

(19)



(11)

EP 4 530 532 A1

(12)

EUROPEAN PATENT APPLICATION

(43) Date of publication:
02.04.2025 Bulletin 2025/14

(51) International Patent Classification (IPC):
F23R 3/06 (2006.01) **F23R 3/34** (2006.01)
F23R 3/42 (2006.01) **F23R 3/50** (2006.01)

(21) Application number: **24191840.8**

(52) Cooperative Patent Classification (CPC):
F23R 3/346; F23R 3/06; F23R 3/42; F23R 3/50

(22) Date of filing: **30.07.2024**

(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:
GE KH MA MD TN

- **GANIGER, Ravindra Shankar**
Cincinnati, 45215-6301 (US)
- **NARASIMHAN SURESH, Sahana**
Cincinnati, 45215-6301 (US)
- **COOPER, Clayton**
Cincinnati, 45215-6301 (US)
- **BENJAMIN, Michael**
Cincinnati, 45215-6301 (US)
- **WISE, Steven**
Cincinnati, 45215-6301 (US)
- **MOHAN, Sripathi**
Cincinnati, 45215-6301 (US)
- **NATH, Hiranya Kumar**
Cincinnati, 45215-6301 (US)

(30) Priority: **28.09.2023 US 202318476595**

(71) Applicant: **General Electric Company**
Cincinnati, Ohio 45215-6301 (US)

(72) Inventors:
• **NAIK, Pradeep**
Cincinnati, 45215-6301 (US)
• **VUKANTI, Perumallu**
Cincinnati, 45215-6301 (US)

(74) Representative: **Openshaw & Co.**
8 Castle Street
Farnham, Surrey GU9 7HR (GB)

(54) **COMBUSTION SECTION WITH A PRIMARY COMBUSTOR AND A SET OF SECONDARY COMBUSTORS**

(57) A turbine engine (10) with a compressor section (12), a combustion section (14, 114, 214, 314, 414, 514), and a turbine section (16) in serial flow arrangement along an engine centerline (20, 320, 420). The combustion section (14, 114, 214, 314, 414, 514) includes a primary combustor liner (38, 138, 238, 338, 438) including an inner liner (42, 342, 442) and an outer liner (40, 240, 340, 440). A dome wall (44, 344, 444) and a primary

dome inlet (66) are located in the dome wall (44, 344, 444). At least one opening (57, 357, 457) located in the outer liner (40, 240, 340, 440) downstream from the primary dome inlet (66). A primary combustion chamber (46, 346, 446, 546) and a set of secondary combustors (50, 150, 250, 350, 450, 550) are fluidly coupled to the primary combustion chamber (46, 346, 446, 546) at the at least one opening (57, 357, 457).

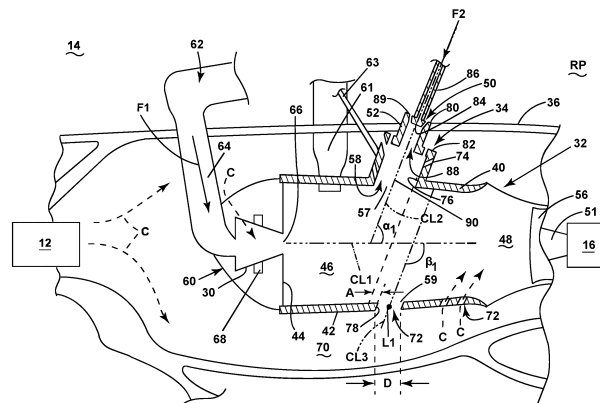


FIG. 3

EP 4 530 532 A1

Description

TECHNICAL FIELD

[0001] The present subject matter relates generally to a combustion section of a turbine engine, and more specifically to a combustion section with a primary combustor and a secondary combustor.

BACKGROUND

[0002] Turbine engines are driven by a flow of combustion gases passing through the engine to rotate a multitude of turbine blades, which, in turn, rotate a compressor to provide compressed air to the combustor for combustion. A combustor can be provided within the turbine engine and is fluidly coupled with a turbine into which the combusted gases flow.

[0003] The use of hydrocarbon fuels in the combustor of a turbine engine is known. Generally, air and fuel are fed to a combustion chamber, the air and fuel are mixed, and then the fuel is burned in the presence of the air to produce hot gas. The hot gas is then fed to a turbine where it cools and expands to produce power. By-products of the fuel combustion typically include environmentally unwanted by-products, such as nitrogen oxide and nitrogen dioxide (collectively called NO_x), carbon monoxide (CO), unburned hydrocarbons (UHC) (e.g., methane and volatile organic compounds that contribute to the formation of atmospheric ozone), and other oxides, including oxides of sulfur (e.g., SO₂ and SO₃).

[0004] Varieties of fuel for use in combustion turbine engines are being explored. Hydrogen or hydrogen mixed with another element or compound can be used for combustion. However, hydrogen or a hydrogen mixed fuel can result in a higher flame temperature than traditional fuels. That is, hydrogen or a hydrogen mixed fuel typically has a wider flammable range and a faster burning velocity than traditional fuels such as petroleum-based fuels, or petroleum and synthetic fuel blends.

[0005] Standards stemming from air pollution concerns worldwide regulate the emission of NO_x, UHC, and CO generated as a result of the turbine engine operation. In particular, NO_x is formed within the combustor as a result of high combustor flame temperatures during operation. It is desirable to decrease NO_x emissions while still maintaining desirable efficiencies by regulating the temperature profile and or flame pattern within the combustor.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] In the drawings:

FIG. 1 is a schematic of a turbine engine.

FIG. 2 depicts a cross-sectional view along line II-II of FIG. 1 of a combustion section of the turbine engine with a set of secondary combustors.

FIG. 3 is a cross-sectional view taken along line III-III of FIG. 2 of a combustor with a dilution opening and in the combustion section and a mini combustor from the set of secondary combustors.

FIG. 4 is the same cross-sectional view of FIG. 3 illustrating an interaction of a primary fuel/air mixture and primary exhaust gasses, a secondary fuel/air mixture and secondary exhaust gasses, and a dilution flow.

FIG. 5 is a schematic of multiple orientations for the mini combustor and for the dilution opening including the orientation from FIG. 3.

FIG. 6 is another embodiment of the combustion section from FIG. 4 according to another aspect of the disclosure herein.

FIG. 7 is another embodiment of the combustion section from FIG. 4 according to yet another aspect of the disclosure herein.

FIG. 8 is another embodiment of the combustion section from FIG. 2 according to yet another aspect of the disclosure herein.

FIG. 9 is another embodiment of the combustion section from FIG. 2 according to yet another aspect of the disclosure herein.

FIG. 10 is another embodiment of the combustion section from FIG. 2 according to yet another aspect of the disclosure herein.

FIG. 11 is a cross-sectional view of the mini combustor taken along line XI-XI of FIG. 10 illustrating a shape of the mini combustor according to an aspect of the disclosure herein.

FIG. 12 is another embodiment of the mini combustor from FIG. 11 illustrating an alternate shape of the mini combustor according to another aspect of the disclosure herein.

FIG. 13 is another embodiment of the mini combustor from FIG. 11 illustrating another alternate shape of the mini combustor according to yet another aspect of the disclosure herein.

FIG. 14 is another embodiment of the mini combustor from FIG. 11 illustrating yet another alternate shape of the mini combustor according to another aspect of the disclosure herein.

DETAILED DESCRIPTION

[0007] Aspects of the disclosure described herein are directed to a combustion section, and in particular, a combustion section with a primary combustor and a secondary combustor, where the primary combustor includes a set of dilution openings. For purposes of illustration, the present disclosure will be described with respect to a turbine engine. It will be understood, however, that aspects of the disclosure described herein are not so limited and that a combustion section as described herein can be implemented in engines, including but not limited to turbojet, turboprop, turboshaft, and turbofan engines. Aspects of the disclosure discussed herein may

have general applicability within non-aircraft engines having a combustor, such as other mobile applications and non-mobile industrial, commercial, and residential applications.

[0008] The word "exemplary" is used herein to mean "serving as an example, instance, or illustration." Any implementation described herein as "exemplary" is not necessarily to be construed as preferred or advantageous over other implementations. Additionally, unless specifically identified otherwise, all embodiments described herein should be considered exemplary.

[0009] As used herein, the terms "first", "second", and "third" may be used interchangeably to distinguish one component from another and are not intended to signify location or importance of the individual components.

[0010] The terms "forward" and "aft" refer to relative positions within a gas turbine engine or vehicle, and refer to the normal operational attitude of the gas turbine engine or vehicle. For example, with regard to a gas turbine engine, forward refers to a position closer to an engine inlet and aft refers to a position closer to an engine nozzle or exhaust.

[0011] As used herein, the term "upstream" refers to a direction that is opposite the fluid flow direction, and the term "downstream" refers to a direction that is in the same direction as the fluid flow. The term "fore" or "forward" means in front of something and "aft" or "rearward" means behind something. For example, when used in terms of fluid flow, fore/forward can mean upstream and aft/rearward can mean downstream.

[0012] The term "fluid" may be a gas or a liquid. The terms "fluidly couples" and "fluidly coupled" mean that a fluid is capable of making the connection between the areas specified.

[0013] Additionally, as used herein, the terms "radial" or "radially" refer to a direction away from a common center. For example, in the overall context of a turbine engine, radial refers to a direction along a ray extending between a center longitudinal axis of the engine and an outer engine circumference.

[0014] All directional references (e.g., radial, axial, proximal, distal, upper, lower, upward, downward, left, right, lateral, front, back, top, bottom, above, below, vertical, horizontal, clockwise, counterclockwise, upstream, downstream, forward, aft, etc.) may be used for identification purposes to aid the reader's understanding of the present disclosure, and do not create limitations, particularly as to the position, orientation, or use of aspects of the disclosure described herein. Connection references (e.g., attached, coupled, connected, and joined) may be used and are to be construed broadly and can include intermediate structural elements between a collection of elements and relative movement between elements unless otherwise indicated. As such, connection references do not necessarily infer that two elements are directly connected and in fixed relation to one another. The exemplary drawings are for purposes of illustration only the dimensions, positions, order and

relative sizes reflected in the drawings attached hereto can vary.

[0015] The singular forms "a", "an", and "the" include plural references unless the context clearly dictates otherwise. Furthermore, as used herein, the term "set" or a "set" of elements can be any number of elements, including only one.

[0016] Approximating language, as used herein throughout the specification and claims, is applied to modify any quantitative representation that could permissibly vary without resulting in a change in the basic function to which it is related. Accordingly, a value modified by a term or terms, such as "about", "approximately", "generally", and "substantially", are not to be limited to the precise value specified. In at least some instances, the approximating language may correspond to the precision of an instrument for measuring the value, or the precision of the methods or machines for constructing or manufacturing the components and/or systems. In at least some instances, the approximating language may correspond to the precision of an instrument for measuring the value, or the precision of the methods or machines for constructing or manufacturing the components and/or systems. For example, the approximating language may refer to being within a 1, 2, 4, 5, 10, 15, or 20 percent margin in either individual values, range(s) of values and/or endpoints defining range(s) of values. Here and throughout the specification and claims, range limitations are combined and interchanged, such ranges are identified and include all the sub-ranges contained therein unless context or language indicates otherwise. For example, all ranges disclosed herein are inclusive of the endpoints, and the endpoints are independently combinable with each other.

[0017] FIG. 1 is a schematic view of a turbine engine 10. As a non-limiting example, the turbine engine 10 can be used within an aircraft. The turbine engine 10 can include, at least, a compressor section 12, a combustion section 14, and a turbine section 16. A drive shaft 18 rotationally couples the compressor section 12 and the turbine section 16, such that rotation of one affects the rotation of the other, and defines a rotational axis or centerline 20 for the turbine engine 10.

[0018] The compressor section 12 can include a low-pressure (LP) compressor 22, and a high-pressure (HP) compressor 24 serially fluidly coupled to one another. The turbine section 16 can include an LP turbine 28, and an HP turbine 26 serially fluidly coupled to one another. The drive shaft 18 can operatively couple the LP compressor 22, the HP compressor 24, the LP turbine 28 and the HP turbine 26 together. Alternatively, the drive shaft 18 can include an LP drive shaft (not illustrated) and an HP drive shaft (not illustrated). The LP drive shaft can couple the LP compressor 22 to the LP turbine 28, and the HP drive shaft can couple the HP compressor 24 to the HP turbine 26. An LP spool can be defined as the combination of the LP compressor 22, the LP turbine 28, and the LP drive shaft such that the rotation of the LP turbine

28 can apply a driving force to the LP drive shaft, which in turn can rotate the LP compressor 22. An HP spool can be defined as the combination of the HP compressor 24, the HP turbine 26, and the HP drive shaft such that the rotation of the HP turbine 26 can apply a driving force to the HP drive shaft which in turn can rotate the HP compressor 24.

[0019] The compressor section 12 can include a plurality of axially spaced stages. Each stage includes a set of circumferentially-spaced rotating blades and a set of circumferentially-spaced stationary vanes. The compressor blades for a stage of the compressor section 12 can be mounted to a disk, which is mounted to the drive shaft 18. Each set of blades for a given stage can have its own disk. The vanes of the compressor section 12 can be mounted to a casing which can extend circumferentially about the turbine engine 10. It will be appreciated that the representation of the compressor section 12 is merely schematic and that there can be any number of stages. Further, it is contemplated, that there can be any other number of components within the compressor section 12.

[0020] Similar to the compressor section 12, the turbine section 16 can include a plurality of axially spaced stages, with each stage having a set of circumferentially-spaced, rotating blades and a set of circumferentially-spaced, stationary vanes. The turbine blades for a stage of the turbine section 16 can be mounted to a disk which is mounted to the drive shaft 18. Each set of blades for a given stage can have its own disk. The vanes of the turbine section 16 can be mounted to the casing in a circumferential manner. It is noted that there can be any number of blades, vanes and turbine stages as the illustrated turbine section is merely a schematic representation. Further, it is contemplated that there can be any other number of components within the turbine section 16.

[0021] The combustion section 14 can be provided serially between the compressor section 12 and the turbine section 16. The combustion section 14 can be fluidly coupled to at least a portion of the compressor section 12 and the turbine section 16 such that the combustion section 14 at least partially fluidly couples the compressor section 12 to the turbine section 16. As a non-limiting example, the combustion section 14 can be fluidly coupled to the HP compressor 24 at an upstream end of the combustion section 14 and to the HP turbine 26 at a downstream end of the combustion section 14.

[0022] During operation of the turbine engine 10, ambient or atmospheric air is drawn into the compressor section 12 via a fan (not illustrated) upstream of the compressor section 12, where the air is compressed defining a pressurized air. The pressurized air can then flow into the combustion section 14 where the pressurized air is mixed with fuel and ignited, thereby generating combustion gases. Some work is extracted from these combustion gases by the HP turbine 26, which drives the HP compressor 24. The combustion gases are dis-

charged into the LP turbine 28, which extracts additional work to drive the LP compressor 22, and the exhaust gas is ultimately discharged from the turbine engine 10 via an exhaust section (not illustrated) downstream of the turbine section 16. The driving of the LP turbine 28 drives the LP spool to rotate the fan (not illustrated) and the LP compressor 22. The pressurized airflow and the combustion gases can together define a working airflow that flows through the fan, compressor section 12, combustion section 14, and turbine section 16 of the turbine engine 10.

[0023] FIG. 2 depicts a cross-sectional view of the combustion section 14 along line II-II of FIG. 1 defining a transverse plane (denoted "TP"). The combustion section 14 can include an annular arrangement of primary fuel injectors 30 disposed around the centerline 20 of the turbine engine 10. Each of the primary fuel injectors 30 are fluidly coupled to a primary combustor 32. It should be appreciated that the annular arrangement of fuel injectors can be one or a plurality of fuel injectors and one or more of the primary fuel injectors 30 can have different characteristics.

[0024] The primary combustor 32 can have a can, can-annular, or annular arrangement depending on the type of engine in which the primary combustor 32 is located. In a non-limiting example, an annular arrangement is illustrated and disposed within a casing 36. The primary combustor 32 is defined by a primary combustor liner 38 including an outer liner 40 and an inner liner 42 concentric with respect to each other and annular about the centerline 20. A dome wall T together with the primary combustor liner 38 define a primary combustion chamber 46 annular about the centerline 20.

[0025] The combustion section 14 further includes a circumferential arrangement of mini combustors 34 defining a set of secondary combustors 50. As used herein "mini" means that the component referenced with the term mini is smaller than the corresponding like component without the term mini (e.g., the mini combustor 34 is smaller than the primary combustor 32). Each mini combustor 34 in the set of secondary combustors 50 is defined by a secondary combustor liner 52 extending generally perpendicular from the primary combustor liner 38. The term "generally perpendicular" is defined as an angle equal to or between 85 degrees and 95 degrees. While illustrated as a 90-degree angle, it is contemplated that in a different and non-limiting example, that the secondary combustor liner 52 can extend from the primary combustor liner 38 at any angle.

[0026] The secondary combustor liner 52 defines at least a portion of a secondary combustion chamber 54 circumferentially spaced about the centerline 20. The set of secondary combustors 50 is fluidly coupled to the primary combustor 32 by at least one opening 57 extending through and defined by the outer liner 40. More specifically, the secondary combustion chamber 54 terminates at the at least one opening 57 to define a secondary combustor outlet 58. In a non-limiting example,

each secondary combustion chamber 54 in the set of secondary combustors 50 is radially aligned with the primary fuel injectors 30. The secondary combustion chamber 54 can define a second centerline (denoted "CL2") extending toward the secondary combustor outlet 58. A radial line (denoted "R") extends from the centerline 20 and overlaps and is aligned with the second centerline CL2 in the transverse plane TP.

[0027] A primary set of dilution openings 72 includes a plurality of dilution openings 59 arranged circumferentially about the centerline 20 and located in the inner liner 42. At least one dilution opening 59 in the primary set of dilution openings 72 is located opposite at least one of the mini combustors 34 and aligned with both the second centerline CL2 and the radial line R. The at least one dilution opening 59 can be the entire primary set of dilution openings 72 where each dilution opening 59 is located opposite each mini combustor 34 as illustrated.

[0028] The primary combustor 32 produces primary exhaust gasses (denoted "G1") in the primary combustion chamber 46. The set of secondary combustors 50 produce secondary exhaust gasses (denoted "G2") in the secondary combustion chamber 54 that flow into the primary combustion chamber 46. The secondary exhaust gasses G2 circulate in the primary combustion chamber 46 starving O₂ levels and reducing temperatures in the primary combustion chamber 46. This results in a reduction of NO_x emissions. A dilution flow (denoted "Df") enters the primary combustion chamber 46 via the primary set of dilution openings 72 to trim an exit temperature profile and complete combustion if there is any unburnt product downstream of the set of secondary combustors 50.

[0029] FIG. 3 depicts a cross-sectional view taken along line III-III of FIG. 2 illustrating the combustion section 14 as viewed in a radial plane (denoted "RP"). The primary combustor 32 extends between the dome wall 44 and a primary combustor outlet 48 at a nozzle assembly 56 defining an inlet 51 to the turbine section 16. A dome assembly 60 includes the dome wall 44 and houses the primary fuel injector 30. The primary fuel injector 30 can be fluidly coupled to a fuel inlet 62 via a fuel passageway 64 that can be adapted to receive a primary flow of fuel (denoted "F1"). The primary fuel injector 30 can terminate in a fuel outlet also referred to herein as a primary dome inlet 66. In some implementations the primary fuel injector 30 can include a swirler 68 circumferentially arranged about the primary dome inlet 66. The at least one opening 57 is located downstream from the primary dome inlet 66.

[0030] A primary igniter 61 is fluidly coupled to the primary combustion chamber 46. A secondary igniter 63 is fluidly coupled to the secondary combustion chamber 54.

[0031] A compressed air passageway 70 can surround the primary combustor 32 and be at least partially defined by the casing 36. Compressed air (denoted "C") can be provided to the combustion section 14 from the compressed

section 12 via the compressed air passageway 70. The primary set of dilution openings 72 connects the compressed air passageway 70 and the primary combustion chamber 46. The at least one dilution opening 59 is located at a first location (denoted "L1") within the inner liner 42. The at least one dilution opening 59 has a diameter (denoted "D"). A dilution centerline (denoted "CL3") extends through a center of the at least one dilution opening 59 to define an orientation of the at least one dilution opening 59. In one non-limiting example the dilution centerline CL3 and the second centerline CL2 are unaligned as illustrated. An axial distance (denoted "A") measured from an aft face 76 of the mini combustor 34 to a forward face 78 of the at least one dilution opening 59. The axial distance A can range from -10D to +20D, where 0D would indicate the aft face 76 aligns with the forward face 78. Any number of dilution openings (not shown) can be located downstream from the mini combustor 34 in both the outer liner and the inner liner 42.

[0032] A secondary set of dilution openings 74 can be provided in the secondary combustor liner 52 for connecting the compressed air passageway 70 and the secondary combustion chamber 54. By way of non-limiting example, when the primary combustor 32 is a rich burn system, the secondary set of dilution openings 74 are at an aft location of the mini combustor 34 for trimming a combustor exit temperature profile and pattern factor associated with the mini combustor 34 and primary combustor 32.

[0033] The compressed air C can be split between the primary combustor 32 and the set of secondary combustors 50 such that the primary combustor 32 receives about 60% to about 90% of the compressed air C from the compressor section 12 while the set of secondary combustors 50 receives between about 10% and about 40%.

[0034] Each mini combustor 34 includes a mini dome assembly 80 including a mini dome wall 82 and housing a mini fuel injector 84. The mini fuel injector 84 can be fluidly coupled to a secondary fuel passageway 86 that can be adapted to receive a secondary flow of fuel (denoted "F2"). The mini fuel injector 84 terminates in a secondary fuel outlet also referred to herein as a mini dome inlet 88 open to the secondary combustion chamber 54. In some implementations the mini fuel injector 84 can include a low swirl number swirler 89, e.g., with a number less than 1 and having a low tangential velocity, circumferentially arranged about the mini dome inlet 88. It is further contemplated that the set of secondary combustors do not include a swirler, but can have non swirling air passages.

[0035] Fuel provided to the primary fuel injectors 30 and to the mini fuel injectors 84 can include jet fuel natural gas or a more reacting fuel like hydrogen (H₂) and blends of H₂. In some implementations, the turbine engine 10 (FIG. 1) can be started on conventional fuel using the set of secondary combustors 50 where the secondary exhaust gasses G2 (FIG. 2) are propagated towards the primary combustion chamber 46 which can be fueled

using conventional fuel or H₂ fuel.

[0036] The primary dome inlet 66 defines a first centerline (denoted "CL1"). The mini dome inlet 88 can define the second centerline CL2 extending toward the secondary combustor outlet 58. The secondary combustor outlet 58 intersects the second centerline CL2 to define a geometric center 90 of the secondary combustor outlet 58. The geometric center, as discussed herein, refers to the arithmetic mean position of all points along the surface of the at least one opening 57 defining the secondary combustor outlet 58 in a plane parallel to the outer liner 42.

[0037] The first centerline CL1 and the second centerline CL2 intersect to define a first primary combustor angle (denoted " α_1 ") in the radial plane RP. The mini combustor 34 can be angled toward the primary dome inlet 66 such that the first primary combustor angle α_1 is 90° or less. The mini combustor 34, when angled toward the primary dome inlet 66, has a first primary combustor angle α_1 that can vary from 25° to 90°.

[0038] The first centerline CL1 and the dilution centerline CL3 intersect to define a first dilution angle (denoted " β_1 ") in the radial plane RP. The at least one dilution opening 59 can be angled away from the primary dome inlet 66 such that the first dilution angle β_1 is greater than 90°. The at least one dilution opening 59, when angled away from the primary dome inlet 66, has a first dilution angle β_1 that can vary from 90° to 165°.

[0039] Referring to FIG. 4, during operation, compressed air C can be fed into the primary fuel injector 30 and mixed with the primary flow of fuel F1 to define a primary fuel/air mixture (denoted "FA1"). The primary fuel injector 30 along with the primary igniter 61 define a primary burn system having a primary flame. The primary fuel injector 30 can dispense a primary fuel/air mixture FA1 that is premixed or partially premixed. Further, the flow of fuel F1 can be a diffusion fuel free of an air mixture prior to entering the primary combustion chamber 46. The primary burn system can be a rich burn system or a lean burn system. A rich burn combustion system includes a fuel/air ratio above the stoichiometric fuel/air ratio whereas a lean burn combustion system includes a fuel/air ratio below the stoichiometric fuel/air ratio. A rich burn system for the primary combustor 32 will create a higher temperature within the primary combustion chamber 46 providing flame stability to the overall combustion system. When combined with a lean burn system for the set of secondary combustors 50, NO_x is reduced from the secondary combustion chamber 54. Similarly, the primary combustor 32 can be a lean burn system for lower NO_x from the primary combustion chamber 46 with the set of secondary combustors 50 having a rich burn system for providing flame stability to the primary combustor 32 and the entire combustion system. Further both the primary combustor 32 and the set of secondary combustors 50 can be a rich burn system or a lean burn system. With both having lean burn systems, the amount of NO_x emissions is greatly reduced. However, at least one or more of the primary fuel injectors 30 or mini fuel injectors

84 will need to be fuel rich to provide flame stability. Likewise, both the primary combustor 32 and the set of secondary combustors 50 can have rich burn systems where lowering NO_x in this system is achieved by staging fuel and starvation of O₂ in the primary combustor 32 from product released from the set of secondary combustors 50 that produces lower NO_x.

[0040] Compressed air C can be fed into the mini fuel injector 84 and mixed with the secondary flow of fuel F2 to define a secondary fuel/air mixture (denoted "FA2"). The mini fuel injector 84 along with the secondary igniter 63 can define a mini burn system including a secondary flame that can be premixed, partially premixed, or diffusion. The mini burn system can be a rich burn system or a lean burn system. Fuel provided to the primary fuel injectors 30 and the mini fuel injectors 84 can include jet fuel natural gas or a more reacting fuel like H₂ and blends of H₂. In some implementations, the turbine engine 10 can be started on conventional fuel using the set of secondary combustors 50 where the secondary exhaust gasses G2 is propagated towards the primary combustion chamber 46 which can be fueled using conventional fuel or H₂ fuel.

[0041] The main combustion zone 94 can have an equivalence ratio from 0.5 to 2, inclusive of endpoints.

The secondary combustion chamber can have an equivalence ratio from 0.4 to 1.5, inclusive of endpoints.

[0042] The dilution flow Df is defined by compressed air C passing through the at least one dilution opening 59. The dilution flow Df directs the secondary exhaust gasses G2 and causing the secondary exhaust gasses to flow back into the main combustion zone 94.

[0043] When the secondary exhaust gasses G2 are directed towards the primary combustion chamber 46, the primary exhaust gasses G1 and the secondary exhaust gasses G2 mix which reduces O₂ levels in the primary combustion chamber 46 that reduces NO_x emissions. Fuel staging between the primary combustion chamber 46 and the secondary combustion chamber 54 reduces the fuel/air ratio in these stages of the combustion section 14 which contributes to a further reduction in temperature and NO_x emissions. In comparison, a single staged combustor will have relatively higher fuel/air ratios and higher temperatures which leads to higher NO_x emissions. The process of directing the secondary exhaust gasses G2 from the mini combustor 34 into the primary combustion chamber 46 at the primary combustor angle α improves turbulence levels. Turbulence helps to thoroughly mix the primary and secondary exhaust gasses G1, G2 which improves a uniform temperature distribution, again resulting in a reduction in NO_x.

[0044] Further, the arrangement described improves the primary combustor 32 exit temperature profile and pattern factor. The dilution flow Df trims the exist temperature profile and forces a complete combustion of any unburnt product from the mini combustor 34. Mixing the products of combustion produced by the set of secondary combustors 50 with those of the primary combustor 32 helps to improve temperature distribution within the pri-

mary combustion chamber 46 due to higher turbulence created by the products impinging on each other. An amount of secondary exhaust gasses G2 re-circulating in primary or main combustion zone 94 can range from 0.1% to 100% to cut down NOx emission.

[0045] Turning to FIG. 5, multiple alternate orientations for the mini combustor 34 and at least one dilution opening 59 of FIG. 3 and FIG. 4 are illustrated. The various orientations are represented by multiple second centerlines CL2a, CL2b and dilution centerlines CL3a, CL3b, CL3c with respect to the first centerline CL1. All components have been removed for clarity.

[0046] A first alternate orientation (denoted "O1") for the mini combustor 34 (FIG. 3) is represented by a first alternate second centerline CL2a. The mini combustor 34 (FIG. 3) extends orthogonally from the outer liner 40 (FIG. 3) to define a second primary combustor angle $\alpha 2$ equal to 90° and measured between the first alternate second centerline CL2a and the first centerline CL1.

[0047] A second alternate orientation (denoted "O2") for the mini combustor 34 (FIG. 3) is represented by a second alternate second centerline CL2b. The mini combustor 34 (FIG. 3) is angled away from the primary dome inlet 66 (FIG. 3) to define a third primary combustor angle $\alpha 3$ that varies from 90° to 165° and is measured between the second alternate second centerline CL2b and the first centerline CL1.

[0048] A third alternate orientation (denoted "O3") for the at least one dilution opening 59 (FIG. 3) is represented by a first alternate dilution centerline CL3a. The at least one dilution opening 59 (FIG. 3) extends orthogonally through the inner liner 42 to define a second dilution angle $\beta 2$ equal to 90° and measured between the first alternate dilution centerline CL3a and the first centerline CL1.

[0049] A first alternate location (denoted "L2") for the mini combustor 34 (FIG. 3) is located in the inner liner 42 and defines a second alternate dilution centerline CL3b parallel to the dilution centerline CL3 and intersecting with the first centerline CL1. The first alternate location L1 is upstream from the location depicted in FIG. 3.

[0050] A second alternate location (denoted "L3") for the at least one dilution opening 59 (FIG. 3) is located in the inner liner 42 and defines a third alternate dilution centerline CL3c parallel to the dilution centerline CL and intersecting with the first centerline CL1. The second alternate location L2 is upstream from the first alternate location L1.

[0051] While the first alternate location L2 and the second alternate location L3 are illustrated with the original orientation for the at least one dilution opening 59 from FIG. 3, it should be understood that the third alternate orientation O3 for either of the first or second alternate locations L2, L3 is also contemplated.

[0052] It should be understood that the set of secondary combustors 50 can include at least one mini combustor 34 angled toward the primary dome inlet 66 and another at least one mini combustor 34 angled away from

the primary dome inlet 66, or any combination thereof. Any combination of the original orientation, the first, second, and third alternate orientations O1, O2, O3, the first location L1, and the first and second alternate locations L2, L3, depicted in FIG. 3 are contemplated depending on desired results in the combustion section 14.

[0053] Turning to FIG. 6, another embodiment of the combustion section 14 is illustrated according to another aspect of the disclosure herein. A combustion section 114 is similar to the combustion section 14 of FIG. 4; therefore, like parts will be identified with like numerals increased by 100, with it being understood that the description of the like parts of the combustion section 14 applies to the combustion section 114, except where noted.

[0054] The combustion section 114 can be provided serially between a compressor section 112 and a turbine section 116. The combustion section 114 includes a set of secondary combustors 150 comprising at least one mini combustor 134. A primary fuel injector 130 is fluidly coupled to a primary combustor 132. A compressed air passageway 170 surrounds the primary combustor 172 and is at least partially defined by a casing 136. A primary combustor liner 138 including an outer liner 140 and an inner liner 142 define at least a portion of the primary combustor. A dome assembly 160 includes a dome wall 144. The dome wall 144 together with the primary combustor liner 138 defines a primary combustion chamber 146 of the primary combustor 132. The primary combustor 132 extends between the dome wall 144 and a primary combustor outlet 148 at a nozzle assembly 156 defining an inlet 151 to the turbine section 116. At least one opening 157 extends through the outer liner 140.

[0055] In a first non-limiting example, the mini combustor 134 has a secondary combustion chamber 154 defined at least in part by a secondary combustor liner 152 and is oriented as illustrated in FIG. 3. The mini combustor 134 is fluidly coupled to the primary combustion chamber 146 at the at least one opening 157 to define a secondary combustor outlet 158. The secondary combustion chamber 154 can define a second centerline (denoted "CL2") extending toward the secondary combustor outlet 158. The secondary combustor outlet 158 intersects the second centerline CL2 to define a geometric center 190 of the secondary combustor outlet 158. A secondary set of dilution openings 174 is provided in the secondary combustor liner 152 for connecting the compressed air passageway 170 and the secondary combustion chamber 154. A primary igniter 161 is fluidly coupled to the primary combustion chamber 146. A secondary igniter 163 is fluidly coupled to the secondary combustion chamber 154. The primary fuel injector 130 is fluidly coupled to a fuel inlet 162 via a fuel passageway 164 that can be adapted to receive a primary flow of fuel (denoted "F1"). The primary fuel injector 130 can terminate in a fuel outlet also referred to herein as a primary dome inlet 166. In some implementations the primary fuel injector 130 can include a swirler 168 circumferentially

arranged about the primary dome inlet 166.

[0056] The mini combustor 134 includes a mini dome assembly 180 including a mini dome wall 182 and housing a mini fuel injector 184. The mini fuel injector 184 is fluidly coupled to a secondary fuel passageway 186 that can be adapted to receive a secondary flow of fuel (denoted "F2"). The mini fuel injector 184 terminates in a secondary fuel outlet also referred to herein as a mini dome inlet 188 open to the secondary combustion chamber 154. In some implementations the mini fuel injector 184 can include a low swirl number swirler 189, e.g., with a number less than 1 and having a low tangential velocity, circumferentially arranged about the mini dome inlet 188. It is further contemplated that the set of secondary combustors do not include a swirler, but can have non swirling air passages.

[0057] At least one dilution opening 159 is located at the first alternate location L2 of FIG. 3 while the at least one dilution opening 159 is located in the original orientation of FIG. 3. The at least one dilution opening 159 is located directly opposite the mini combustor 134.

[0058] Turning to FIG. 7, another embodiment of the combustion section 14 is illustrated according to an aspect of the disclosure herein. A combustion section 214 is similar to the combustion section 14 of FIG. 4; therefore, like parts will be identified with like numerals increased by 200, with it being understood that the description of the like parts of the combustion section 14 applies to the combustion section 214, except where noted.

[0059] The combustion section 214 can be provided serially between a compressor section 212 and a turbine section 216. The combustion section 214 includes a set of secondary combustors 250 comprising at least one mini combustor 234. The mini combustor 234 includes a mini dome assembly 280 including a mini dome wall 282 and housing a mini fuel injector 284. The mini fuel injector 284 is fluidly coupled to a secondary fuel passageway 286 that can be adapted to receive a secondary flow of fuel F2. The mini fuel injector 284 terminates in a secondary fuel outlet also referred to herein as a mini dome inlet 288 open to the secondary combustion chamber 254. In some implementations the mini fuel injector 184 can include a low swirl number swirler 289, e.g., with a number less than 1 and having a low tangential velocity, circumferentially arranged about the mini dome inlet 288. It is further contemplated that the set of secondary combustors do not include a swirler, but can have non swirling air passages.

[0060] A primary fuel injector 230 is fluidly coupled to a primary combustor 232. A compressed air passageway 270 surrounds the primary combustor 232 and is at least partially defined by a casing 236. A primary combustor liner 238 including an outer liner 240 and an inner liner 242 define at least a portion of the primary combustor. A dome assembly 260 includes a dome wall 244. The dome wall 244 together with the primary combustor liner 238 defines a primary combustion chamber 246 of the primary combustor 232. The primary combustor 232 ex-

tends between the dome wall 244 and a primary combustor outlet 248 at a nozzle assembly 256 defining an inlet 251 to the turbine section 216. At least one opening 257 extends through the outer liner 240.

[0061] In a second non-limiting example, the mini combustor 234 is defined at least in part by a secondary combustor liner 252 and is oriented in the first alternate orientation O1 (FIG. 5). The mini combustor 234 is fluidly coupled to the primary combustion chamber 246 at the at least one opening 257 to define a secondary combustor outlet 258. The secondary combustion chamber 254 can define a second centerline (denoted "CL2") extending toward the secondary combustor outlet 258. The secondary combustor outlet 158 intersects the second centerline CL2 to define a geometric center 290 of the secondary combustor outlet 258. A secondary set of dilution openings 274 is provided in the secondary combustor liner 252 for connecting the compressed air passageway 270 and the secondary combustion chamber 254. A primary igniter 261 is fluidly coupled to the primary combustion chamber 246. A secondary igniter 263 is be fluidly coupled to the secondary combustion chamber 254. The primary fuel injector 230 is fluidly coupled to a fuel inlet 262 via a fuel passageway 264 that can be adapted to receive a primary flow of fuel (denoted "F1"). The primary fuel injector 230 can terminate in a fuel outlet also referred to herein as a primary dome inlet 266. In some implementations the primary fuel injector 230 can include a swirler 268 circumferentially arranged about the primary dome inlet 266.

[0062] At least one dilution opening 259 is located at the first location L1 and oriented with the third alternate orientation O3 (FIG. 5). The at least one dilution opening 259 is located directly opposite the mini combustor 234. Further, an additional set of dilution openings 273 is located in an outer liner 240 downstream from the mini combustor 234.

[0063] As illustrated in FIGs 6 and 7, providing the mini combustors 134, 234 in direct opposition of the at least one dilution openings 159, 259 causes a first portion G2a of the secondary exhaust gasses G2 from the mini combustors 134, 234 to circulate back into a main combustion zone 194, 294. A first portion Da of the dilution flow Df mixes in the main combustion zone 194, 294. A remaining portion G2b of the secondary exhaust gasses G2 along with a second portion Db of the dilution flow Df flows aft toward a primary combustor outlet 148, 248.

[0064] FIG. 8 illustrates a combustion section 314 with a set of secondary combustors 350 oriented circumferentially about a primary combustor 332 according to another aspect of the disclosure herein. The combustion section 314 is similar to the combustion section 14 of FIG. 2; therefore, like parts will be identified with like numerals increased by 300, with it being understood that the description of the like parts of the combustion section 14 applies to the combustion section 314, except where noted. While eight mini combustors 334 are illustrated as the set of secondary combustors 350, it should be

understood that any number of mini combustors 334 is contemplated. Likewise, any number of associated primary fuel injectors 330 and mini fuel injectors (not shown) is contemplated including that they can be the same or different amounts and that the figures depicted herein are non-limiting examples.

[0065] The combustion section 314 includes an annular arrangement of the primary fuel injectors 330 disposed around an engine centerline 320. Each of the primary fuel injectors 330 are fluidly coupled to the primary combustor 332. In a non-limiting example, an annular arrangement is illustrated and disposed within a casing 336. The primary combustor 332 is defined by a primary combustor liner 338 including an outer liner 340 and an inner liner 342 concentric with respect to each other and annular about the engine centerline 320. A dome wall 344 together with the primary combustor liner 338 define a primary combustion chamber 346 annular about the engine centerline 320.

[0066] The combustion section 314 further includes a circumferential arrangement of the mini combustors 334 defining the set of secondary combustors 350. Each mini combustor 334 in the set of secondary combustors 350 is defined by a secondary combustor liner 352 extending generally perpendicular from the primary combustor liner 338. The secondary combustor liner 352 defines at least a portion of a secondary combustion chamber 354 circumferentially spaced about the engine centerline 320. The set of secondary combustors 350 is fluidly coupled to the primary combustor 332 by at least one opening 357 extending through the outer liner 340. More specifically, the secondary combustion chamber 354 terminates at the at least one opening 357 to define a secondary combustor outlet 358. In a non-limiting example, each secondary combustion chamber 354 in the set of secondary combustors 350 is aligned with the primary fuel injectors 330.

[0067] A primary set of dilution openings 372 includes a plurality of dilution openings 359 arranged circumferentially about the engine centerline 320 and located in the inner liner 342. At least one dilution opening 359 in the primary set of dilution openings 372 is offset from at least one of the mini combustors 334. The at least one dilution opening 359 can be the entire primary set of dilution openings 372 where each dilution opening 359 is unaligned with respect to the mini combustors 334. In other words, each dilution opening 359 is staggered with respect to sequential secondary combustion chambers 354 as illustrated.

[0068] Locating the at least one dilution opening 359 in-between the mini combustors 334 enables forming a low-pressure zone (denoted "LPZ") between secondary exhaust gasses G2 coming from the mini combustors 334. The low-pressure zone LPZ creates an exhaust stream that moves in a lateral direction (denoted "LD") increasing spreading of the primary exhaust gasses G1 and the secondary exhaust gasses G2 and recirculation of the gasses G1, G2. The recirculation in the primary combus-

tion chamber 346 starves O2 levels and reduces temperatures in the primary combustion chamber 346. This results in a reduction of NOx emissions.

[0069] FIG. 9 illustrates a combustion section 414 with a set of secondary combustors 450 oriented circumferentially about a primary combustor 432 according to another aspect of the disclosure herein. The combustion section 414 is similar to the combustion section 14 of FIG. 2; therefore, like parts will be identified with like numerals increased by 400, with it being understood that the description of the like parts of the combustion section 14 applies to the combustion section 414, except where noted. While eight mini combustors 434 are illustrated as the set of secondary combustors 450, it should be understood that any number of mini combustors 434 is contemplated. Likewise, any number of associated primary fuel injectors 430 and mini fuel injectors (not shown) is contemplated including that they can be the same or different amounts and that the figures depicted herein are non-limiting examples.

[0070] The combustion section 414 includes an annular arrangement of the primary fuel injectors 430 disposed around an engine centerline 420. Each of the primary fuel injectors 430 are fluidly coupled to the primary combustor 432. In a non-limiting example, an annular arrangement is illustrated and disposed within a casing 436. The primary combustor 432 is defined by a primary combustor liner 438 including an outer liner 440 and an inner liner 442 concentric with respect to each other and annular about the engine centerline 420. A dome wall 444 together with the primary combustor liner 438 define a primary combustion chamber 446 annular about the engine centerline 420.

[0071] The combustion section 414 further includes a circumferential arrangement of the mini combustors 434 defining the set of secondary combustors 450. Each mini combustor 434 in the set of secondary combustors 450 is defined by a secondary combustor liner 452 extending generally perpendicular from the primary combustor liner 438. The secondary combustor liner 452 defines at least a portion of a secondary combustion chamber 454 circumferentially spaced about the engine centerline 420. The set of secondary combustors 450 is fluidly coupled to the primary combustor 432 by at least one opening 457 extending through the outer liner 440. More specifically, the secondary combustion chamber 454 terminates at the at least one opening 457 to define a secondary combustor outlet 458. In a non-limiting example, each secondary combustion chamber 454 in the set of secondary combustors 450 is aligned with the primary fuel injectors 430.

[0072] A primary set of dilution openings 472 includes a plurality of dilution openings 459 arranged circumferentially about the engine centerline 420 and located in the inner liner 442. At least one dilution opening 459 in the primary set of dilution openings 472 extends between an inlet 496 and an outlet 498. A fourth centerline (denoted "CL4") extends through the at least one dilution opening

459 from a geometric center 497 of the inlet 496 and through a geometric center 499 of the outlet 498. A second radial line (denoted "R2") extends from the engine centerline 420 through the geometric center 499 of the outlet 498 of the at least one dilution opening 459. The at least one dilution opening 459 is tangentially angled such that the fourth centerline CL4 and the second radial line R2 define a tangential angle θ . The at least one dilution opening 359 can be the entire primary set of dilution openings 372 where each dilution opening 359 is tangentially angled as illustrated.

[0073] Tangentially angling the at least one dilution opening 459 creates a flow of exhaust gasses in a circumferential direction (denoted "CD"). Flowing the primary and secondary exhaust gasses G1, G2 in the circumferential direction CD creates a uniform temperature distribution. The tangential angle θ can vary from 0° to $\pm 180^\circ$. The varying angles can produce swirl of the primary and secondary gasses G1, G2 in the same direction or in opposite directions.

[0074] FIG. 10 illustrates a combustion section 514 with a set of secondary combustors 550 oriented circumferentially about a primary combustor 532 according to another aspect of the disclosure herein. The combustion section 514 is similar to the combustion section 14 of FIG. 2; therefore, like parts will be identified with like numerals increased by 500, with it being understood that the description of the like parts of the combustion section 14 applies to the combustion section 514, except where noted. While eight mini combustors 534 are illustrated as the set of secondary combustors 550, it should be understood that any number of mini combustors 534 is contemplated. Likewise, any number of associated primary fuel injectors 530 and mini fuel injectors (not shown) is contemplated including that they can be the same or different amounts and that the figures depicted herein are non-limiting examples.

[0075] The combustion section 514 includes additional features that can be implemented in any of the combustion sections 14, 114, 214, 314, 414 discussed herein. An exhaust wall 591 can extend into a primary combustion chamber 546. The exhaust wall 591 can provide protection of hardware and define a secondary combustor outlet 558.

[0076] Further, a primary set of dilution openings 572 includes a plurality of dilution openings 559 arranged circumferentially about a centerline 520 of the combustion section 514. At least one dilution opening 559 in the set of dilution openings 572 includes dilution component 592. The dilution component 592 can be a hot side feature that improves penetration of the dilution flow Df into the core of the primary combustor 532 thereby enabling air to reach a middle of the primary combustor 532 and reduce temperature in the primary combustion chamber 546. The dilution component 592 can include a metal extension either facing the primary combustion chamber 546, or a hot side, or facing a compressed air passageway 570, or a cold side, to provide flow direction

for the dilution flow Df. Controlling direction of the dilution flow Df controls mixing of exhaust gases from the secondary combustion chamber 554 and makes the temperature within the primary combustor 532 as uniform as possible. The dilution component 592 can also be an insert for controlling a direction of the dilution flow Df. The at least one dilution opening 559 can be the entire primary set of dilution openings 572 where each dilution opening 559 includes the dilution component 592 as illustrated.

[0077] FIGS. 11, 12, 13, and 14 illustrate various shapes of the mini combustors 34, 134, 234, 334, 434, 534 described herein.

[0078] FIG. 11 is a cylindrical shape (denoted "CS") defined by the secondary combustor liner 552 for the secondary combustion chamber 554 as taken along line XI-XI of FIG. 10.

[0079] FIG. 12 is another embodiment of the mini combustor from FIG. 11 defined by a secondary combustor liner 652 for a secondary combustion chamber 654 as a rectangular shape (denoted "RS").

[0080] FIG. 13 is another embodiment of the mini combustor from FIG. 11 defined by a secondary combustor liner 752 for a secondary combustion chamber 754 as an oval shape (denoted "OS").

[0081] FIG. 14 is another embodiment of the mini combustor from FIG. 11 defined by the secondary combustor liner 852 for a secondary combustion chamber 854 as a rounded rectangular shape (denoted "RRS").

[0082] Any combination of the locations and orientations with respect to the at least one dilution opening 59, 159, 259, 359, 459, 559 and the mini combustors 34, 134, 234, 334, 434, 534 described herein is contemplated. Further the number of dilution openings 59, 159, 259, 359, 459, 559 and mini combustors 34, 134, 234, 334, 434, 534 can vary. Further still, the shape of the mini combustors 34, 134, 234, 334, 434, 534 can vary. The locations, orientations, number, and shapes be tuned to achieve sufficient mixing between the two exhaust gasses G1, G2.

[0083] A method for controlling nitrogen oxides present within the combustion sections 14, 114, 214, 314, 414, 514 described herein includes generating the primary exhaust gasses G1 in the primary combustion chambers 46, 146, 246, 346, 446, 546 and generating secondary exhaust gasses G2 in the set of secondary combustors 50, 150, 250, 350, 450, 550 including the secondary combustion chambers 54, 154, 254, 354, 454, 554, 654, 754. The method further includes injecting the secondary exhaust gasses G2 into the main combustion zones 94, 194, 294 of the primary combustion chambers 46, 146, 246, 346, 446, 546. The method further includes introducing a dilution flow Df into the primary combustion chambers 46, 146, 246, 346, 446, 546.

[0084] The method can further include introducing the dilution flow Df downstream from the secondary combustion chambers 54, 154, 254, 354, 454, 554, 654, 754. The method can include directing all of the secondary exhaust gasses G2 toward the main combustion zones 94, 194,

294 with the dilution flow Df.

[0085] The method can further include introducing the dilution flow Df directly opposite from the secondary combustion chambers 54, 154, 254, 354, 454, 554, 654, 754. The method can include directing a portion of the secondary exhaust gasses G2 toward the main combustion zones 94, 194, 294 with the dilution flow Df.

[0086] Benefits associated with the set of secondary combustors in combination with the primary combustor and methods described herein are to reduce NOx emissions even in a severe cycle with a higher operating air pressure, higher temperature, higher fuel/air ratio and with heated fuel. Typically, higher fuel/air ratio within a combustion system leads to a higher flame temperature which results in higher NOx. By having two combustion chambers within the combustion system, fuel can be split between these chambers thereby reducing the fuel/air ratio in each chamber and in turn achieving lower temperature and hence lower NOx emission. By directing product of combustion from a secondary combustion into a primary combustion chamber, O2 levels in the primary combustion chamber can be reduced, further reducing NOx emission. The combustions section herein can operate with 100% H2 fuel.

[0087] While described with respect to a turbine engine, it should be appreciated that the combustor as described herein can be for any engine with a having a combustor that emits NOx. It should be appreciated that application of aspects of the disclosure discussed herein are applicable to engines with propeller sections or fan and booster sections along with turbojets and turbo engines as well.

[0088] To the extent not already described, the different features and structures of the various embodiments can be used in combination, or in substitution with each other as desired. That one feature is not illustrated in all of the embodiments is not meant to be construed that it cannot be so illustrated, but is done for brevity of description. Thus, the various features of the different embodiments can be mixed and matched as desired to form new embodiments, whether or not the new embodiments are expressly described. All combinations or permutations of features described herein are covered by this disclosure.

[0089] This written description uses examples to describe aspects of the disclosure described herein, including the best mode, and also to enable any person skilled in the art to practice aspects of the disclosure, including making and using any devices or systems and performing any incorporated methods. The patentable scope of aspects of the disclosure is defined by the claims, and may include other examples that occur to those skilled in the art. Such other examples are intended to be within the scope of the claims if they have structural elements that do not differ from the literal language of the claims, or if they include equivalent structural elements with insubstantial differences from the literal languages of the claims.

[0090] Further aspects are provided by the subject

matter of the following clauses:

A combustion section for a turbine engine, the combustion section comprising a primary combustor liner including an inner liner and an outer liner; a dome wall extending between the inner liner and the outer liner; a primary dome inlet located in the dome wall and defining a first centerline, wherein the outer liner defines at least one opening downstream from the primary dome inlet; a primary combustor having a primary combustion chamber defined at least in part by the inner liner, the outer liner, and the dome wall; a set of secondary combustors including at least one secondary combustion chamber fluidly coupled to the primary combustion chamber at the at least one opening; and at least one dilution opening located in the inner liner and defining a dilution centerline intersecting the first centerline to define a dilution angle β opening away from the primary dome inlet and ranging from 25° to 165°.

[0091] The combustion section of any preceding clause, further comprising a mini dome wall radially spaced from the outer liner and further defining the at least one secondary combustion chamber and a mini dome inlet located in the mini dome wall and fluidly coupled to the at least one secondary combustion chamber.

[0092] The combustion section of any preceding clause, further comprising a primary fuel injector fluidly coupled to the primary dome inlet and a mini fuel injector fluidly coupled to the mini dome inlet.

[0093] The combustion section of any preceding clause, wherein the mini dome inlet defines a second centerline that intersects the first centerline to define a primary combustor angle α opening away from the primary dome inlet and ranging from 25° to 165°.

[0094] The combustion section of any preceding clause, wherein the mini dome inlet defines a second centerline that intersects the first centerline to define a primary combustor angle α opening away from the primary dome inlet and ranging from 25° to 90°.

[0095] The combustion section of any preceding clause, wherein the primary combustor angle α is equal to 90°.

[0096] The combustion section of any preceding clause, wherein the mini dome inlet defines a second centerline that intersects the first centerline to define a primary combustor angle α opening away from the primary dome inlet and ranging from 90° to 165°.

[0097] The combustion section of any preceding clause, wherein the dilution centerline and the second centerline are unaligned.

[0098] The combustion section of any preceding clause, wherein the dilution centerline is downstream of the second centerline.

[0099] The combustion section of any preceding clause, wherein the dilution centerline is upstream of the second centerline.

[0100] The combustion section of any preceding clause, wherein the at least one secondary combustion

chamber is directed toward the primary dome inlet.

[0101] The combustion section of any preceding clause, wherein the primary combustor angle α is less than 90° .

[0102] The combustion section of any preceding clause, wherein the at least one secondary combustion chamber is directed away from the primary dome inlet

[0103] The combustion section of any preceding clause, wherein the primary combustor the primary combustor angle α is greater than 90° .

[0104] The combustion section of any preceding clause, wherein the at least one secondary combustion chamber and the at least one dilution opening are located directly opposite of each other.

[0105] The combustion section of any preceding clause, wherein a radial line extending from an engine centerline of the turbine engine intersects with a geometric center of the at least one dilution opening in a transverse plane and the radial line and the dilution centerline overlap and are aligned.

[0106] The combustion section of claim 1, wherein a radial line extending from an engine centerline of the turbine engine intersects with a geometric center of the at least one dilution opening in a transverse plane and the radial line and the dilution centerline are angled with respect to each other to form a tangential angle θ ranging from -180° to 180° .

[0107] The combustion section of any preceding clause, wherein the at least one secondary combustion chamber is a plurality of secondary combustion chambers circumferentially arranged about the outer liner, and the at least one dilution opening is a plurality of dilution openings circumferentially arranged about the inner liner.

[0108] The combustion section of any preceding clause, wherein the plurality of dilution openings are circumferentially staggered with respect to a plurality of secondary combustion chambers.

[0109] The combustion section of any preceding clause, wherein the plurality of dilution openings are staggered mid-way between sequential secondary combustion chambers.

[0110] The combustion section of any preceding clause, wherein the at least one dilution opening comprises a dilution component.

[0111] The combustion section of any preceding clause, wherein the set of secondary combustors comprise an aft face and the at least one dilution opening defines a diameter (D) and comprises a forward face spaced from the aft face an axial distance from $-10D$ to $+20D$.

[0112] The combustion section of any preceding clause, further comprising an exhaust wall extending into the primary combustor and bordering the at least one opening to define at least a portion of a secondary combustor outlet.

[0113] A turbine engine, comprising a compressor section, a combustion section, and a turbine section in serial flow arrangement along an engine centerline, the com-

bustion section comprising: a primary combustor liner including an inner liner and an outer liner; a dome wall extending between the inner liner and the outer liner; a primary dome inlet located in the dome wall and defining a first centerline, wherein the outer liner defines at least one opening downstream from the primary dome inlet; a primary combustor having a primary combustion chamber defined at least in part by the inner liner, the outer liner, and the dome wall; a set of secondary combustors including at least one secondary combustion chamber fluidly coupled to the primary combustion chamber at the at least one opening; and at least one dilution opening located in the inner liner and defining a dilution centerline intersecting the first centerline to define a dilution angle β opening away from the primary dome inlet and ranging from 25° to 165° .

[0114] A method for controlling nitrogen oxides comprising generating primary exhaust gasses in a primary combustion chamber and generating secondary exhaust gasses in a set of secondary combustors including a secondary combustion chamber; injecting the secondary exhaust gasses into a main combustion zone of the primary combustion chambers; introducing a dilution flow into the primary combustion chamber.

[0115] The method of any preceding clause further comprising introducing the dilution flow at a location downstream from the secondary combustion chambers.

[0116] The method of any preceding clause further comprising directing all of the secondary exhaust gasses toward the main combustion zones with the dilution flow.

[0117] The method of any preceding clause further comprising introducing the dilution flow directly opposite from the secondary combustion chambers.

[0118] The method of any preceding clause further comprising directing a portion of the secondary exhaust gasses toward the main combustion zones with the dilution flow.

[0119] A combustion section (14, 114, 214, 314, 414, 514) for a turbine engine (10), the combustion section (14, 114, 214, 314, 414, 514) comprising: a primary combustor liner (38, 138, 238, 338, 438) including an inner liner (42, 342, 442) and an outer liner (40, 240, 340, 440); a dome wall (44, 344, 444) extending between the inner liner (42, 342, 442) and the outer liner (40, 240, 340, 440); a primary dome inlet (66) located in the dome wall (44, 344, 444) and defining a first centerline (CL1); at least one opening (57, 357, 457) located in the outer liner (40, 240, 340, 440) downstream from the primary dome inlet (66); a primary combustor (32, 332, 432, 532) having a primary combustion chamber (46, 346, 446, 546) defined at least in part by the inner liner (42, 342, 442), the outer liner (40, 240, 340, 440), and the dome wall (44, 344, 444); and a set of secondary combustors (50, 150, 250, 350, 450, 550) including at least one secondary combustion chamber (54, 154, 254, 354, 454, 554, 654, 754) fluidly coupled to the primary combustion chamber (46, 346, 446, 546) at the at least one opening (57, 357, 457); and at least one dilution opening (59, 159,

259, 359, 459, 559) located in the inner liner (42, 342, 442) and defining a dilution centerline (20, 320, 420, 520) intersecting the first centerline (CL1) to define a dilution angle β opening away from the primary dome inlet (66) and ranging from 25° to 165°.

[0120] The combustion section (14, 114, 214, 314, 414, 514) of any preceding clause, further comprising a mini dome wall (44, 344, 444) radially spaced from the outer liner (40, 240, 340, 440) and further defining the at least one secondary combustion chamber (54, 154, 254, 354, 454, 554, 654, 754) and a mini dome inlet (51, 496) located in the mini dome wall (44, 344, 444) and fluidly coupled to the at least one secondary combustion chamber (54, 354, 454, 554, 654, 754).

[0121] The combustion section (14, 114, 214, 314, 414, 514) of any preceding clause, further comprising a primary fuel injector (30) fluidly coupled to the primary dome inlet (66) and a mini fuel injector (84) fluidly coupled to the mini dome inlet (51, 496).

[0122] The combustion section (14, 114, 214, 314, 414, 514) of any preceding clause, wherein the primary dome inlet (66) defines a first centerline (CL1) and the mini dome inlet (51, 496) defines a second centerline (CL2) that intersects the first centerline (CL1) to define a primary combustor (32, 332, 432, 532) angle α opening away from the primary dome inlet (66) inlet (51, 496) and ranging from 25 to 165 degrees.

[0123] The combustion section (14, 114, 214, 314, 414, 514) of any preceding clause, wherein the primary combustor (32, 332, 432, 532) angle α is equal to 90°.

[0124] The combustion section (14, 114, 214, 314, 414, 514) of any preceding clause, wherein the dilution centerline (20, 320, 420, 520) and the second centerline (CL2) are unaligned.

[0125] The combustion section (14, 114, 214, 314, 414, 514) of any preceding clause, wherein the dilution centerline (20, 320, 420, 520) is downstream of the second centerline (CL2).

[0126] The combustion section (14, 114, 214, 314, 414, 514) of any preceding clause, wherein the dilution centerline (20, 320, 420, 520) is upstream of the second centerline (CL2).

[0127] The combustion section (14, 114, 214, 314, 414, 514) of any preceding clause wherein the at least one secondary combustion chamber (54, 354, 454, 554, 654, 754) is directed toward the primary dome inlet (66) and the primary combustor (32, 332, 432, 532) angle α is less than 90°.

[0128] The combustion section (14, 114, 214, 314, 414, 514) of any preceding clause wherein the at least one secondary combustion chamber (54, 354, 454, 554, 654, 754) is directed away from the primary dome inlet (66) and the primary combustor (32, 332, 432, 532) angle α is greater than 90°.

[0129] The combustion section (14, 114, 214, 314, 414, 514) of any preceding clause, wherein the at least one secondary combustion chamber (54, 354, 454, 554, 654, 754) and the at least one dilution opening (59, 159,

259, 359, 459, 559) are located directly opposite of each other.

[0130] The combustion section (14, 114, 214, 314, 414, 514) of any preceding clause, wherein a radial line extending from an engine centerline (20, 320, 420, 520) of the turbine engine (10) intersects with a geometric center (90, 497, 499) of the at least one dilution opening (59, 159, 259, 359, 459, 559) in a transverse plane and the radial line and the dilution centerline (20, 320, 420, 520) overlap and are aligned.

[0131] The combustion section (14, 114, 214, 314, 414, 514) of any preceding clause, wherein a radial line extending from an engine centerline (20, 320, 420, 520) of the turbine engine (10) intersects with a geometric center (90, 497, 499) of at least one dilution opening (59, 159, 259, 359, 459, 559) in a transverse plane and the radial line and the dilution centerline (20, 320, 420, 520) are angled with respect to each other to form a tangential angle θ ranging from -180° to 180°.

[0132] The combustion section (14, 114, 214, 314, 414, 514) of any preceding clause, wherein the set of secondary combustion chambers (54, 354, 454, 554, 654, 754) includes multiple secondary combustion chambers (54, 154, 254, 354, 454, 554) circumferentially arranged about the outer liner (40, 240, 340, 440), and the at least one dilution opening (59, 159, 259, 359, 459, 559) is multiple dilution openings (59, 159, 259, 359, 459, 559) circumferentially arranged about the inner liner (42, 342, 442).

[0133] The combustion section (14, 114, 214, 314, 414, 514) of any preceding clause, wherein the multiple dilution openings (59, 159, 259, 359, 459, 559) are circumferentially staggered with respect to the multiple secondary combustion chambers (54, 354, 454, 554, 654, 754).

Claims

1. A combustion section (14, 114, 214, 314, 414, 514) for a turbine engine (10), the combustion section (14, 114, 214, 314, 414, 514) comprising:
 - a primary combustor liner (38, 138, 238, 338, 438) including an inner liner (42, 342, 442) and an outer liner (40, 240, 340, 440);
 - a dome wall (44, 344, 444) extending between the inner liner (42, 342, 442) and the outer liner (40, 240, 340, 440);
 - a primary dome inlet (66) located in the dome wall (44, 344, 444) and defining a first centerline (CL1);
 - at least one opening (57, 357, 457) located in the outer liner (40, 240, 340, 440) downstream from the primary dome inlet (66);
 - a primary combustor (32, 332, 432, 532) having a primary combustion chamber (46, 346, 446, 546) defined at least in part by the inner liner (42,

- 342, 442), the outer liner (40, 240, 340, 440), and the dome wall (44, 344, 444); and a set of secondary combustors (50, 150, 250, 350, 450, 550) including at least one secondary combustion chamber (54, 154, 254, 354, 454, 554, 654, 754) fluidly coupled to the primary combustion chamber (46, 346, 446, 546) at the at least one opening (57, 357, 457); and at least one dilution opening (59, 159, 259, 359, 459, 559) located in the inner liner (42, 342, 442) and defining a dilution centerline (20, 320, 420, 520) intersecting the first centerline (CL1) to define a dilution angle β opening away from the primary dome inlet (66) and ranging from 25° to 165°.
2. The combustion section (14, 114, 214, 314, 414, 514) of claim 1, further comprising a mini dome wall (44, 344, 444) radially spaced from the outer liner (40, 240, 340, 440) and further defining the at least one secondary combustion chamber (54, 154, 254, 354, 454, 554, 654, 754) and a mini dome inlet (51, 496) located in the mini dome wall (44, 344, 444) and fluidly coupled to the at least one secondary combustion chamber (54, 354, 454, 554, 654, 754).
 3. The combustion section (14, 114, 214, 314, 414, 514) of claim 2, further comprising a primary fuel injector (30) fluidly coupled to the primary dome inlet (66) and a mini fuel injector (84) fluidly coupled to the mini dome inlet (51, 496).
 4. The combustion section (14, 114, 214, 314, 414, 514) of claim 3, wherein the primary dome inlet (66) defines a first centerline (CL1) and the mini dome inlet (51, 496) defines a second centerline (CL2) that intersects the first centerline (CL1) to define a primary combustor (32, 332, 432, 532) angle α opening away from the primary dome inlet (66) inlet (51, 496) and ranging from 25 to 165 degrees.
 5. The combustion section (14, 114, 214, 314, 414, 514) of claim 4, wherein the primary combustor (32, 332, 432, 532) angle α is equal to 90°.
 6. The combustion section (14, 114, 214, 314, 414, 514) of claim 4, wherein the dilution centerline (20, 320, 420, 520) and the second centerline (CL2) are unaligned.
 7. The combustion section (14, 114, 214, 314, 414, 514) of claim 6, wherein the dilution centerline (20, 320, 420, 520) is downstream of the second centerline (CL2).
 8. The combustion section (14, 114, 214, 314, 414, 514) of claim 6, wherein the dilution centerline (20, 320, 420, 520) is upstream of the second centerline (CL2).
 9. The combustion section (14, 114, 214, 314, 414, 514) of claim 4 wherein the at least one secondary combustion chamber (54, 354, 454, 554, 654, 754) is directed toward the primary dome inlet (66) and the primary combustor (32, 332, 432, 532) angle α is less than 90°.
 10. The combustion section (14, 114, 214, 314, 414, 514) of claim 4 wherein the at least one secondary combustion chamber (54, 354, 454, 554, 654, 754) is directed away from the primary dome inlet (66) and the primary combustor (32, 332, 432, 532) angle α is greater than 90°.
 11. The combustion section (14, 114, 214, 314, 414, 514) of claim 4, wherein the at least one secondary combustion chamber (54, 354, 454, 554, 654, 754) and the at least one dilution opening (59, 159, 259, 359, 459, 559) are located directly opposite of each other.
 12. The combustion section (14, 114, 214, 314, 414, 514) of claim 1, wherein a radial line extending from an engine centerline (20, 320, 420, 520) of the turbine engine (10) intersects with a geometric center (90, 497, 499) of the at least one dilution opening (59, 159, 259, 359, 459, 559) in a transverse plane and the radial line and the dilution centerline (20, 320, 420, 520) overlap and are aligned.
 13. The combustion section (14, 114, 214, 314, 414, 514) of claim 1, wherein a radial line extending from an engine centerline (20, 320, 420, 520) of the turbine engine (10) intersects with a geometric center (90, 497, 499) of at least one dilution opening (59, 159, 259, 359, 459, 559) in a transverse plane and the radial line and the dilution centerline (20, 320, 420, 520) are angled with respect to each other to form a tangential angle θ ranging from -180° to 180°.
 14. The combustion section (14, 114, 214, 314, 414, 514) of claim 1, wherein the set of secondary combustion chambers (54, 354, 454, 554, 654, 754) includes multiple secondary combustion chambers (54, 154, 254, 354, 454, 554) circumferentially arranged about the outer liner (40, 240, 340, 440), and the at least one dilution opening (59, 159, 259, 359, 459, 559) is multiple dilution openings (59, 159, 259, 359, 459, 559) circumferentially arranged about the inner liner (42, 342, 442).
 15. The combustion section (14, 114, 214, 314, 414, 514) of claim 14, wherein the multiple dilution openings (59, 159, 259, 359, 459, 559) are circumferentially staggered with respect to the multiple secondary combustion chambers (54, 354, 454, 554, 654,

754).

5

10

15

20

25

30

35

40

45

50

55

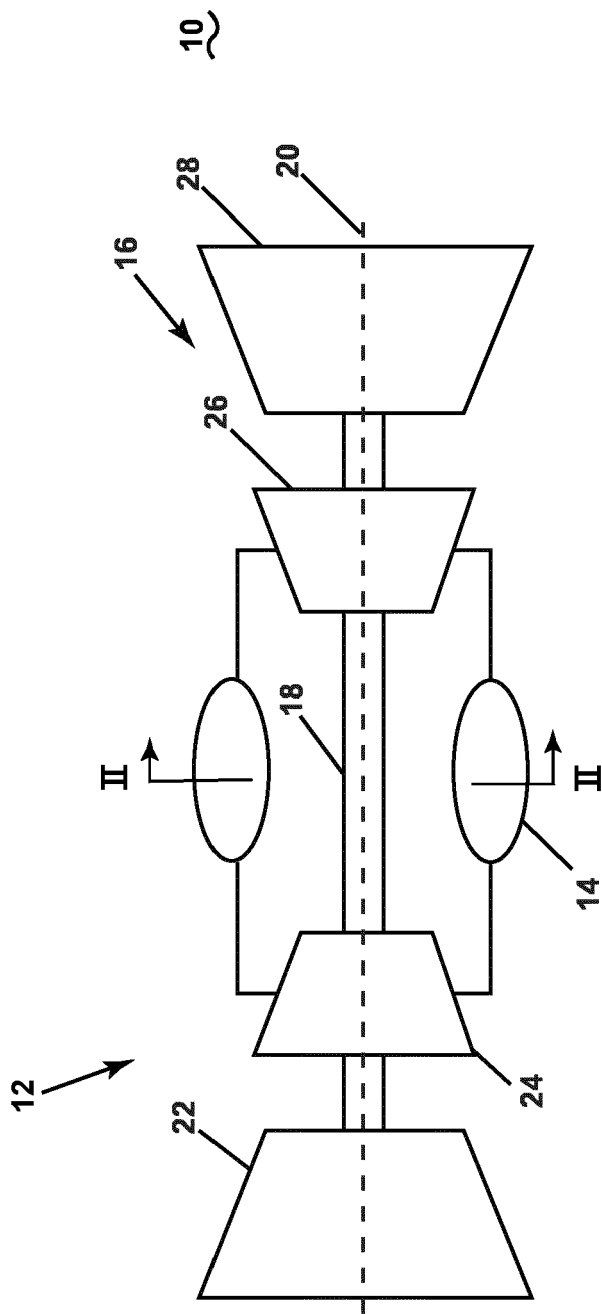


FIG. 1

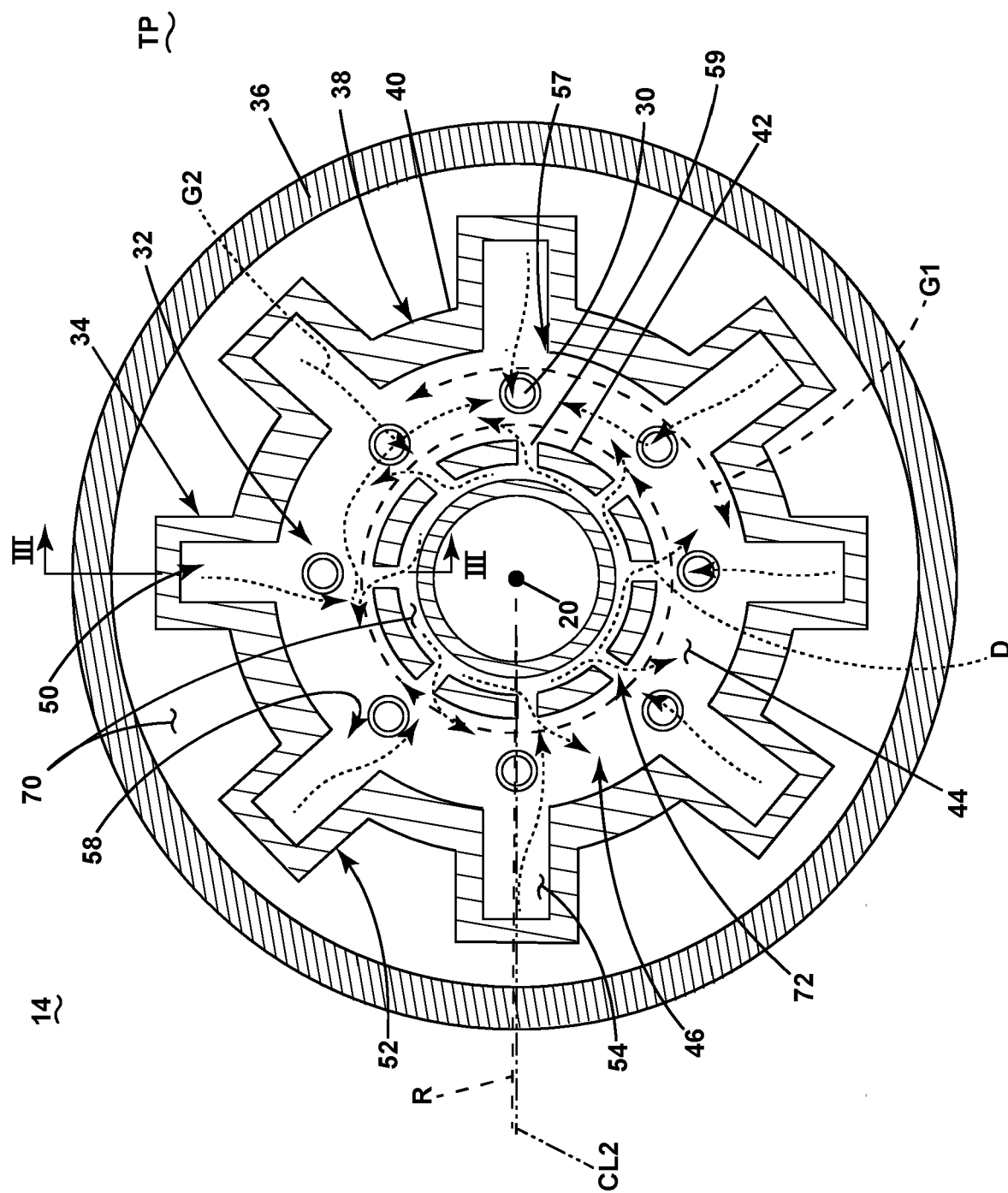


FIG. 2

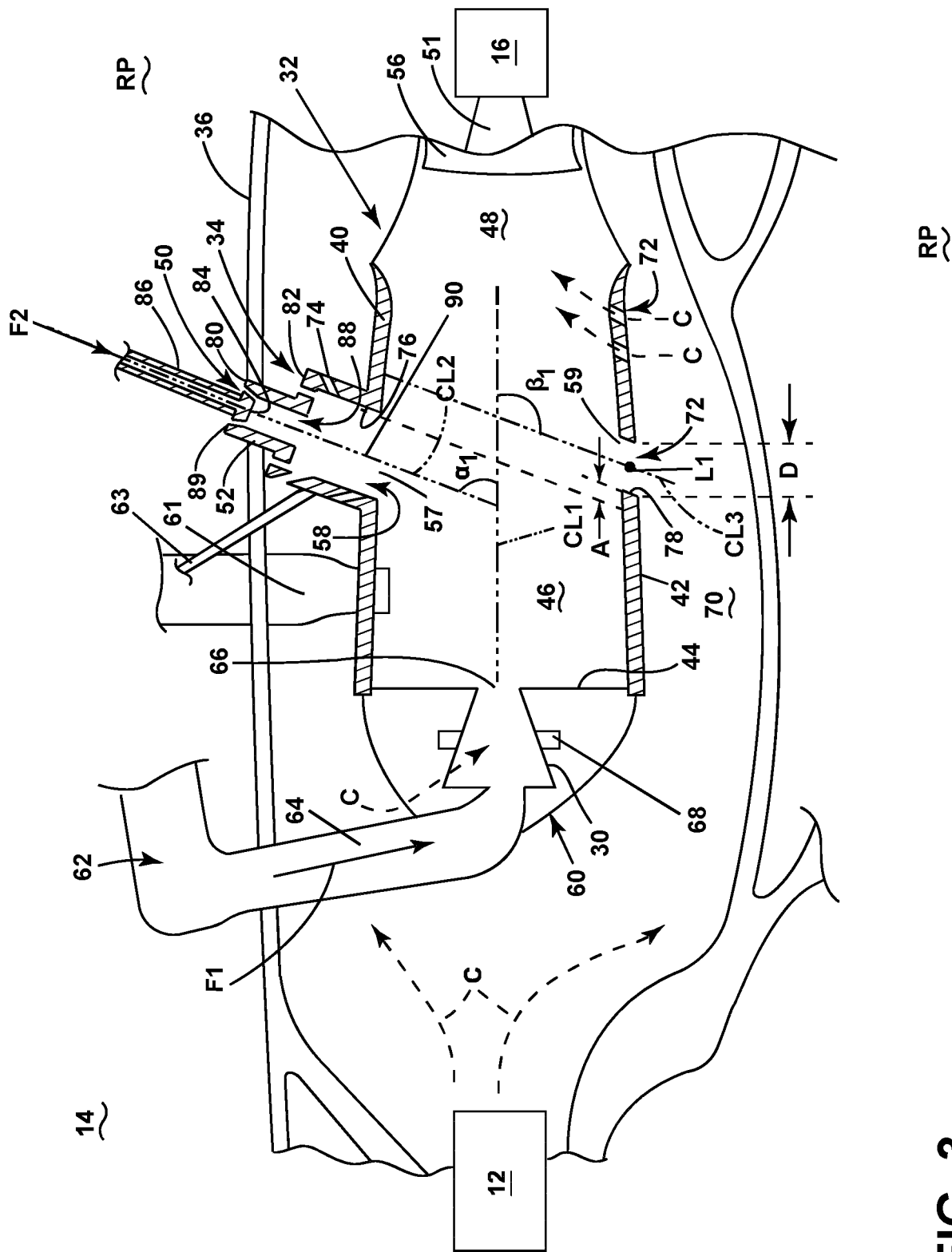


FIG. 3

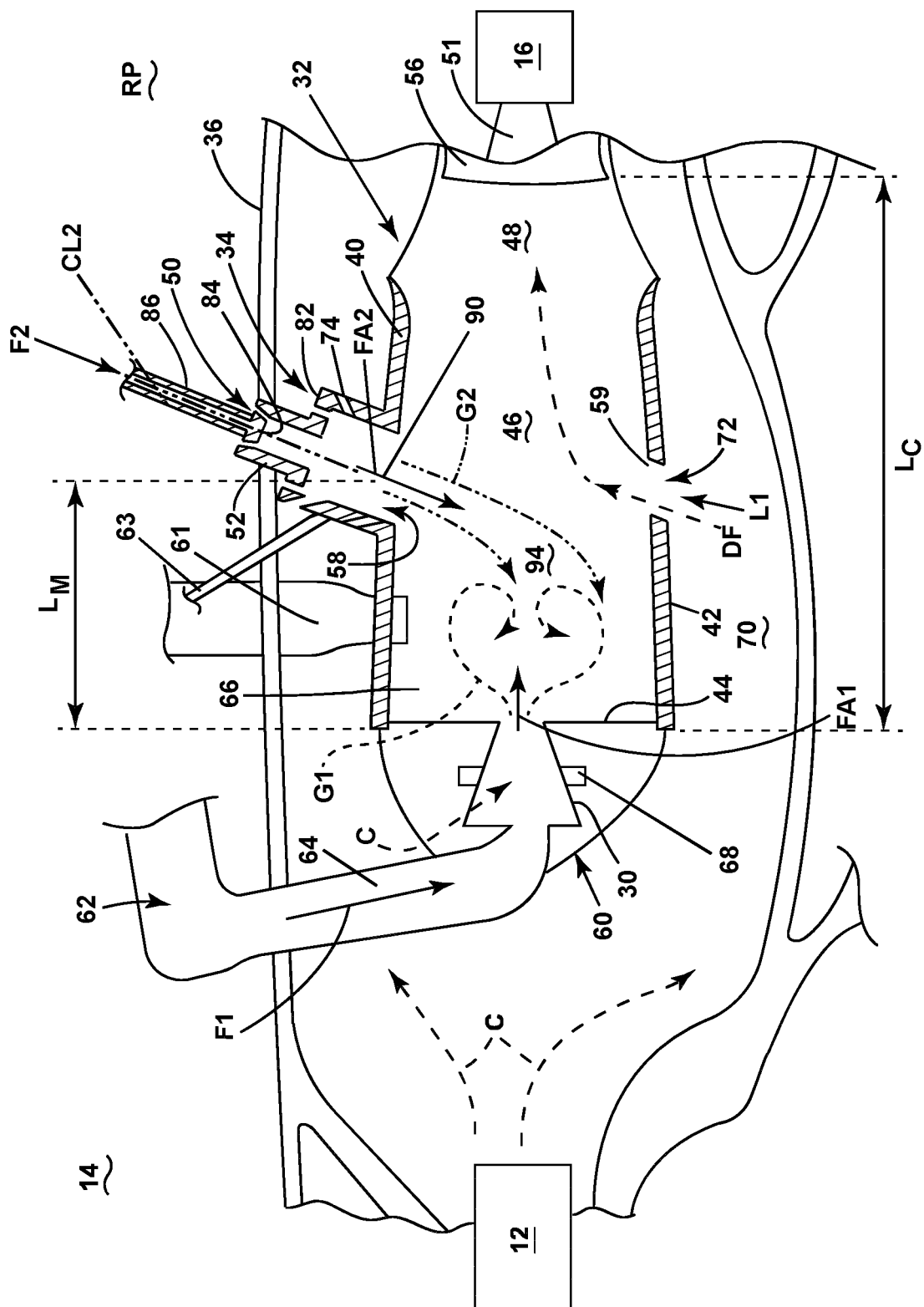


FIG. 4

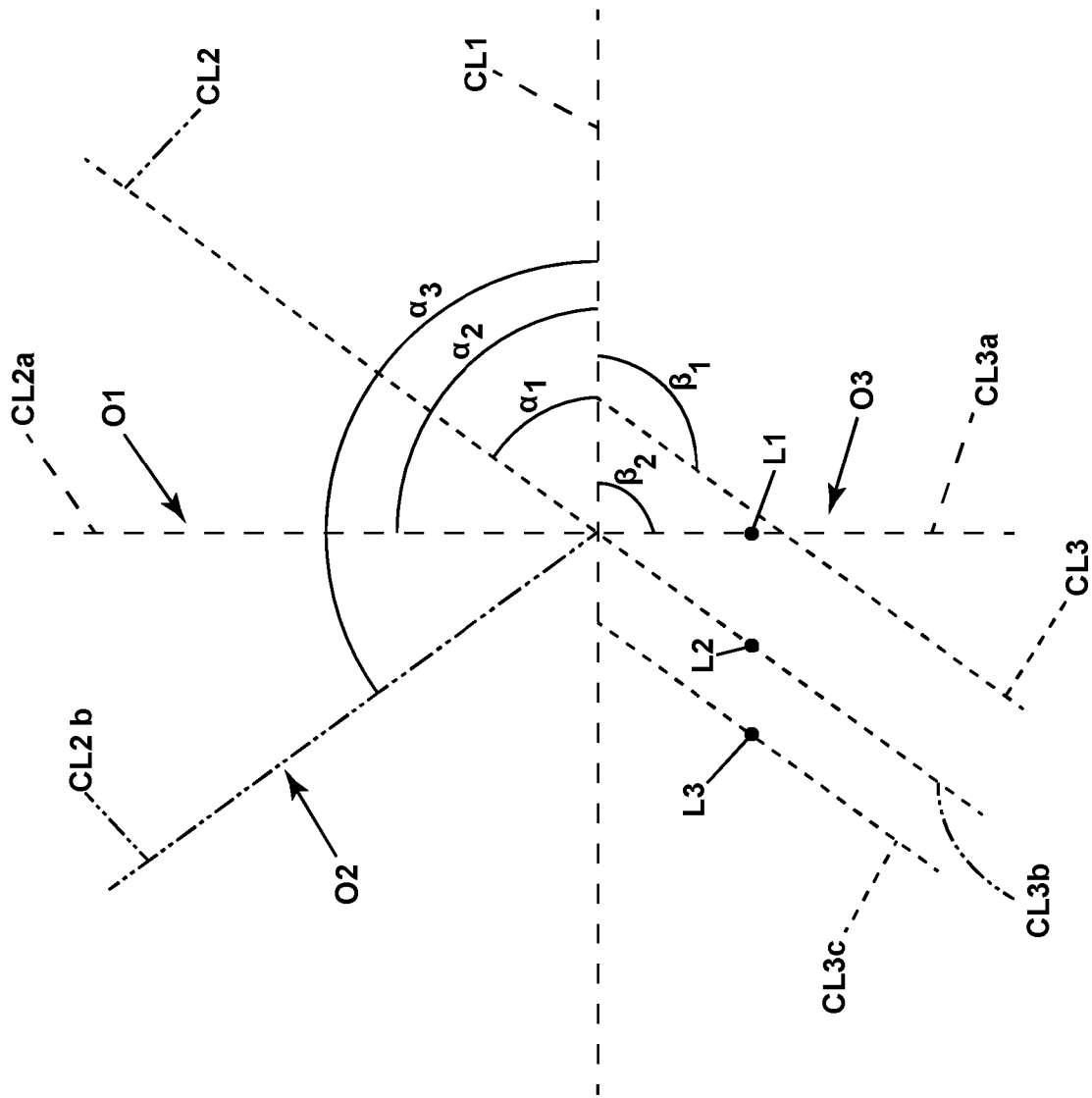


FIG. 5

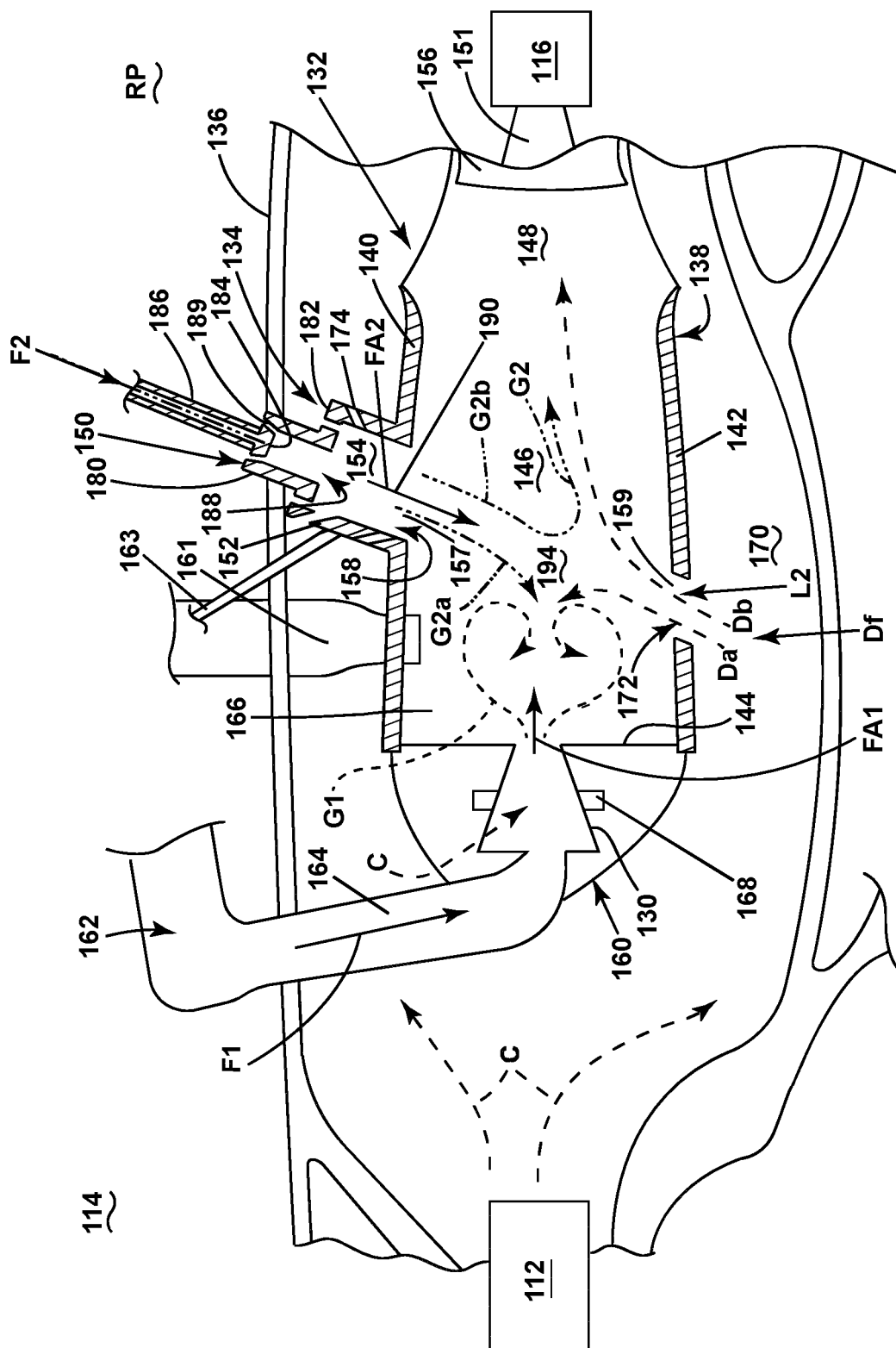


FIG. 6

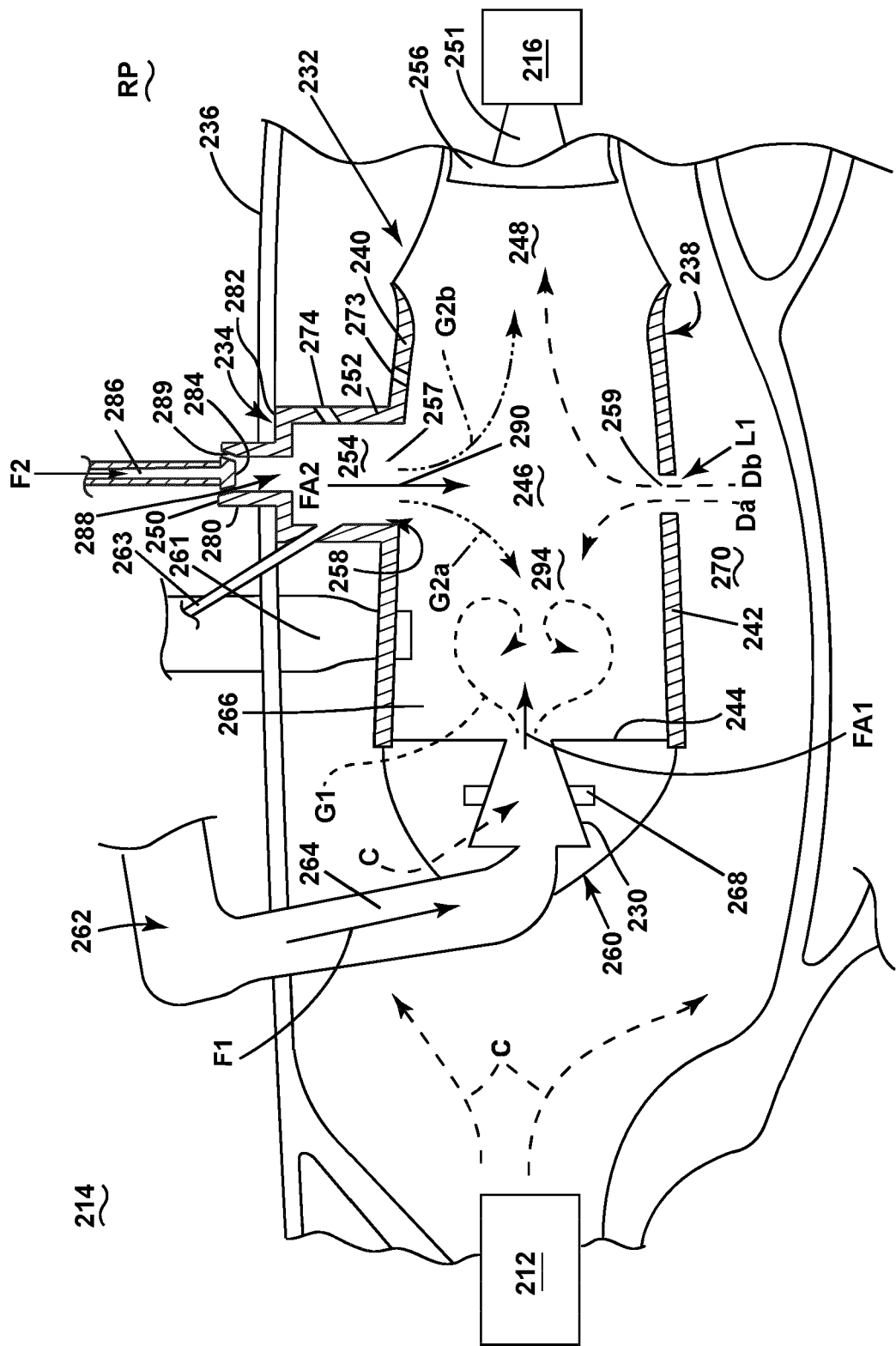


FIG. 7

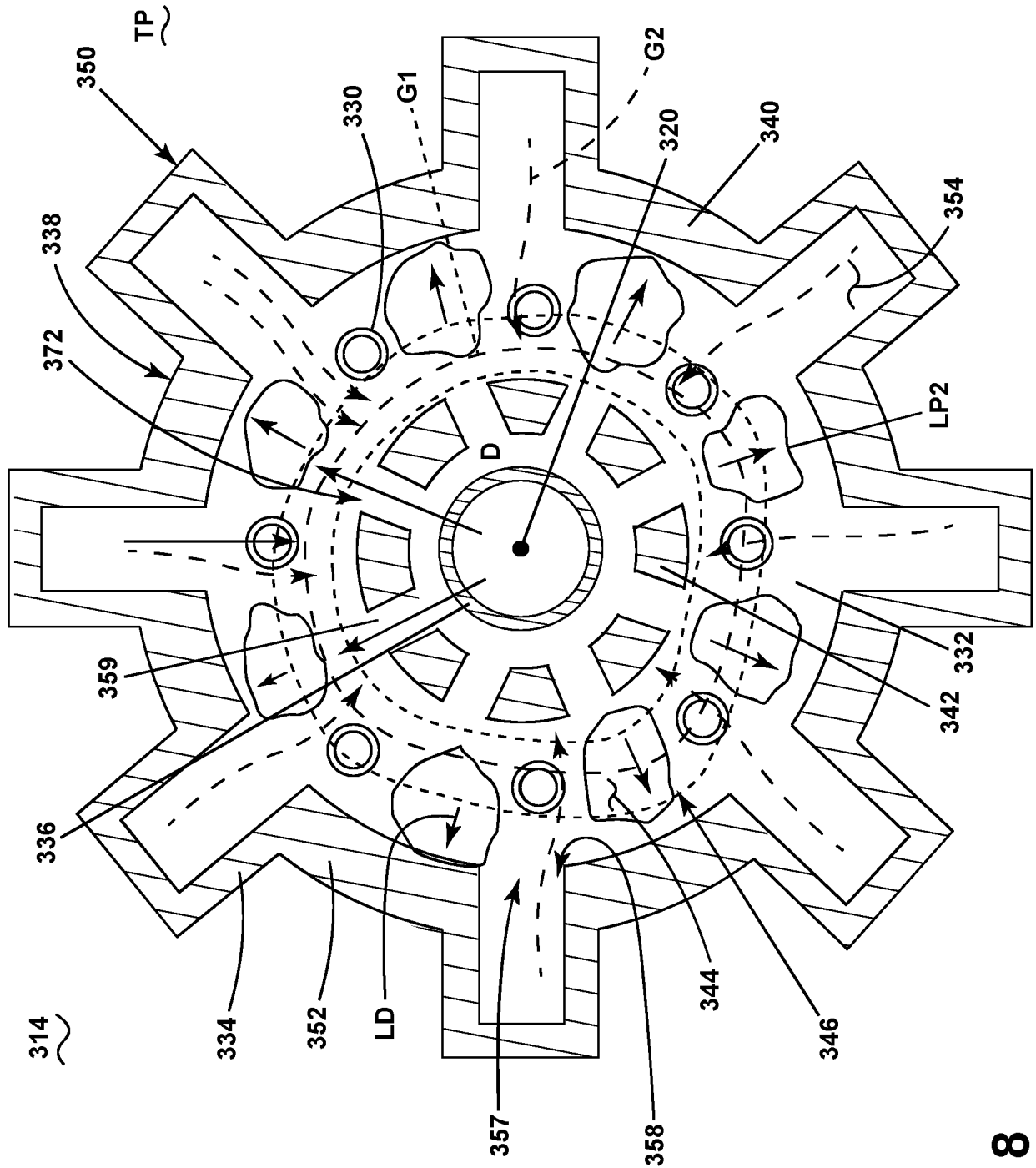


Fig. 8

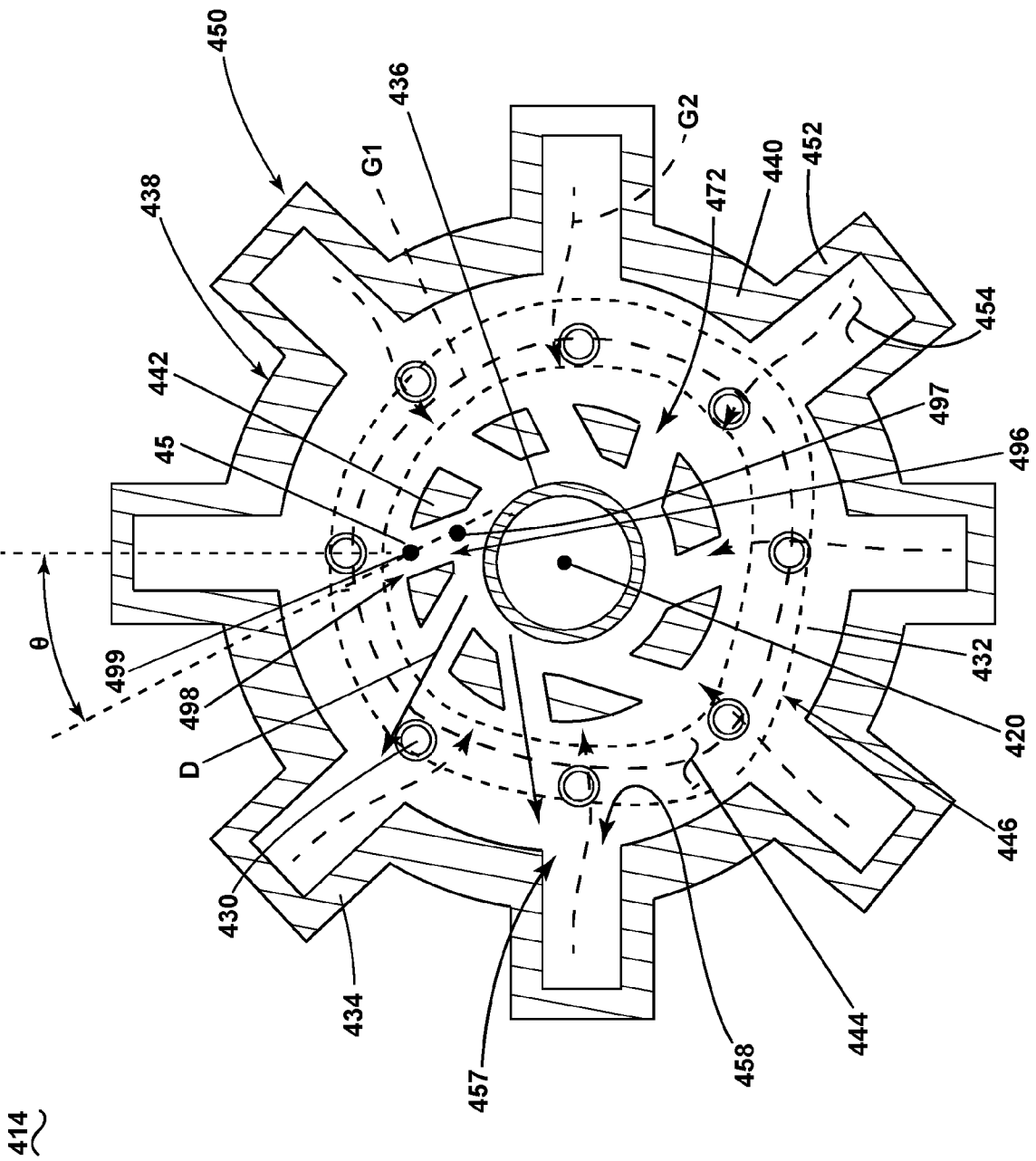


FIG. 9

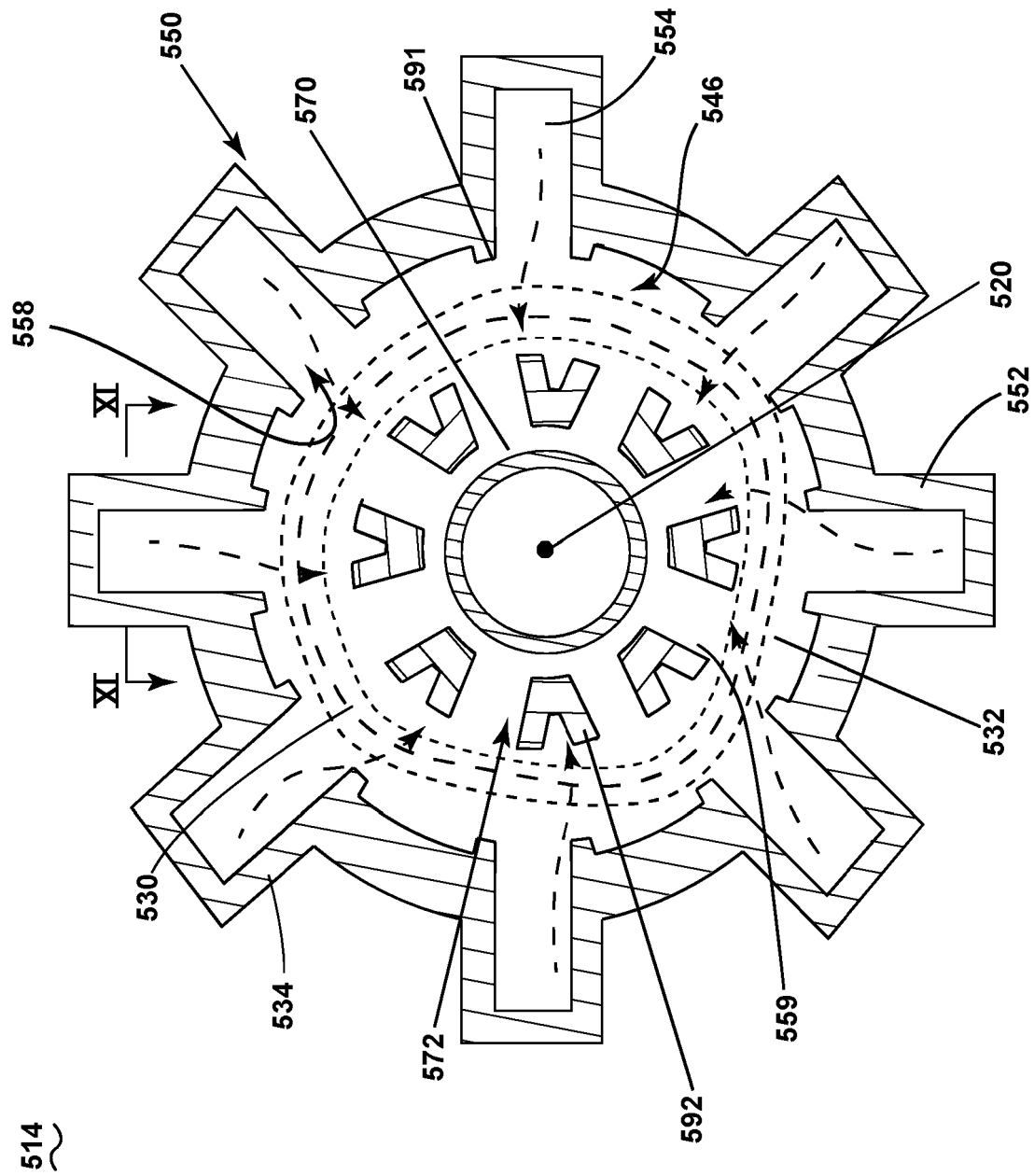
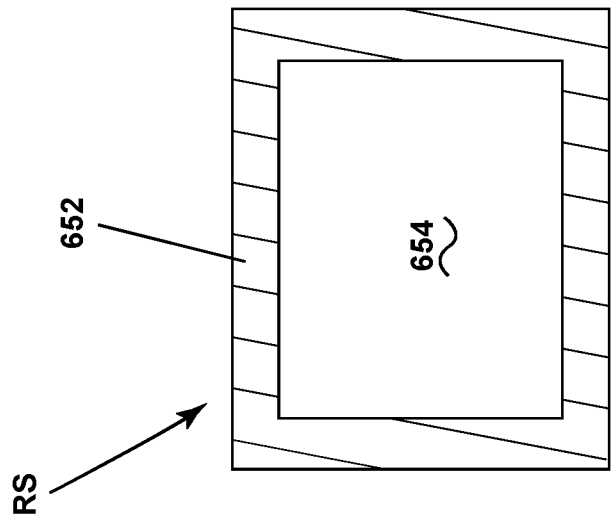
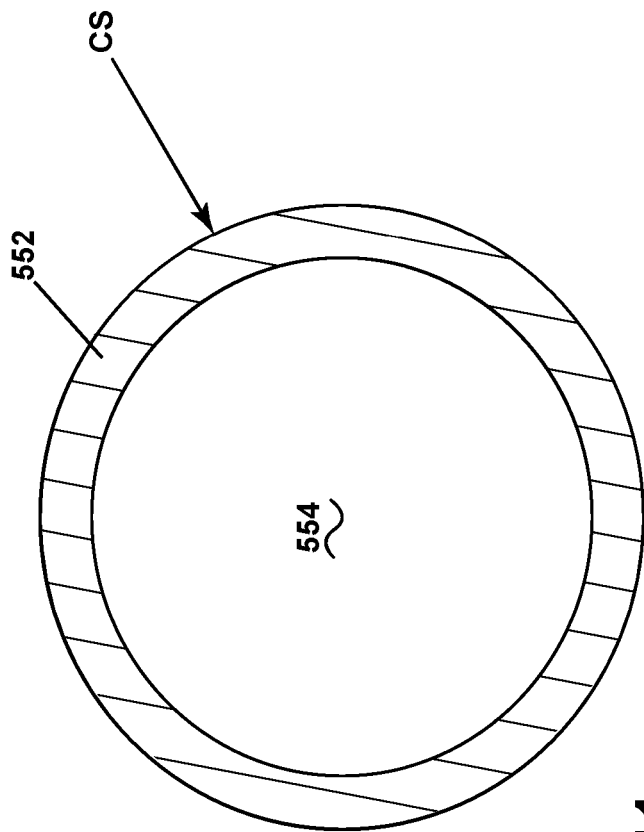
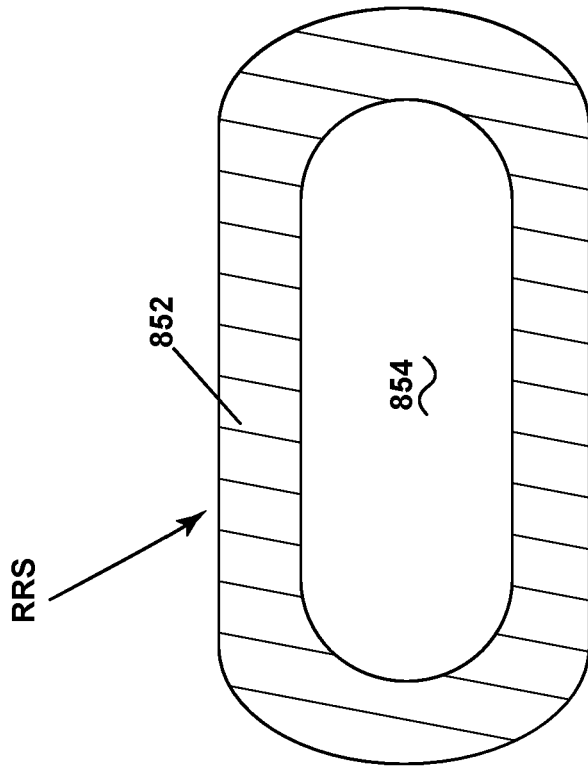
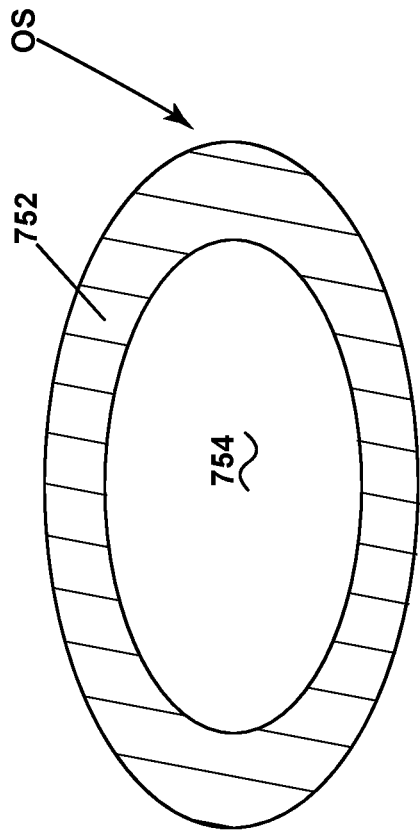


FIG. 10







EUROPEAN SEARCH REPORT

Application Number

EP 24 19 1840

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 5 295 354 A (BARBIER GERARD Y G [FR] ET AL) 22 March 1994 (1994-03-22)	1-4,6-8, 10,11,13	INV. F23R3/06
Y	* column 2, line 31 - line 60; figure 1 *	5,9,14, 15	F23R3/34 F23R3/42 F23R3/50
Y	US 5 687 571 A (ALTHAUS ROLF [JP] ET AL) 18 November 1997 (1997-11-18) * column 2, line 65 - column 3, line 39; figures 1,2 *	5,14,15	
Y	US 4 192 139 A (BUCHHEIM ROLF [DE]) 11 March 1980 (1980-03-11) * column 3, line 1 - line 44; figure 1 *	9	
Y	US R E34 962 E (SHEKLETON JACK R [US] ET AL) 13 June 1995 (1995-06-13) * column 4, line 22 - line 53; figures 1-3 * * column 5, line 1 - line 14 *	15	
X	US 2013/145766 A1 (HAWIE EDUARDO [CA] ET AL) 13 June 2013 (2013-06-13) * paragraphs [0017] - [0019]; figure 3 *	1-4,6,7, 10,12,13	TECHNICAL FIELDS SEARCHED (IPC) F23R
A	US 5 473 882 A (ZARZALIS NIKOLAOS [DE] ET AL) 12 December 1995 (1995-12-12) * column 4, line 54 - column 5, line 11; figures 2a,2b *	1-15	
The present search report has been drawn up for all claims			
Place of search The Hague		Date of completion of the search 25 February 2025	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	

EPO FORM 1503 03.82 (P04C01)

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

EP 24 19 1840

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.

25 - 02 - 2025

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 5295354 A	22-03-1994	DE 69201062 T2	14-06-1995
		EP 0499535 A1	19-08-1992
		FR 2672667 A1	14-08-1992
		JP H04316921 A	09-11-1992
		US 5295354 A	22-03-1994

US 5687571 A	18-11-1997	CN 1142587 A	12-02-1997
		US 5687571 A	18-11-1997

US 4192139 A	11-03-1980	DE 2629761 A1	05-01-1978
		US 4192139 A	11-03-1980

US RE34962 E	13-06-1995	DE 3878902 T2	17-06-1993
		EP 0348500 A1	03-01-1990
		JP H02503110 A	27-09-1990
		US 4928479 A	29-05-1990
		US RE34962 E	13-06-1995
		WO 8906308 A1	13-07-1989

US 2013145766 A1	13-06-2013	CA 2776539 A1	07-06-2013
		US 2013145766 A1	13-06-2013
		US 2016320064 A1	03-11-2016
		US 2021348764 A1	11-11-2021

US 5473882 A	12-12-1995	DE 4318405 A1	08-12-1994
		FR 2706020 A1	09-12-1994
		GB 2278675 A	07-12-1994
		US 5473882 A	12-12-1995

EPO FORM P0459

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82