US 20250264055A1

(19) United States

(12) Patent Application Publication

Verma et al.

(10) Pub. No.: US 2025/0264055 A1

(43) Pub. Date: Aug. 21, 2025

(54) CYCLONIC SEPARATOR FOR GAS TURBINE ENGINE

(71) Applicant: **General Electric Company**, Schenectady, NY (US)

(72) Inventors: **Ajay Kumar Verma**, Bengaluru (IN); **Raju Sanjay**, Bengaluru (IN); **Veera Venkata Amarnath Manem**, Bengaluru (IN)

(21) Appl. No.: **19/042,136**

(22) Filed: **Jan. 31, 2025**

(30) **Foreign Application Priority Data**

Feb. 21, 2024 (IN) 202411012304

Publication Classification

(51) **Int. Cl.**

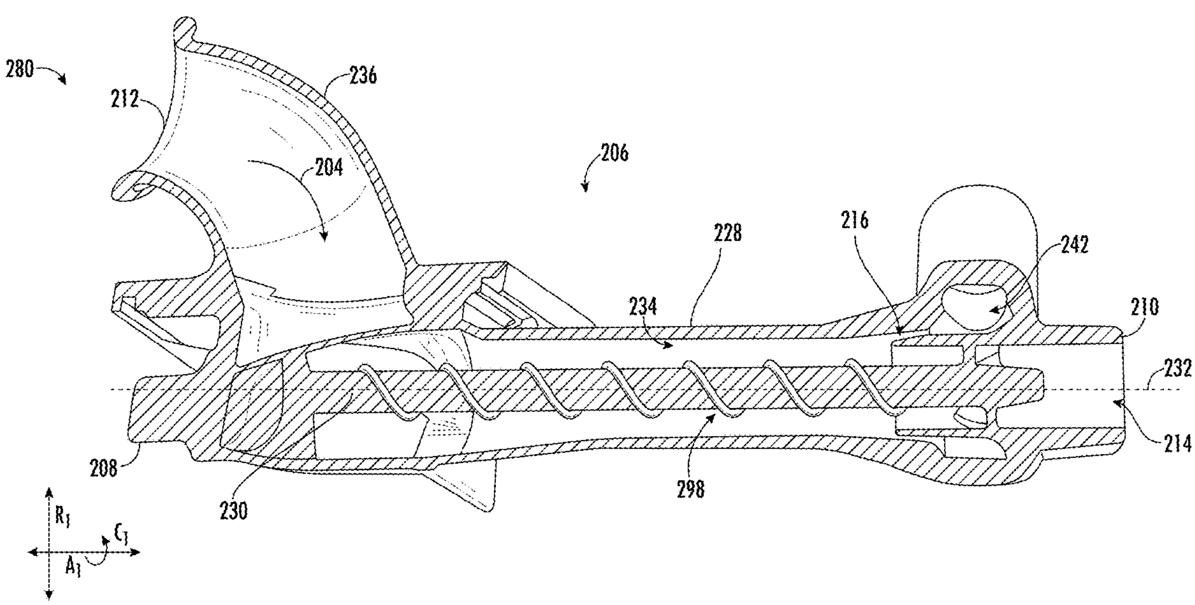
F02C 7/057	(2006.01)
F02C 7/18	(2006.01)

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

CPC ***F02C 7/057*** (2013.01); ***F02C 7/18*** (2013.01); *F05D 2260/232* (2013.01)

(57) **ABSTRACT**

A cyclonic separator for a turbine cooling airflow of a gas turbine engine includes a housing, a central body, an inlet, a first fluid outlet, a second fluid outlet, and a fluid deflector. The housing includes a first end, a second end, and an outer wall extending between the first end and the second end. The central body is disposed in the housing and defines an annular chamber with the outer wall. The inlet is disposed at the first end and is in fluid communication with the annular chamber. The first fluid outlet is disposed at the second end. The second fluid outlet is disposed in the outer wall downstream of the first end and extends outward at least partially in the radial direction. The fluid deflector is disposed on the central body and extends outward in the radial direction and rearward in the axial direction.



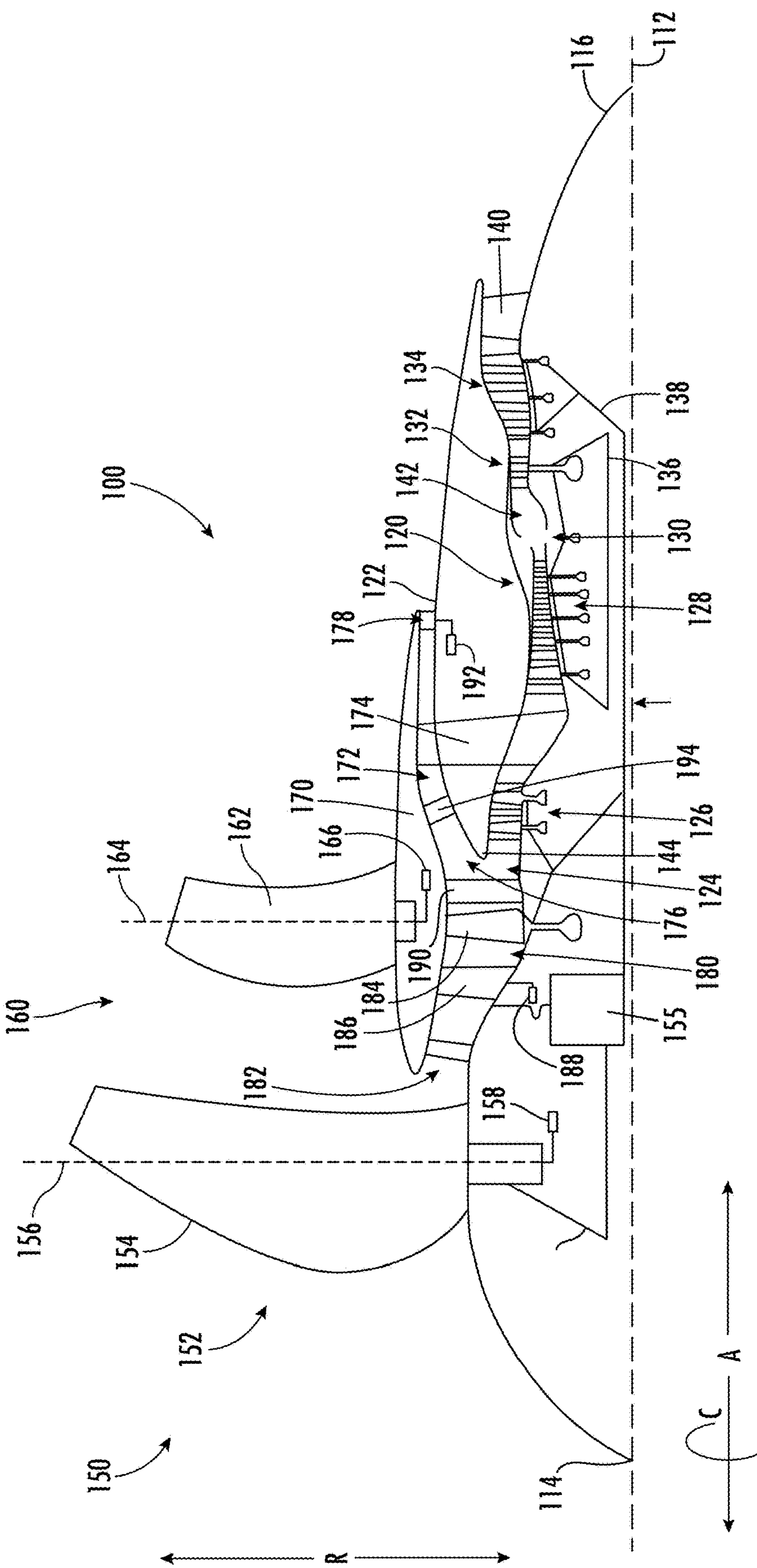

100
112
114
116
120
122
124
126
128
130
132
134
136
138
140
142
144
150
152
154
155
156
158
160
162
164
166
170
172
174
176
178
180
182
184
186
188
190
192
194
R
A
C

FIG. 1

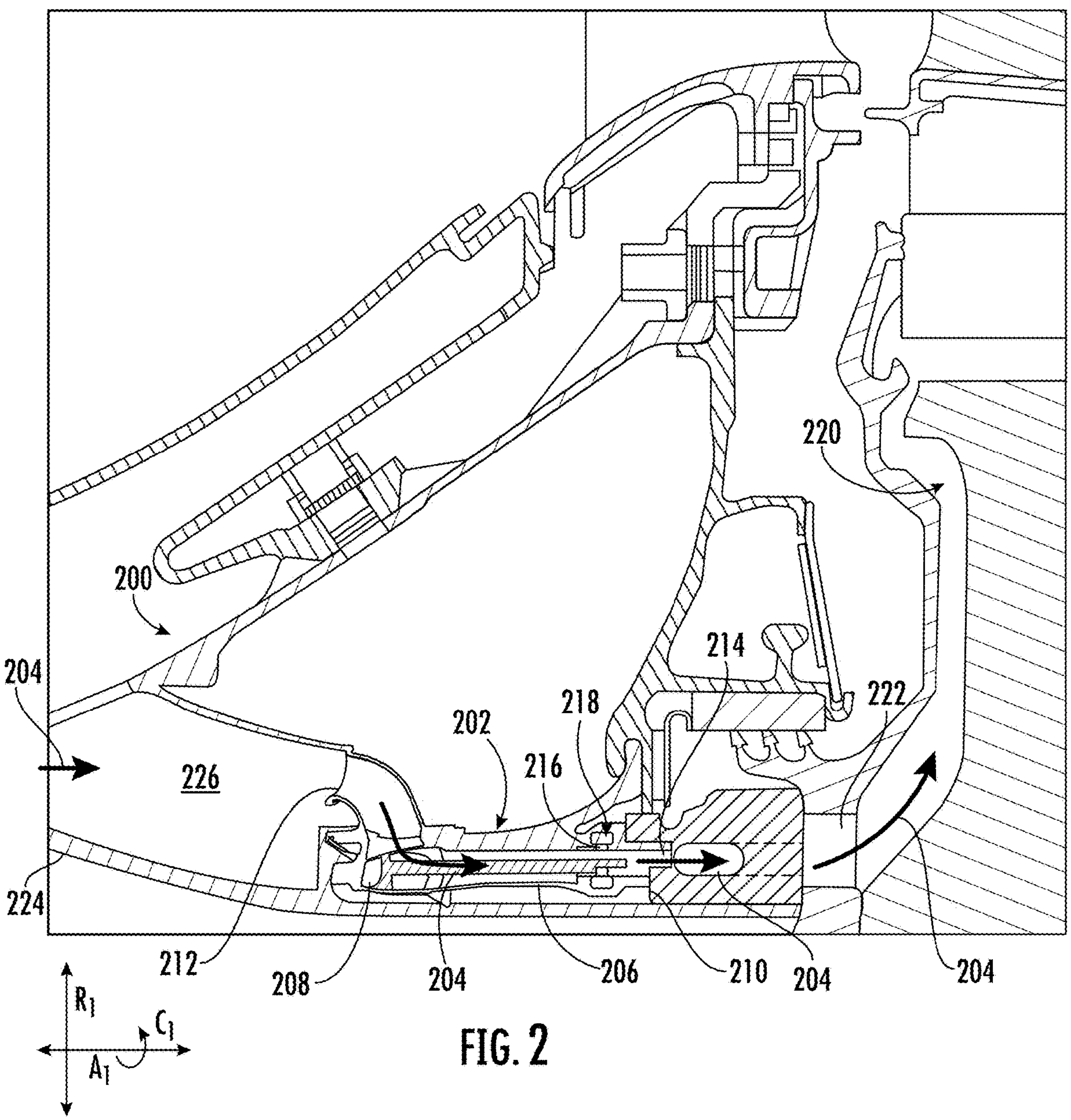
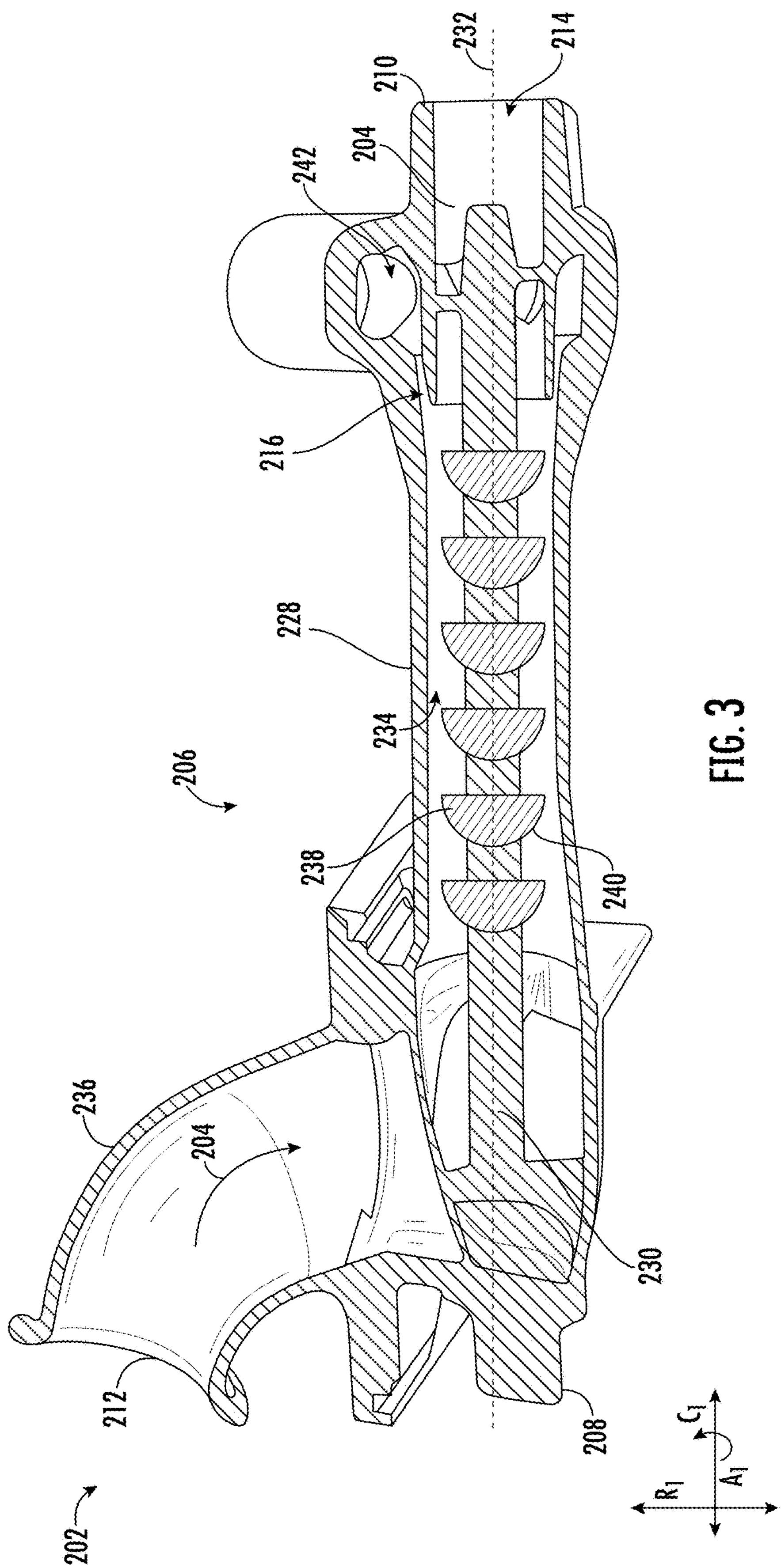

200
204
226
202
218
214
216
222
220
224
212
208
204
206
210
204
204
R1
C1
A1

FIG. 2



232
214
210
204
242
216
228
234
206
238
240
236
204
230
212
208
202
R_1
C_1
A_1

FIG. 3

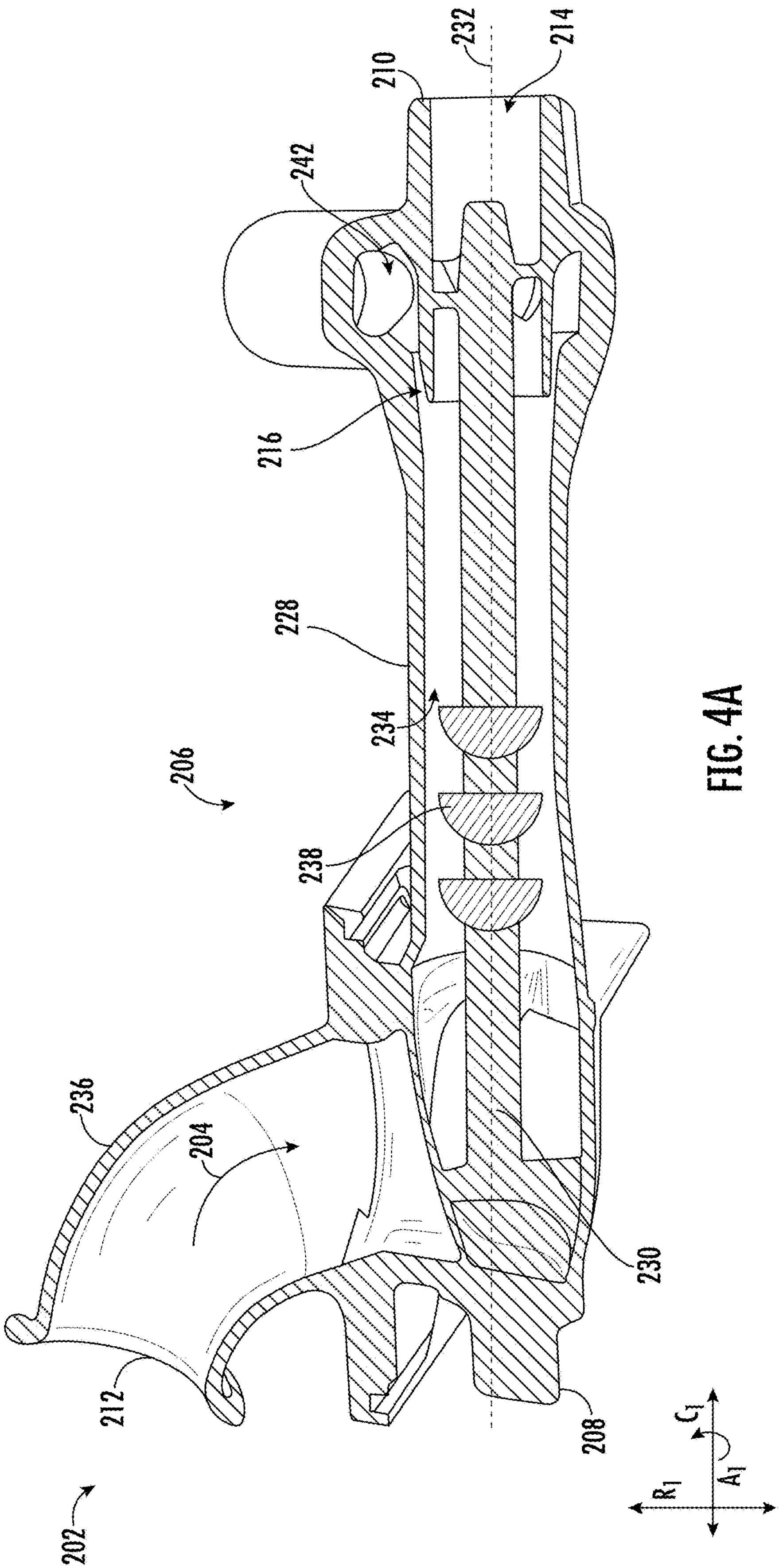

232
214
210
242
216
228
234
206
238
236
204
230
212
208
202
R_1
C_1
A_1

FIG. 4A

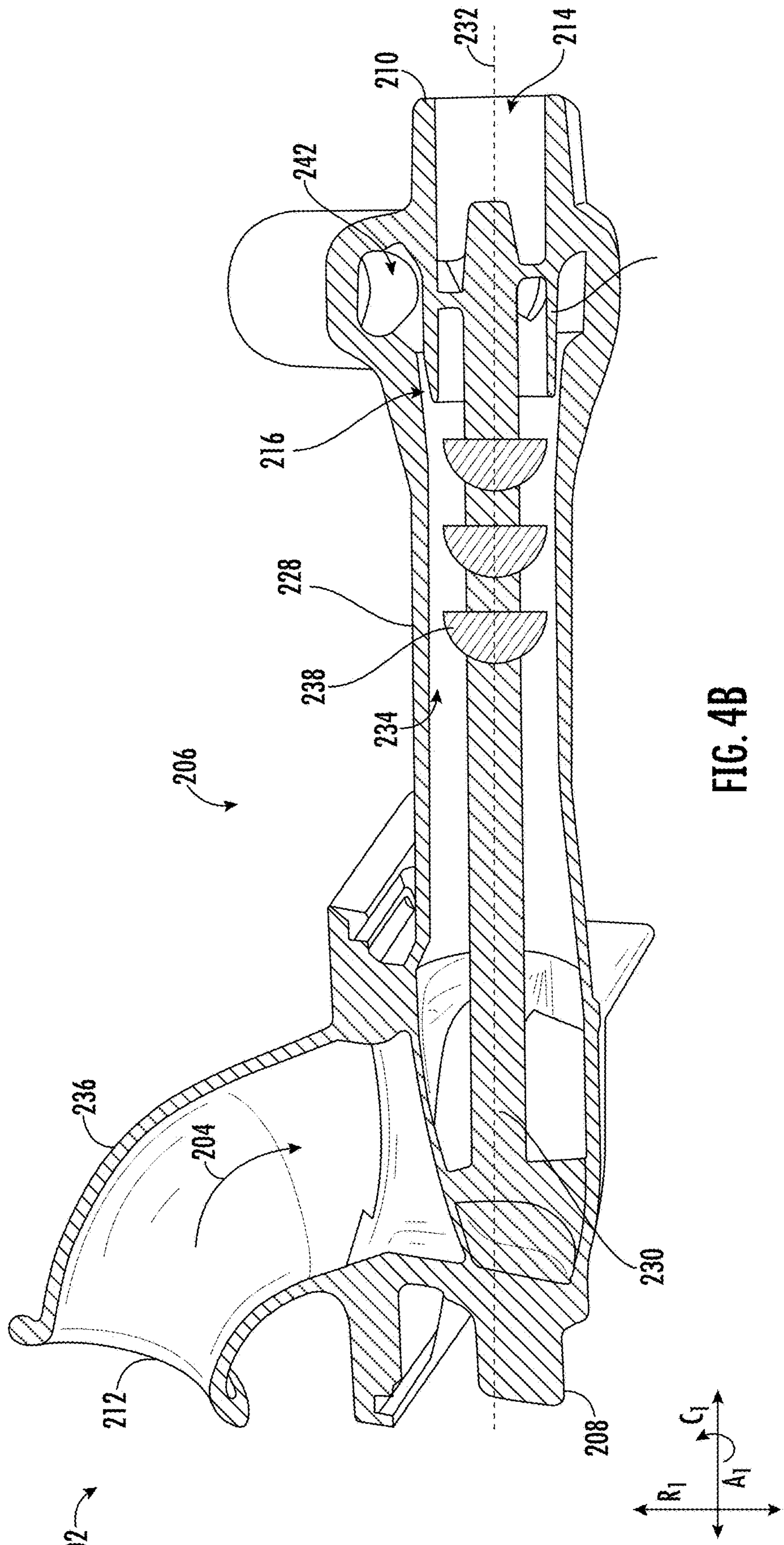

232
214
210
242
216
228
238
234
206
236
204
230
212
208
202
C_1
R_1
A_1

FIG. 4B

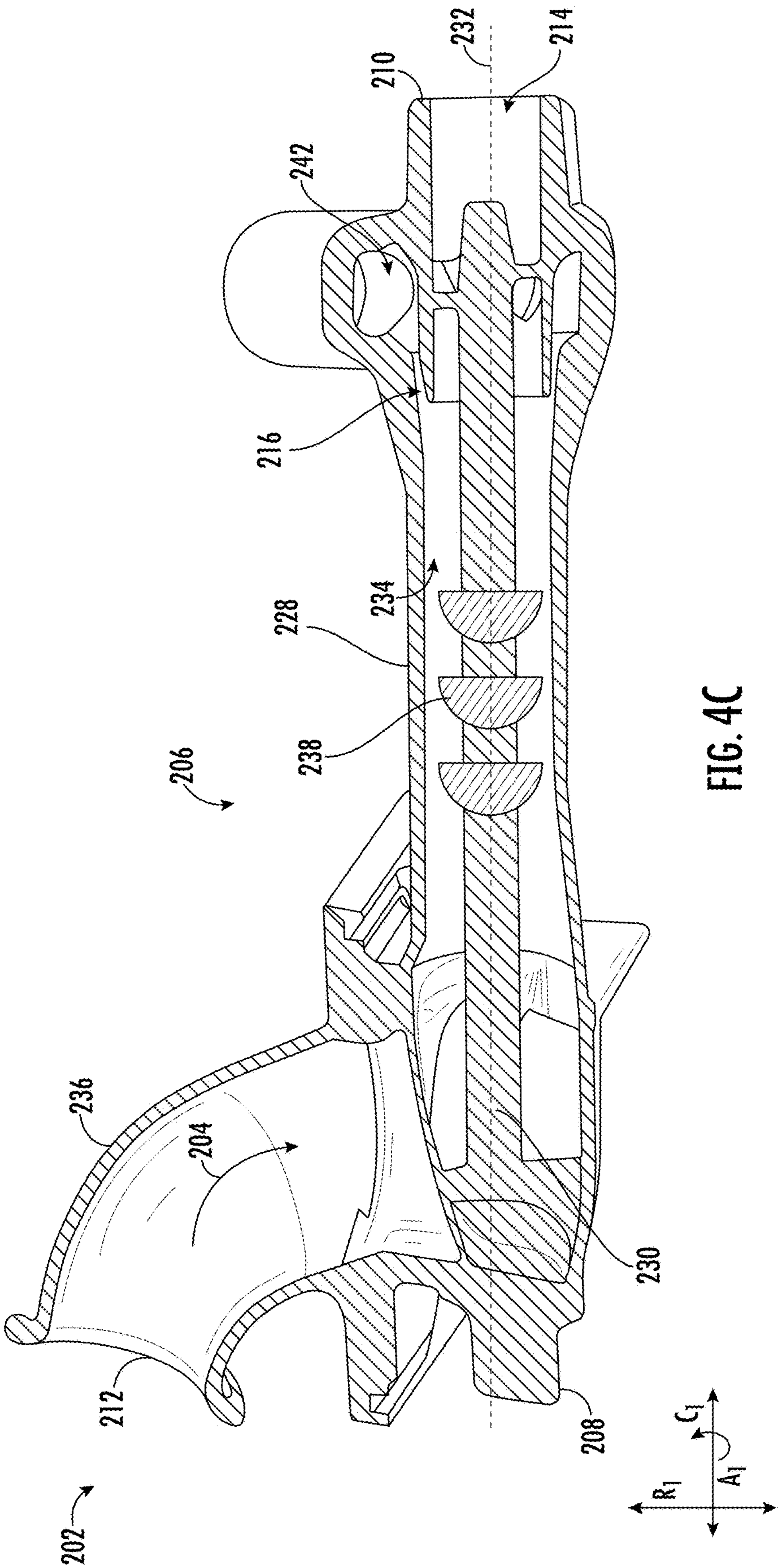

232
214
210
242
216
228
234
238
206
236
204
230
212
208
202
R_1
C_1
A_1

FIG. 4C

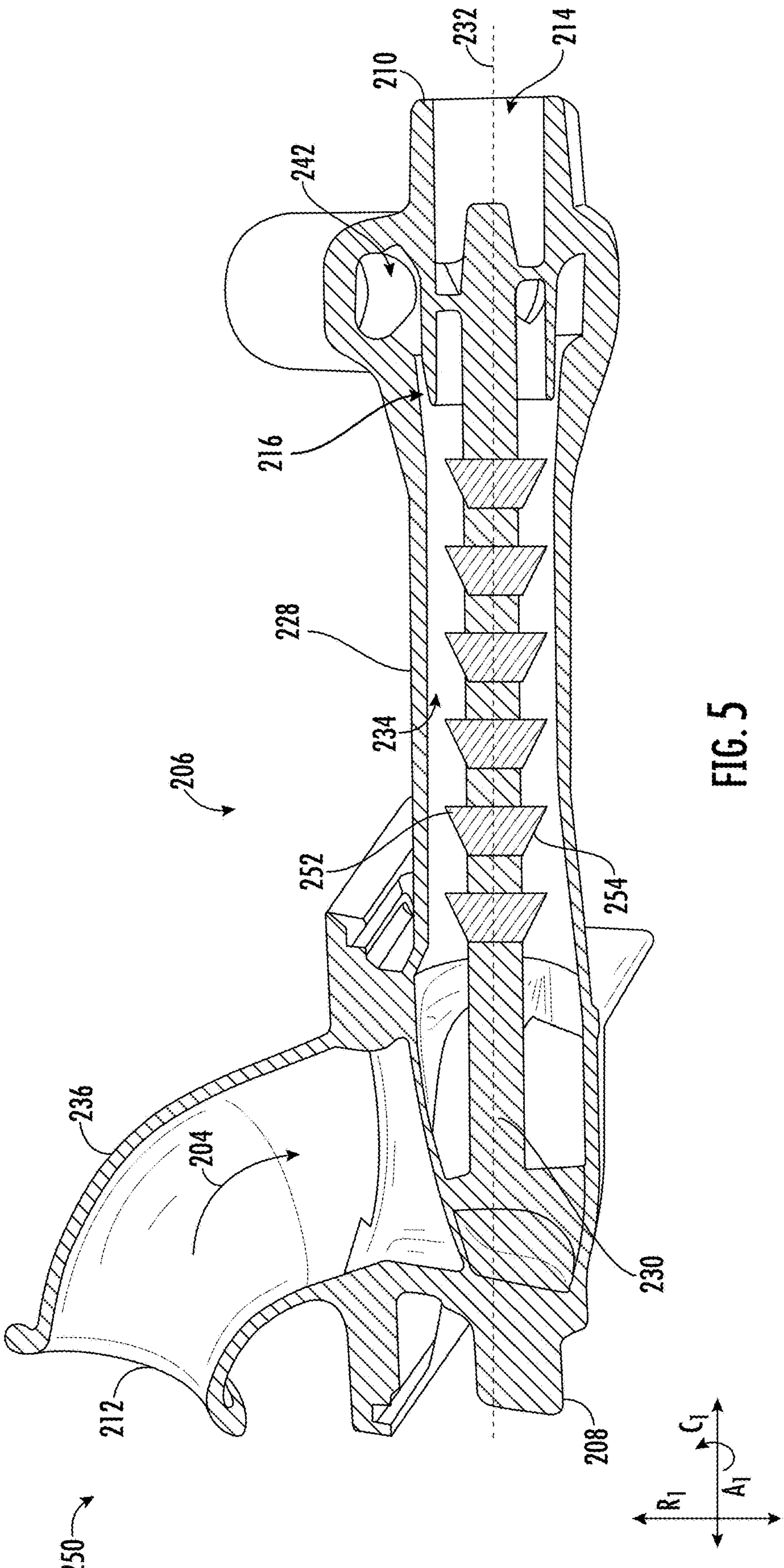

232
214
210
242
216
228
234
206
252
254
236
204
230
212
208
250
C_1
R_1
A_1

FIG. 5

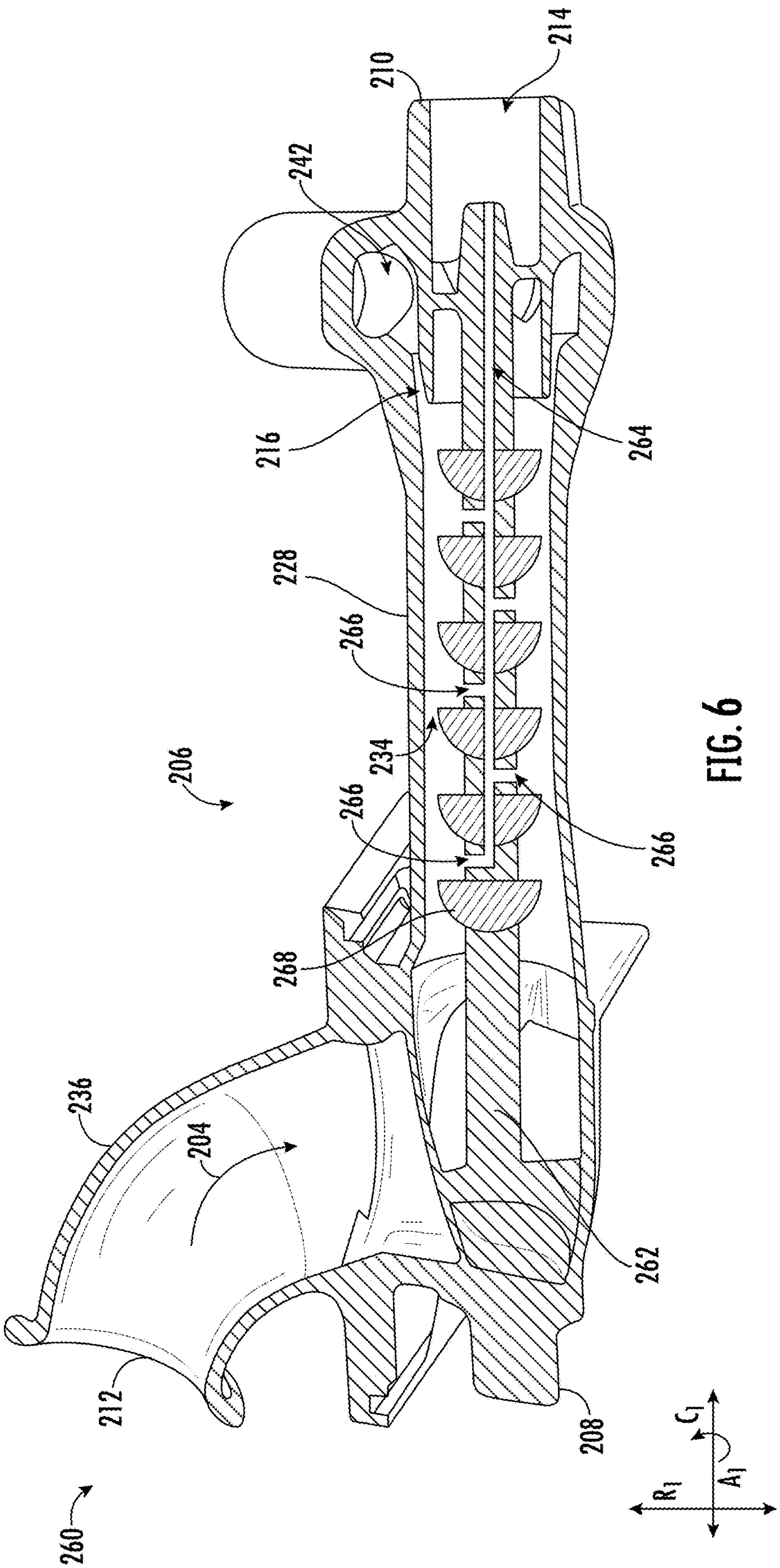

210
214
242
216
264
228
266
234
266
266
206
268
236
204
262
212
208
260
R_1
C_1
A_1

FIG. 6

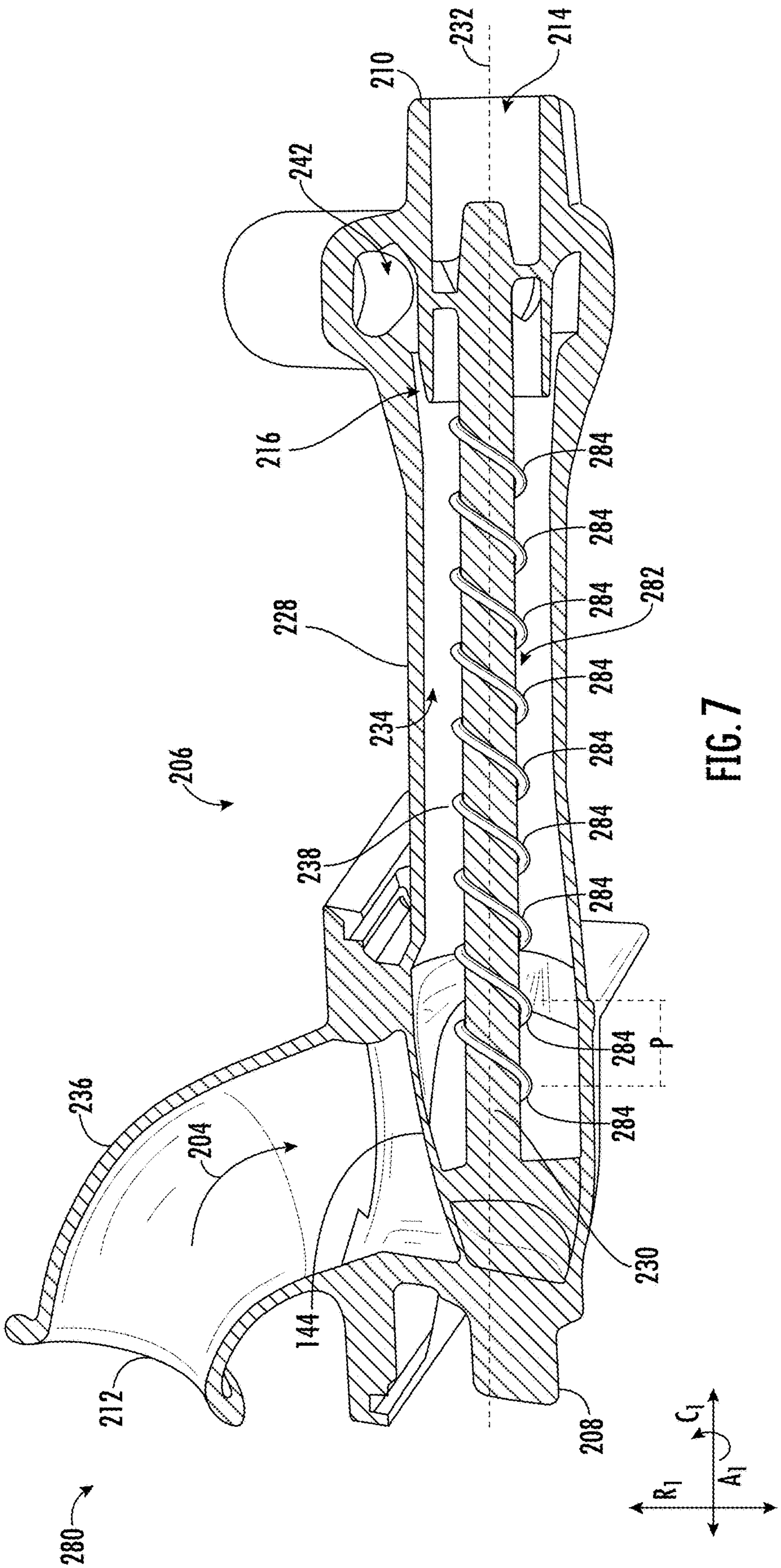

232
214
210
242
216
284
284
282
284
228
284
234
206
284
238
284
284
P
284
236
204
284
230
144
212
208
C_1
A_1
R_1
280

FIG. 7

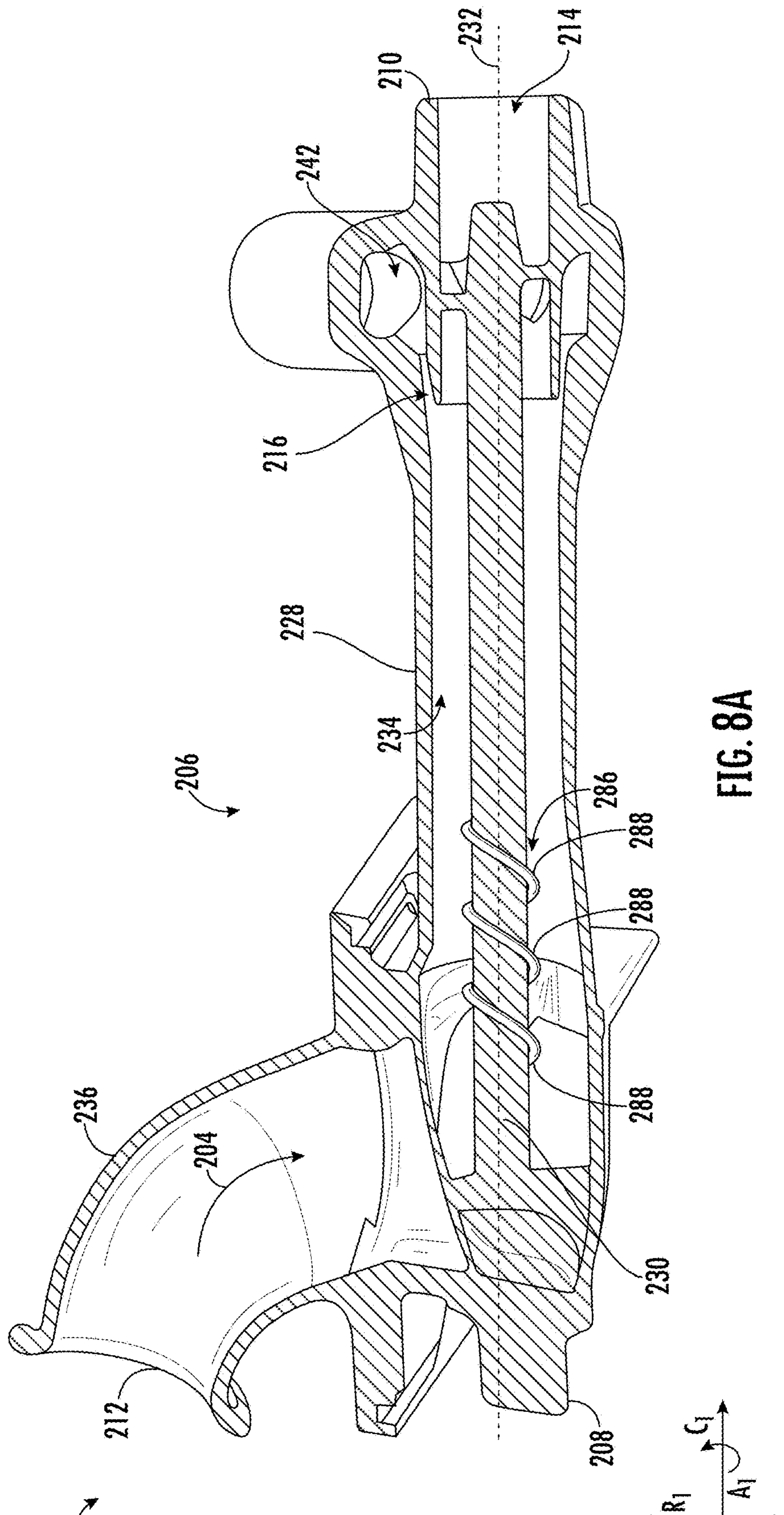

210
232
214
242
216
228
234
206
286
288
288
288
236
204
230
212
208
280
C_1
R_1
A_1

FIG. 8A

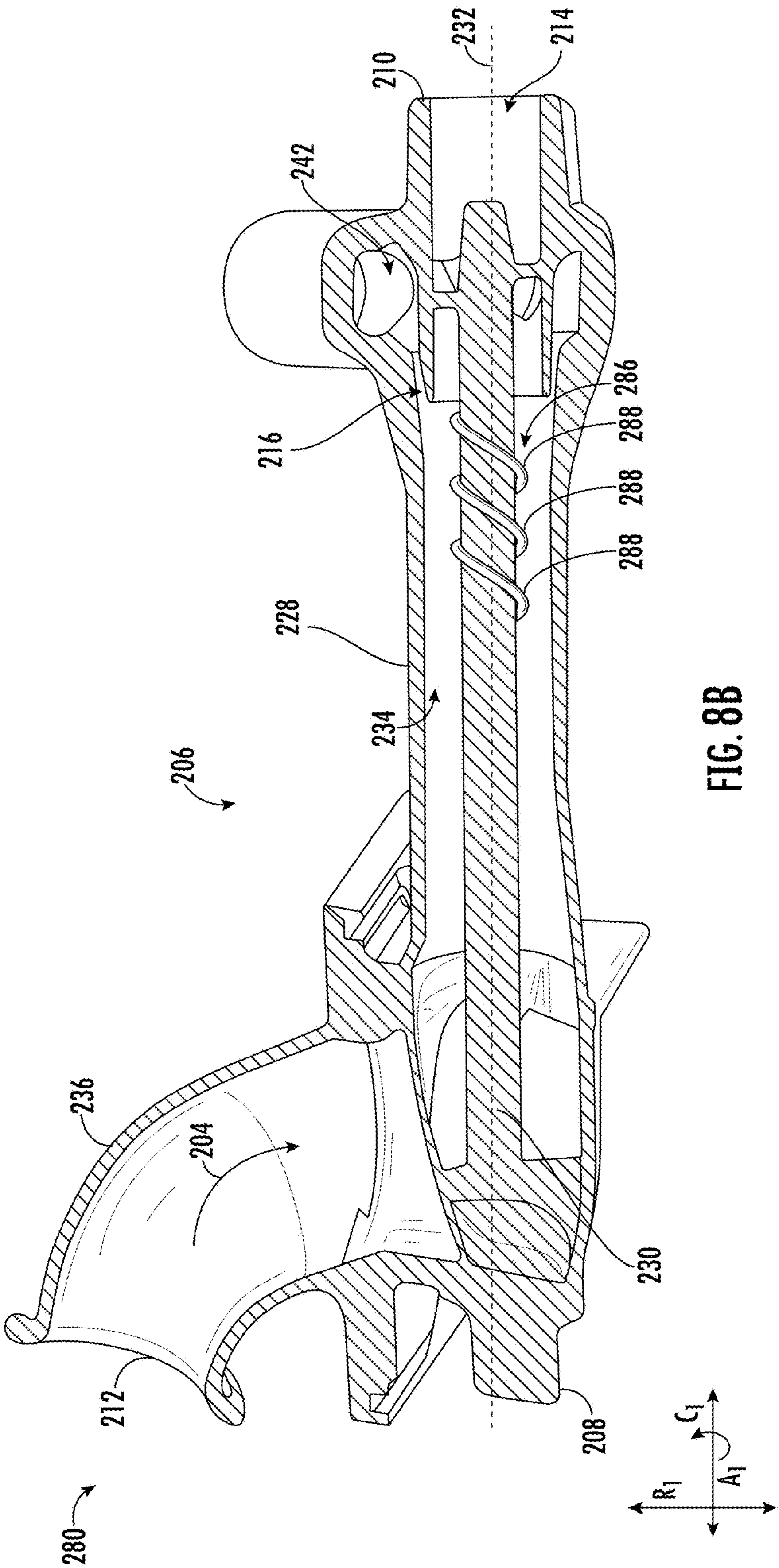

232
214
210
242
286
288
288
288
216
228
234
206
236
204
230
212
208
280
C_1
R_1
A_1

FIG. 8B

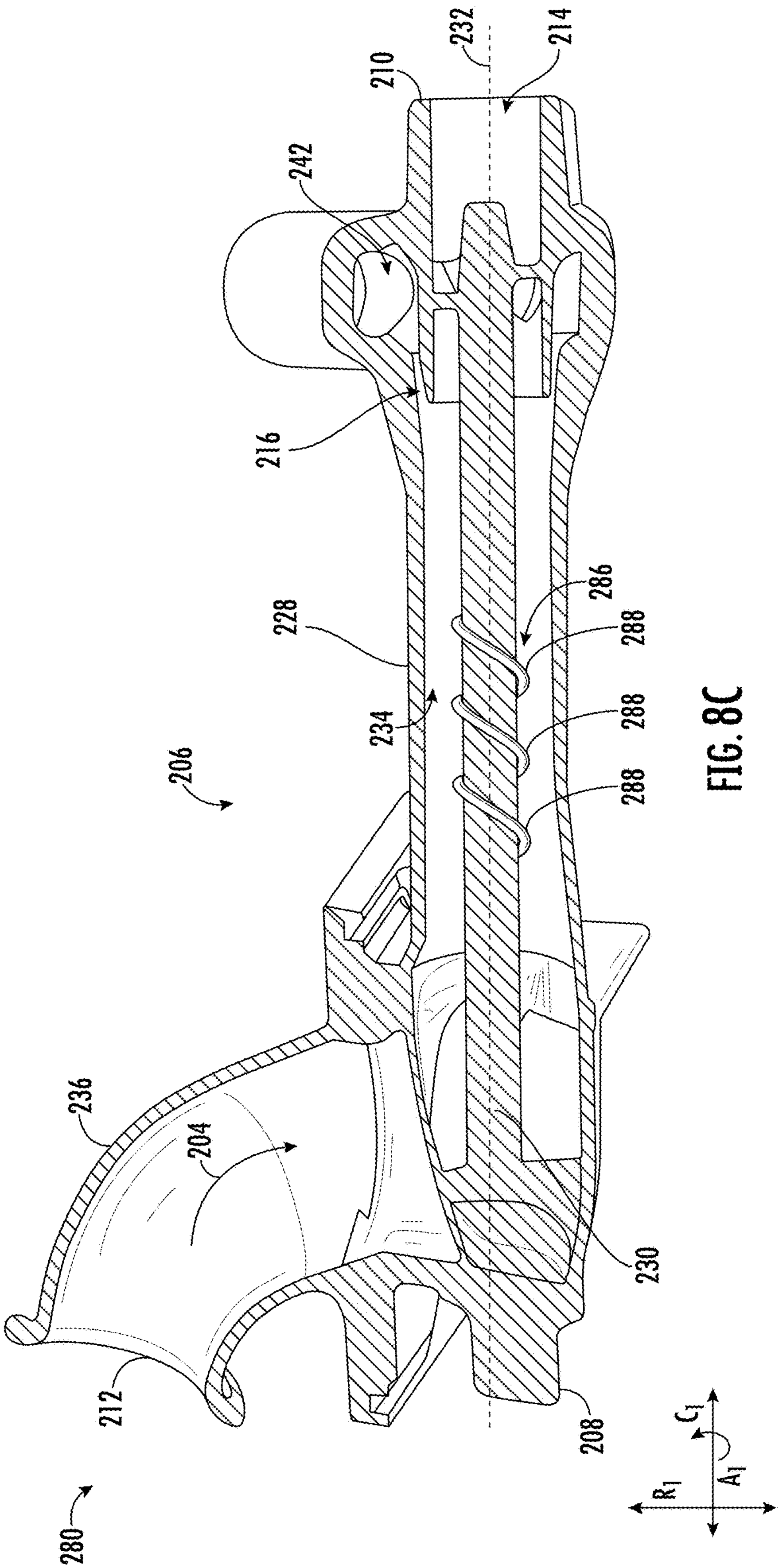
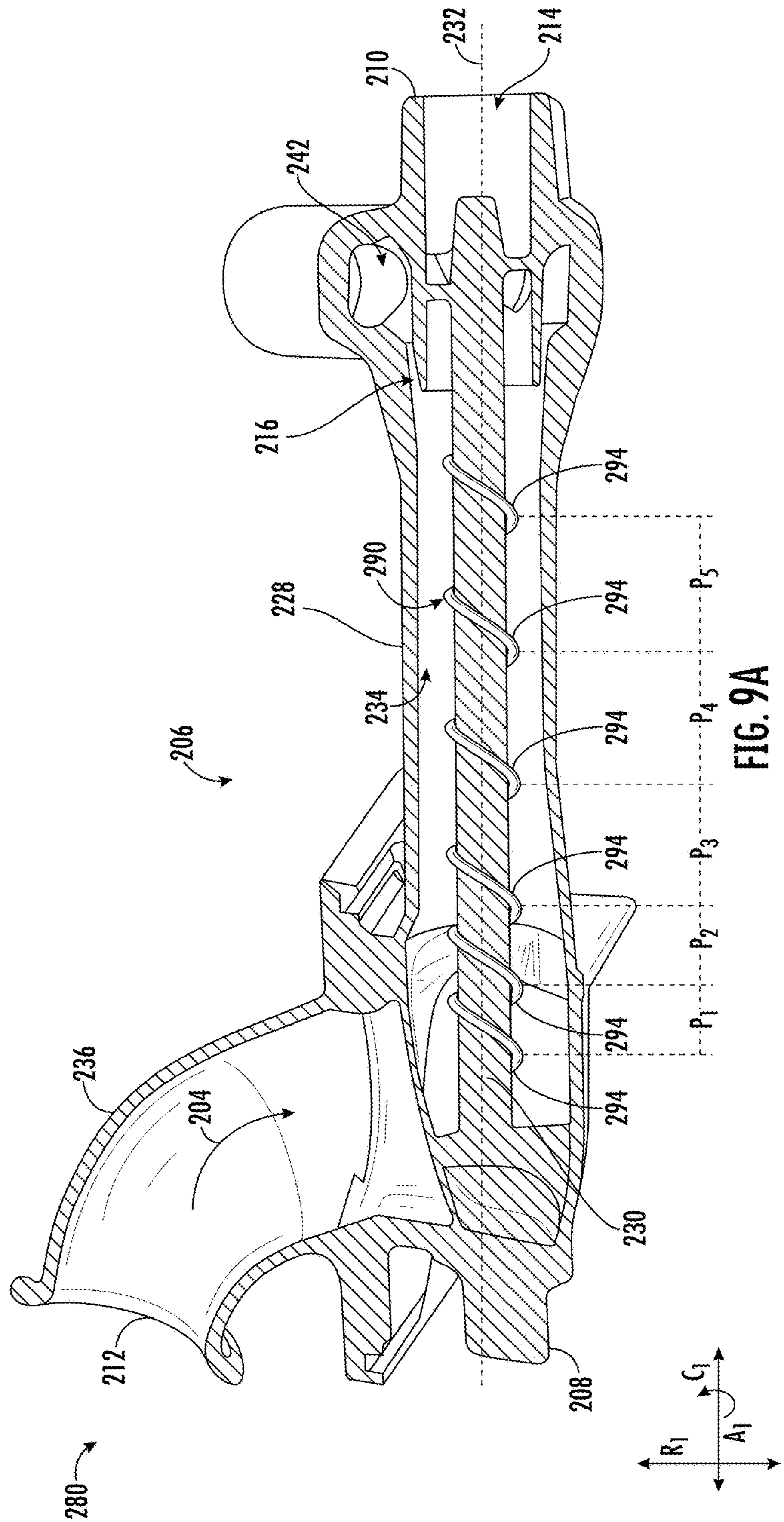

232
214
210
242
216
286
228
288
288
234
206
288
236
204
230
212
208
280
C_1
R_1
A_1

FIG. 8C



232
214
210
242
216
294
290
228
234
206
P1
P2
P3
P4
P5
236
204
230
212
208
280
C1
R1
A1

FIG. 9A

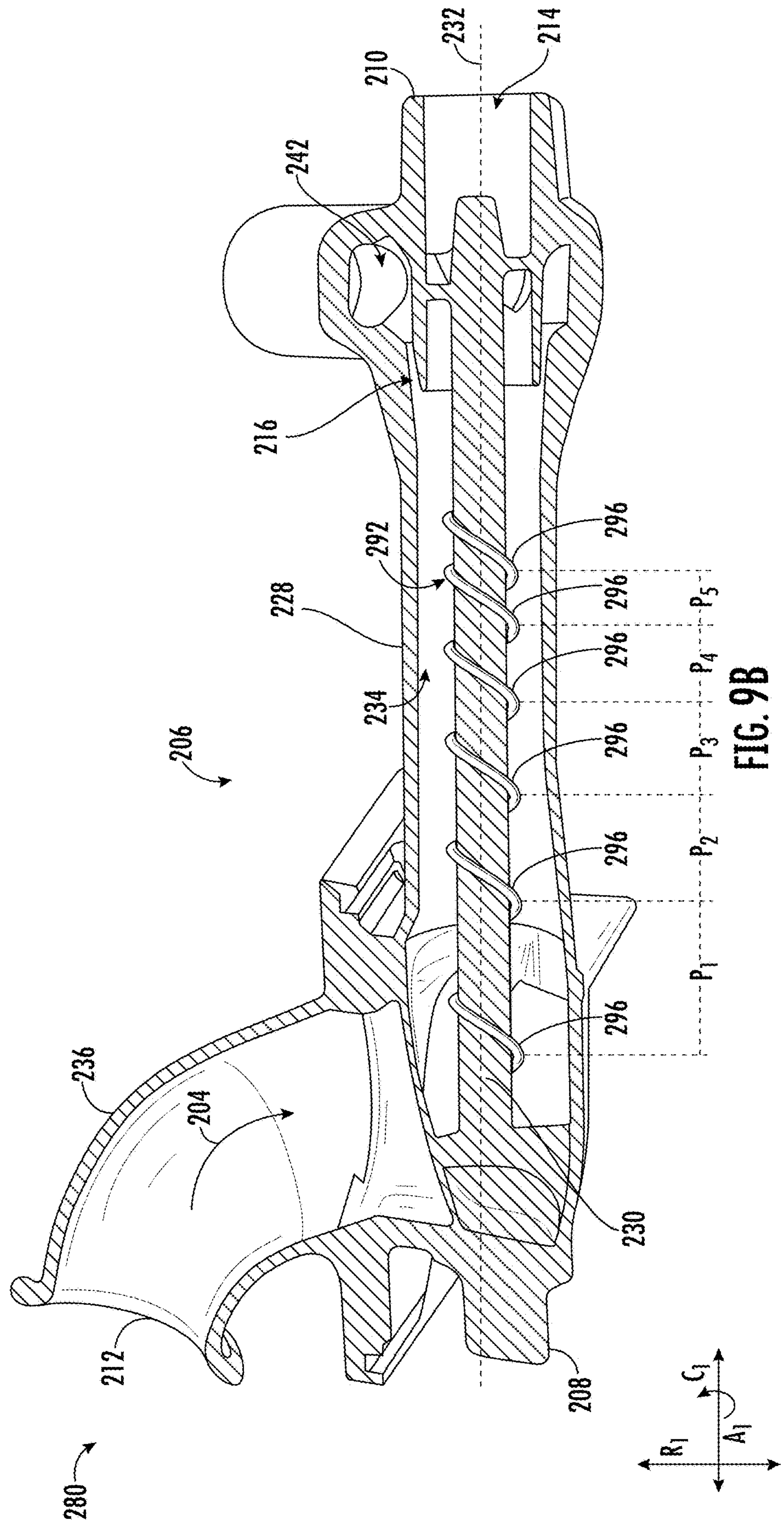

206
210
232
214
242
216
292
228
234
296
296
296
296
296
296
P_5
P_4
P_3
P_2
P_1
236
204
230
212
208
280
C_1
R_1
A_1

FIG. 9B

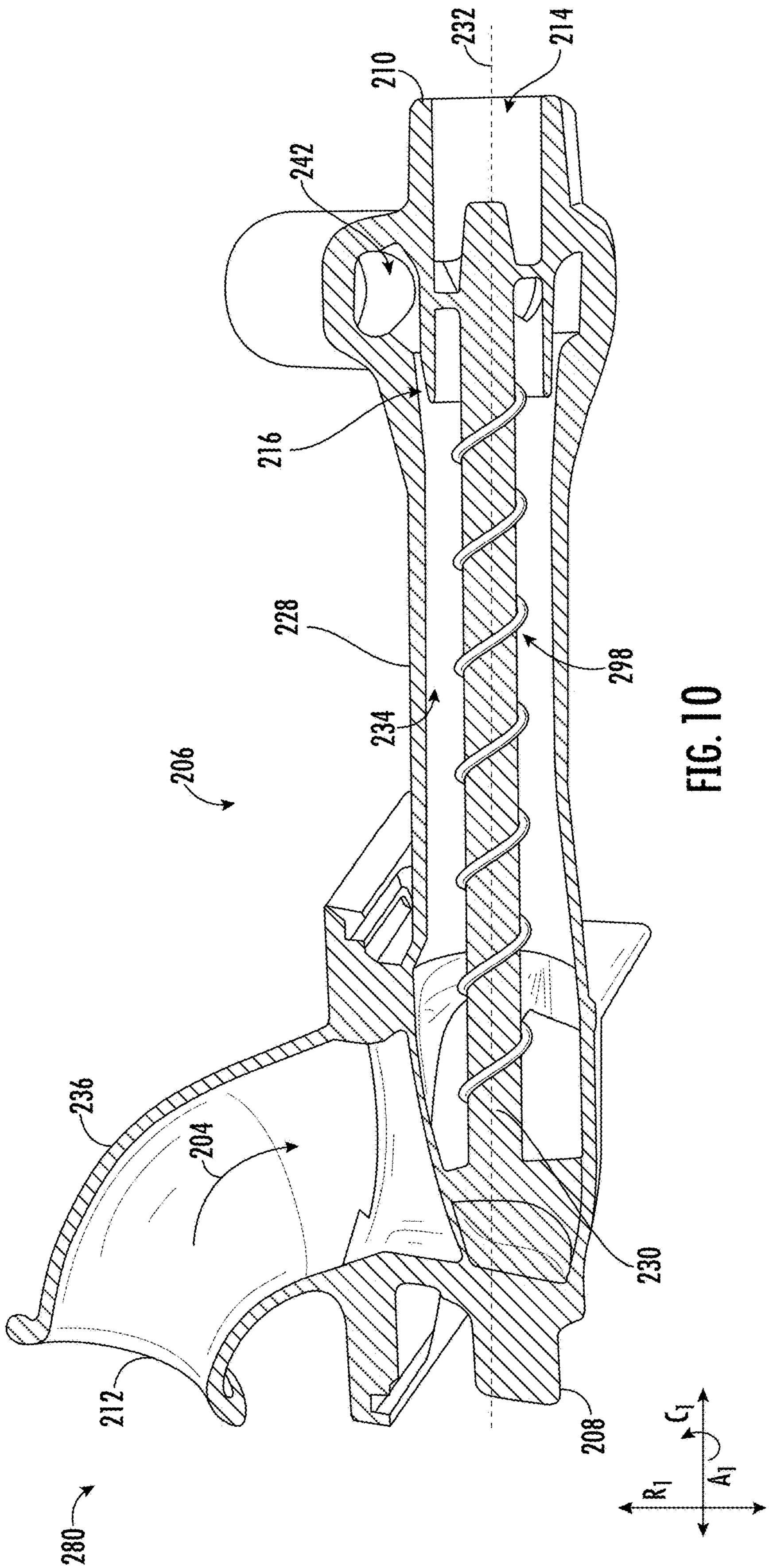

232
214
210
242
216
228
298
234
206
236
204
230
212
208
280
C_1
R_1
A_1

FIG. 10

CYCLONIC SEPARATOR FOR GAS TURBINE ENGINE

PRIORITY INFORMATION

[0001] The present application claims priority to Indian patent application Ser. No. 20/241,1012304 filed on Feb. 21, 2024.

FIELD

[0002] The present disclosure relates to a gas turbine engine, and more particularly to a cyclonic separator for a gas turbine engine.

BACKGROUND

[0003] Turbine engines, and particularly gas or combustion turbine engines, are rotary engines that extract energy from a flow of combusted gases passing through the engine onto a multitude of turbine blades. Gas turbine engines have been used for land and nautical locomotion and power generation, but are most commonly used for aeronautical applications such as for aircraft. In aircraft, gas turbine engines are used for propulsion of the aircraft. In terrestrial applications, turbine engines are often used for power generation.

[0004] Gas turbine engines for aircraft are designed to operate at high temperatures to maximize engine efficiency, so cooling of certain engine components, such as the high pressure turbine and the low pressure turbine, can be necessary. Typically, cooling is accomplished by ducting cooler air from the high and/or low pressure compressors to the engine components that require cooling. While the compressor air is provided at a high temperature, it is cooler relative to the turbine air, and can be used to cool the turbine. When cooling the turbines, cooling air can be supplied to various turbine components, including the interior of the turbine blades and the turbine shroud.

BRIEF DESCRIPTION OF THE DRAWINGS

[0005] A full and enabling disclosure of the present disclosure, including the best mode thereof, directed to one of ordinary skill in the art, is set forth in the specification, which makes reference to the appended figures, in which:

[0006] FIG. **1** is a cross-sectional view of an exemplary gas turbine engine.

[0007] FIG. **2** is a cross-sectional view of a cooling circuit of the gas turbine engine of FIG. **1**.

[0008] FIG. **3** is a cross-sectional view of a cyclonic separator of the cooling circuit with a fluid deflector.

[0009] FIGS. **4**A-**4**C are cross-sectional views of arrangements of the fluid deflector in the cyclonic separator.

[0010] FIG. **5** is a cross-sectional view of another cyclonic separator of the cooling circuit with a fluid deflector having a conical shape.

[0011] FIG. **6** is a cross-sectional view of another cyclonic separator of the cooling circuit with a central body having an internal channel.

[0012] FIG. **7** is a cross-sectional view of another cyclonic separator of the cooling circuit with a fluid deflector with a counterclockwise chirality.

[0013] FIGS. **8**A-**8**C are cross-sectional views of arrangements of the fluid deflector in the cyclonic separator of FIG. **7**.

[0014] FIGS. **9**A-**9**B are cross-sectional views of fluid deflectors in the cyclonic separator of FIG. **7** with varying thread pitch.

[0015] FIG. **10** is a cross-sectional view of another fluid deflector in the cyclonic separator of FIG. **7** with a clockwise chirality.

DETAILED DESCRIPTION

[0016] Reference will now be made in detail to present embodiments of the disclosure, one or more examples of which are illustrated in the accompanying drawings. The detailed description uses numerical and letter designations to refer to features in the drawings. Like or similar designations in the drawings and description have been used to refer to like or similar parts of the disclosure.

[0017] 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.

[0018] The singular forms “a”, “an”, and “the” include plural references unless the context clearly dictates otherwise.

[0019] The terms “forward” and “aft” refer to relative positions within a gas turbine engine, with “forward” referring to a position closer to an engine inlet and “aft” referring to a position closer to an engine nozzle or exhaust.

[0020] The terms “upstream” and “downstream” refer to the relative direction with respect to fluid flow in a fluid pathway. For example, “upstream” refers to the direction from which fluid flows, and “downstream” refers to the direction to which the fluid flows.

[0021] The present disclosure is generally related to removal of particulate matter from air flows in a gas turbine engine. Air flowing through the engine for cooling various components of the gas turbine engine may accumulate particulate matter. The particulate matter, such as dirt, dust, sand, ash, and other environmental contaminants, in the cooling air can cause a loss of cooling and reduced operational time for the aircraft environment. Particles supplied to the turbine components can clog, obstruct, or coat the flow passages and surfaces of the components, which can reduce the lifespan of the components.

[0022] To reduce the amount of particulate matter in the cooling air flows, a cyclonic separator swirls air in cyclic motion, applying centrifugal force on the particulate matter. The centrifugal forces push the particulate matter to a radial edge of the cyclonic separator, and a particle separator inhibits movement of the particulate matter back into the swirled air flow. An exit flow removes the particulate matter from the cyclonic separator, and the swirled air flow exits the cyclonic separator to cool the components of the gas turbine engine.

[0023] Referring now to FIG. **1**, a schematic cross-sectional view of a gas turbine engine **100** is provided according to an example embodiment of the present disclosure. Particularly, FIG. **1** provides a turbofan engine having a rotor assembly with a single stage of unducted rotor blades. In such a manner, the rotor assembly may be referred to herein as an “unducted fan,” or the entire engine **100** may be referred to as an “unducted turbofan engine.” In addition, the engine **100** of FIG. **1** includes a third stream extending from the compressor section to a rotor assembly flowpath over the turbomachine, as will be explained in more detail below.

[0024] For reference, the engine **100** defines an axial direction A, a radial direction R, and a circumferential direction C. Moreover, the engine **100** defines an axial centerline or longitudinal axis **112** that extends along the axial direction A. In general, the axial direction A extends parallel to the longitudinal axis **112**, the radial direction R extends outward from and inward to the longitudinal axis **112** in a direction orthogonal to the axial direction A, and the circumferential direction extends three hundred sixty degrees (360°) around the longitudinal axis **112**. The engine **100** extends between a forward end **114** and an aft end **116**, e.g., along the axial direction A.

[0025] The engine **100** includes a turbomachine **120** and a rotor assembly, also referred to a fan section **150**, positioned upstream thereof. Generally, the turbomachine **120** includes, in serial flow order, a compressor section, a combustion section, a turbine section, and an exhaust section. Particularly, as shown in FIG. **1**, the turbomachine **120** includes a core cowl **122** that defines an annular core inlet **124**. The core cowl **122** further encloses at least in part a low pressure system and a high pressure system. For example, the core cowl **122** depicted encloses and supports at least in part a booster or low pressure ("LP") compressor (referred to as an LP compressor **126** herein) for pressurizing the air that enters the turbomachine **120** through core inlet **124**. A high pressure ("HP"), multi-stage, axial-flow compressor (referred to as an HP compressor **128** herein) receives pressurized air from the LP compressor **126** and further increases the pressure of the air. The pressurized air stream flows downstream to a combustor **130** of the combustion section where fuel is injected into the pressurized air stream and ignited to raise the temperature and energy level of the pressurized air.

[0026] It will be appreciated that as used herein, the terms "high/low speed" and "high/low pressure" are used with respect to the high pressure/high speed system and low pressure/low speed system interchangeably. Further, it will be appreciated that the terms "high" and "low" are used in this same context to distinguish the two systems, and are not meant to imply any absolute speed and/or pressure values.

[0027] The high energy combustion products flow from the combustor **130** downstream to an HP turbine **132**. The HP turbine **132** drives the HP compressor **128** through an HP shaft **136**. In this regard, the HP turbine **132** is drivingly coupled with the HP compressor **128**. The high energy combustion products then flow to an LP turbine **134**. The LP turbine **134** drives the LP compressor **126** and components of the fan section **150** through an LP shaft **138**. In this regard, the LP turbine **134** is drivingly coupled with the LP compressor **126** and components of the fan section **150**. The LP shaft **138** is coaxial with the HP shaft **136** in this example embodiment. After driving each of the turbines **132**, **134**, the combustion products exit the turbomachine **120** through a turbomachine exhaust nozzle **140**.

[0028] Accordingly, the turbomachine **120** defines a working gas flowpath or core duct **142** that extends between the core inlet **124** and the turbomachine exhaust nozzle **140**. The core duct **142** is an annular duct positioned generally inward of the core cowl **122** along the radial direction R. The core duct **142** (e.g., the working gas flowpath through the turbomachine **120**) may be referred to as a second stream.

[0029] The fan section **150** includes a fan **152**, which is the primary fan in this example embodiment. For the depicted embodiment of FIG. **1**, the fan **152** is an open rotor or unducted fan **152**. In such a manner, the engine **100** may be referred to as an open rotor engine.

[0030] As depicted, the fan **152** includes an array of fan blades **154** (only one shown in FIG. **1**). The fan blades **154** are rotatable, e.g., about the longitudinal axis **112**. As noted above, the fan **152** is drivingly coupled with the LP turbine **134** via the LP shaft **138**. For the embodiments shown in FIG. **1**, the fan **152** is coupled with the LP shaft **138** via a speed reduction gearbox **155**, e.g., in an indirect-drive or geared-drive configuration.

[0031] Moreover, the array of fan blades **154** can be arranged in equal spacing around the longitudinal axis **112**. Each fan blade **154** has a root and a tip and a span defined therebetween. Each fan blade **154** defines a central blade axis **156**. For this embodiment, each fan blade **154** of the fan **152** is rotatable about its central blade axis **156**, e.g., in unison with one another. One or more actuators **158** are provided to facilitate such rotation and therefore may be used to change a pitch of the fan blades **154** about their respective central blades' axes **156**.

[0032] The fan section **150** further includes a fan guide vane array **160** that includes fan guide vanes **162** (only one shown in FIG. **1**) disposed around the longitudinal axis **112**. For this embodiment, the fan guide vanes **162** are not rotatable about the longitudinal axis **112**. Each fan guide vane **162** has a root and a tip and a span defined therebetween. The fan guide vanes **162** may be unshrouded as shown in FIG. **1** or, alternatively, may be shrouded, e.g., by an annular shroud spaced outward from the tips of the fan guide vanes **162** along the radial direction R or attached to the fan guide vanes **162**.

[0033] Each fan guide vane **162** defines a central blade axis **164**. For this embodiment, each fan guide vane **162** of the fan guide vane array **160** is rotatable about its respective central blade axis **164**, e.g., in unison with one another. One or more actuators **166** are provided to facilitate such rotation and therefore may be used to change a pitch of the fan guide vane **162** about its respective central blade axis **164**. However, in other embodiments, each fan guide vane **162** may be fixed or unable to be pitched about its central blade axis **164**. The fan guide vanes **162** are mounted to the fan cowl **170**.

[0034] As shown in FIG. **1**, in addition to the fan **152**, which is unducted, a ducted fan **184** is included aft of the fan **152**, such that the engine **100** includes both a ducted and an unducted fan which both serve to generate thrust through the movement of air without passage through at least a portion of the turbomachine **120** (e.g., without passage through the HP compressor **128** and combustion section for the embodiment depicted). The ducted fan **184** is rotatable about the same axis (e.g., the longitudinal axis **112**) as the fan blade **154**. The ducted fan **184** is, for the embodiment depicted, driven by the LP turbine **134** (e.g. coupled to the LP shaft **138**). In the embodiment depicted, as noted above, the fan **152** may be referred to as the primary fan, and the ducted fan **184** may be referred to as a secondary fan. It will be appreciated that these terms "primary" and "secondary" are terms of convenience, and do not imply any particular importance, power, or the like.

[0035] The ducted fan **184** includes a plurality of fan blades (not separately labeled in FIG. **1**) arranged in a single stage, such that the ducted fan **184** may be referred to as a single stage fan. The fan blades of the ducted fan **184** can be arranged in equal spacing around the longitudinal axis **112**. Each blade of the ducted fan **184** has a root and a tip and a span defined therebetween.

[0036] The fan cowl **170** annularly encases at least a portion of the core cowl **122** and is generally positioned outward of at least a portion of the core cowl **122** along the radial direction R. Particularly, a downstream section of the fan cowl **170** extends over a forward portion of the core cowl **122** to define a fan duct flowpath, or simply a fan duct **172**. According to this embodiment, the fan flowpath or fan duct **172** may be understood as forming at least a portion of the third stream of the engine **100**.

[0037] Incoming air may enter through the fan duct **172** through a fan duct inlet **176** and may exit through a fan exhaust nozzle **178** to produce propulsive thrust. The fan duct **172** is an annular duct positioned generally outward of the core duct **142** along the radial direction R. The fan cowl **170** and the core cowl **122** are connected together and supported by a plurality of substantially radially-extending, circumferentially-spaced stationary struts **174** (only one shown in FIG. **1**). The stationary struts **174** may each be aerodynamically contoured to direct air flowing thereby. Other struts in addition to the stationary struts **174** may be used to connect and support the fan cowl **170** and/or core cowl **122**. In many embodiments, the fan duct **172** and the core duct **142** may at least partially co-extend (generally axially) on opposite sides (e.g., opposite radial sides) of the core cowl **122**. For example, the fan duct **172** and the core duct **142** may each extend directly from a leading edge **144** of the core cowl **122** and may partially co-extend generally axially on opposite radial sides of the core cowl **122**.

[0038] The engine **100** also defines or includes an inlet duct **180**. The inlet duct **180** extends between the engine inlet **182** and the core inlet **124**/fan duct inlet **176**. The engine inlet **182** is defined generally at the forward end of the fan cowl **170** and is positioned between the fan **152** and the fan guide vane array **160** along the axial direction A. The inlet duct **180** is an annular duct that is positioned inward of the fan cowl **170** along the radial direction R. Air flowing downstream along the inlet duct **180** is split, not necessarily evenly, into the core duct **142** and the fan duct **172** by a fan duct splitter or leading edge **144** of the core cowl **122**. In the embodiment depicted, the inlet duct **180** is wider than the core duct **142** along the radial direction R. The inlet duct **180** is also wider than the fan duct **172** along the radial direction R.

[0039] Notably, for the embodiment depicted, the engine **100** includes one or more features to increase an efficiency of a third stream thrust (e.g., a thrust generated by an airflow through the fan duct **172** exiting through the fan exhaust nozzle **178**, generated at least in part by the ducted fan **184**). In particular, the engine **100** further includes an array of inlet guide vanes **186** positioned in the inlet duct **180** upstream of the ducted fan **184** and downstream of the engine inlet **182**. The array of inlet guide vanes **186** are arranged around the longitudinal axis **112**. For this embodiment, the inlet guide vanes **186** are not rotatable about the longitudinal axis **112**. Each inlet guide vanes **186** defines a central blade axis (not labeled for clarity), and is rotatable about its respective central blade axis, e.g., in unison with one another. In such a manner, the inlet guide vanes **186** may be considered a variable geometry component. One or more actuators **188** are provided to facilitate such rotation and therefore may be used to change a pitch of the inlet guide vanes **186** about their respective central blade axes. However, in other embodiments, each inlet guide vanes **186** may be fixed or unable to be pitched about its central blade axis.

[0040] Further, located downstream of the ducted fan **184** and upstream of the fan duct inlet **176**, the engine **100** includes an array of outlet guide vanes **190**. As with the array of inlet guide vanes **186**, the array of outlet guide vanes **190** are not rotatable about the longitudinal axis **112**. However, for the embodiment depicted, unlike the array of inlet guide vanes **186**, the array of outlet guide vanes **190** are configured as fixed-pitch outlet guide vanes.

[0041] Further, it will be appreciated that for the embodiment depicted, the fan exhaust nozzle **178** of the fan duct **172** is further configured as a variable geometry exhaust nozzle. In such a manner, the engine **100** includes one or more actuators **192** for modulating the variable geometry exhaust nozzle. For example, the variable geometry exhaust nozzle may be configured to vary a total cross-sectional area (e.g., an area of the nozzle in a plane perpendicular to the longitudinal axis **112**) to modulate an amount of thrust generated based on one or more engine operating conditions (e.g., temperature, pressure, mass flowrate, etc. of an airflow through the fan duct **172**). A fixed geometry exhaust nozzle may also be adopted.

[0042] The combination of the array of inlet guide vanes **186** located upstream of the ducted fan **184**, the array of outlet guide vanes **190** located downstream of the ducted fan **184**, and the fan exhaust nozzle **178** may result in a more efficient generation of third stream thrust during one or more engine operating conditions. Further, by introducing a variability in the geometry of the inlet guide vanes **186** and the fan exhaust nozzle **178**, the engine **100** may be capable of generating more efficient third stream thrust across a relatively wide array of engine operating conditions, including takeoff and climb (where a maximum total engine thrust is generally needed) as well as cruise (where a lesser amount of total engine thrust is generally needed).

[0043] Moreover, referring still to FIG. **1**, in exemplary embodiments, air passing through the fan duct **172** may be relatively cooler (e.g., lower temperature) than one or more fluids utilized in the turbomachine **120**. In this way, one or more heat exchangers **194** may be positioned in thermal communication with the fan duct **172**. For example, one or more heat exchangers **194** may be disposed within the fan duct **172** and utilized to cool one or more fluids from the core engine with the air passing through the fan duct **172**, as a resource for removing heat from a fluid, e.g., compressor bleed air, oil or fuel.

[0044] Although not depicted, the heat exchanger **194** may be an annular heat exchanger extending substantially 360 degrees in the fan duct **172** (e.g., at least 300 degrees, such as at least 330 degrees). In such a manner, the heat exchanger **194** may effectively utilize the air passing through the fan duct **172** to cool one or more systems of the engine **100** (e.g., lubrication oil systems, compressor bleed air, electrical components, etc.). The heat exchanger **194** uses the air passing through the fan duct **172** as a heat sink and correspondingly increases the temperature of the air downstream of the heat exchanger **194** and exiting the fan exhaust nozzle **178**.

[0045] It will be appreciated, however, that the exemplary gas turbine engine **100** is provided by way of example only. In other exemplary embodiments, the gas turbine engine **100**

may have any other configuration. For example, in other exemplary embodiments, the turbomachine **120** may have any other number and arrangement of shafts, spools, compressors, turbines, etc. Further, in other exemplary embodiments, the gas turbine engine **100** may alternatively be configured as a ducted turbofan engine (including an outer nacelle surrounding the fan **152** and a portion of the turbomachine **120**); as a direct drive gas turbine engine (may not include a reduction gearbox, such as the speed reduction gearbox **155**); as a fixed pitch gas turbine engine (may not include a variable pitch fan, such as fan **152**); as a two-stream gas turbine engine (may not include the fan duct **172**); etc.

[0046] Now referring to FIG. **2**, the gas turbine engine **100** includes a cooling circuit **200**. The cooling circuit **200** is disposed between the compressor section and the turbine section to provide cooling air from the compressor section to the turbine section. More specifically, the cooling air flows from the HP compressor **128**, bypassing the combustor **130**, through the cooling circuit **200**. The cooling air then flows to the HP turbine **132**. In such a manner, it will be appreciated that the phrase "between the compressor section and the turbine section" may refer to being downstream of at least a portion of the compressor section (e.g., receiving an airflow from a portion of the compressor section) and upstream of at least a portion of the turbine section (e.g., providing an airflow to at least a portion of the turbine section).

[0047] The cooling circuit **200** includes a cyclonic separator **202** to remove impurities from cooling air **204**, such as dust or debris. The cyclonic separator **202** defines a radial direction R**1**, an axial direction A**1**, and a circumferential direction C**1**. It will be appreciated that the directions R**1**, A**1**, C**1** of the cyclonic separator **202** are locally defined with respect to the cyclonic separator **202**. However, in the embodiment shown, the axial direction Al is arranged parallel to the axial direction A of the gas turbine engine **100** (FIG. **1**).

[0048] The cyclonic separator **202** includes a housing **206** extending from a first end **208** to a second end **210**, a fluid inlet **212** disposed at the first end **208** of the housing **206**, a first fluid outlet **214** disposed at the second end **210** of the housing **206**, and a second fluid outlet **216**. The fluid inlet **212** receives air from the compressor section, and the first fluid outlet **214** transmits air to the turbine section. The second fluid outlet **216** transmits air containing impurities to an exit flow **218**, which is directed away from the combustion section and turbine section. The cooling circuit **200** provides air suitable for cooling one or more components of the gas turbine engine **100**, such as the HP turbine **132** and the LP turbine **134**.

[0049] More specifically, the HP turbine **132** defines a cooling passage **220** and includes an inducer **222** configured to introduce a circumferential swirl to the cooling air **204** provided by the cooling circuit **200** to the cooling passage **220** of the HP turbine **132**. In particular, the cooling circuit **200** may receive the cooling air **204** from the compressor section, such as from an exit of the compressor section. The gas turbine engine **100** includes, at the combustion section, an inner airflow passage **224** located inward of the combustor **130** along the radial direction R of the gas turbine engine **100**, and a chamber **226**. The cooling air **204** is, in the embodiment shown, provided through the inner airflow passage **224** and into the chamber **226**. The cooling air **204** in the chamber **226** is provided to the cooling circuit **200** of the present disclosure, where particles within the cooling air **204** are separated out, as described herein. The cleaned cooling air **204** is provided through the inducer **222** and into the cooling passage **220** of the HP turbine **132** to cool the HP turbine **132**.

[0050] With reference to FIG. **3**, a cross-sectional schematic view of the cyclonic separator **202** of the cooling circuit is provided. The exemplary cyclonic separator **202** of FIG. **3** may be incorporated into the cooling circuit **200** described above with reference to FIG. **2**.

[0051] As described above, the cyclonic separator **202** includes the housing **206** extending from the first end **208** to the second end **210**, the fluid inlet **212** disposed at the first end **208** of the housing **206**, the first fluid outlet **214** disposed at the second end **210** of the housing **206**, and the second fluid outlet **216**. The housing **206** includes an outer wall **228** that extends between the first end **208** and the second end **210** and a central body **230** disposed along a centerline **232**. The housing **206** defines an annular chamber **234** between the outer wall **228** and the central body **230**. The annular chamber **234** may define a circular cross-sectional shape. Alternatively, the annular chamber **234** define an oblong shape, or other suitable cross-sectional shape capable of achieving the benefits disclosed herein.

[0052] The fluid inlet **212** includes a bend **236** that is arranged to swirl the cooling air **204** through the annular chamber **234** around the central body **230**. As the cooling air **204** flows from the chamber **226**, the bend **236** directs the cooling air **204** into circular motion. The cooling air **204** then swirls into the annular chamber **234** along the central body **230**.

[0053] The cyclonic separator **202** includes one or more fluid deflectors **238** disposed on the central body **230**. The fluid deflectors **238** direct the cooling air **204** toward the outer wall **228** and the second fluid outlet **216**, causing particles in the cooling air **204** to accumulate along the outer wall **228** by centrifugal forces. More specifically, the fluid deflectors **238** are disposed on the central body **230** between the first end **208** of the housing **206** and the second end **210** of the housing **206** to direct the cooling air **204** swirled by the fluid inlet **212** in the axial direction A**1** outward in the radial direction R**1** toward the second fluid outlet **216**, removing particles from the cooling air **204**. The exemplary cyclonic separator **202** of FIG. **3** shows six fluid deflectors **238**, and the cyclonic separator **202** may have a different number of fluid deflectors **238**, such as three, eight, or any other suitable number.

[0054] To provide direction to the cooling air **204**, the fluid deflectors **238** each extend outward in the radial direction R**1** and rearward in the axial direction A**1** into the annular chamber **234** toward the outer wall **228**. Specifically, the fluid deflectors **238** each include an upstream surface **240** that extends outward in the radial direction R**1** and rearward in the axial direction A**1**. As the cooling air **204** reaches one of the fluid deflectors **238**, the fluid deflector **238** provides a flow path for the cooling air **204** toward the outer wall **228**. In the exemplary embodiment of FIG. **3**, the upstream surface **240** of each fluid deflector **238** has a hemispherical shape. The hemispherical shape provides a curved surface on which the cooling air **204** swirls to push the particulates toward the outer wall **228**. It will be appreciated that the upstream surface **240** may have a different convex shape, such as a parabola or a wave.

[0055] The first fluid outlet **214** directs the cooling air **204** flowing through the annular chamber **234** out from the second end **210** of the housing **206** to the turbine section. As the cooling air **204** swirls through the annular chamber **234**, a portion of the cooling air **204** from which particulates were removed flows in the axial direction A**1** toward the first fluid outlet **214**. The cooling air **204** flows out through the first fluid outlet and into the inducer **222**.

[0056] The second fluid outlet **216** removes particulates from the cooling air **204**. When the cooling air **204** is deflected by the fluid deflectors **238**, heavier particulates accumulate along the outer wall **228**. The second fluid outlet **216** is disposed in the outer wall **228** downstream of the first end **208** of the housing **206** to receive the cooling air **204** with the particulates. The second fluid outlet **216** extends outward at least partially in the radial direction RI relative to the outer wall **228**, defining an outlet passage **242** in fluid communication with the exit flow **218** shown in FIG. **2**.

[0057] The particulates move in the axial direction Al along the outer wall **228** through the outlet passage **242** to the exit flow **218**. The second fluid outlet **216** thus removes the particulates from the cyclonic separator **202**, reducing the amount of particulates in the remaining cooling air **204** that flows to the first fluid outlet **214**.

[0058] As shown in FIGS. **4**A-**4**C, cross-sectional schematic views of exemplary fluid deflectors **238** are provided. FIG. **4**A shows the fluid deflectors **238** arranged at a first axial position proximate to the fluid inlet **212**. FIG. **4**B shows the fluid deflectors **238** arranged at a second axial position proximate to the first fluid outlet **214**. FIG. **4**C shows the fluid deflectors **238** at a third axial position substantially halfway between the fluid inlet **212** and the first fluid outlet **214**. In this context, the fluid deflectors **238** are "proximate" to the fluid inlet **212** or the first fluid outlet **214** when they are closer the specified one of the fluid inlet **212** or the first fluid outlet **214** than the other of the fluid inlet **212** or the first fluid outlet.

[0059] The fluid deflectors **238** are positioned on the central body **230** at specified axial positions in the axial direction A**1** to control where the particulates in the cooling air **204** are directed toward the outer wall **228**. As an example, the arrangement of FIG. **4**A removes the particulates soon after the cooling air **204** flows through the fluid inlet **212**, allowing the remaining cooling air **204** to swirl along the central body **230** unencumbered.

[0060] The arrangement of FIG. **4**B removes the particulates close to the second fluid outlet **216**, which may inhibit the particulates from flowing back into the cooling air **204**. The axial position of the fluid deflector of FIG. **4**B may improve separation of the particulates from the cooling air **204** immediately before the cooling air **204** leaves the cyclonic separator **202**.

[0061] The arrangement of FIG. **4**C balances the benefits of fluid deflection near the fluid inlet **212** and near the first fluid outlet **214**. That is, when the axial position of the fluid deflector **238** is near the middle of the central body **230**, the swirled cooling air **204** may move to the first fluid outlet **214** unencumbered, and the particulates may not have sufficient time to return to the cooling air **204** before the particulates are collected by the second fluid outlet **216**.

[0062] Now referring to FIG. **5**, a cross-sectional schematic view of another cyclonic separator **250** is provided. Parts of the cyclonic separator **250** of FIG. **5** that are similar in name or function to parts of the cyclonic separators **202** of FIGS. **3**-**4**C will use similar numerals, and descriptions of such parts as described above apply to those parts in FIG. **5**.

[0063] The cyclonic separator **250** includes a plurality of fluid deflectors **252**, each fluid deflector **252** having an upstream surface **254** with a conical shape. More specifically, the upstream surface **254** of each fluid deflector **252** starts at the central body **230** and extends outward in the radial direction R**1** and rearward in the axial direction A**1** along a straight diagonal line. The conical shape of the upstream surface **254** may provide additional swirl to the cooling air **204**, which may improve movement of the particulates to the outer wall **228**. FIG. **5** shows six fluid deflectors **252** arranged as in FIG. **3**, and it will be appreciated that the fluid deflectors **252** may be arranged in a different arrangement, such as one of the arrangements of FIGS. **4**A-**4**C.

[0064] Now referring to FIG. **6**, a schematic, cross-sectional view of another exemplary embodiment of a cyclonic separator **260** is shown. Parts of the cyclonic separator **260** of FIG. **6** that are similar in name or function to parts of the cyclonic separators **202**, **250** of FIGS. **3**-**5** will use similar numerals, and descriptions of such parts as described above apply to those parts in FIG. **6**.

[0065] The cyclonic separator **260** includes a central body **262** defining an annular chamber **234** with a housing **206**. The central body **262** defines an internal channel **264** in fluid communication with the first fluid outlet **214** and one or more vents **266** that are in fluid communication with the annular chamber **234**. The vents **266** transmit cooling air **204** from the annular chamber **234** the internal channel **264**, which transmits the cooling air **204** to the first fluid outlet **214**. Because the cooling air **204** closer to the central body **262** has fewer particulates than the cooling air **204** closer to the outer wall **228**, the cooling air **204** that is cleaner flows through the internal channel **264** and out to the first fluid outlet **214**, bypassing the rest of the cyclonic separator **260**.

[0066] The cyclonic separator **260** includes one or more fluid deflectors **268** disposed on the central body **262**. The fluid deflectors **268** swirl the cooling air **204** in the housing **206**, separating particulates away from the central body **262**. Some of the cooling air **204** swirled by the fluid deflectors **268** flows into the vents **266** to the internal channel **264**.

[0067] With reference to FIG. **7**, a cross-sectional, schematic view of another exemplary embodiment of a cyclonic separator **280** is provided. Parts of the cyclonic separator **280** of FIG. **7** that are similar in name or function to parts of the cyclonic separators **202**, **250**, **260** of FIGS. **3**-**6** will use similar numerals, and descriptions of such parts as described above apply to those parts in FIG. **7**.

[0068] The cyclonic separator **280** includes a central body **230** and a fluid deflector **282** disposed on the central body **230**. The fluid deflector **282** directs cooling air **204** from a fluid inlet **212** toward an outer wall **228** to remove particulates through a second fluid outlet **216**. The fluid deflector **282** of FIG. **7** is a helical screw extending along an axial direction A**1**. The helical screw defines a plurality of threads **284** and a thread pitch P. That is, the plurality of threads **284** form a single continuous helical surface extending around and along the helical screw. In this context, the "thread pitch" P is a distance between two consecutive threads **284** of the helical screw. The thread pitch P of the fluid deflector **282** of FIG. **7** is consistent along the axial direction A**1** such that the spacing between each adjacent pair of threads **284** is substantially the same.

[0069] The fluid deflector **282** is a left-handed helix with a counterclockwise chirality. That is, the fluid deflector **282** curves in a counterclockwise direction moving rearward in the axial direction. The counterclockwise chirality directs the cooling air **204** into a counterclockwise swirl as the cooling air **204** moves in the axial direction A**1** toward a first fluid outlet **214**.

[0070] Now referring to FIGS. **8**A-**8**C, cross-sectional schematic views of an exemplary fluid deflector **286** are provided. FIG. **8**A shows the fluid deflector **286** arranged at a first axial position proximate to the fluid inlet **212**. FIG. **8**B shows the fluid deflector **286** arranged at a second axial position proximate to the first fluid outlet **214**. FIG. **8**C shows the fluid deflector **286** at a third axial position substantially halfway between the fluid inlet **212** and the first fluid outlet **214**. In these embodiments, the fluid deflector **286** is a helical screw with a counterclockwise chirality, as with the fluid deflector **282**, and has fewer threads **288** than the fluid deflector **282** depicted in FIG. **7**.

[0071] Still referring to FIGS. **8**A-**8**C, the fluid deflector **286** is positioned on the central body **230** at specified axial positions in the axial direction Al to control where the particulates in the cooling air **204** are directed toward the outer wall **228** and where the fluid deflectors could induce additional swirl to the cooling air **204**. As an example, the arrangement of FIG. **8**A provides the swirl soon after the cooling air **204** leaves the fluid inlet **212**, allowing the cooling air **204** to swirl along the central body **230** toward the first fluid outlet **214** unencumbered.

[0072] The arrangement of FIG. **8**B provides swirl to the cooling air **204** close to the first fluid outlet **214**, increasing the swirl soon before the cooling air **204** leaves the cyclonic separator **280**. The particulates may separate directly into the second fluid outlet **216**, and thereby are removed from the cyclonic separator **280**.

[0073] The arrangement of FIG. **8**C provides the swirl in the middle of the cyclonic separator **280**, which may improve particulate movement toward the outer wall **228** and the second fluid outlet **216**. The swirled cooling air **204** may move to the first fluid outlet **214** unencumbered, and the particulates may not have sufficient time to return to the cooling air **204** before the particulates are collected by the second fluid outlet **216**.

[0074] Now referring to FIGS. **9**A-**9**B, cross-sectional schematic views of exemplary fluid deflectors **290**, **292** are provided. FIG. **9**A shows a fluid deflector **290** with a thread pitch P that increases in the axial direction A**1**. FIG. **9**B shows a fluid deflector **292** with a thread pitch that decreases in the axial direction A**1**.

[0075] By varying the thread pitch of the fluid deflector **290**, **292**, the cooling air **204** has more or less swirl when moving along the axial direction A**1**. The change in swirl may improve separation of the particulates from the cooling air **204**, particularly when the cooling air **204** approaches the first fluid outlet **214** to leave the cyclonic separator.

[0076] In the exemplary embodiment of FIG. **9**A, the thread pitch P increase in the axial direction A**1**, arranging threads **294** farther from each other when moving along the central body **230**. The thread pitches P_1, P_2, P_3, P_4, and P_5 are provided to illustrate the increasing thread pitch P, where $P_1<P_2<P_3<P_4<P_5$. Increasing the thread pitch P from P_1 to P_5 provides less swirl to the cooling air **204** as the cooling air **204** moves through the annular chamber **234**, which may allow the cooling air **204** to move unencumbered through the first fluid outlet **214**.

[0077] Alternatively, in the exemplary embodiment of FIG. **9**B, the thread pitch P decreases in the axial direction A**1** such that the threads **296** are arranged closer to each other when moving along the central body **230** in the axial direction A**1**. The thread pitches P_1, P_2, P_3, P_4, and P_5 are provided to illustrate the decreasing thread pitch P, where $P_1>P_2>P_3>P_4>P_5$. Decreasing the thread pitch P provides less swirl to the cooling air **204** as the cooling air **204** moves through the annular chamber **234**, which may cause more particulates to separate from the cooling air **204** closer to the second fluid outlet **216**.

[0078] With reference to FIG. **10**, a cross-sectional schematic view of an exemplary fluid deflector **298** for a cyclonic separator **280** is provided. The fluid deflector **298** of FIG. **10** is a right-hand helix with a clockwise chirality. The fluid deflector **298** curves in a clockwise direction moving rearward in an axial direction A**1**. The clockwise chirality directs the cooling air **204** into a clockwise swirl as the cooling air **204** moves in the axial direction A**1** toward a first fluid outlet **214**. It will be appreciated that the chirality of the fluid deflector **282**, **298** may be determined to match the chirality of the swirl that the fluid inlet **212** provides to the cooling air **204**. The similar chirality between the fluid inlet **212** and the fluid deflector **282**, **298** improves the swirl of the cooling air **204**, reducing eddies and other potential turbulence that could mix the particles back into the cooling air **204**.

[0079] It will be appreciated that any or all the fluid deflectors and the helical screws described above in FIGS. **3**-**10** may be combined, entirely or in part, for specified fluid flow characteristics in the cyclonic separator.

[0080] As disclosed in the FIGS. and described above, the fluid deflectors swirl air in cyclic motion, applying centrifugal force on particulate matter in air flowing through a cyclonic separator. The centrifugal forces push the particulate matter to a radial edge of the cyclonic separator, where an exit flow removes the particulate matter from the cyclonic separator, leaving cleaned air to flow to a fluid outlet. The cleaned air exits the cyclonic separator to cool the components of the gas turbine engine.

[0081] Further aspects are provided by the subject matter of the following clauses:

[0082] A gas turbine engine includes a compressor section, a turbine section downstream of the compressor section, and a cyclonic separator between the compressor section and the turbine section, the cyclonic separator defining an axial direction and a radial direction, the cyclonic separator including a housing including a first end, a second end, and an outer wall extending between the first end and the second end, a central body disposed in the housing and defining an annular chamber with the outer wall, an inlet disposed at the first end of the housing and in fluid communication with the annular chamber and the compressor section, a first fluid outlet disposed at the second end of the housing and in fluid communication with the turbine section, a second fluid outlet disposed in the outer wall downstream of the first end of the housing, the second fluid outlet extending outward at least partially in the radial direction relative to the outer wall, and a fluid deflector disposed on the central body between the first end of the housing and the second end of the housing, the fluid deflector extending outward in the radial direction and rearward in the axial direction into the annular chamber toward the outer wall.

[0083] The gas turbine engine of any of the preceding clauses, wherein the fluid deflector is a helical screw.

[0084] The gas turbine engine of any of the preceding clauses, wherein the fluid deflector includes an upstream surface, the upstream surface extending outward in the radial direction and rearward in the axial direction.

[0085] The gas turbine engine of any of the preceding clauses, wherein the central body defines an internal channel in fluid communication with the first fluid outlet.

[0086] The gas turbine engine of any of the preceding clauses, wherein the turbine section includes a turbine having a cooling passage, and wherein the first fluid outlet disposed at the second end of the housing is fluidly connected to the cooling passage of the turbine.

[0087] The gas turbine engine of any of the preceding clauses, further including a cooling circuit fluidly connecting the compressor section to the turbine section, wherein the cooling circuit includes the cyclonic separator.

[0088] A cyclonic separator for a turbine cooling airflow of a gas turbine engine, the cyclonic separator defining a centerline, an axial direction, and a radial direction, the cyclonic separator includes a housing including a first end, a second end, and an outer wall extending between the first end and the second end, a central body disposed in the housing along the centerline, the housing defining an annular chamber with the outer wall, an inlet disposed at the first end of the housing and in fluid communication with the annular chamber, a first fluid outlet disposed at the second end of the housing, a second fluid outlet disposed in the outer wall downstream of the first end of the housing, the second fluid outlet extending outward at least partially in the radial direction relative to the outer wall, and a fluid deflector disposed on the central body between the first end of the housing and the second end of the housing, the fluid deflector extending outward in the radial direction and rearward in the axial direction into the annular chamber toward the outer wall.

[0089] The cyclonic separator of any of the preceding clauses, wherein the fluid deflector is a helical screw.

[0090] The cyclonic separator of any of the preceding clauses, wherein the helical screw defines a plurality of threads and a thread pitch between the plurality of threads.

[0091] The cyclonic separator of any of the preceding clauses, wherein the thread pitch is consistent along the axial direction.

[0092] The cyclonic separator of any of the preceding clauses, wherein the thread pitch varies along the axial direction.

[0093] The cyclonic separator of any of the preceding clauses, wherein the fluid deflector includes an upstream surface, the upstream surface extending outward in the radial direction and rearward in the axial direction.

[0094] The cyclonic separator of any of the preceding clauses, wherein the upstream surface has a hemispherical shape.

[0095] The cyclonic separator of any of the preceding clauses, wherein the upstream surface has a conical shape.

[0096] The cyclonic separator of any of the preceding clauses, wherein the central body defines an internal channel in fluid communication with the first fluid outlet.

[0097] The cyclonic separator of any of the preceding clauses, wherein the central body defines a vent in fluid communication with the internal channel.

[0098] The cyclonic separator of any of the preceding clauses, wherein the inlet has a bend arranged to swirl air around the central body.

[0099] The cyclonic separator of any of the preceding clauses, wherein the fluid deflector extends toward the second fluid outlet.

[0100] The cyclonic separator of any of the preceding clauses, wherein the second fluid outlet defines an outlet passage in fluid communication with an exit flow.

[0101] The cyclonic separator of any of the preceding clauses, wherein the fluid deflector is arranged to direct air moving in the axial direction outward in the radial direction toward the second fluid outlet.

[0102] This written description uses examples to disclose the present disclosure, including the best mode, and also to enable any person skilled in the art to practice the disclosure, including making and using any devices or systems and performing any incorporated methods. The patentable scope 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 include 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.

What is claimed is:

1. A gas turbine engine comprising:

a compressor section;

a turbine section downstream of the compressor section; and

a cyclonic separator disposed between the compressor section and the turbine section, the cyclonic separator defining an axial direction and a radial direction, the cyclonic separator comprising:

a housing comprising a first end, a second end, and an outer wall extending between the first end and the second end;

a central body disposed in the housing and defining an annular chamber with the outer wall;

an inlet disposed at the first end of the housing and in fluid communication with the annular chamber and the compressor section;

a first fluid outlet disposed at the second end of the housing and in fluid communication with the turbine section;

a second fluid outlet disposed in the outer wall downstream of the first end of the housing, the second fluid outlet extending outward at least partially in the radial direction relative to the outer wall; and

a fluid deflector disposed on the central body between the first end of the housing and the second end of the housing, the fluid deflector extending outward in the radial direction and rearward in the axial direction into the annular chamber toward the outer wall.

2. The gas turbine engine of claim **1**, wherein the fluid deflector is a helical screw.

3. The gas turbine engine of claim **1**, wherein the fluid deflector includes an upstream surface, the upstream surface extending outward in the radial direction and rearward in the axial direction.

4. The gas turbine engine of claim **1**, wherein the central body defines an internal channel in fluid communication with the first fluid outlet.

5. The gas turbine engine of claim **1**, wherein the turbine section comprises a turbine having a cooling passage, and wherein the first fluid outlet disposed at the second end of the housing is fluidly connected to the cooling passage of the turbine.

6. The gas turbine engine of claim **1**, further comprising a cooling circuit fluidly connecting the compressor section to the turbine section, wherein the cooling circuit comprises the cyclonic separator.

7. A cyclonic separator for a turbine cooling airflow of a gas turbine engine, the cyclonic separator defining a centerline, an axial direction, and a radial direction, the cyclonic separator comprising:

a housing comprising a first end, a second end, and an outer wall extending between the first end and the second end;

a central body disposed in the housing along the centerline, the housing defining an annular chamber with the outer wall;

an inlet disposed at the first end of the housing and in fluid communication with the annular chamber;

a first fluid outlet disposed at the second end of the housing;

a second fluid outlet disposed in the outer wall downstream of the first end of the housing, the second fluid outlet extending outward at least partially in the radial direction relative to the outer wall; and

a fluid deflector disposed on the central body between the first end of the housing and the second end of the housing, the fluid deflector extending outward in the radial direction and rearward in the axial direction into the annular chamber toward the outer wall.

8. The cyclonic separator of claim **7**, wherein the fluid deflector is a helical screw.

9. The cyclonic separator of claim **8**, wherein the helical screw defines a plurality of threads and a thread pitch between the plurality of threads.

10. The cyclonic separator of claim **9**, wherein the thread pitch is consistent along the axial direction.

11. The cyclonic separator of claim **9**, wherein the thread pitch varies along the axial direction.

12. The cyclonic separator of claim **7**, wherein the fluid deflector includes an upstream surface, the upstream surface extending outward in the radial direction and rearward in the axial direction.

13. The cyclonic separator of claim **12**, wherein the upstream surface has a hemispherical shape.

14. The cyclonic separator of claim **12**, wherein the upstream surface has a conical shape.

15. The cyclonic separator of claim **7**, wherein the central body defines an internal channel in fluid communication with the first fluid outlet.

16. The cyclonic separator of claim **15**, wherein the central body defines a vent in fluid communication with the internal channel.

17. The cyclonic separator of claim **7**, wherein the inlet has a bend arranged to swirl air around the central body.

18. The cyclonic separator of claim **7**, wherein the fluid deflector extends toward the second fluid outlet.

19. The cyclonic separator of claim **7**, wherein the second fluid outlet defines an outlet passage in fluid communication with an exit flow.

20. The cyclonic separator of claim **7**. wherein the fluid deflector is arranged to direct air moving in the axial direction outward in the radial direction toward the second fluid outlet.

* * * * *