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COMBUSTION APPARATUS FOR A GAS TURBINE ENGINE

Abstract

An aircraft including first and second like gas turbine engines having like combustion apparatus each of which includes a respective plurality of fuel injectors arranged in an annular array and having a first and second sets of fuel-emitting apertures arranged to emit fuel normally to the plane of the array and in a direction having a component in the plane of the array directed towards an adjacent fuel injector. The aircraft further includes a fuel system which for any given engine increases the proportion of the total fuel flow rate to that engine which is provided to the second set of apertures during lighting or re-lighting of that engine's combustion apparatus, or upon detection of aircraft manoeuvring likely to increase the risk of flame-out. The aircraft provides faster and more reliable lighting and re-lighting, and additional resistance to flame-out, especially for use of hydrogen fuel.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application is based upon and claims the benefit of priority from United Kingdom of Great Britain & Northern Ireland patent application GB 2402326.9, filed on Feb. 19, 2024, the entire contents of which are hereby incorporated by reference.

BACKGROUND OF THE INVENTION

Field of the Invention

[0002] The invention relates to aircraft comprising gas turbine engines, for example turbofan or turboprop engines.

Description of Related Art

[0003] Flameout-out of a gas turbine engine may have one of several possible causes, for example fuel starvation or compressor stall or, specifically in the case of an aero engine, excessive altitude, severe precipitation or foreign object damage. In the case of an aero engine, flame-out is more likely during certain aircraft manoeuvres, and efficient and reliable re-lighting is of key importance. However, lighting and relighting can be difficult and unreliable, especially for certain types of fuel, such as gaseous hydrogen. For aero engines in particular, resistance to flame-out and the ability to rapidly light, and re-light after a flame-out incident, are important objectives in the design of combustion apparatus.

BRIEF SUMMARY OF THE INVENTION

[0004] According to an example, an aircraft comprises an engine system, the engine system comprising [0005] (a) a gas turbine engine including combustion apparatus having a plurality of fuel injectors arranged in an annular array, any given fuel injector having a fuel-emitting face having a first set of fuel-emitting apertures arranged to emit fuel in a direction normal to the plane of the annular array and a second set of fuel-emitting apertures arranged to emit fuel in a direction having a component in the plane of the array directed towards the fuel-emitting face of an adjacent fuel injector, all such components having the same sense with respect to the array; and [0006] (b) a fuel system arranged to provide fuel to the first and second sets of fuel-emitting apertures of each fuel injector of the combustion apparatus of the gas turbine engine at a total fuel flow rate or total chemical energy flow rate;

wherein the fuel system further comprises a controller arranged to receive one or more signals indicative of one or more of [0007] (i) starting of the gas turbine engine; [0008] (ii) flame-out of the combustion apparatus; and [0009] (iii) manoeuvring of the aircraft associated with a risk of flame-out of the combustion apparatus, or preparation for such manoeuvring;

and in response to increase either [0010] (a) the proportion of the total fuel flow rate or total chemical energy flow rate which is provided to the second sets of fuel-emitting apertures; or [0011] (b) the fuel flow rate or chemical energy flow rate provided to the second sets of fuel-emitting apertures.

[0012] The second set of fuel-emitting apertures of any given fuel injector may be disposed at an azimuthal edge of the fuel-emitting face of the fuel injector, the azimuthal edge being that azimuthal edge of the fuel-emitting face nearest the adjacent fuel injector. The second set of fuel-emitting apertures may be distributed radially with respect to the array.

[0013] The second set of fuel-emitting apertures of any given fuel injector may comprise at least two fuel-emitting apertures and be arranged to emit fuel in first and second directions each having a respective component in the plane of the array directed towards the fuel-emitting face of a respective adjacent fuel injector. The second set of fuel-emitting apertures may comprise first and second subsets of fuel-emitting apertures, each subset being disposed at a respective azimuthal edge of the fuel-emitting face of the fuel injector. Each subset of the second set of fuel-emitting apertures may comprise at least two fuel-emitting apertures distributed radially with respect to the array. The first set of fuel-emitting apertures may comprise a subset of fuel-emitting apertures which comprises [0014] (a) a plurality of parallel linear arrays of apertures; or [0015] (b) a plurality of linear arrays of apertures, each linear array lying on a respective diameter of a circular area of the fuel-emitting face of the fuel injector; or [0016] (c) an annular aperture or a plurality of concentric annular apertures.
[0017] The fuel system may be arranged to provide a first fuel to the first set of fuel-emitting apertures of each fuel injector and a second fuel to the second set of fuel-emitting apertures of each fuel injector. The controller may be arranged to control at least one of [0018] (a) the proportion of the total fuel flow rate or total chemical energy flow rate to the gas turbine engine which is provided to the second sets of fuel-emitting apertures of the combustion apparatus of the gas turbine engine; and [0019] (b) the fuel flow rate or chemical energy flow rate provided to the second sets of fuel-emitting apertures of the combustion apparatus of the gas turbine engine, [0020] in order to increase or maximise the range of the aircraft or to mitigate climate forcing produced by products of fuel combustion and/or contrails of the aircraft.

Description

BRIEF DESCRIPTION OF SEVERAL VIEWS OF THE DRAWINGS
[0021] Examples are described below with reference to the accompanying drawings in which:
[0022] FIGS. **1**, **3** & **5** show first to third example combustion apparatus respectively;
[0023] FIGS. **2**, **4** & **6** each show part of a respective fuel-injector comprised in the combustion apparatus of FIGS. **1**, **3** & **5** respectively;
[0024] FIGS. **7-9** show alternative arrangements of fuel-emitting nozzles which may be employed in the fuel-injector of FIG. **6**;
[0025] FIG. **10** shows an example engine system; and
[0026] FIG. **11** shows an example aircraft comprising the FIG. **10** engine system.
DETAILED DESCRIPTION
[0027] Referring to FIGS. **1** and **2**, a first example combustion apparatus **100** comprises a set of 16 like fuel-injectors **102** each having a respective fuel-emitting face **104**. The fuel-emitting faces **104** of the fuel-injectors **102** are arranged in an annular, circular array such that any given fuel-injector **102** has a fuel-emitting face **104** in the plane **199** of the circular array. The fuel-injectors **102** are each located inwardly and towards one end of a cylindrical outer casing **130** having a central longitudinal axis **196**, which also defines an axial direction with unit vector z. The fuel-emitting faces **104** of the fuel-injectors **102** each have the same orientation with respect to the axis **196**. Azimuthal and radial directions with respect to the axis **196** are indicated by unit vectors ϕ **197**, r **198** respectively.
[0028] The fuel-emitting face **104** of any given fuel-injector **102** has first **122** and second **124** azimuthal edges at respective azimuthal positions, first **126** and second **128** radial edges at respective radial positions and includes first **106** and second **108** sets of fuel-emitting apertures. The first set **106** of fuel-emitting apertures is made up of substantially parallel linear arrays of apertures, each of which is arranged to emit fuel in a direction normal to the plane **199** of the annular, circular array of fuel-injectors, i.e. parallel to the central longitudinal axis **196** of the outer

casing **130** in the direction z. The second set **108** of fuel-emitting apertures is a linear array of apertures disposed at the azimuthal edge **122** of the fuel-emitting face **104** and distributed radially with respect to the axis **196** between the first **126** and second **128** radial edges of the fuel-emitting face **104**. Each of the second set **108** of fuel-emitting apertures is arranged to emit fuel in a direction having a component **194**A in the plane **199** directed towards the fuel-emitting face of the adjacent fuel-injector nearest the azimuthal edge **122**. The components **194**A associated with all the fuel-injectors **102** have the same azimuthal sense, i.e. an anti-clockwise sense in FIG. **1** when viewed in the −z direction towards the fuel-emitting faces **104** of the fuel-injectors **102**, and in the direction ϕ. The direction (the fuel-emission direction) in which fuel is emitted by the second set **108** of fuel-emitting apertures of any given fuel-injector has in general components in the −r, ϕ and z directions. In variants of the apparatus **100**, the fuel-emission direction may have components only in the ϕ and z directions (i.e. no component directed towards the axis **196**) or only a component in the ϕ direction (i.e. no axial component and no component towards the axis **196**). In a variant of the combustion apparatus **100**, the second set **108** of fuel-emitting apertures of any given fuel-injector **102** is located at the azimuthal edge **124**, with the component **194** being in the direction −ϕ, i.e. towards the fuel-emitting face of the fuel-injector which is adjacent in the clockwise direction in FIG. **1** (when viewed in the −z direction).

[0029] Referring to FIGS. **3** and **4**, in which reference numerals differ by **100** from those labelling corresponding parts in FIGS. **1** and **2** respectively, a second example combustion apparatus **200** comprises **16** like fuel-injectors **204** arranged in an annular, circular array within a cylindrical outer casing **230**. Any given fuel-injector **202** has a fuel-emitting face **204** which includes first **206** and second **208** sets of fuel-emitting apertures. The second set **208** consists of first **208**A and second **208**B subsets of apertures each located at a respective azimuthal edge **222**, **224** of the fuel-emitting face **204**, the individual fuel emitting apertures of the subsets **208**A, B being distributed radially between radial edges **226**, **228** of the fuel-emitting face **204**. Each subset **208**A, B of apertures is arranged to emit fuel in a respective direction having a component in the direction of the fuel-emitting face of the adjacent fuel-injector located nearest the azimuthal edge **222**, **224** at which the subset **208**A, B is located. Thus, subset **208**A of apertures is arranged to emit fuel in a direction having a component **294**A in the direction ϕ and subset **208**B of apertures is arranged to emit fuel in a direction having a component **294**B in the direction −ϕ. In variants of the combustion apparatus **20**, the respective directions of fuel-emission from apertures of the subset **208**A, B may each have components in either or both of the −r and z directions in addition to a component in the ϕ or −ϕ direction. Fuel is transported within the combustion apparatus **200** in both clockwise and anti-clockwise directions −ϕ, ϕ thus providing additional resistance to flame-out and faster re-lighting compared to the combustion apparatus **100** of FIG. **1**.

[0030] Referring to FIGS. **5** to **9** in which reference numerals differ by **200** from those labelling corresponding parts in FIGS. **1** and **2**, a third example combustion apparatus **300** comprises a circular array of **16** like fuel-injectors **302** arranged within a cylindrical outer casing **330**. Any given fuel-injector **302** has a fuel-emitting face **304** having first **306** and second **308** sets of fuel-emitting apertures. The second set **308** of apertures consists of two subsets of apertures **308**A, **308**B located at respective azimuthal edges **322**, **324** of the fuel-emitting face **304**. The apertures of each subset **308**A, **308**B are arranged to emit fuel in respective fuel-emission directions having components **394**A, **394**B in the plane **399** of the circular array respectively, i.e. in the ϕ, −ϕ directions respectively. In variants of the combustion apparatus **300** the fuel emission directions associated with the subsets **308**A, **308**B may each have components in the z direction, or in both the −r and z directions, in addition to a component in the ϕ and −ϕ directions. Apertures of the first set **306** of fuel-emitting apertures are arranged to emit fuel in the z direction only, i.e. normal to the plane of the annular array of fuel-injectors **302** and along axis **396**, in the direction z. The first set **306** is made up of subsets **306**A, **306**B, **306**C of fuel-emitting apertures. Subsets **306**B and **306**C are each a linear array of apertures located at radial edges **328**, **326** respectively of fuel-emitting face **304**. Subset **306**A may comprise a series **306**A**1** of parallel linear arrays of apertures (FIG. **7**), a plurality **306**A**2** of linear arrays of apertures each lying on a respective diameter of a circular area of the fuel-emitting face **304** (FIG. **8**) or one or more annular apertures **306**A**3** (FIG. **9**), the annular apertures being concentric where there is more than one such aperture.

[0031] Any of the combustion apparatus **100**, **200**, **300** may be comprised in a gas turbine engine arranged to operate on any suitable fuel, for example kerosene, methane or hydrogen. The second sets **108**, **208**, **308** of fuel-emitting apertures each provide resistance to flame-out by providing transport of fuel between pairs of adjacent fuel-injectors **102**, **202**, **302**. In the event of flame-out, relighting is more reliable and occurs more rapidly than is the case in similar, known, combustion apparatus. The combustion apparatus **100**, **200**, **300** is particularly advantageous in the case of hydrogen fuel. Flame-out and unreliable relighting are particular problems when using hydrogen in similar combustion apparatus of the prior art, due to the negligible bulk swirl of hydrogen within such apparatus.

[0032] Referring to FIGS. **10** and **11**, an example aircraft **500** comprises an engine system **490**, the engine system **490** comprising a turbofan engines **401**, **451** having combustion apparatus **400**, **450** respectively. The combustion apparatus **400**, **450** are identical and are each the same as or similar to any of the combustion apparatus **100**, **200**, **300** of FIGS. **1**, **3** and **5** respectively. Fuel injectors (not shown) of the combustion apparatus **400** each have a respective first set of fuel-emitting apertures, designated collectively as **406**, and a respective second set of fuel-emitting apertures, designated collectively as **408**. Similarly, fuel injectors (not shown) of the combustion apparatus **450** each have a respective first set of fuel-emitting apertures, designated collectively as **456**, and a respective second set of fuel-emitting apertures, designated collectively as **458**.

[0033] The engine system **490** further includes a fuel system **476** which includes first and second fuel tanks **470**A, **470**B. The first fuel tank **470**A is arranged to provide fuel to the first sets **406**, **456** of fuel-emitting apertures of the combustion apparatus **400**, **450**. The second fuel tank **470**B is arranged to provide fuel to the second sets **408**, **458** of fuel-emitting apertures of the combustion apparatus **400**, **450**. In addition to the fuel tanks **470**A, **470**B, the fuel system **476** comprises a controller **474** and a balance-of-fuel-system **472**, the latter including one or more fuel pumps and other equipment necessary to provide fuel from the fuel tanks **470**A, **470**B to the sets of fuel-emitting apertures **406**, **408**, **456**, **458**.

[0034] If the first and second fuel tanks **470**A, **470**B contain the same type of fuel, they may be portions of a single fuel tank. If they contain different types of fuel, then they are discrete tanks. The controller **474** is arranged to receive a signal corresponding to a thrust demanded of the engine system, **490** and to provide a signal to the balance-of- fuel-system **472** such that fuel is provided from the fuel tanks **470**A, **470**B to the first sets **406**, **456** and second sets **408**, **458** of fuel-emitting apertures at a total flow rate sufficient to provide the demanded thrust. The controller **474** is also arranged to receive signals from one or more sensors (not shown) of the aircraft **500** indicative of one or more of [0035] (i) flame-out of either or both turbofan engines **401**, **451**; [0036] (ii) manoeuvring of the aircraft **500** associated with a risk of flame-out of the combustion apparatus **400**, **450**, or preparations for such manoeuvring; and [0037] (iii) starting of one or both of the turbofan engines **401**, **451**;

and in response provide a control signal to the balance-of fuel-system **472** such that either (a) the proportion of the total fuel flow rate or total chemical energy flow rate provided to one, or both, second sets **408**, **458** of apertures of one, or both, combustion apparatus **400**, **450** is increased or (b) the fuel flow rate or chemical energy flow rate provided to one or both second sets **408**, **458** of apertures is increased. Lighting and re-lighting of an engine **401**, **451** occurs more rapidly and with greater reliability than in the prior art, and the probability of a flame-out incident occurring during certain aircraft manoeuvres is reduced, especially in a case where hydrogen fuel is used. Also, the combustion apparatus **400**, **450** provides improved resistance to flame-out during certain aircraft manoeuvres. Engine starting, and relighting after a flame-out, may involve lighting or re-lighting a particular single engine, in which case the controller **474** is arranged to increase the proportion of the total fuel flow to the combustion apparatus of that particular single engine which is provided to the second set of fuel-emitting apertures of that particular single engine.

[0038] According to another example, the aircraft **500** is a so-called “dual-fuel” aircraft and different fuel types are applied the two first **406**, **456** sets and two second **408**, **458** sets of fuel-emitting apertures from the (separate) fuel tanks **470**A, **470**B respectively. According to operational and flight requirements for maximising aircraft range, or meeting other flight mission objectives, the controller **474** is arranged to vary the proportion x of the total fuel flow (or total chemical energy flow) to the combustion apparatus **400**, **450** which is provided to the two first sets **406**, **408** of fuel-emitting apertures between 0 and 1, with arbitrary precision, and the corresponding proportion 1-x which is provided to the two second sets **408**, **458** of apertures. An example of a flight mission objective is minimising climate forcing resulting from a flight mission caused by products of fuel combustion and/or formation of contrails.

SUMMARY OF REFERENCE NUMERALS USED IN THE ACCOMPANYING DRAWINGS

[0039] **100**, **200**, **300**, **400**, **450** combustion apparatus [0040] **102**, **202**, **302** fuel-injector [0041] **104**, **204**, **304** fuel-emitting face of fuel-injector [0042] **106**, **206**, **306**, **406**, **456** fuel-emitting apertures, first set [0043] **206**A & B, **306**A, B & C fuel-emitting apertures, subsets of first set [0044] **108**, **208**, **308**, **408**, **458** fuel-emitting apertures, second set [0045] **208**A & B, **308**A & B fuel-emitting apertures, subsets of second set [0046] **122**, **222**, **322** first azimuthal edge of fuel-emitting face of fuel-injector [0047] **124**, **224**, **324** second azimuthal edge of fuel-emitting face of fuel-injector [0048] **126**, **226**, **326** first radial edge of fuel-emitting face of fuel-injector [0049] **128**, **228**, **328** second radial edge of fuel-emitting face of fuel-injector [0050] **130**, **230**, **330** cylindrical outer casing [0051] **194**A, **294**A, **394**A component of fuel direction in ϕ direction [0052] **294**B, **394**B component of fuel direction in −ϕ direction [0053] **196**, **296**, **396** longitudinal axis of cylindrical casing, axial unit vector z [0054] **197**, **297**, **397** azimuthal unit vector ϕ [0055] **198**, **298**, **398** radial unit vector r [0056] **199**, **299**, **399** plane of annular array of fuel-injectors [0057] **306**A**1-3** fuel-emitting aperture(s), subset of first set [0058] **450**, **451** turbofan engine [0059] **470**A, **470**B fuel tank [0060] **472** balance of fuel system [0061] **474** controller [0062] **476** fuel system [0063] **490** engine system [0064] **500** aircraft

Claims

1. An aircraft comprising an engine system, the engine system comprising (a) a gas turbine engine including combustion apparatus having a plurality of fuel injectors arranged in an annular array, any given fuel injector having a fuel-emitting face having a first set of fuel-emitting apertures arranged to emit fuel in a direction normal to the plane of the annular array and a second set of fuel-emitting apertures arranged to emit fuel in a direction having a component in the plane of the array directed towards the fuel-emitting face of an adjacent fuel injector, all such components having the same sense with respect to the array; and (b) a fuel system arranged to provide fuel to the first and second sets of fuel-emitting apertures of each fuel injector of the combustion apparatus of the gas turbine engine at a total fuel flow rate or total chemical energy flow rate; wherein the fuel system further comprises a controller arranged to receive one or more signals indicative of one or more of (i) starting of the gas turbine engine; (ii) flame-out of the combustion apparatus; and (iii) manoeuvring of the aircraft associated with a risk of flame-out of the combustion apparatus, or preparation for such manoeuvring; and in response to increase either (a) the proportion of the total fuel flow rate or total chemical energy flow rate which is provided to the second sets of fuel-emitting apertures; or (b) the fuel flow rate or chemical energy flow rate provided to the second sets of fuel-emitting apertures.

2. An aircraft according to claim 1 wherein the second set of fuel-emitting apertures of any given fuel injector is disposed at an azimuthal edge of the fuel-emitting face of the fuel injector, the azimuthal edge being that azimuthal edge of the fuel-emitting face nearest the adjacent fuel injector.

3. An aircraft according to claim 2 wherein the second set of fuel-emitting apertures is distributed radially with respect to the array.

4. An aircraft according to claim 1 wherein the second set of fuel-emitting apertures of any given fuel injector comprises at least two fuel-emitting apertures and is arranged to emit fuel in first and second directions each having a respective component in the plane of the array directed towards the fuel-emitting face of a respective adjacent fuel injector.

5. An aircraft according to claim 4 wherein the second set of fuel-emitting apertures comprises first and second subsets of fuel-emitting apertures, each subset being disposed at a respective azimuthal edge of the fuel-emitting face of the fuel injector.

6. An aircraft according to claim 5 wherein each subset of the second set of fuel-emitting apertures comprises at least two fuel-emitting apertures distributed radially with respect to the array.

7. An aircraft according to claim 6 wherein the first set of fuel-emitting apertures comprises a subset of fuel-emitting apertures which comprises (a) a plurality of parallel linear arrays of apertures; or (b) a plurality of linear arrays of apertures, each linear array lying on a respective diameter of a circular area of the fuel-emitting face of the fuel injector; or (c) an annular aperture or a plurality of concentric annular apertures.

8. An aircraft according to claim 1 wherein the fuel system is arranged to provide a first fuel to the first set of fuel-emitting apertures of each fuel injector and a second fuel to the second set of fuel-emitting apertures of each fuel injector.

9. An aircraft according to claim 8 wherein the controller is arranged to control at least one of (a) the proportion of the total fuel flow rate or total chemical energy flow rate to the gas turbine engine which is provided to the second sets of fuel-emitting apertures of the combustion apparatus of the gas turbine engine; and (b) the fuel flow rate or chemical energy flow rate provided to the second sets of fuel-emitting apertures of the combustion apparatus of the gas turbine engine, in order to increase or maximise the range of the aircraft or to mitigate climate forcing produced by products of fuel combustion and/or contrails of the aircraft.