

(19)



(11)

EP 4 321 805 A1

(12)

EUROPEAN PATENT APPLICATION

(43) Date of publication:
14.02.2024 Bulletin 2024/07

(51) International Patent Classification (IPC):
F23R 3/14 (2006.01) **F23R 3/16** (2006.01)
F23R 3/28 (2006.01)

(21) Application number: **23184348.3**

(52) Cooperative Patent Classification (CPC):
F23R 3/14; F23R 3/16; F23R 3/286

(22) Date of filing: **10.07.2023**

(84) Designated Contracting States:
**AL AT BE BG CH CY CZ DE DK EE ES FI FR GB
GR HR HU IE IS IT LI LT LU LV MC ME MK MT NL
NO PL PT RO RS SE SI SK SM TR**
Designated Extension States:
BA
Designated Validation States:
KH MA MD TN

(71) Applicant: **Rolls-Royce plc**
London N1 9FX (GB)

(72) Inventor: **Harding, Stephen**
Derby, DE24 8BJ (GB)

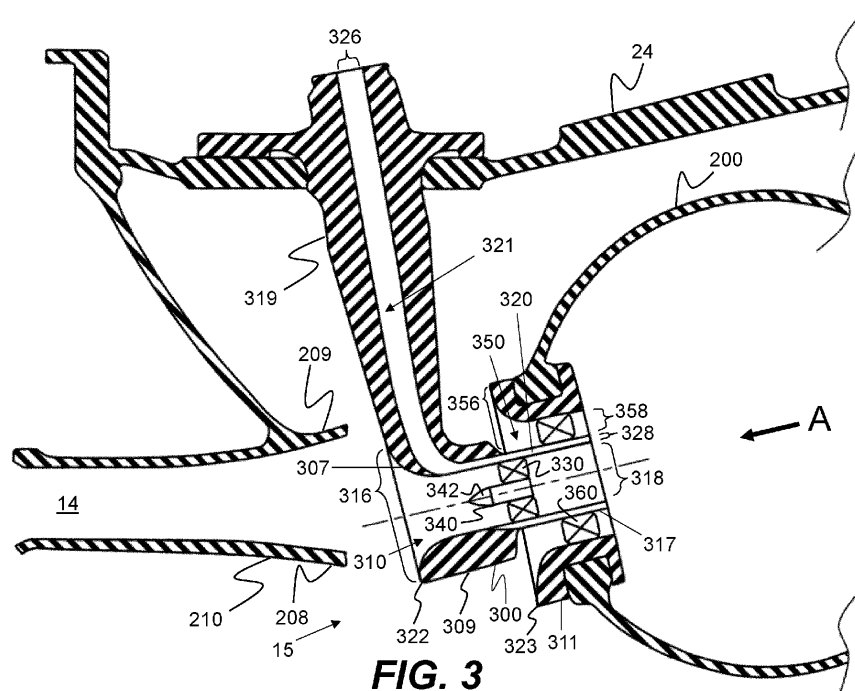
(74) Representative: **Rolls-Royce plc**
Intellectual Property Dept SinA-48
PO Box 31
Derby DE24 8BJ (GB)

(30) Priority: **10.08.2022 GB 202211656**

(54) FUEL INJECTOR

(57) There is described a fuel injector 300 for a gas turbine engine 10. The fuel injector 300 comprises an air passageway 310 having an inlet region 312 and an outlet region 314 in fluid communication with the inlet region 312 at an air passageway interface 313, the inlet region 312 being configured to receive a flow of air from a compressor 14 of the gas turbine engine 10 at an air inlet 316, the outlet region 314 being configured to receive the flow of air from the inlet region 312 via the air pas-

sageway interface 313 and discharge the flow of air to a combustor head 200 of the gas turbine engine 10. The fuel injector 300 also comprises a fuel passageway 320 having a fuel outlet 328 configured to discharge a flow of fuel into the combustor head 200. A 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.

**FIG. 3****EP 4 321 805 A1**

Description

FIELD OF THE DISCLOSURE

[0001] The present disclosure relates to a fuel injector for a gas turbine engine.

BACKGROUND

[0002] 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.

[0003] 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

[0004] 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.

[0005] 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.

[0006] 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.

[0007] 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.

[0008] 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.

[0009] The width of the further inlet region may decrease non-linearly from the further air inlet to the further air passageway interface.

[0010] 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.

[0011] 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.

[0012] 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.

[0013] 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.

[0014] 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.

[0015] The air passageway may be cylindrical at the air passageway interface. The further air passageway may be cylindrical at the further air passageway interface.

[0016] 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.

[0017] 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.

BRIEF DESCRIPTION OF THE DRAWINGS

[0018] Embodiments will now be described by way of example and with reference to the accompanying drawings, in which:

Figure 1 is a plan view of an aircraft comprising a gas turbine engine;

Figure 2 is a cross-sectional side view of the gas turbine engine;

Figure 3 is a cross-sectional side view of a combustion apparatus of the gas turbine engine comprising a fuel injector and a combustor head;

Figure 4A is a simplified rear view of the combustion apparatus;

Figure 4B is a simplified rear view of an alternative combustion apparatus;

Figure 5 is a close-up cross-sectional side view of the fuel injector of Figure 3;

Figure 6 is a front view of the fuel injector; and

Figure 7 is a cross-sectional front view of the fuel injector.

DETAILED DESCRIPTION

[0019] Figure 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 Figure 2. The aircraft 100 may comprise any number of gas turbine engines 10.

[0020] Figure 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.

[0021] 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.

[0022] 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 Figure 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.

[0023] Figure 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 Figure 2, with like reference signs indicating common or similar features. The combustion apparatus 15 comprises a fuel injector 300

and a combustor head 200.

[0024] 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.

[0025] 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 passageway 320 is fluidically connected to the supply passageway 321 such that the fuel inlet 326 and the fuel outlet 328 are fluidically connected.

[0026] 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.

[0027] 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 outlet 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.

[0028] The combustion apparatus 15 is now described in further detail with reference to **Figure 4A**, which shows a rear view of the combustion apparatus 15 viewed from the direction indicated by arrow A on Figure 3. Figure 4A shows the profile of the pre-diffuser 210 in phantom as projected through the combustor head 200 or seen through the fuel injector 300.

[0029] 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 Figure 4A for clarity, however it will be appreciated that the structure shown in Figure 4A may extend around the entirety of the principal rotation axis X-X of the gas turbine engine 10.

[0030] 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 Figure 4A).

[0031] In the example of Figure 4A, 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 Figure 4A 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.

[0032] Figure 4B 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.

[0033] However, in contrast to the combustion apparatus 15 described above with reference to Figure 4A, the narrow portions 212 of the pre-diffuser 210 of the alternative combustion apparatus shown in Figure 4B 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 Figure 4B 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.

[0034] Figure 5 shows a detailed cross-sectional side view of the fuel injector 300. Figure 6 shows a simplified (i.e., schematic) front view of the fuel injector 300 as viewed in the direction indicated by arrow B on Figure 5. Figure 7 shows a simplified (i.e., schematic) sectional front view of the example fuel injector 300 along section C-C indicated in Figure 5.

[0035] 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 Figure 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 Figure 5) at the air outlet 318.

[0036] 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 Figures 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.

[0037] 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.

[0038] The specific case of the diameter 315 of the inlet region 312 at the air inlet 316 is denoted by d_1 in Figure 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 Figure 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, $(d_1 - d_2)/d_2$, may be at least equal to or greater than 0.5. It will be appreciated that Figure 6 is not to scale, and so the relative dimensional proportions of d_1 and d_2 as shown in Figure 6 are not indicative of preferable relative dimensional proportions of d_1 and d_2 .

[0039] As best shown in Figure 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.

[0040] 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.

[0041] 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.

[0042] 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 Figure 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.

[0043] 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.

[0044] 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 Figures 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.

[0045] 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 re-

duces 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.

[0046] 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 Figure 5, the entirety of the further outlet region 354 is cylindrical, however it will be appreciated that this need not be the case.

[0047] 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.

[0048] 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.

[0049] 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.

[0050] 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 Figure 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 Figure 7. As with Figure 6, it will be appreciated that Figure 7 is not to scale, and so the relative dimensional proportions of d_3 and d_4 as shown in Figure 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.

[0051] 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 Figure 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.

[0052] 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.

[0053] 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.

[0054] 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 Figure 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.

[0055] 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.

[0056] 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 Figure 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.

[0057] 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.

[0058] 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 Figure 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.

[0059] 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.

[0060] It will be understood that the invention 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.

Claims

1. A fuel injector (300) for a gas turbine engine (10), the fuel injector (300) comprising:

an air passageway (310) having an inlet region (312) and an outlet region (314) in fluid communication with the inlet region (312) at an air passageway interface (313), the inlet region (312) being configured to receive a flow of air from a compressor (14) of the gas turbine engine (10) at an air inlet (316), the outlet region (314) being configured to receive the flow of air from the inlet region (312) via the air passageway interface (313) and discharge the flow of air to a combustor head (200) of the gas turbine engine (10); and a fuel passageway (320) having a fuel outlet (328) configured to discharge a flow of fuel into the combustor head (200), wherein a width (315) of the inlet region (312) in a direction perpendicular to a centreline (D-D) of the air passageway (310) decreases continuously from the air inlet (316) to the air passageway interface (313) along the centreline (D-D) of the air passageway (310).

2. The fuel injector (300) of Claim 1, wherein the width (315) of the inlet region (312) decreases non-linearly from the air inlet (316) to the air passageway interface (313).
3. The fuel injector (300) of any one of the preceding claims, wherein a cross-sectional profile of the inlet region (312) on a plane perpendicular to the centreline (D-D) of the air passageway (310) is circular, and wherein a diameter (315) of the inlet region (312) decreases continuously from the air inlet (316) to the air passageway interface (313).
4. The fuel injector (300) of any one of the preceding claims, wherein the inlet region (312) is in the form of a bellmouth.
5. The fuel injector (300) of any one of the preceding

claims, wherein the cross-sectional area of the inlet region (312) decreases linearly from the air inlet (316) to the air passageway interface (313).

6. The fuel injector (300) of any one of the preceding claims, wherein a cross-sectional profile of the inlet region (312) on a plane coplanar with the centreline (D-D) of the air passageway (310) is parabolic.
7. The fuel injector (300) of any one of Claims 3 to 6, wherein a ratio of a 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) is equal to or greater than 0.5.
8. The fuel injector (300) of Claim 7, wherein 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) is equal to or greater than 1.
9. The fuel injector (300) of any one of the preceding claims, comprising a swirler (330) disposed within the air passageway (310), the swirler (330) including a plurality of vanes (332, 334) configured to increase a component of a velocity of air within the air passageway (310) in a circumferential direction (406) of the air passageway (310).
10. The fuel injector (300) of Claim 9, wherein the plurality of vanes (332, 334) are radially disposed around a deflection body (340), the deflection body (340) being configured to direct air within the air passageway (310) toward the plurality of vanes (332, 334).
11. The fuel injector (300) of any one of the preceding claims, comprising:

a further air passageway (350) disposed around the fuel passageway (320) and having a further inlet region (352) and a further outlet region (354) in fluid communication with the further inlet region (352) at a further air passageway interface (353), the further inlet region (352) being configured to receive a further flow of air from the compressor (14) of the gas turbine engine at a further air inlet (356), the further outlet region (354) being configured to receive the further flow of air from the further inlet region (352) via the further air passageway interface (353) and discharge the further flow of air to the combustor head (200) of the gas turbine engine (10), wherein a width (316) of the further inlet region

(352) in a direction perpendicular to the centreline (D-D) of the air passageway (310) decreases continuously from the further air inlet (356) to the further air passageway interface (353) along the centreline (D-D) of the air passageway (310). 5

12. The fuel injector (300) of Claim 11, wherein the width (316) of the further inlet region (352) decreases non-linearly from the further air inlet (356) to the further air passageway interface (353). 10

13. The fuel injector (300) of Claim 11 or Claim 12, wherein the cross-sectional profile of the further inlet region (352) on a plane perpendicular to the centreline (D-D) of the air passageway (310) is circular, and wherein a diameter (315) of the further inlet region (352) decreases continuously from the further air inlet (356) to the further air passageway interface (353). 15 20

14. The fuel injector (300) of Claim 12 or Claim 13, wherein 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) is equal to or greater than 0.5. 25 30

15. The fuel injector (300) of Claim 14, wherein the ratio of 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) is equal to or greater than 1. 35 40

40

45

50

55

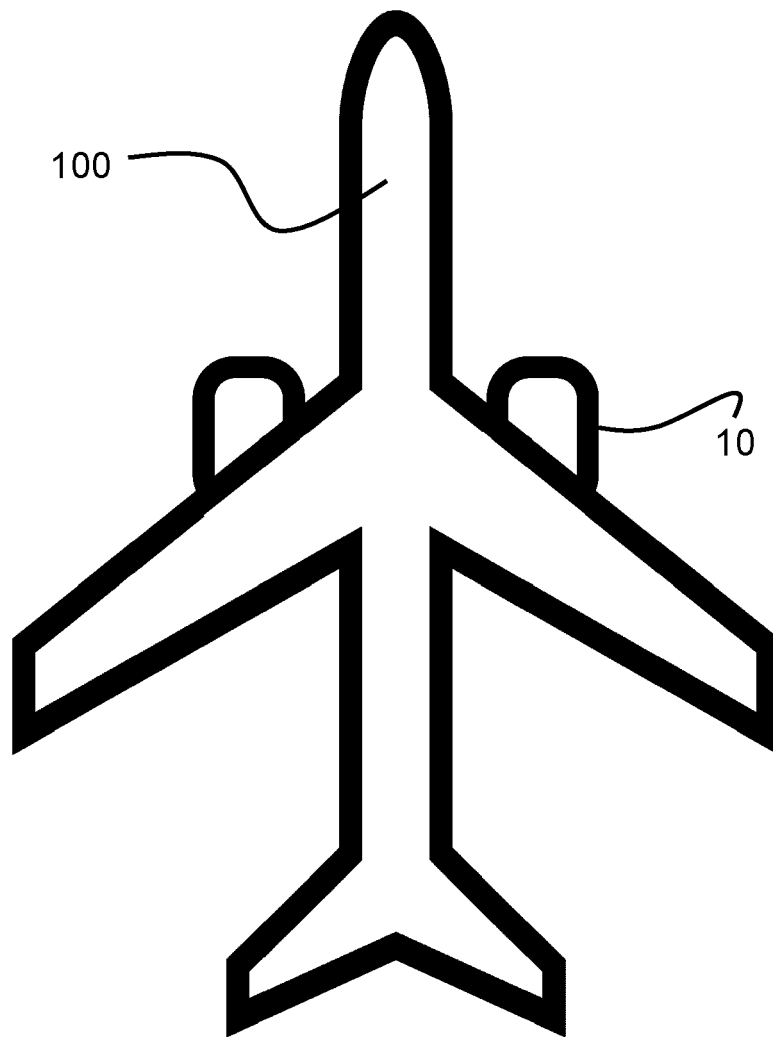


FIG. 1

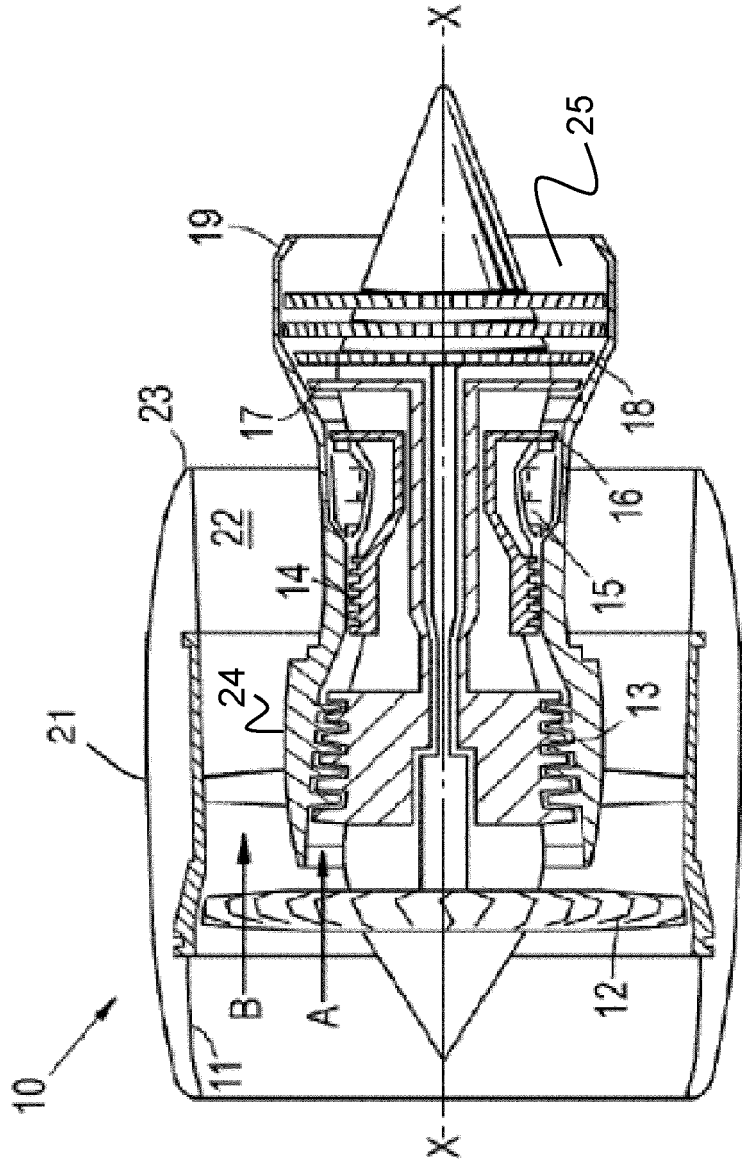


FIG. 2

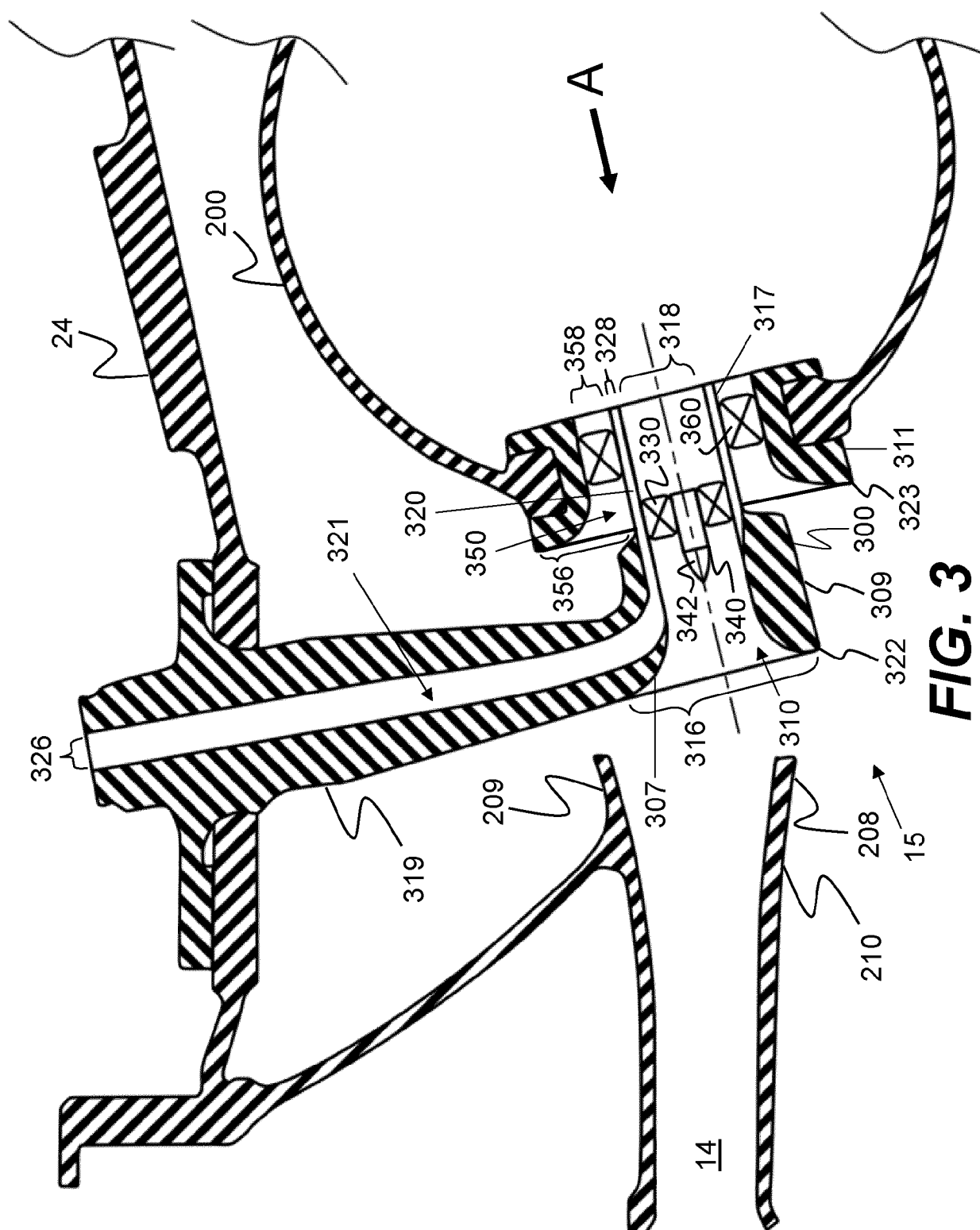
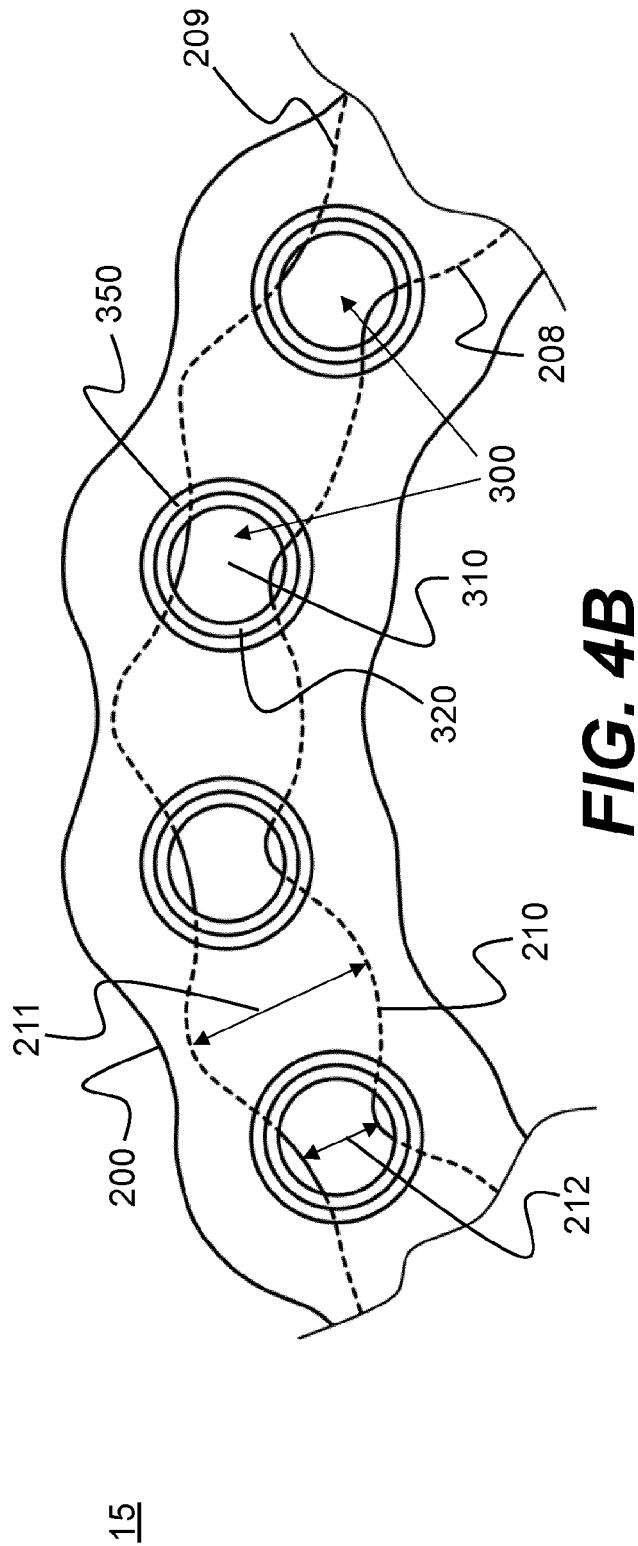
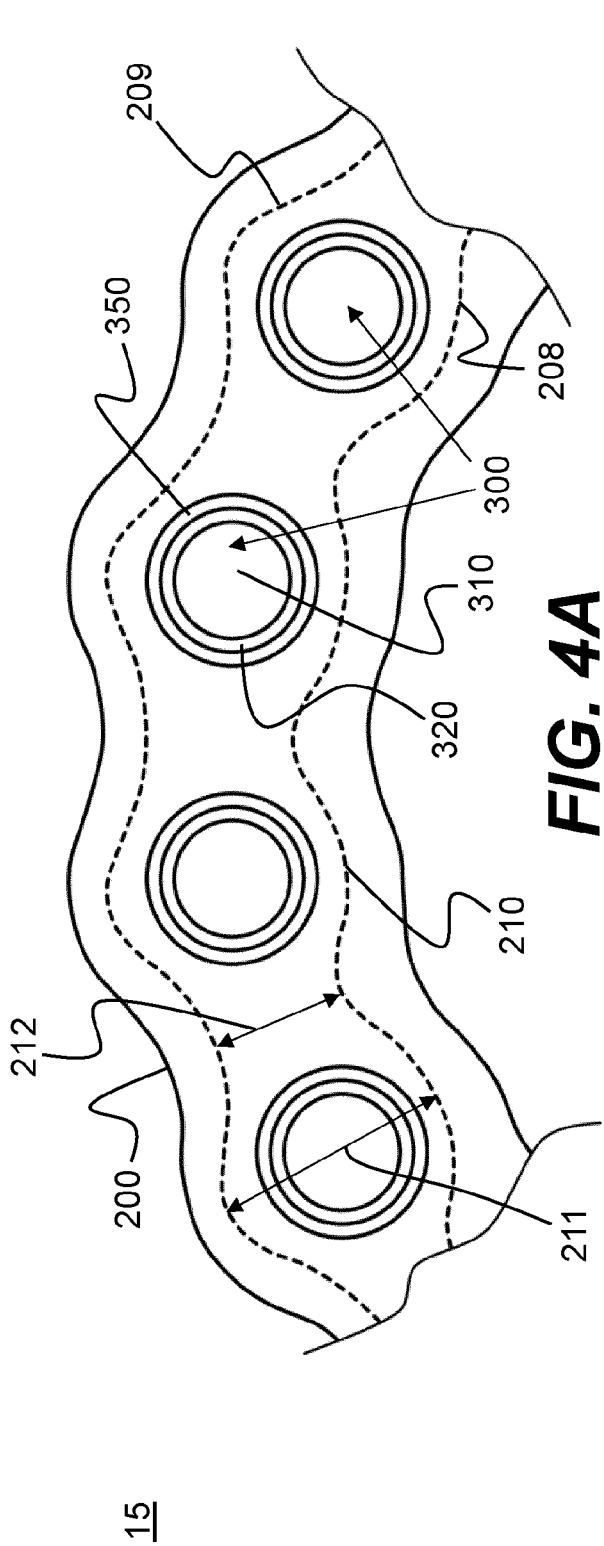


FIG. 3



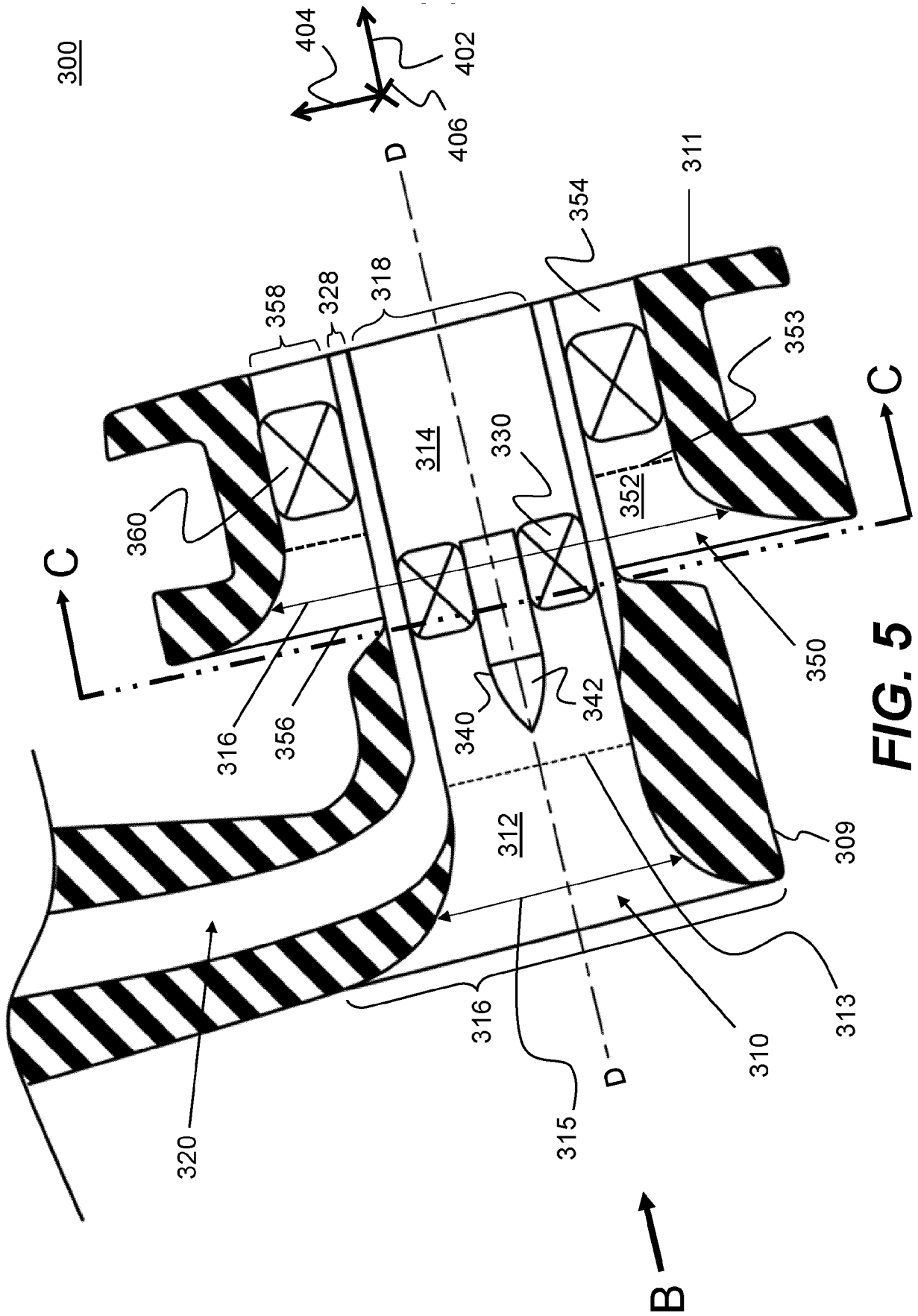


FIG. 5

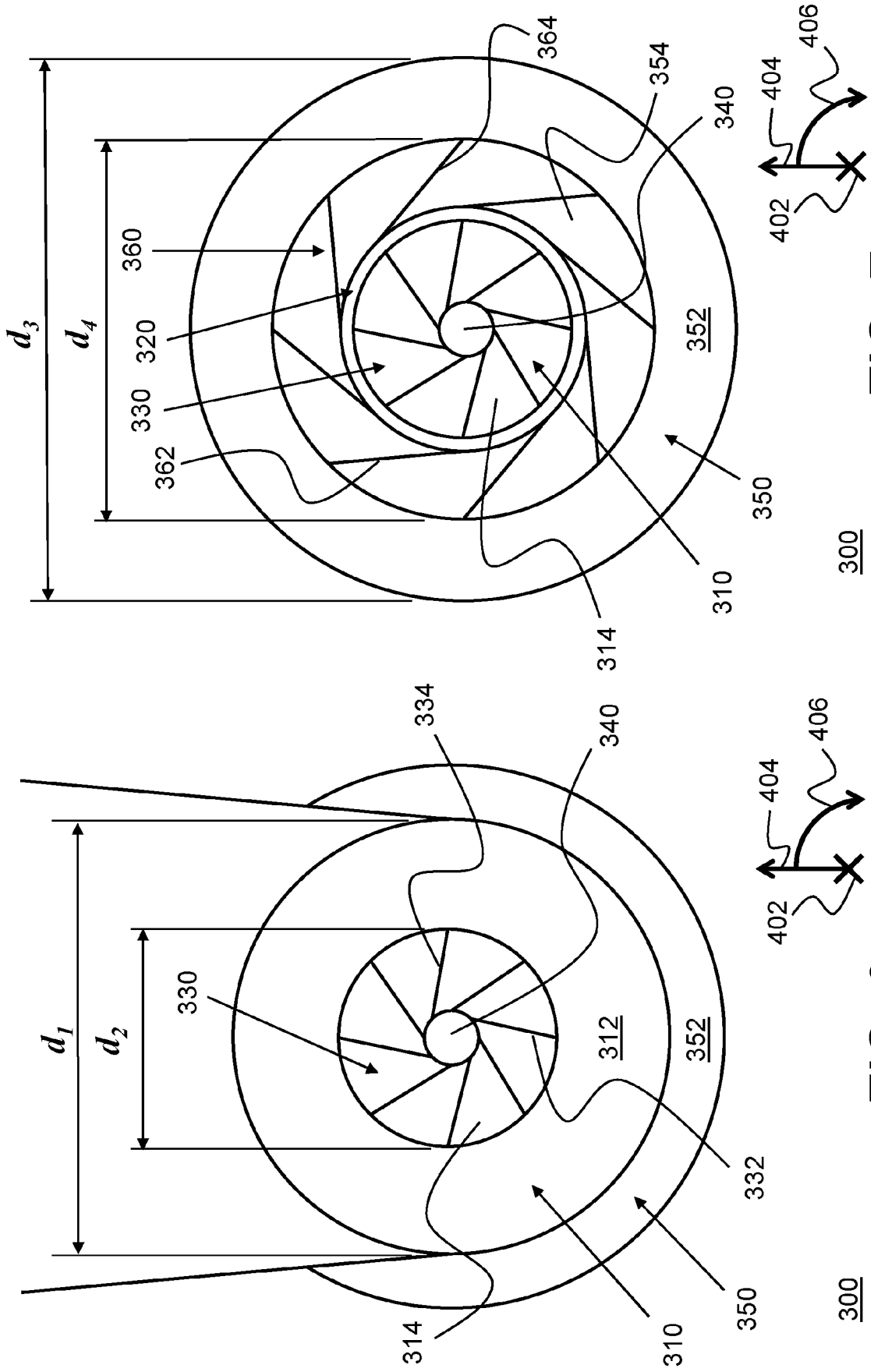


FIG. 7

FIG. 6



EUROPEAN SEARCH REPORT

Application Number

EP 23 18 4348

5

10

15

20

25

30

35

40

45

50

55

1

EPO FORM 1503 03:82 (P04C01)

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	US 4 977 740 A (MADDEN THOMAS J [US] ET AL) 18 December 1990 (1990-12-18) * column 4, line 60 - column 5, line 44; figures 2,3 *	1,3,5,9,10	INV. F23R3/14 F23R3/16 F23R3/28
X	US 5 102 054 A (HALVORSEN ROBERT M [US]) 7 April 1992 (1992-04-07) * column 3, line 25 - line 50; figures 1,2 *	1,3,5,7-11,13	
X	US 2017/082288 A1 (RYON JASON A [US] ET AL) 23 March 2017 (2017-03-23) * paragraphs [0019] - [0021], [0024]; figures 3-5 *	1,2,4,6-10	
X	US 2020/139390 A1 (THOMSON NEAL [US] ET AL) 7 May 2020 (2020-05-07) * paragraph [0050] - paragraph [0052]; figure 8 *	1-4,6,7,9-11,13	
X	US 4 773 596 A (WRIGHT RICHARD R [US] ET AL) 27 September 1988 (1988-09-27) * column 2, line 9 - line 18; figure 1 *	1-4,8,9,11,13-15	TECHNICAL FIELDS SEARCHED (IPC) F23R
X	US 2010/186412 A1 (STEVENSON CHRISTIAN XAVIER [US] ET AL) 29 July 2010 (2010-07-29) * paragraphs [0016] - [0020]; figure 6 *	1-4,7,8,11-15	
X	US 2021/372622 A1 (DAI ZHONGTAO [US] ET AL) 2 December 2021 (2021-12-02) * paragraph [0068] - paragraph [0072]; figure 5 *	1,4,9-12	
The present search report has been drawn up for all claims			
Place of search The Hague		Date of completion of the search 27 November 2023	Examiner Mougey, Maurice
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document		T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document	

**ANNEX TO THE EUROPEAN SEARCH REPORT
ON EUROPEAN PATENT APPLICATION NO.**

EP 23 18 4348

5

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

27-11-2023

10

15

20

25

30

35

40

45

50

55

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 4977740 A	18-12-1990	FR 2648184 A1	14-12-1990
		GB 2232479 A	12-12-1990
		US 4977740 A	18-12-1990
US 5102054 A	07-04-1992	NONE	
US 2017082288 A1	23-03-2017	EP 3144594 A1	22-03-2017
		US 2017082288 A1	23-03-2017
US 2020139390 A1	07-05-2020	US 2020139390 A1	07-05-2020
		US 2021197218 A1	01-07-2021
US 4773596 A	27-09-1988	CA 1280611 C	26-02-1991
		EP 0286569 A2	12-10-1988
		JP 2866960 B2	08-03-1999
		JP S63255528 A	21-10-1988
		US 4773596 A	27-09-1988
US 2010186412 A1	29-07-2010	CN 101788149 A	28-07-2010
		EP 2211096 A2	28-07-2010
		JP 5572366 B2	13-08-2014
		JP 2010175237 A	12-08-2010
		US 2010186412 A1	29-07-2010
US 2021372622 A1	02-12-2021	EP 3333485 A2	13-06-2018
		EP 4047274 A2	24-08-2022
		US 2018156464 A1	07-06-2018
		US 2021372622 A1	02-12-2021