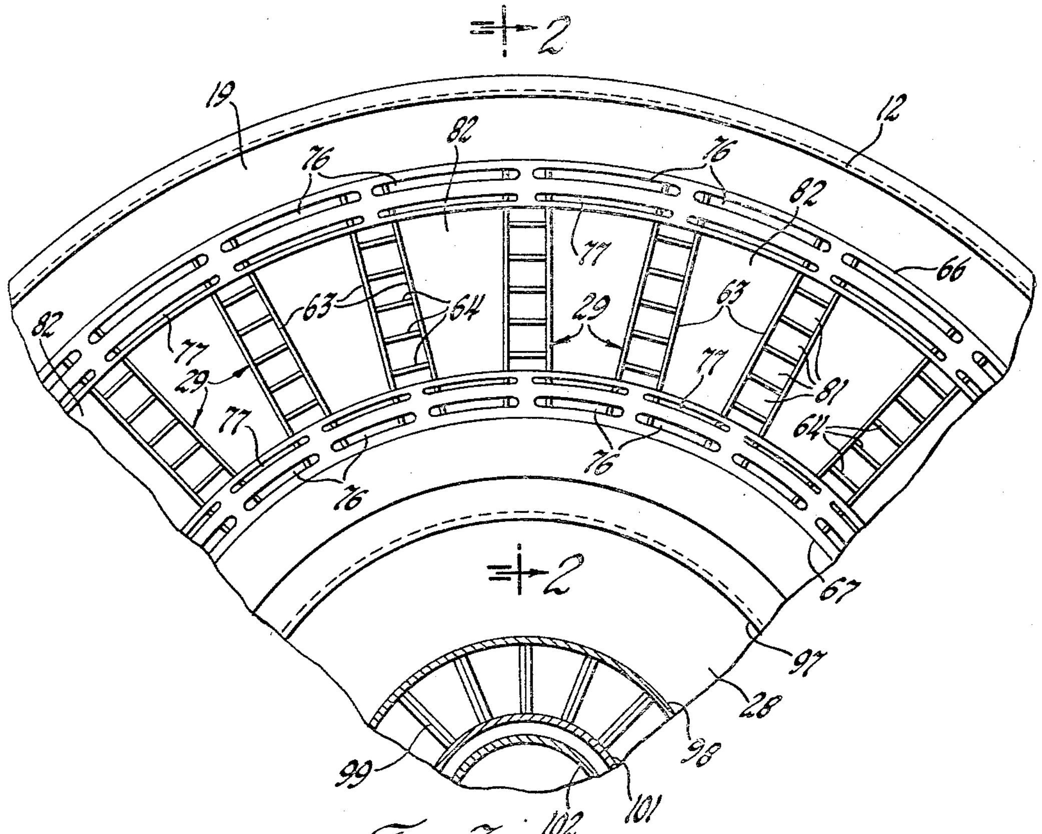

Fig. 3

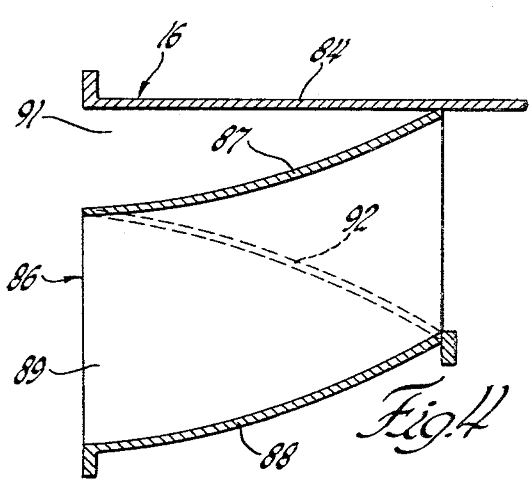

Fig. 4

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United States Patent Office

3,398,538

Patented Aug. 27, 1968

3,398,538

COMBUSTION APPARATUS

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Filed Aug. 14, 1959, Ser. No. 833,884
7 Claims. (Cl. 60—267)

Our invention relates to combustion apparatus particularly suited for the use of vaporizable fuels, which may be used in various environments. The apparatus is particularly suited to fuels which are gases or vapors under normal atmospheric conditions, but which are stored in liquid form before use. Certain portions of the system are well suited to gaseous fuels which need not be vaporized. The preferred embodiment of the invention is illustrated and described herein in an application to a jet propulsion engine.

The combustion apparatus of the invention is adapted to vaporize a liquid fuel, utilizing the expanding vapor to drive a turbine which powers an air compressor. The vaporized fuel discharged from the turbine is mixed with air supplied by the compressor, and combustion is effected in a combustion apparatus which operates on a fuel-rich basis so that it discharges a hot mixture of fuel and combustion products. This mixture flows through a heat exchanger to vaporize the fuel entering the turbine and thus provide the vapor which drives the turbine. A part of the air delivered by the compressor bypasses the combustion apparatus and is mixed with and burns the fuel of the fuel-rich mixture discharged from the heat exchanger. The resulting hot combustion products may be used for various purposes and, as illustrated, are employed to provide a propulsive jet. It will be understood that the foregoing is merely a very general introduction to the nature of the invention, which will be made clear by the succeeding detailed description.

The principal objects of the invention are to provide an improved combustion apparatus particularly suited to gaseous or vaporizable fuels; to provide a combustion system adapted to provide a jet of hot combustion products but which does not require a high temperature turbine; to provide combustion apparatus particularly suited to fuel-rich combustion; to provide a compact, efficient combustion system; and to provide novel and particularly effective combustion apparatus for such a system.

The preferred embodiment of the invention is illustrated in the accompanying drawings, of which FIGURE 1 is an axonometric view of a vapor cycle jet engine with parts cut away and in section.

FIGURE 2 is a partial sectional view of the inlet end of the combustion apparatus taken on a plane containing the axis of the engine as indicated by the line 2—2 in FIGURE 3.

FIGURE 3 is a partial transverse sectional view of the inlet end of the combustion apparatus taken on the plane indicated by the line 3—3 in FIGURE 2.

FIGURE 4 is a fragmentary sectional view of a mixer taken on a plane containing the axis of the engine.

Referring first to FIGURE 1 for a general description of the organization of the combustion apparatus and the jet engine in which it is included, the engine includes from front to rear an inlet section **10**, a compressor **11**, a diffuser or transition section **12**, combustion apparatus **13**, a heat exchanger **14**, a mixer **16**, secondary combustion apparatus **17**, and an exhaust duct **18** within which may be mounted a variable jet nozzle (not illustrated). Part of the air discharged by the compressor flows through the combustion apparatus **13** and part flows through a bypass duct **19** around the combustion apparatus to the mixer **16** and combustion apparatus **17**. Liquid vaporizable fuel is supplied to the engine by any suitable means adapted to control the flow, indicated schematically as a pump **21**, and through annular fuel manifolds **22** which conduct it to numerous radial heat exchange tubes **23** extending from the outer to the inner boundary of the heat exchanger **14**. Fuel is heated and vaporized in the heat exchanger, and the vaporized fuel flows through a turbine entrance annulus or nozzle box **24** inside the heat exchanger into an axial-flow turbine **26**. The turbine **26** is driven by the expansion of the vapor and drives the compressor **11** through a shaft **102** (FIG. 3) mounted in a housing **27**. The turbine exhausts into a plenum chamber **28** within the diffuser section **12** and the fuel is conducted from the plenum chamber to the inlet of the combustion apparatus **13** by a number of circumferentially spaced recurved fuel ducts **29**.

The inlet section **10** of the compressor comprises an outer wall **31**, an inlet spike **32**, and inlet vanes **33** mounting the spike. The compressor **11** comprises a main compressor having a number of stages of rotary blading **34** and stationary blading **36**, the rotary blading being mounted on a rotor structure **37**. The outlet of the compressor is divided between two annular ducts, an outer or bypass duct **19** previously referred to, the forward portion of which is defined by the outer wall or case of the diffuser, and a conical intermediate wall **38**. An inner diverging diffusing duct **39** is defined between the wall **38** and an inner wall **41**. An additional compressor stage **42** operates in the duct **39**. Struts **43** extending from the inner walls support the compressor-turbine shaft arrangement.

The turbine **26** comprises a rotor **44** on which are mounted a number of rows of blades and a case **46** mounting a number of rows of stator blades. The case **46** is double-walled. The combustion apparatus **13** is bounded by a cylindrical outer wall or case **47** and a cylindrical inner wall **48** mounted around the turbine case. The portion of the bypass duct to the rear of the diffuser section **12** is defined between an outer engine case **49** and the outer combustion apparatus case **47**.

The combustion apparatus also comprises an annular outer shroud **51** and an annular inner shroud **52** which define between them a combustion space **53**. An annular fuel passage **54** (see also FIG. 2) is defined between the wall **47** and shroud **51** and a second annular fuel passage **55** is defined between the wall **48** and shroud **52**. The shrouds **51** and **52** may be composed of a number of annular sections connected by corrugated or zig-zag strips **57** welded to the adjacent ends of adjacent sections. This is known combustion liner structure. The shrouds **51** and **52** diverge from each other toward the outlet or discharge end of the combustion chamber, and the passages **54** and **55** correspondingly converge in this direction. The forward ends of the shrouds may be supported and located by circumferentially spaced brackets or clips **58** fixed to structure at the forward end of the combustion apparatus, and the rear ends may be suitably supported by means not illustrated.

Means are provided at the inlet end of the combustion apparatus within the intermediate wall **38** to conduct the vaporized fuel from the turbine exhaust chamber **28** and air from the diffuser **39** into the combustion apparatus. As previously stated, a number of circumferentially spaced recurved fuel ducts **29** are provided to conduct the fuel. Referring particularly to FIGS. 2 and 3, each of these ducts **29** is of rectangular or box section and curves from a radial direction at its connection to the plenum chamber to an axial direction at its outlet. Each duct **29** comprises a radially outer wall **61**, an inner wall **62**, and side walls **63**. A considerable number of substantially 90° arc turning vanes **64** are provided, extending from one side wall **63** to the other, to promote smooth flow of the fuel and prevent improper distribution at the outlet of the fuel duct. The discharge ends of the ducts **29** are interconnected by two annular fuel manifold structures **66** and **67**, the former being at the outer edge and the latter at the inner edge of the duct. As will be more apparent from FIGURE 2, each of these manifolds is of box section and is divided by a ring **68** into two portions, an outer fuel manifold **69** aligned with the passage **54** or **55** and an inner fuel manifold **71**, the wall **68** of which is substantially coincident with the adjoining shroud **51** or **52**. Openings **73** and **74** in the forward walls of these manifolds permit entrance of fuel from the ducts **29**. The forward wall is closed where it crosses the spaces between the ducts **29**.

Elongated discharge slots **76** which form almost a complete annular opening discharge fuel into the passages **54** and **55**. Similar elongated fuel discharge slots **77**, which are of smaller width and, therefore, area, discharge fuel into the combustion space **53** immediately adjacent the shrouds **51** and **52** to provide a fuel flow or cooling film along the inside surfaces of the walls. Since the fuel after expansion through the turbine is cooler than the compressed air (which may be heated by ram compression as well as by the compressor **11, 42**), the circulation of fuel along both sides of the shrouds **51** and **52** provides considerable cooling of the shrouds and minimizes damage to the shrouds from overheating. As will be apparent, the clips **58** are welded to the rear walls of the manifold structures **66** and **67**.

The greater part of the fuel delivered by the ducts **29** is discharged from the open ends of the ducts through the areas indicated as **81**, thus providing a number of axially directed fuel streams extending from one shroud to the other. As illustrated, there are twenty-four of the ducts **29** and, therefore, twenty-four openings **82** between the ducts through which air flows from the diffuser **39** into the inlet end of the combustion space. There are thus a number of cores of air surrounded by fuel entering through entrances **77** and **81**.

Preferably, the fuel and air are introduced at different velocities so that the parallel streams of fuel and air mix thoroughly because of the different velocities and rapid efficient combustion is effected. With hydrogen, which is a preferred fuel, the velocity of the fuel may be about three times that of the air. The pressures of the two fuels are of the same order of magnitude and the Mach number of flow is about the same. It should be remembered that the combustion apparatus operates on a fuel-rich basis; that is, with an excess of fuel over the stoichiometric ratio. The fuel is used to blanket and cool the shrouds bounding the combustion space. Fuel from the passages **54** and **55** enters the combustion space **53** at each of the annular film cooling gaps defined by the corrugated strips **57**. The gas discharged from the combustion apparatus is a hot mixture of fuel and combustion products, the combustion products being the products of combustion of the fuel plus the non-combustible gases in the air; the oxygen will be substantially entirely consumed. This combustible mixture flows rearwardly between and around the radial tubes **23** of the heat exchanger **14**, vaporizing the fuel and then flows into the mixer **16** mounted within the wall **84** of the exhaust duct portion of the engine.

The mixer provides a structure for mixing the combustible mixture with the compressed air supplied through the bypass duct **19** similar in structure and principle to mixing arrangement for the fuel and air in the inlet end of the combustion apparatus. As indicated most clearly in FIGURE 4, the mixer is defined by a relatively large number of box section ducts **86** for the mixture which are spaced circumferentially from each other and are bounded by outer walls **87** and inner walls **88**. The inner wall **88** is preferably annular, but the outer wall 87 is a separate wall for each duct **86** extending from one side wall **89** to the other side wall of the mixture duct. Ducts **91** for the bypass air are bounded by the wall **84** and by inwardly converging walls **92** bridging the gaps between the ducts **86**. The combustible mixture and air are discharged in generally parallel interleaved jets into the entrance portion of the secondary combustion apparatus defined between the wall **84** and a tailcone **93** which closes the forward end of the combustion apparatus. A flameholder **94** comprising the usual V-shaped gutters is mounted in the upstream end of the combustion apparatus **17** to anchor the flame.

Suitable ignition means for the combustion apparatuses **13** and **17** (not illustrated) may be provided. Struts **96** extending inwardly from the mixer **16** provide a support for the rear end of the turbine rotor **26**. Referring to FIGURE 3, the turbine exhaust plenum chamber **28** is bounded by an outer wall **97** from which the fuel ducts **29** extend and by an inner wall **98**. Struts **99** support a shaft housing **101** within the plenum chamber through which the shaft **102** connecting the turbine to the compressor extends.

The operation of the engine will presumably be clear to those skilled in the art from the foregoing, but may be reviewed briefly. To start the engine gaseous fuel may be supplied from a source of such fuel under pressure. The expanding gaseous fuel drives the turbine **26** and flows into the combustion apparatus **13**. Operation of the turbine drives the compressor **11** to force air into the combustion apparatus. A suitable igniter initiates combustion and the hot combustion products flow rearwardly. As soon as the heat exchanger **14** is heated, liquid fuel may be supplied by suitable means. The operation of the engine remains essentially the same, except for the added feature of vaporization of the fuel. In normal operation, the fuel is in excess relative to the air in combustion apparatus **13** and the unburned fuel is consumed in the combustion apparatus **17** by the air supplied through the bypass duct **19**. If the combustion apparatus is embodied in a jet engine as shown, the resulting hot combustion products may form a propulsive jet. In this case, a variable propulsive jet nozzle (not illustrated) may be provided, as is customary.

It will be understood that the rotating machinery such as the turbine and compressor and shafting connecting them have not been described in detail since these may follow standard practice, and the details of structure of these are not material to the invention.

It will be apparent that the combustion apparatus described and illustrated is suitable for use with gaseous fuel which is supplied to the apparatus is the gaseous state, in which case the heat exchanger for vaporizing the fuel may be omitted. Also, the combustion apparatus **13** may be used independently of the presence or absence of a second combustion apparatus **17**.

While the organization of the combustion apparatus including the turbine and compressor is believed to be a significant part of the invention, it will also be realized that the part of the apparatus in which combustion takes place may be used with means for supplying the fuel and air other than those illustrated and such supplying means may be physically remote from the combustion apparatus itself. However, the compact concentric arrangement shown in FIGURE 1 is particularly suited to certain purposes.

Reference to gaseous fuel in the succeeding claims is intended to include both gases and vapors, as distinguished from liquid or solid fuels.

The adavntages of the invention in providing a compact, efficient combustion apparatus or combustion system will be clear to those skilled in the art. The invention provides a compact machine for handling gaseous fuels and provides combustion apparatus for such fuels which is of small dimensions relative to the energy release rate, and which is adequately cooled by the fuel to promote reliability and endurance.

The detailed description of the preferred embodiment of the invention to explain the principles thereof is not to be considered as limiting or restricting the invention, as many modifications may be made within the scope of the invention by the exercise of skill in the art.

We claim:

1. A combustion system for vaporizable fuel comprising, in combination, means for supplying liquid fuel, an annular heat exchanger for vaporizing the fuel, a turbine supplied with vaporized fuel by the heat exchanger and driven thereby, an annular axial-flow combustion apparatus including outer and inner annular walls disposed around the turbine, mutually circumferentially spaced recurved fuel ducts connecting the outlet of the turbine to one end of the combustion apparatus, the heat exchanger being disposed at the other end of the combustion apparatus for flow of mixed fuel and combustion products therethrough, an air compressor driven by the turbine, a duct connecting the outlet of the compressor to the combustion apparatus enclosing the said fuel ducts and supplying air to the combustion apparatus through the spaces between the ducts, outer and inner annular shrouds within the combustion apparatus defining a combustion space and defining annular fuel passages between the shrouds and the walls, and two annular fuel manifolds connecting the said ducts with the said annular fuel passages.

2. A combustion system for vaporizable fuel comprising, in combination, means for supplying liquid fuel, an annular heat exchanger for vaporizing the fuel, an annular axial-flow combustion apparatus including outer and inner annular walls, means including mutually circumferentially spaced recurved fuel ducts connecting the outlet of the heat exchanger to one end of the combustion apparatus, the heat exchanger being disposed at the other end of the combustion apparatus for flow of mixed fuel and combustion products therethrough, an air supply means, a duct connecting the air supply to the combustion apparatus enclosing the said fuel ducts and supplying air to the combustion apparatus through the spaces between the ducts in less than stoichiometric ratio to the said fuel, outer and inner annular shrouds within the combustion apparatus defining a combustion space and defining annular fuel passages between the shrouds and the walls, two annular fuel manifolds connecting the said ducts with the said passages, an annular bypass duct supplied by the air supply means surrounding and bypassing the combustion apparatus, a mixing device interconnecting the bypass duct and the outlet of the heat exchanger to mix the air with the mixture of fuel and combustion products flowing from the combustion apparatus through the heat exchanger, and combustion means downstream of the mixing device for burning the fuel in the bypassed air.

3. A combustion system for vaporizable fuel comprising, in combination, means for supplying liquid fuel, an annular heat exchanger for vaporizing the fuel, a turbine supplied with vaporized fuel by the heat exchanger and driven thereby, an annular axial-flow combustion apparatus including outer and inner annular walls disposed around the turbine, mutually circumferentially spaced recurved fuel ducts connecting the outlet of the turbine to one end of the combustion apparatus, the heat exchanger being disposed at the other end of the combustion apparatus for flow of mixed fuel and combustion products therethrough, an air compressor driven by the turbine, a duct connecting the outlet of the compressor to the combustion apparatus enclosing the said fuel ducts and supplying air to the combustion apparatus through the spaces between the ducts in less than stoichiometric ratio to the said fuel, outer and inner annular shrouds within the combustion apparatus defining a combustion space and defining annular fuel passages between the shrouds and the walls, two annular fuel manifolds connecting the said ducts with the said passages, an annular bypass duct supplied by the compressor surrounding and bypassing the combustion apparatus, a mixing device interconnecting the bypass duct and the outlet of the heat exchanger to mix the air with the mixture of fuel and combustion products flowing from the combustion apparatus through the heat exchanger, and combustion means downstream of the mixing device for burning the fuel in the bypassed air.

4. A combustion system for vaporizable fuel comprising, in combination, means for supplying liquid fuel, an annular heat exchanger for vaporizing the fuel, a turbine supplied with vaporized fuel by the heat exchanger and driven thereby, an annular axial-flow combustion apparatus including outer and inner annular walls disposed around the turbine, mutually circumferentially spaced recurved fuel ducts connecting the outlet of the turbine to one end of the combustion apparatus, the heat exchanger being disposed at the other end of the combustion apparatus for flow of mixed fuel and combustion products therethrough, an air compressor driven by the turbine, a duct connecting the outlet of the compressor to the combustion apparatus enclosing the said fuel ducts and supplying air to the combustion apparatus through the spaces between the ducts in less than stoichiometric ratio to the said fuel, outer and inner annular shrouds within the combustion apparatus defining a combustion space open to the fuel ducts for supply of fuel thereto and defining annular fuel passages between the shrouds and the walls, two annular fuel manifolds connecting the said ducts with the said passages and discharging a layer of fuel over the inside surfaces of the shrouds, an annular bypass duct supplied by the compressor surrounding and bypassing the combustion apparatus, a mixing device interconnecting the bypass duct and the outlet of the heat exchanger to mix the air with the mixture of fuel and combustion products flowing from the combustion apparatus through the heat exchanger, and combustion means downstream of the mixing device for burning the fuel in the bypassed air.

5. A combustion apparatus for gaseous fuel comprising, in combination, outer and inner annular walls defining an annular combustion chamber, mutually circumferentially spaced fuel ducts supplying the fuel to the inlet end of the combustion chamber, a first air duct enclosing the said fuel ducts and supplying air to the combustion chamber through the spaces between the ducts, outer and inner annular shrouds within the combustion chamber defining a combustion space and defining annular fuel passages between the shrouds and the walls, and two annular fuel manifolds connecting the said ducts with the said annular fuel passages, the fuel ducts having circumferentially spaced fuel outlets extending radially from one said manifold to the other and discharging into the combustion space.

6. A combustion apparatus for gaseous fuel comprising, in combination, outer and inner annular walls defining an annular combustion chamber, mutually circumferentially spaced fuel ducts supplying the fuel to the inlet end of the combustion chamber, a first air duct enclosing the said fuel ducts and supplying air to the combustion chamber through the spaces between the ducts, outer and inner annular shrouds within the combustion chamber defining a combustion space and defining annular fuel passages between the shrouds and the walls, and two annular fuel manifolds connecting the said ducts with the said passages and discharging a layer of fuel over the inside surfaces of the shrouds, the fuel ducts having circumferentially spaced fuel outlets extending radially from one said manifold to the other and discharging into the combustion space.

7. A combustion apparatus for gaseous fuel comprising, in combination, outer and inner annular walls defining an annular combustion chamber, mutually circumferentially spaced fuel ducts supplying the fuel to the inlet end of the combustion chamber, a first air duct enclosing the said fuel ducts and supplying air to the combustion chamber through the spaces between the ducts in less than stoichiometric ratio to the said fuel, outer and inner annular shrouds within the combustion chamber defining a combustion space and defining annular fuel passages

between the shrouds and the walls, two annular fuel manifolds connecting the said ducts with the said passages and discharging a layer of fuel over the inside surfaces of the shrouds, the fuel ducts having circumferentially spaced fuel outlets extending radially from one said manifold to the other and discharging into the combustion space, a second air duct, a mixing device interconnecting the second air duct and the outlet of the combustion chamber to mix the air with the mixture of fuel and combustion products flowing from the combustion chamber, and combustion means downstream of the mixing device for burning the fuel in the air supplied through the second air duct.

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