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(54) **A FUEL INJECTOR**

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(52) **U.S. Cl.**

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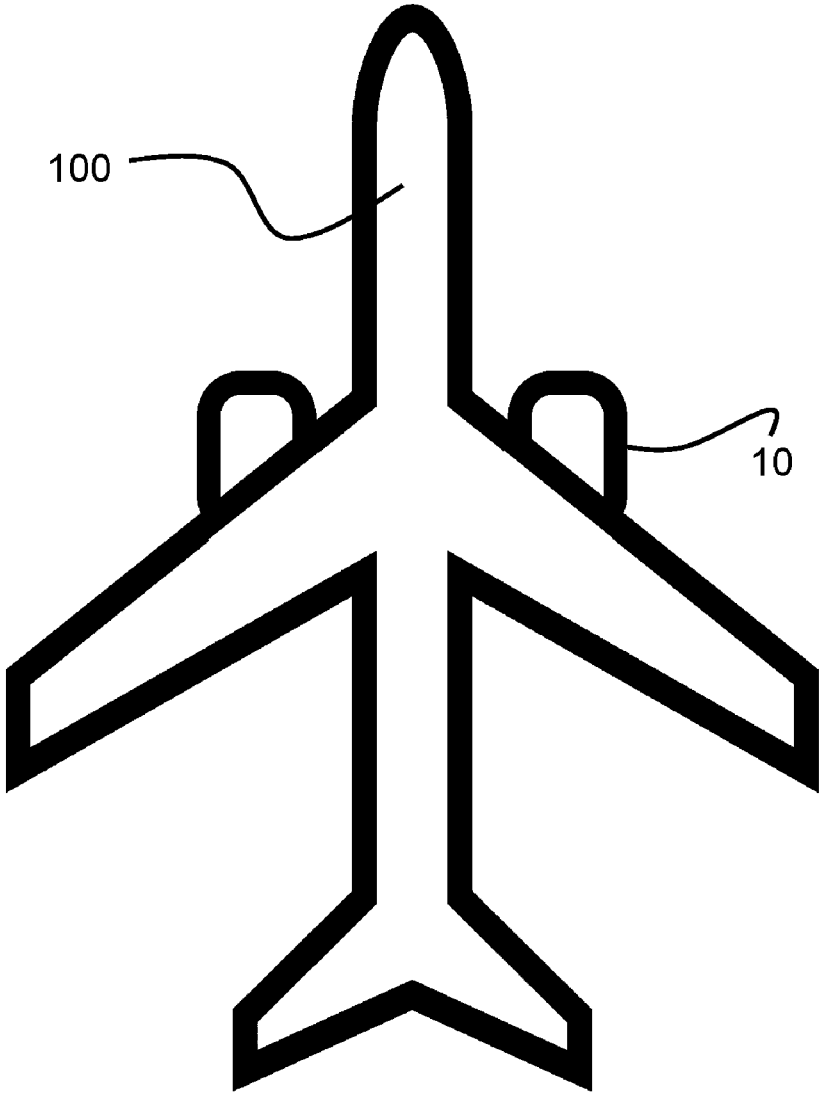
(57) **ABSTRACT**

There is described a fuel injector for a gas turbine engine. The fuel injector comprises an air passageway having an inlet region and an outlet region in fluid communication with the inlet region at an air passageway interface, the inlet region being configured to receive a flow of air from a compressor of the gas turbine engine at an air inlet, the outlet region being configured to receive the flow of air from the inlet region via the air passageway interface and discharge the flow of air to a combustor head of the gas turbine engine. The fuel injector also comprises a fuel passageway having a fuel outlet configured to discharge a flow of fuel into the combustor head. A width of the inlet region in a direction perpendicular to a centreline of the air passageway decreases continuously from the air inlet to the air passageway interface.



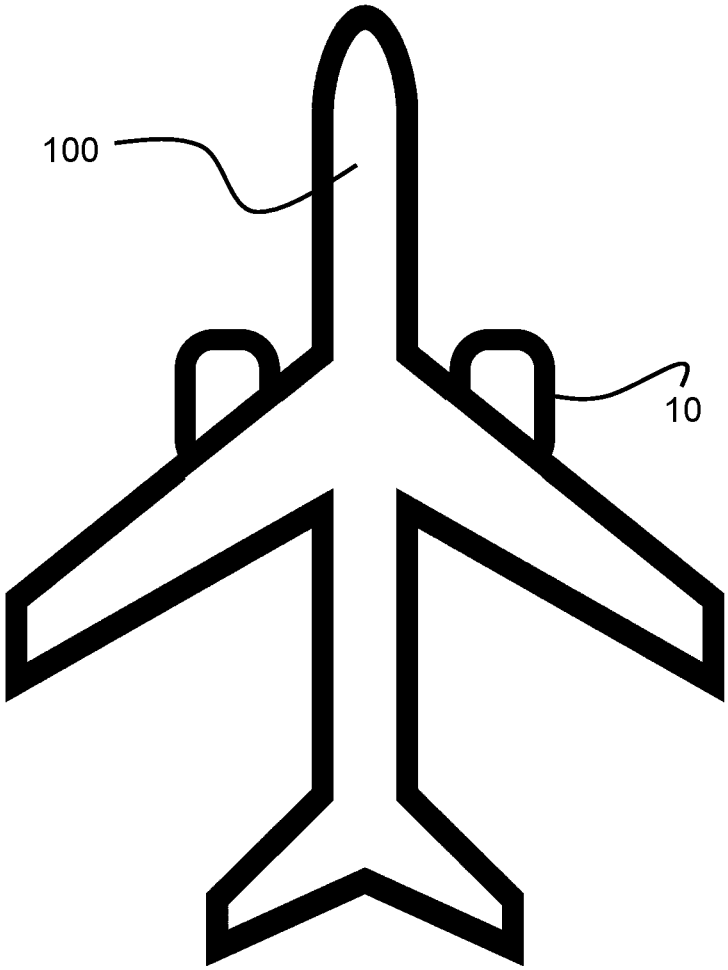


FIG. 1

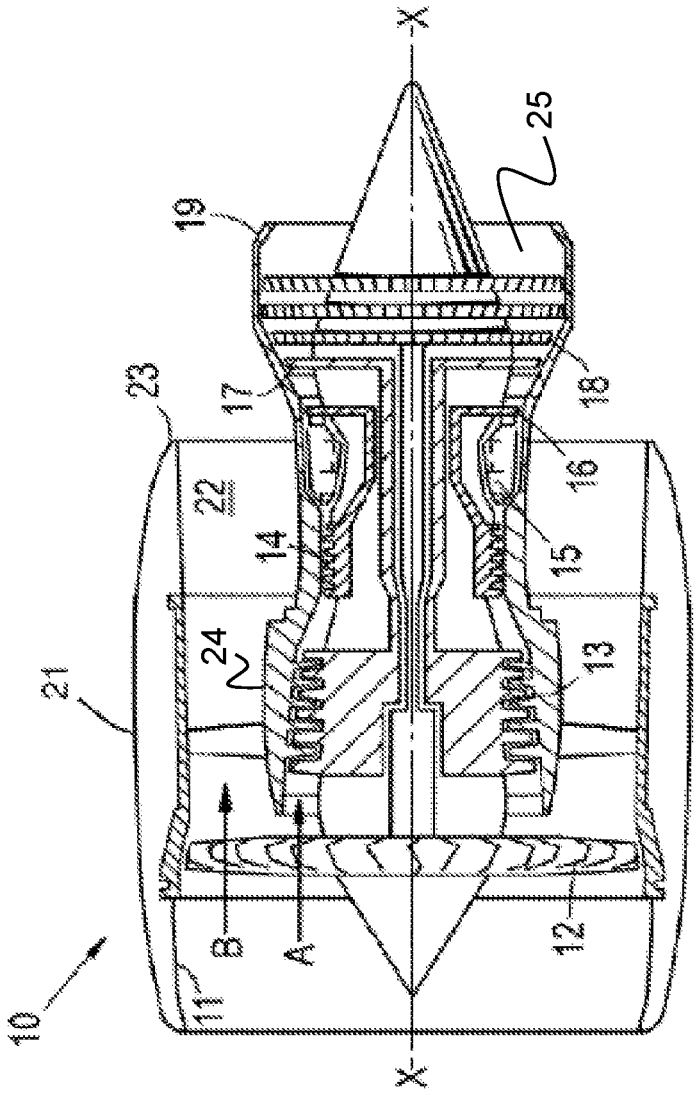


FIG. 2

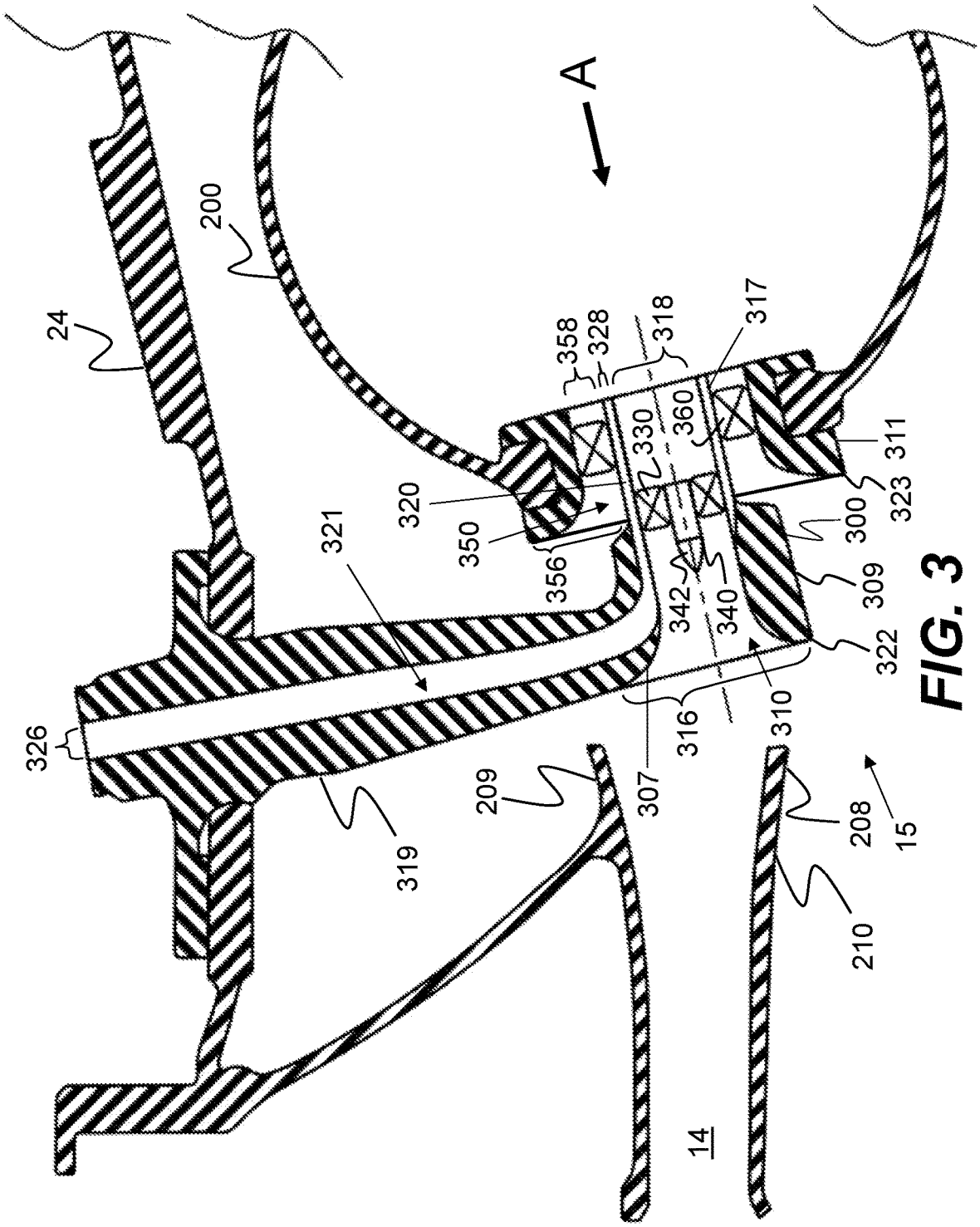

A
200
24
358
328
318
317
330
360
311
320
350
321
356
342
340
300
323
309
322
326
316
310
307
319
209
208
15
210
14

FIG. 3

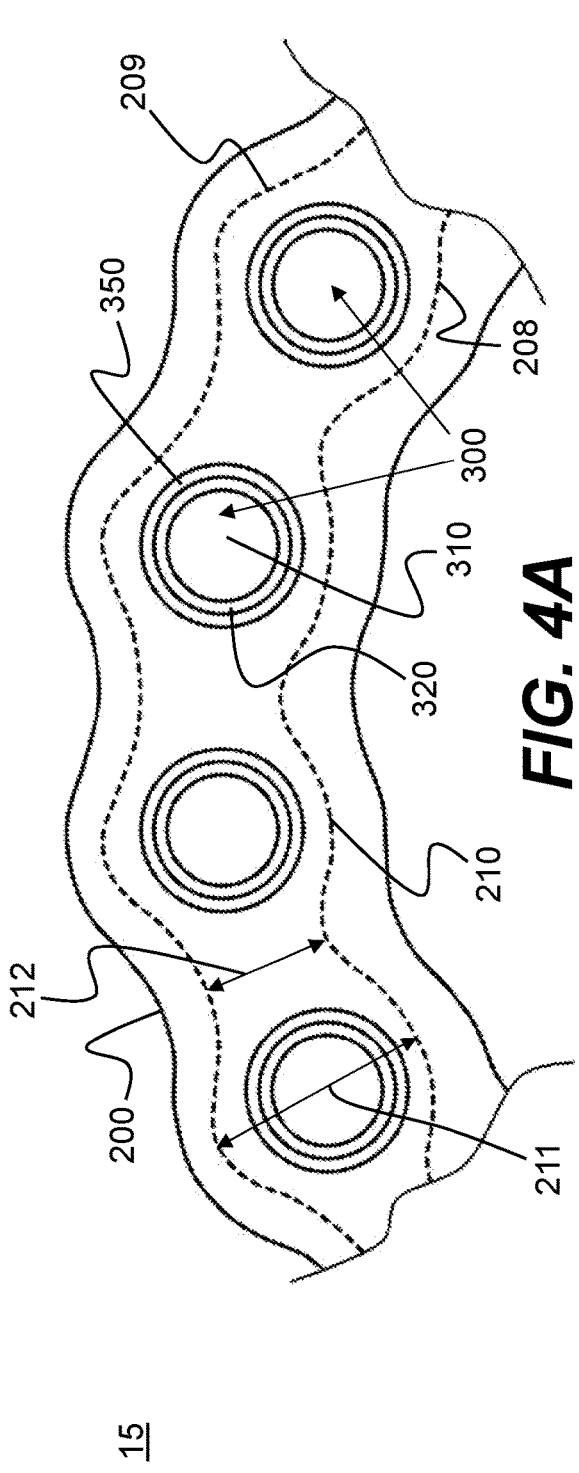

15
200
212
211
210
320
310
300
208
350
209

FIG. 4A

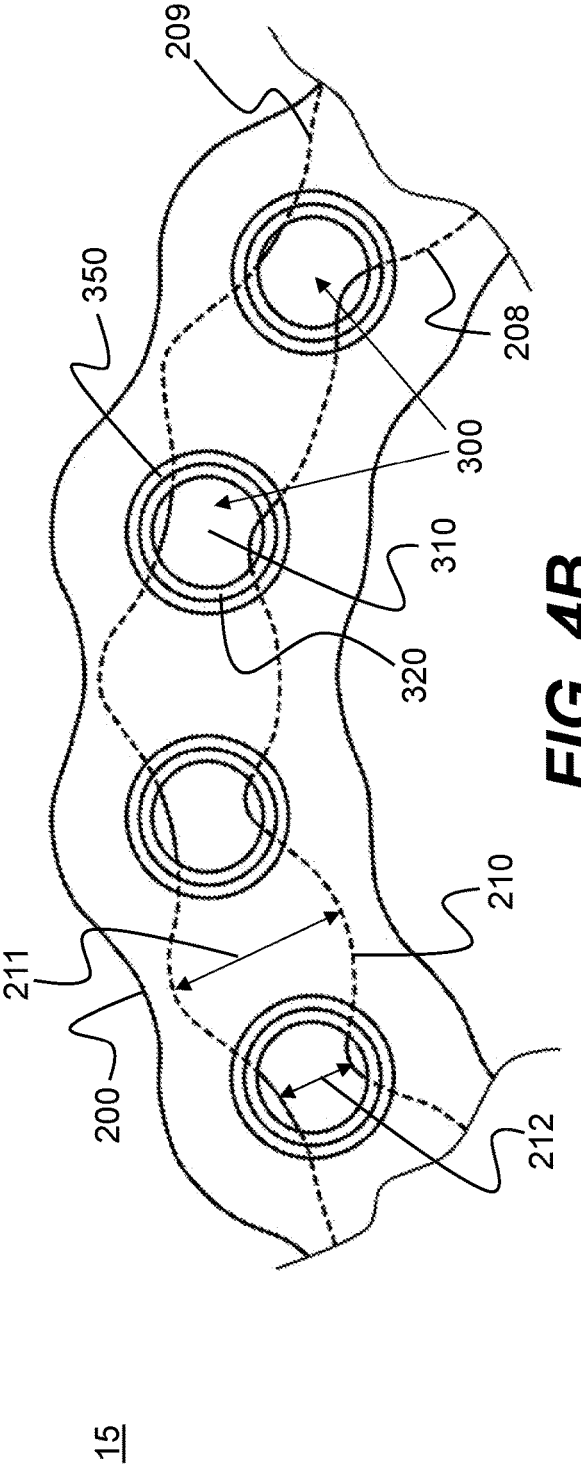

15
200
211
212
210
320
310
300
208
350
209

FIG. 4B

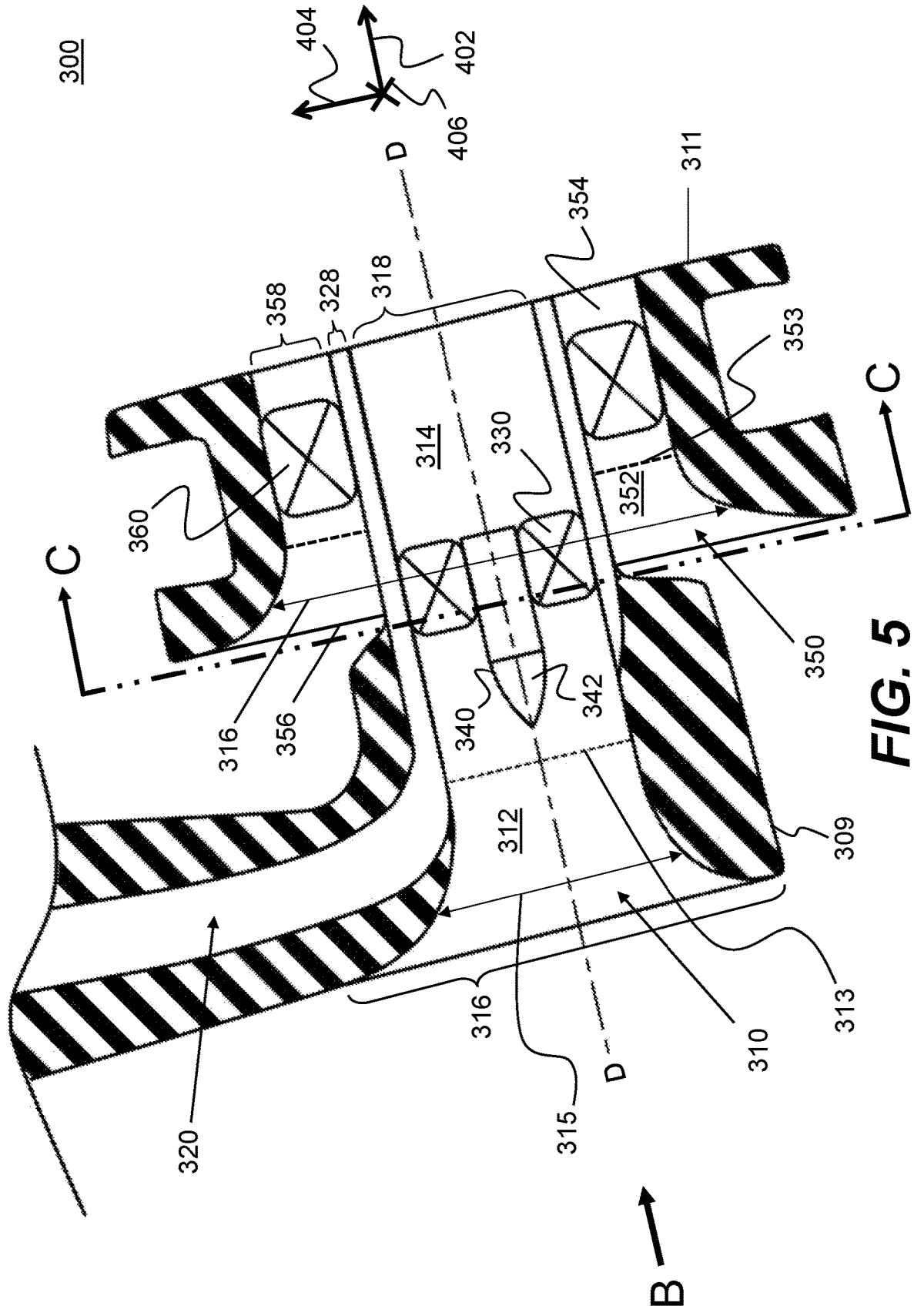

300
404
402
406
D
311
354
358
328
318
353
C
314
330
360
352
C
316
356
340
342
350
312
309
316
313
310
315
D
320
B

FIG. 5

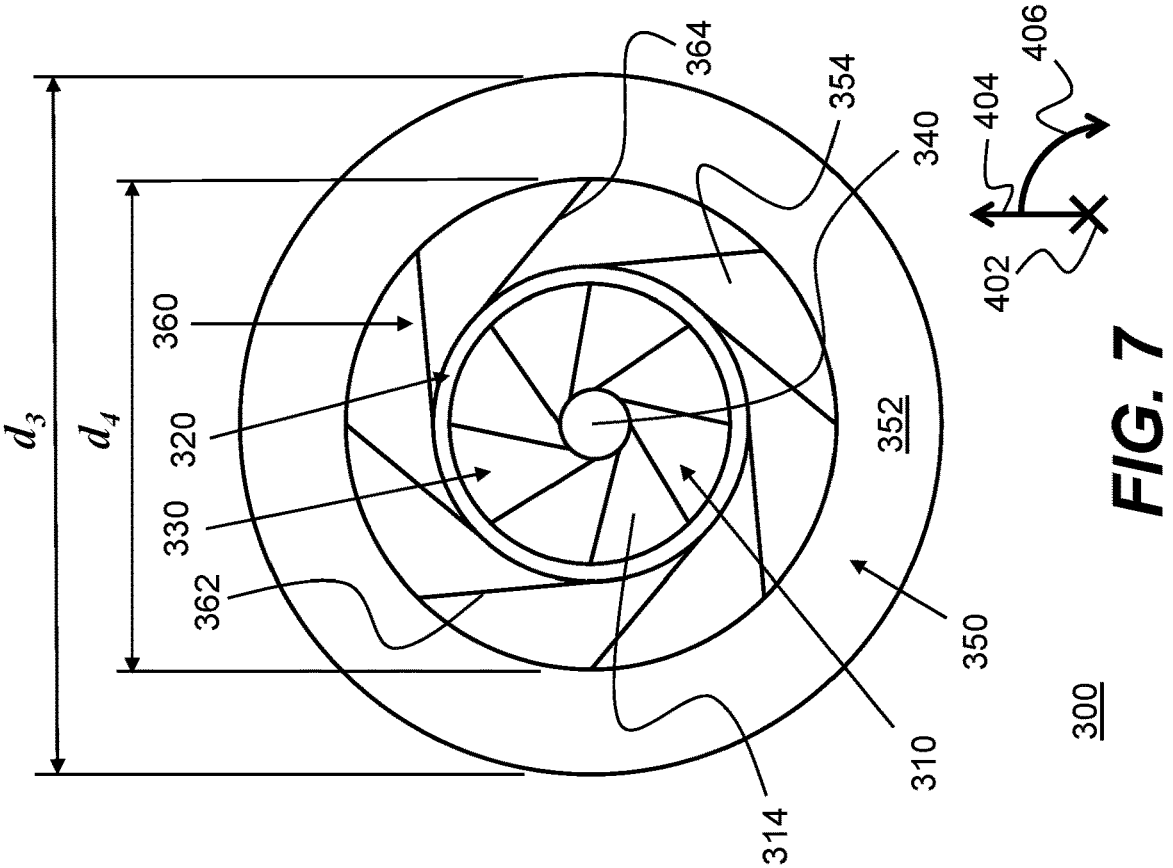

d_3
d_4
360
320
330
362
364
354
340
352
350
310
314
300
402
404
406

FIG. 7

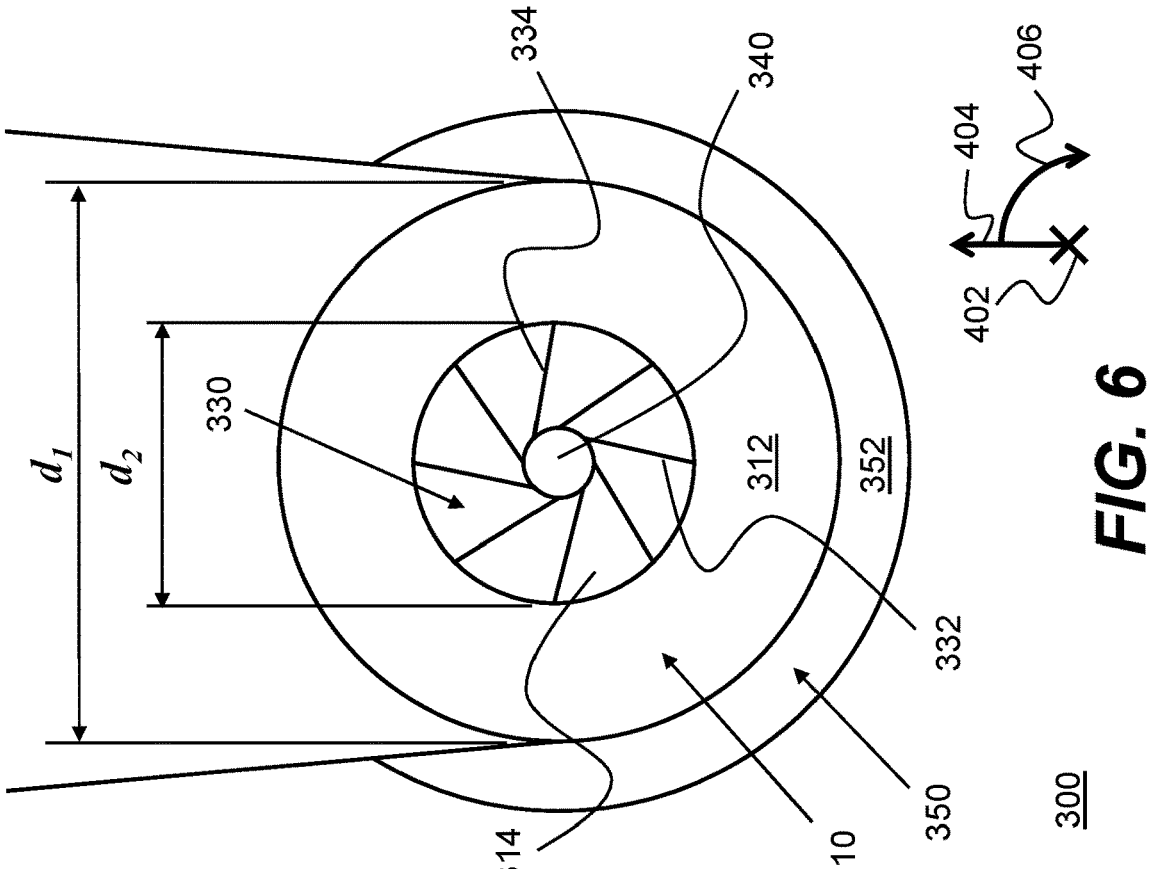

d_1
d_2
330
334
340
312
352
332
350
310
314
300
402
404
406

FIG. 6

A FUEL INJECTOR

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This disclosure claims the benefit of UK Patent Application No. GB 2211656.0, filed on 10 Aug. 2022, which is hereby incorporated herein in its entirety.

BACKGROUND

Technical Field

[0002] The present disclosure relates to a fuel injector for a gas turbine engine.

Description of the Related Art

[0003] It is known to use fuel injectors or fuel spray nozzles as part of a combustion apparatus in a gas turbine engine. The combustion apparatus instigates and facilitates combustion of fuel with relatively high-pressure air received from a compressor stage of the gas turbine engine and thereby adds thermal energy to the relatively high-pressure air prior to the air being expanded in a turbine stage of the gas turbine engine and subsequently being exhausted at an exhaust nozzle to provide propulsive thrust. In the turbine stage, energy is extracted from the expanding air in the form of mechanical work. The turbine stage may drive, for example, a propulsive fan which provides additional propulsive thrust to the gas turbine engine.

[0004] The performance of the fuel injector is important for effective and efficient operation of the gas turbine engine. In particular, the performance of the fuel injector is directly linked to the thermal efficiency of the gas turbine engine and/or emissions produced by the gas turbine engine. It is therefore desirable to provide an improved fuel injector for a gas turbine engine.

SUMMARY

[0005] According to a first aspect of the present disclosure, there is provided a fuel injector for a gas turbine engine, the fuel injector comprising: an air passageway having an inlet region and an outlet region in fluid communication with the inlet region at an air passageway interface, the inlet region being configured to receive a flow of air from a compressor of the gas turbine engine at an air inlet, the outlet region being configured to receive the flow of air from the inlet region via the air passageway interface and discharge the flow of air to a combustor head of the gas turbine engine; and a fuel passageway having a fuel outlet configured to discharge a flow of fuel into the combustor head, wherein a width of the inlet region in a direction perpendicular to a centreline of the air passageway decreases continuously from the air inlet to the air passageway interface along the centreline of the air passageway.

[0006] The width of the inlet region may decrease non-linearly from the air inlet to the air passageway interface. It may be that a cross-sectional profile of the inlet region on a plane perpendicular to the centreline of the air passageway is circular such that the width of the inlet region in the direction perpendicular to a centreline of the air passageway is a diameter of the inlet region. The diameter of the inlet region may decrease continuously from the air inlet to the air passageway interface. The inlet region may be in the form of a bellmouth. The cross-sectional area of the inlet region may decrease linearly from the air inlet to the air passageway interface. A cross-sectional profile of the inlet region on a plane coplanar with the centreline of the air passageway may be parabolic.

[0007] It may be that a ratio of a difference between the diameter of the inlet region at the air inlet and the diameter of the inlet region at the air passageway interface to the diameter of the inlet region at the air passageway interface is equal to or greater than 0.5. It may be that the ratio of the difference between the diameter of the inlet region at the air inlet and the diameter of the inlet region at the air passageway interface to the diameter of the inlet region at the air passageway interface is equal to or greater than 1.

[0008] The fuel injector may comprise a swirler disposed within the air passageway. The swirler may include a plurality of vanes. Each vane may be configured to increase a component of a velocity of air within the air passageway in a circumferential direction of the air passageway. The plurality of vanes may be radially disposed around a deflection body. The deflection body may be configured to direct air within the air passageway toward the plurality of vanes.

[0009] The fuel injector may comprise a further air passageway disposed around the fuel passageway and having a further inlet region and a further outlet region in fluid communication with the further inlet region at a further air passageway interface. The further inlet region may be configured to receive a further flow of air from the compressor of the gas turbine engine at a further air inlet. The further outlet region may be configured to receive the further flow of air from the further inlet region via the further air passageway interface and discharge the further flow of air to the combustor head. A width of the further inlet region in a direction perpendicular to the centreline of the air passageway may decrease continuously from the further air inlet to the further air passageway interface along the centreline of the air passageway.

[0010] The width of the further inlet region may decrease non-linearly from the further air inlet to the further air passageway interface.

[0011] It may be that the cross-sectional profile of the further inlet region on a plane perpendicular to the centreline of the air passageway is circular such that the width of the further inlet region in the direction perpendicular to a centreline of the further air passageway is a diameter of the inlet region. The diameter of the further inlet region may decrease continuously from the further air inlet to the further air passageway interface.

[0012] The further inlet region may be in the form of a bellmouth. The cross-sectional area of the further inlet region may decrease linearly from the further air inlet to the further air passageway interface. A cross-sectional profile of the further inlet region on a plane coplanar with the centreline of the air passageway may be parabolic.

[0013] It may be that a ratio of a difference between the diameter of the further inlet region at the further air inlet and the diameter of the further inlet region at the further air passageway interface to the diameter of the further inlet region at the further air passageway interface is equal to or greater than 0.5. It may be that the ratio of the diameter of the further inlet region at the further air inlet and the diameter of the further inlet region at the further air passageway interface to the diameter of the further inlet region at the further air passageway interface is equal to or greater than 1.

[0014] The fuel injector may comprise a further swirler disposed within the further air passageway. The further swirler may include a plurality of further vanes. Each further vane may be configured to increase a component of a velocity of air within the further air passageway in a circumferential direction of the further air passageway.

[0015] The air inlet may be defined by an end face of the fuel injector. The further air inlet may be defined by an end face of a body defining the further air passageway.

[0016] The air passageway may be cylindrical at the air passageway interface. The further air passageway may be cylindrical at the further air passageway interface.

[0017] There may be provided a combustion apparatus comprising the fuel injector of any preceding statement and a combustor head configured to: receive air from the air outlet; receive fuel from the fuel outlet; and facilitate mixing and atomisation of fuel received from the fuel outlet with air received from the air outlet.

[0018] There may be provided a gas turbine engine for an aircraft, the gas turbine engine comprising: the fuel injector of any preceding statement; or the combustion apparatus of any preceding statement.

DESCRIPTION OF THE DRAWINGS

[0019] Embodiments will now be described by way of example and with reference to the accompanying drawings, in which:

[0020] FIG. **1** is a plan view of an aircraft comprising a gas turbine engine;

[0021] FIG. **2** is a cross-sectional side view of the gas turbine engine;

[0022] FIG. **3** is a cross-sectional side view of a combustion apparatus of the gas turbine engine comprising a fuel injector and a combustor head;

[0023] FIG. **4**A is a simplified rear view of the combustion apparatus;

[0024] FIG. **4**B is a simplified rear view of an alternative combustion apparatus;

[0025] FIG. **5** is a close-up cross-sectional side view of the fuel injector of FIG. **3**;

[0026] FIG. **6** is a front view of the fuel injector; and

[0027] FIG. **7** is a cross-sectional front view of the fuel injector.

DETAILED DESCRIPTION

[0028] FIG. **1** is a plan view of an aircraft **100** comprising a gas turbine engine **10**. The gas turbine engine **10** may be a ducted fan gas turbine engine as described below with reference to FIG. **2**. The aircraft **100** may comprise any number of gas turbine engines **10**.

[0029] FIG. **2** shows an example ducted fan gas turbine engine **10** having a principal and rotational axis X-X. The engine comprises, in axial flow series, an air intake **11**, a propulsive fan **12**, an intermediate pressure compressor **13**, a high-pressure compressor **14**, a combustion apparatus **15**, a high-pressure turbine **16**, an intermediate pressure turbine **17**, a low-pressure turbine **18** and a core engine exhaust nozzle **19**. A nacelle **21** generally surrounds the engine **10** and defines the intake **11**, a bypass duct **22** and a bypass exhaust nozzle **23**. A core casing **24** located within the nacelle **21** defines the core engine exhaust nozzle **19** and a core duct **25** in which the intermediate pressure compressor **13**, the high-pressure compressor **14**, the combustion apparatus **15**, the high-pressure turbine **16**, the intermediate pressure turbine **17** and the low-pressure turbine **18** are disposed.

[0030] During operation, air entering the intake **11** is accelerated by the fan **12** to produce two air flows: a first air flow A into the intermediate pressure compressor **13** and a second air flow B which passes through the bypass duct **22** to provide propulsive thrust. The intermediate pressure compressor **13** compresses the air flow A directed into it before delivering that air to the high-pressure compressor **14** where further compression takes place.

[0031] The compressed air exhausted from the high-pressure compressor **14** is directed into the combustion apparatus **15** disposed within a midstream portion of the gas turbine engine **10** where it is mixed with fuel and the mixture combusted. The combustion apparatus **15** may comprise at least a fuel injector and a combustor head, as described below with reference to FIG. **3**. The resultant hot combustion products then expand through, and thereby drive the high, intermediate and low-pressure turbines **16**, **17**, **18** before being exhausted through the nozzle **19** to provide additional propulsive thrust. The high, intermediate and low-pressure turbines respectively drive the high and intermediate pressure compressors **14**, **13** and the fan **12** by suitable interconnecting shafts.

[0032] FIG. **3** is a cross-sectional side view of an example combustion apparatus **15** within a midstream portion of a gas turbine engine. The gas turbine engine may be in accordance with the gas turbine engine **10** described above with respect to FIG. **2**, with like reference signs indicating common or similar features. The combustion apparatus **15** comprises a fuel injector **300** and a combustor head **200**.

[0033] The fuel injector **300** generally comprises a central body **309**, an outer body **311** and a supply tube **319**. The central body **309** comprises an inner tube **307**. The outer tube **317** is disposed radially outward of the inner tube **307**. The inner wall of the inner tube **307** defines an air passageway **310**. The air passageway **310** extends between an air inlet **316** and an air outlet **318**. The air inlet **316** is defined by an end face **322** of the fuel injector **300**. In particular, the air inlet **316** is defined by an end face **322** of the central body **309**. The outer tube **307** is spaced radially outward of the inner tube **307**. The outer wall of the inner tube **307** and the inner wall of the outer tube **317** define a fuel passageway **320** therebetween. The fuel passageway **320** is substantially annular. The outer body **311** is annular. A radially outward surface of the outer body **311** defines a groove. The combustor head **200** engages with the groove of the outer body **311**. The outer body **311** is spaced radially outward of the outer tube **317**. A further air passageway **350** is defined between the outer wall of the outer tube **317** and an inner wall of the outer body **311**. The further air passageway **350** extends between a further air inlet **356** and a further air outlet **358**. The further air inlet **356** is defined by an end face **323** of the outer body **311**. The air passageway **310**, the fuel passageway **320** and the further air passageway **350** are concentric.

[0034] A first end of the supply tube **319** is mechanically coupled to the core casing **24** of the gas turbine engine **10**. A second end of the supply tube **319** extends from the central body **309**. The supply tube **319** defines a supply passageway **321**. The supply passageway **321** has a fuel inlet **326**. The fuel passageway **320** has a fluid outlet **328**. The fuel pas-

sageway **320** is fluidically connected to the supply passageway **321** such that the fuel inlet **326** and the fuel outlet **328** are fluidically connected.

[0035] The fuel injector **300** is configured to receive air from a compressor **14** of the gas turbine engine **10** and to discharge air into the combustor head **200**. In particular, the fuel injector **300** is configured to receive air from the compressor **14** via a pre-diffuser **210** at the air inlet **316** and at the further air inlet **356**. The pre-diffuser **210** is defined by a radially inward wall **208** and a radially outward wall **209**. The radially inward wall **208** and the radially outward wall **209** extend circumferentially around the principal rotational axis X-X of the gas turbine engine **10**. The pre-diffuser **210** may be configured to control airflow from the compressor **14** into the midstream portion of the gas turbine engine **10**, such as toward the air inlet **316** and the further air inlet **356**, as well as around the fuel injector **300**. Airflow around the fuel injector **300** may be used for a purpose other than combustion or be used for subsequent supply to the combustor head **200** without passing through the fuel injector **300**. For example, the combustor head **200** may be provided with at least one aperture configured to enable air directed around the fuel injector **300** by the pre-diffuser **210** to flow into the combustor head **200**. The fuel injector **300** is configured to receive fuel from a fuel supply line of the gas turbine engine at the fuel inlet **326** and to discharge fuel into the combustor head **200** of the gas turbine engine at the fuel outlet **328**.

[0036] The combustor head **200** is configured to receive air from the air outlet **318** and the further air outlet **358**. In addition, the combustor head **200** is configured to receive fuel from the fuel outlet **328** and to facilitate mixing and atomisation (e.g. evaporation) of fuel received from the fuel outlet **328** with air received from the air outlet **318** and air received from the further air outlet **358**. In use, fuel discharged at the fuel outlet **328** is in proximity to air discharged from the air outlet **318** and air discharged from the further air outlet **328**. Air discharged from the respective air outlets typically has a relatively high temperature as a result of prior compression by the compressor **14**. Accordingly, air discharged from the air outer **318** and the further air outlet **358** heats the fuel discharged from the fuel outlet **328**, which in turn causes atomisation (e.g. evaporation) of fuel exiting the fuel outlet **328**.

[0037] The combustion apparatus **15** is now described in further detail with reference to FIG. **4**A, which shows a rear view of the combustion apparatus **15** viewed from the direction indicated by arrow A on FIG. **3**. FIG. **4**A shows the profile of the pre-diffuser **210** in phantom as projected through the combustor head **200** or seen through the fuel injector **300**.

[0038] The combustion apparatus **15** comprises a plurality of fuel injectors **300** that are circumferentially offset with respect to each other around the principal rotation axis X-X of the gas turbine engine **10**. Each fuel injector **300** is configured to discharge air into the combustor head **200** in the manner described above. The combustor head **200** extends annularly around the principal rotational axis X-X of the gas turbine engine **10**. A single portion (i.e., angular sector) of the respective combustion apparatus **15** is shown in FIG. **4**A for clarity, however it will be appreciated that the structure shown in FIG. **4**A may extend around the entirety of the principal rotation axis X-X of the gas turbine engine **10**.

[0039] The radial width of the pre-diffuser **210** (i.e., the distance between the radially inward wall **208** of the pre-diffuser **210** and the radially outward wall **209** of the pre-diffuser **210**) sequentially increases and decreases in a circumferential direction around the principal rotation axis X-X of the gas turbine engine **10**, such that the pre-diffuser **210** comprises a series of successive wide portions **211** and narrow portions **212**. The radially inward wall **208** of the pre-diffuser **210** and the radially outward wall **209** of the pre-diffuser **210** have the profile of respective opposing waves when viewed in profile (e.g. from the view shown in FIG. **4**A).

[0040] In the example of FIG. **4**A, the wide portions of the pre-diffuser **210** are aligned with the air inlets **316**, **356** of the fuel injectors **300**, whereas the narrow portions of the pre-diffuser **210** are circumferentially disposed between adjacent fuel injectors **300**. Accordingly, the radial profile of the pre-diffuser **210** is formed such that, in use, airflow from the compressor **14** of the gas turbine engine is preferentially directed into each of the air passageways **310**, **350** of the plurality of fuel injectors **300** so as to maximise a flow rate and/or a momentum of air directed into the combustor head **200** via each of the air outlets **318**, **358** of the fuel injectors **300**. The example arrangement of FIG. **4**A may enable the combustion apparatus **15** to be more easily operated at a high air-fuel ratio (AFR), such as for a rich burn cycle of the gas turbine engine or an ultra-high temperature ratio rich burn engine cycle of the gas turbine engine.

[0041] FIG. **4**B shows a simplified rear view of an alternative combustion apparatus. The alternative combustion apparatus corresponds to the combustion apparatus **15** described above, with like reference signs indicating common or similar features. However, in contrast to the combustion apparatus **15** described above with reference to FIG. **4**A, the narrow portions **212** of the pre-diffuser **210** of the alternative combustion apparatus shown in FIG. **4**B are aligned with the air inlets **316**, **356** of the fuel injectors **300** and the wide portions **212** of the pre-diffuser are circumferentially disposed between adjacent fuel injectors **300**. Accordingly, the radial profile of the pre-diffuser **210** is formed such that, in use, airflow from the compressor **14** of the gas turbine engine is preferentially directed away from each of the air passageways **310**, **350** the plurality of fuel injectors **300** so as to maximum a flow rate and/or a momentum of air directed around the plurality of fuel injectors **300**. As discussed above, airflow around the or each fuel injector **300** may be used for subsequent supply to the combustor head **200** without passing through the air outlets **318**, **358** of the fuel injector **300**. The arrangement of FIG. **4**B may enable the combustion apparatus **15** to be more easily operated at a low air-fuel ratio (AFR), such as for a lean burn cycle of the gas turbine engine **10**.

[0042] FIG. **5** shows a detailed cross-sectional side view of the fuel injector **300**. FIG. **6** shows a simplified (i.e., schematic) front view of the fuel injector **300** as viewed in the direction indicated by arrow B on FIG. **5**. FIG. **7** shows a simplified (i.e., schematic) sectional front view of the example fuel injector **300** along section C-C indicated in FIG. **5**.

[0043] The air passageway **310** has an inlet region **312** and an outlet region **314**. The inlet region **312** and the outlet region **314** are in fluid communication with each other at an air passageway interface **313**. The air passageway **310** is cylindrical at the air passageway interface **313**. In the

arrangement shown in FIG. **5**, the entirety of the outlet region **314** is cylindrical, however it will be appreciated that this need not be the case. The inlet region **312** is configured to receive air from the compressor **14** at the air inlet **316**. The outlet region **314** is configured to discharge air to a combustor head **200** (not shown in FIG. **5**) at the air outlet **318**.

[0044] The air passageway **310** has a centreline D-D. The centreline D-D is linear. For reference, a coordinate system for the fuel injector **300** is shown on each of FIGS. **5** to **7**. The coordinate system specifies an axial direction **402**, a radial direction **404** and a circumferential direction **406** of the fuel injector **300**. The coordinate system is defined with respect to the air passageway **310**, such that the axial direction **402** is parallel to the centreline D-D of the air passageway **310**, the radial direction **404** is parallel to a radius of the air passageway **310** and the circumferential direction **406** is parallel to a radius of the air passageway **310** and orthogonal to the axial direction **402** and radial direction **404**.

[0045] The inlet region **312** has a width **315** in a direction perpendicular to the centreline D-D (i.e., the radial direction **404**) of the air passageway **310**. The width **315** of the inlet region **312** changes along the length of the inlet region **312**. A cross-sectional profile of the inlet region **312** defined on a plane perpendicular to the centreline D-D of the air passageway **310** is substantially circular, such that the width **315** defining the inlet region **312** is the diameter of the inlet region **312**.

[0046] The specific case of the diameter **315** of the inlet region **312** at the air inlet **316** is denoted by d_1 in FIG. **6**. The specific case of the diameter **315** of the inlet region **312** at the air passageway interface **313** is denoted by d_2 in FIG. **6**. A ratio of the difference between the diameter, d_1, of the inlet region **312** at the air inlet **316** and the diameter, d_2, of the inlet region **312** at the air passageway interface **313** to the diameter, d_2, of the inlet region **312** at the air passageway interface **313**, $(d_1-d_2)/d_2$, may be at least equal to or greater than 0.5. It will be appreciated that FIG. **6** is not to scale, and so the relative dimensional proportions of d_1 and d_2 as shown in FIG. **6** are not indicative of preferable relative dimensional proportions of d_1 and d_2.

[0047] As best shown in FIG. **5**, the diameter **315** of the inlet region **312** decreases continuously from the air inlet **316** to the air passageway interface **313** along the centreline D-D. That is, the inlet region **312** is not stepped and smoothly decreases in diameter from the air inlet **316** to the air passageway interface **313** for the entirety of the length of the inlet region **312**. Compared with existing combustion apparatus in which the width of the air passageway is constant in an inlet region and does not decrease, the diameter **315** of the inlet region **312** decreasing continuously from the air inlet **316** to the air passageway interface **313** results in a reduced pressure drop of air across the air passageway **310** (i.e., a parasitic pressure loss across the air passageway **310**). This improves fuel atomisation within the combustor head **200** to which the fuel injector **300** is coupled and increases the thermal efficiency of the gas turbine engine **10**. A reduced pressure drop may also enable an installation size of the fuel injector **300** to be reduced compared to a previously-considered fuel injector without resulting in a lower airflow rate through the fuel injector **300** in use. This is especially advantageous in a space-limited context, such as in the context of a high-performance gas turbine engine. Additionally, the diameter **315** of the inlet region **312** decreasing continuously from the air inlet **316** to the air passageway interface **313** aids aerodynamic mixing of fuel and air within the combustor head **200**, which increases fuel-air mixture uniformity therein and which is in turn associated with improved combustion characteristics and more effective emissions control during operation of the gas turbine engine **10**.

[0048] The pressure drop of air across the air passageway **310** may be characterised by an air entry discharge coefficient. The ratio of the difference between the diameter, d_1, of the inlet region **312** at the air inlet **316** and the diameter, d_2, of the inlet region **312** at the air passageway interface **313** to the diameter, d_2, of the inlet region **312** at the air passageway interface **313**, $(d_1-d_2)/d_2$, may be equal to or greater than 0.5. This ratio being greater than or equal to 0.5 may provide a significantly reduced pressure drop across the air passageway **310**, which corresponds to a substantially increased air entry discharge coefficient.

[0049] Preferably, the ratio of the difference between the diameter, d_1, of the inlet region **312** at the air inlet **316** to and the diameter, d_2, of the inlet region **312** at the air passageway interface **313** to the diameter, d_2, of the inlet region **312** at the air passageway interface **313**, $(d_1-d_2)/d_2$, is greater than or equal to 1. The ratio of the difference between the diameter, d_1, of the inlet region **312** at the air inlet **316** and the diameter, d_2, of the inlet region **312** at the air passageway interface **313** to the diameter, d_2, of the inlet region **312** at the air passageway interface **313**, $(d_1-d_2)/d_2$, being equal to or greater than 1 provides a further reduced pressure drop across the air passageway **310**, with the associated further improvements in terms of fuel atomisation and/or increased thermal efficiency discussed above.

[0050] The diameter **315** of the inlet region **312** decreases non-linearly from the air inlet **316** to the air passageway interface **313**, as shown in FIG. **5**. That is, the inlet region **312** is not frustoconical (i.e., chamfered) and does not have a linear sectional profile between the air inlet **316** and the air passageway interface **313**. The diameter of the inlet region **312** decreasing non-linearly from the air inlet **316** to the air passageway interface **313** may provide a yet further reduced pressure drop across the air passageway **310** and/or further aid aerodynamic mixing of fuel and air within the combustor head **200**. The gradient of the wall forming the inlet region **312** decreases from the air inlet **316** to the air passageway interface **313**. Accordingly, the non-linear sectional profile of the inlet region **312** is in the form of a bellmouth.

[0051] In some embodiments, the inlet region **312** has a constant radius of curvature from the air inlet **316** to the air passageway interface **313**. In such embodiments, the difference between the diameter d_1 of the inlet region **312** at the air inlet **316** to and the diameter d_2 of the inlet region **312** at the air passageway interface **313** (i.e. d_1-d_2) is equal to the magnitude of the radius of curvature of the inlet region **312** from the air inlet **316** to the air passageway interface **313**. In alternative embodiments, the cross-sectional area of the inlet region **312** decreases linearly from the air inlet **316** to the air passageway interface **313**. That is, the cross-sectional area of the inlet region **312** has a constant change in area as a function of axial distance from the air inlet **316** to the air passageway interface **313**.

[0052] The fuel injector **300** additionally comprises a swirler **330** disposed within the air passageway **310**. The swirler **330** is located within the outlet region **314**. As shown in FIGS. **6** and **7**, the swirler **330** comprises a plurality of

swirler vanes **332**, **334**. Each swirler vane **332**, **334** is configured to redirect air conveyed by the air passageway **310** in use so as to increase a velocity of air within the air passageway **310** in a circumferential direction of the air passageway **310**. Each swirler vane **332**, **334** is substantially helical. This reduces the velocity of air within the air passageway **310** parallel to the centreline D-D of the air passageway **310** (i.e., in the axial direction **402** of the fuel injector **300**). The swirler **330** therefore promotes the formation of a recirculating low-speed eddy downstream of the swirler **330**, which in turn promotes the formation of a wake-stabilised region downstream of the air passageway **310**. This promotes the stable combustion of fuel discharged at the fuel outlet **328** with air discharged at the air outlet **318** downstream of the fuel injector **300** by reducing a fluid speed within the wake-stabilised region and thereby reducing the likelihood of flame blow-out or blow-off as a result of flame lift-off from the fuel injector **300**. In addition, the formation of the recirculating eddy downstream of the swirler **330** promotes a transfer of momentum from air discharged from the air inlet **318** to the fuel discharged from the fuel outlet **328** by, for example, viscous or shear forces. The transfer of momentum from air discharged from the air inlet **318** into the discharged fuel causes disaggregation (i.e., breaking apart) of relatively large fuel droplets discharged from the fuel outlet **328** into smaller fuel droplets. Relatively small fuel droplets have a larger surface area-to-volume ratio than relatively large fuel droplets, and, consequently, are more easily and readily evaporated as a result of heating by the air discharged from the air inlet **318**. The swirler **330** improves the atomisation of fuel downstream of the fuel injector **300**, which increases the effectiveness of combustion and thermal efficiency and improves emissions characteristics of a gas turbine engine in which the fuel injector **300** is incorporated.

[0053] Each swirler vane **332**, **334** is radially disposed around a deflection body **340**. The deflection body **340** is disposed along the centreline D-D of the air passageway **310**, in the outlet region **314**. A portion **342** of the deflection body **340** upstream of the swirler **330** has a tapered shape such that the deflection body **340** is bullet-shaped. The deflection body **340** is configured to direct air within the air passageway **310** radially outwards (i.e., in a direction parallel to the radial direction **404** of the fuel injector **300**) and toward the plurality of swirler vanes **362**, **364**. The portion **342** of the deflection body **340** reduces a fraction of the pressure drop across the air passageway **310** associated with the presence of the deflection body **340** therein. The deflection body **340** further promotes stable combustion of fuel discharged at the fuel outlet **328** with air discharged at the air outlet **318** downstream of the fuel injector **300** by increasing a fraction of air within the air passageway **310** which passes through the swirler **330**. In addition, the effectiveness with which the swirler **330** is able to increase the velocity of air within the air passageway **310** in the circumferential direction of the air passageway **310** is increased as a result of the air having been directed radially outward by the deflection body **340**. Consequently, the swirler **300** is better able to promote the formation of the recirculating low-speed eddy downstream of the plurality of swirler vanes **332**, **334** as described above.

[0054] The further air passageway **350** has a further inlet region **352** and a further outlet region **354**. The further air passageway **350** is disposed radially outwards of the fuel passageway **320** and extends around the fuel passageway **320**. The further inlet region **352** and the further outlet region **354** are in fluid communication with each other at a further air passageway interface **353**. The further air passageway **350** is cylindrical at the further air passageway interface **353**. In the arrangement shown in FIG. **5**, the entirety of the further outlet region **354** is cylindrical, however it will be appreciated that this need not be the case.

[0055] In a similar manner to the inlet region **312** of the air passageway **310** described above, the further inlet region **352** has a width **316** in a direction perpendicular to the centreline D-D of the further air passageway **350**. The width **316** of the further inlet region **352** changes along the length of the further inlet region **352**. A cross-sectional profile of the further inlet region **352** defined on a plane perpendicular to the centreline D-D of the further air passageway **350** is substantially circular, such that the width **317** that defines the further inlet region **352** is the diameter of the further inlet region **352**.

[0056] The further inlet region **352** is configured to receive air from a compressor **14** of a gas turbine engine at the further air inlet **356**. The further outlet region **354** is configured to discharge air to the combustor head **200** at the further air outlet **358**. The further air passageway **350** is annular and extends around the centreline D-D of the air passageway **310**. The further air outlet **358** has a substantially circular shape and has a centre which corresponds to the centre of the air outlet **318**. The further air outlet **358**, the fuel outlet **328** and the air outlet **318** are concentric.

[0057] The inclusion of the further air passageway **350** within the fuel injector **300** enables, in use, a transfer of momentum from air discharged from the further air outlet **358** to the fuel discharged from the fuel outlet **328** by, for example, viscous or shear forces such that the transfer of momentum from the air to the fuel is increased. This improves disaggregation (i.e. breaking apart) of relatively large fuel droplets discharged from the fuel outlet **328** into smaller fuel droplets and therefore with more effective combustion and therefore higher thermal efficiency and improved emissions characteristics of the gas turbine engine **10**.

[0058] A cross-sectional profile of the further inlet region **352** defined on a plane perpendicular to the centreline D-D of the air passageway **310** is substantially circular, such that the width **316** that defines the further inlet region **352** is the diameter of the further inlet region **352**. The specific case of the diameter **316** of the further inlet region **352** at the further air inlet **356** is denoted by d_3 in FIG. **7**. The specific case of the diameter **316** of the further inlet region **352** at the further air passageway interface **353** is denoted by d_4 in FIG. **7**. As with FIG. **6**, it will be appreciated that FIG. **7** is not to scale, and so the relative dimensional proportions of d_3 and d_4 as shown in FIG. **7** are not indicative of preferable relative dimensional proportions of d_3 and d_4. A ratio of a difference between the diameter, d_3, of the further inlet region **352** at the further air inlet **356** and the diameter, d_4, of the further inlet region **352** at the further air passageway interface **353** to the diameter, d_4, of the further inlet region **352** at the further air passageway interface **353**, $(d_3-d_4)/d_4$, may be at least equal to or greater than 0.5.

[0059] The diameter **316** of the further inlet region **352** also decreases continuously from the further air inlet **356** to the further air passageway interface **353** along the centreline D-D, as best shown by FIG. **5**. Compared with existing

combustion apparatus in which the width **316** of the further air passageway is substantially constant in the further inlet region **352** and does not decrease, the disclosed arrangement results in a reduced pressure drop of air across the further air passageway **350** (i.e., a parasitic pressure loss across the further air passageway **350**). As described above with respect to the inlet region **312**, this may also aid aerodynamic mixing of fuel and air within the combustor head **200**, which is associated with improved combustion characteristics and more effective emissions control during operation of the gas turbine engine **10**.

[0060] The pressure drop of air across the further air passageway **350** may be characterised by a further air entry discharge coefficient. Specifically, the ratio of the difference between the diameter, d_3, of the further inlet region **352** at the further air inlet **356** and the diameter, d_4, of the further inlet region **352** at the further air passageway interface **353** to the diameter, d_4, of the further inlet region **352** at the further air passageway interface **353**, $(d_3-d_4)/d_4$, being equal to or greater than 0.5 may provide a significantly reduced pressure drop across the further air passageway **350**, which corresponds to a substantially increased further air entry discharge coefficient. These effects are each associated with improved fuel atomisation within the combustor head **200** to which the fuel injector **300** is coupled and an increased thermal efficiency of a gas turbine engine **10** in which the fuel injector **300** is incorporated.

[0061] Preferably, the ratio of the difference between the diameter, d_3, of the further inlet region **352** at the further air inlet **356** and the diameter, d_4, of the further inlet region **352** at the further air passageway interface **353** to the diameter, d_4, of the further inlet region **352** at the further air passageway interface **353**, $(d_3-d_4)/d_4$, is equal to or greater than 1. The ratio the difference between of the diameter, d_3, at the further air inlet **356** and the diameter, d_4, of the further inlet region **352** at the further air passageway interface **353** to the diameter, d_4, of the further inlet region **352** at the further air passageway interface **353**, $(d_3-d_4)/d_4$, being equal to or greater than 1 provides a further reduced pressure drop across the further air passageway **350**, with the associated further improvements in terms of fuel atomisation, increased thermal efficiency and/or aerodynamic mixing of fuel and air within the combustor head **200** as discussed above.

[0062] The diameter **316** of the further inlet region **352** decreases non-linearly from the further air inlet **356** to the further air passageway interface **353**, as shown in FIG. **5**. That is, the further inlet region **352** is not chamfered and does not have a non-linear sectional profile between the further air inlet **356** and the further air passageway interface **353**. The diameter of the further inlet region **352** decreasing non-linearly from the further air inlet **356** to the further air passageway interface **353** may provide a yet further reduced pressure drop across the further air passageway **350**. The gradient of the wall forming the further inlet region **352** decreases from the further air inlet **356** to the further air passageway interface **353**. Accordingly, the non-linear sectional profile of the further inlet region **352** is in the form of a bellmouth.

[0063] In some embodiments, the further inlet region **352** has a substantially constant radius of curvature from the further air inlet **356** to the further air passageway interface **353**. In such embodiments, the difference between the diameter of the further inlet region **352** at the further air inlet **356** to and the diameter of the further inlet region **352** at the further air passageway interface **353**, d_3-d_4, is equal to the magnitude of the substantially constant radius of curvature of the further inlet region **352** from the further air inlet **356** to the further air passageway interface **353**. In alternative embodiments, the cross-sectional area of the further inlet region **352** decreases linearly from the further air inlet **356** to the further air passageway interface **353**. That is, the cross-sectional area of the further inlet region **352** has a constant change in area as a function of axial distance from the further air inlet **356** to the further air passageway interface **353**.

[0064] The fuel injector **300** additionally comprises a further swirler **350** disposed within the further air passageway **350**. The further swirler **350** is located within the further outlet region **354**. As shown in FIG. **7**, the further swirler **350** comprises a plurality of further swirler vanes **352**, **354**. Each further swirler vane **352**, **354** is configured to redirect air conveyed by the further air passageway **350** in use so as to increase a velocity of air within the further air passageway **350** in a circumferential direction of the further air passageway **350**. In particular, each further swirler vane **352**, **354** is substantially helical. This reduces the velocity of air within the further air passageway **350** parallel to the centreline D-D of the air passageway **350** (i.e., in the axial direction **402** of the fuel injector **300**). The further swirler **350** therefore promotes the formation of a recirculating low-speed eddy downstream of the further swirler **350**, which in turn promotes the formation of a further wake-stabilised region downstream of the further air passageway **350**. This promotes the stable combustion of fuel discharged at the fuel outlet **328** with air discharged at the further air outlet **358** downstream of the fuel injector **300** by reducing a fluid speed within the further wake-stabilised region and thereby reducing the likelihood of flame blow-out or blow-off as a result of flame lift-off with respect to the fuel injector **300**.

[0065] Although it has been described that the cross-sectional profile of the inlet region **312** and the further inlet region **352** are circular, this need not be the case. By way of example, the cross-sectional profile of the inlet region **312** and/or the further inlet region **352** could instead be oval or elliptical.

[0066] Although it has been described that the fuel injector **300** comprises an outer body **311** that defines a further air passageway **350**, in alternative embodiments the outer body **311** and/or further air passageway **350** may be omitted. In addition, while it has been described that the fuel passageway **320** is annular, this need not be the case. In particular, it may be that the outer body **311** and/or the further air passageway **350** are omitted and the fuel passageway **320** is non-annular. Further, although FIG. **3** shows the fuel passageway **320** as extending in a direction generally along the principal rotational axis X-X of the gas turbine engine **10** (i.e., in an axial direction) such that the fuel outlet **328** injects fuel into the combustor head **200** in a direction parallel to the axial direction, this need not necessarily be the case. For instance, the outer body **311** and the further air passageway **350** may be omitted and the fuel passageway **320** may extend in a direction generally perpendicular to the principal rotational axis X-X of the gas turbine engine **10** (i.e., a radial direction) such that fuel outlet **328** injects fuel into the combustor head **200** in a direction parallel to the radial direction.

[0067] Although it has been described that the non-linear sectional profile of the inlet region **312** has a bellmouth

profile, in alternative embodiments the inlet region **312** may have any other profile in which the width of the inlet region **312** in a direction perpendicular to a centreline of the air passageway **310** decreases continuously from the air inlet **316** to the air passageway interface **313** along the centreline of the air passageway **310**. The inlet region **312** may have a parabolic profile. That is, the cross-sectional profile of the inlet region **312** on a plane coplanar with the centreline D-D of the air passageway **310** may be parabolic. The same applies, mutatis mutandis, to the further inlet region **352**. That is, the further inlet region **352** may have a parabolic profile in which the cross-sectional profile of the further inlet region **352** on a plane coplanar with the centreline D-D of the air passageway **310** is parabolic.

[0068] It will be understood that the disclosure is not limited to the examples above-described and various modifications and improvements can be made without departing from the concepts described herein. Except where mutually exclusive, any of the features may be employed separately or in combination with any other features and the disclosure extends to and includes all combinations and sub-combinations of one or more features described herein. The scope of protection is defined by the appended claims.

What is claimed is:

1. A fuel injector for a gas turbine engine, the fuel injector comprising:

an air passageway having an inlet region and an outlet region in fluid communication with the inlet region at an air passageway interface, the inlet region being configured to receive a flow of air from a compressor of the gas turbine engine at an air inlet, the outlet region being configured to receive the flow of air from the inlet region via the air passageway interface and discharge the flow of air to a combustor head of the gas turbine engine; and

a fuel passageway having a fuel outlet configured to discharge a flow of fuel into the combustor head,

wherein a width of the inlet region in a direction perpendicular to a centreline of the air passageway decreases continuously from the air inlet to the air passageway interface along the centreline of the air passageway.

2. The fuel injector of claim **1**, wherein the width of the inlet region decreases non-linearly from the air inlet to the air passageway interface.

3. The fuel injector of claim **1**, wherein a cross-sectional profile of the inlet region on a plane perpendicular to the centreline of the air passageway is circular, and wherein a diameter of the inlet region decreases continuously from the air inlet to the air passageway interface.

4. The fuel injector of claim **3**, wherein a ratio of a difference between the diameter of the inlet region at the air inlet and the diameter of the inlet region at the air passageway interface to the diameter of the inlet region at the air passageway interface is equal to or greater than 0.5.

5. The fuel injector of claim **4**, wherein the ratio of the difference between the diameter of the inlet region at the air inlet and the diameter of the inlet region at the air passageway interface to the diameter of the inlet region at the air passageway interface is equal to or greater than 1.

6. The fuel injector of claim **1**, wherein the inlet region is in the form of a bellmouth.

7. The fuel injector of claim **1**, wherein the cross-sectional area of the inlet region decreases linearly from the air inlet to the air passageway interface.

8. The fuel injector of claim **1**, wherein a cross-sectional profile of the inlet region on a plane coplanar with the centreline of the air passageway is parabolic.

9. The fuel injector of claim **1**, comprising a swirler disposed within the air passageway, the swirler including a plurality of vanes configured to increase a component of a velocity of air within the air passageway in a circumferential direction of the air passageway.

10. The fuel injector of claim **9**, wherein the plurality of vanes are radially disposed around a deflection body, the deflection body being configured to direct air within the air passageway toward the plurality of vanes.

11. The fuel injector of claim **1**, comprising:

a further air passageway disposed around the fuel passageway and having a further inlet region and a further outlet region in fluid communication with the further inlet region at a further air passageway interface, the further inlet region being configured to receive a further flow of air from the compressor of the gas turbine engine at a further air inlet, the further outlet region being configured to receive the further flow of air from the further inlet region via the further air passageway interface and discharge the further flow of air to the combustor head of the gas turbine engine,

wherein a width of the further inlet region in a direction perpendicular to the centreline of the air passageway decreases continuously from the further air inlet to the further air passageway interface along the centreline of the air passageway.

12. The fuel injector of claim **11**, wherein the width of the further inlet region decreases non-linearly from the further air inlet to the further air passageway interface.

13. The fuel injector of claim **12**, wherein a ratio of a difference between the diameter of the further inlet region at the further air inlet and the diameter of the further inlet region at the further air passageway interface to the diameter of the further inlet region at the further air passageway interface is equal to or greater than 0.5.

14. The fuel injector of claim **13**, wherein the ratio of the diameter of the further inlet region at the further air inlet and the diameter of the further inlet region at the further air passageway interface to the diameter of the further inlet region at the further air passageway interface is equal to or greater than 1.

15. The fuel injector of claim **11**, wherein the cross-sectional profile of the further inlet region on a plane perpendicular to the centreline of the air passageway is circular, and wherein a diameter of the further inlet region decreases continuously from the further air inlet o the further air passageway interface.

16. The fuel injector of claim **11**, comprising a further swirler disposed within the further air passageway, the further swirler including a plurality of further vanes configured to increase a component of a velocity of air within the further air passageway in a circumferential direction of the further air passageway.

17. The fuel injector of claim **1**, wherein at least one of the air inlet is defined by an end face of the fuel injector or the further air inlet is defined by an end face of a body defining the further air passageway.

18. The fuel injector of claim **1**, wherein at least one of the air passageway is cylindrical at the air passageway interface or the further air passageway is cylindrical at the further air passageway interface.

19. A combustion apparatus comprising the fuel injector of claim **1**, and a combustor head configured to:

receive air from the air outlet;

receive fuel from the fuel outlet; and

facilitate mixing and atomisation of fuel received from the fuel outlet with air received from the air outlet.

20. A gas turbine engine for an aircraft, the gas turbine engine comprising:

the fuel injector of claim **1**.

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