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CYCLONIC SEPARATOR FOR GAS TURBINE ENGINE

Abstract

A cyclonic separator for a gas turbine engine includes a housing, a fluid inlet, a first fluid outlet, a second fluid outlet, and a particle separator. The housing includes a first end, a second end, and an outer wall extending between the first end and the second end. The fluid inlet is disposed at the first end of the housing. The first fluid outlet is disposed at the second end of the housing. The second fluid outlet is disposed in the outer wall downstream of the first end of the housing and extends outward at least partially in the radial direction. The particle separator is disposed in the housing between the first end and the second end inward of the outer wall in the radial direction and extends in the circumferential direction. The particle separator defines a plurality of openings extending in the radial direction.

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Background/Summary

FIELD
[0001] The present disclosure relates to a gas turbine engine, and more particularly to a cyclonic separator for a gas turbine engine.
BACKGROUND
[0002] 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 plurality 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.
[0003] 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.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
[0004] 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:
[0005] FIG. **1** is a cross-sectional view of an exemplary gas turbine engine.
[0006] FIG. **2** is a cross-sectional view of a cooling circuit of the gas turbine engine of FIG. **1**.
[0007] FIGS. **3**A-**3**B are side and axial views of a cyclonic separator of the cooling circuit of FIG. **2**.
[0008] FIG. **4** is a side view of a particle separator of the cyclonic separator of FIGS. **3**A-**3**B.
[0009] FIGS. **5**A-**5**F are magnified views of exemplary arrangements of openings of the particle separator of FIG. **4**.
[0010] FIGS. **6**A-**6**E are cross-sectional views of particle separators with projections.
[0011] FIGS. **7**A-**7**C are cross-sections view of additional exemplary particle separators of a cyclonic separator.
[0012] FIG. **8** is another exemplary cyclonic separator for a cooling circuit.
DETAILED DESCRIPTION
[0013] 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.
[0014] 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.
[0015] The singular forms “a”, “an”, and “the” include plural references unless the context clearly dictates otherwise.
[0016] The term “at least one of” in the context of, e.g., “at least one of A, B, and C” refers to only A, only B, only C, or any combination of A, B, and C.

[0017] As used herein, the terms “first,” “second,” and other ordinals are used to distinguish one component from another and are not intended to signify location or importance of the individual components.
[0018] 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.
[0019] 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.
[0020] 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.
[0021] 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 gas turbine engine **100** may be referred to as an “unducted turbofan engine.” In addition, the gas turbine 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.
[0022] For reference, the gas turbine engine **100** defines an axial direction A, a radial direction R, and a circumferential direction C. Moreover, the gas turbine 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 gas turbine engine **100** extends between a forward end **114** and an aft end **116**, e.g., along the axial direction A.
[0023] The gas turbine 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 herein as an LP compressor **126**) for pressurizing the air that enters the turbomachine **120** through core inlet **124**. A high pressure (“HP”), multi-stage, axial-flow compressor (referred to herein as an HP compressor **128**) 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.
[0024] 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.

[0025] 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**.

[0026] 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.

[0027] 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. In such a manner, the gas turbine engine **100** may be referred to as an open rotor engine.

[0028] 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.

[0029] 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**.

[0030] 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**.

[0031] 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**.

[0032] 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 gas turbine 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.

[0033] 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.

[0034] 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 gas turbine engine **100**.

[0035] 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**.

[0036] The gas turbine 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.

[0037] Notably, for the embodiment depicted, the gas turbine 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 gas turbine 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.

[0038] Further, located downstream of the ducted fan **184** and upstream of the fan duct inlet **176**, the gas turbine 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.

[0039] 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 gas turbine 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.

[0040] 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 gas turbine 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).

[0041] 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.

[0042] 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 gas turbine 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**.

[0043] 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 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.

[0044] 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 **201** from the compressor section to the turbine section. More specifically, the cooling air **201** flows from the HP compressor **128**, bypassing the combustor **130**, through the cooling circuit **200**. The cooling air **201** then flows to the HP turbine **132**.

[0045] The cooling circuit **200** includes a cyclonic separator **202** to remove impurities from the air, 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 A**1** is arranged parallel to the axial direction A of the gas turbine engine **100**.

[0046] The cyclonic separator **202** includes a housing **204** extending from a first end **206** to a second end **208**, a fluid inlet **210** disposed at the first end **206** of the housing **204**, a first fluid outlet **212** disposed at the second end **208** of the housing **204**, and a second fluid outlet **214** extending at least partially outward in the radial direction R**1** from the housing **204**. The fluid inlet **210** receives air from the compressor section, and the first fluid outlet **212** transmits air to the turbine section. The fluid inlet **210** may be angled relative to the circumferential direction C**1** to induce a swirl to the incoming air. As an example, the fluid inlet **210** may be angled between 30 and 70 degrees relative to the circumferential direction C**1**, and the fluid inlet **210** may be angled clockwise or counterclockwise. The second fluid outlet **214** transmits air containing impurities to an exit flow **216**, 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**.

[0047] More specifically, the HP turbine **132** defines a cooling passage **218** and includes an inducer **220** configured to introduce a circumferential swirl to a cooling air provided by the cooling circuit **200** to the cooling passage **218** of the HP turbine **132**. In particular, the cooling circuit **200** may receive the cooling air **201** 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 **222** located inward of the combustor **130** along the radial direction R of the gas turbine engine **100** and an annular chamber **224**. The cooling air **201** is, in the embodiment shown, provided through the inner airflow passage **222** to the annular chamber **224**. The cooling air **201** in the annular chamber **224** is provided to the cooling circuit **200** of the present disclosure, where particles within the cooling air **201** are separated out, as described herein. The cleaned cooling air **201** is provided through the inducer **220** and into the cooling passage **218** of the HP turbine **132** to cool the HP turbine **132**.

[0048] With reference to FIGS. **3**A-**3**B, the cyclonic separator **202** is shown in a cross-sectional view. In particular, FIG. **3**A shows a side cross-sectional view of the cyclonic separator **202**. FIG. **3**B shows a head-on cross-sectional view of the cyclonic separator along the line B-B.

[0049] The housing **204** of the cyclonic separator **202** includes an outer wall **228** extending between the first end **206** and the second end **208**. The fluid inlet **210** is disposed at the first end **206** and introduces air to the housing **204**. The first fluid outlet **212** is disposed at the second end **208** of the housing **204**, and the second fluid outlet **214** is disposed in the outer wall **228** downstream of the first end **206**.

[0050] The cyclonic separator **202** includes a particle separator **230**. The particle separator **230** is disposed in the housing **204** between the first end **206** and the second end **208** inward of the outer wall **228** in the radial direction R**1**. The particle separator **230** extends in the circumferential direction C**1** around the center of the housing **204**, allowing particulate matter to flow to the outer wall **228** while inhibiting the particulate matter from returning to the center of the housing **204**. As described in greater detail below, the particle separator **230** includes one or more openings that allow air and particulate matter to pass therethrough.

[0051] As shown in FIG. **3**A, the particle separator **230** extends from the first end **206** of the housing to the second end **208** of the housing. In such a form, the housing **204** may support the particle separator **230** at the first end **206**, the second end **208**, or both. As an example, the particle separator **230** may be welded, fastened, or adhered to the first end **206** or the second end **208**.

[0052] Alternatively, the particle separator **230** may extend partially between the first end **206** and the second end **208**. In such a form, the particle separator **230** is spaced from one of the first end **206** or the second end **208**.

[0053] Additionally or alternatively, the cyclonic separator **202** may include one or more pins **232** that extend radially from the outer wall **228** to the particle separator **230**. The pins **232**, if included, fix the particle separator **230** to the outer wall **228**, securing the particle separator **230** within the housing **204**.
[0054] For clarity, air flow within the cyclonic separator **202** is shown with arrows in FIG. **3**B, illustrating the movement of air from the fluid inlet **210** to the first and second fluid outlets **212**, **214**. The fluid inlet **210** is disposed inward of the particle separator **230** in the radial direction R**1**, and the particulate matter in the air is introduced to the interior of the housing **204** through the fluid inlet **210**. In the exemplary embodiment of FIGS. **3**A-**3**B, the cyclonic separator **202** includes two fluid inlets **210**, and it will be appreciated that the cyclonic separator **202** may include a different number of fluid inlets **210**. The cyclonic separator **202** swirls air from the fluid inlets **210**, causing the particulate matter to accumulate radially outward of the particle separator **230** and causing the remaining air to flow to the first fluid outlet **212**. More specifically, the fluid inlets **210** are disposed radially outward of the center of the center of the housing **204**, which induces a vortex along the center of the housing toward the first fluid outlet **212**. This vortex swirls air in the circumferential direction C**1**.
[0055] The second fluid outlet **214** is disposed radially outward of the particle separator **230**. The second fluid outlet **214** defines an outlet passage **234** therethrough, and the outlet passage **234** is in fluid communication with the exit flow **216** that removes air from the cyclonic separator **202**. As the air swirls in the housing **204**, at least some of the particulate matter is pushed by centrifugal forces through the openings of the particle separator **230** to the outer wall **228**. Because the openings of the particle separator **230** are in fluid communication with the outlet passage **234** and the exit flow, the particulate matter flows circumferentially around the outer wall **228** and through the outlet passage **234** of the second fluid outlet **214** to the exit flow, removing the particulate matter from the cyclonic separator **202**. Meanwhile, the remaining swirling air flows through the housing **204** toward the first fluid outlet **212**, having lost at least some of the particulate matter, to the turbine section as described above with reference to FIG. **2**.
[0056] Now referring to FIG. **4**, a schematic view of the particle separator **230** is shown according to one exemplary embodiment of the present disclosure. The exemplary particle separator **230** of FIG. **4** may be incorporated into the cyclonic separator described above with reference to FIGS. **2-3**B.
[0057] The particle separator **230** defines a plurality of openings **236**. When arranged in the cyclonic separator **202**, the openings **236** extend in the radial direction R**1** toward the outer wall **228** (see FIGS. **3**A, **3**B). The openings **236** are evenly distributed around the particle separator **230** in the circumferential and axial directions C**1**, A**1**, such as in a lattice pattern as shown in FIG. **4**.
[0058] Alternatively, however, in other exemplary embodiments, the openings **236** may be arranged in a different pattern, such as a staggered configuration. Referring still to FIG. **4**, and as will be discussed in greater detail below, the plurality of openings **236** may include a circular opening, an elliptical opening, a polygonal opening, or combinations thereof.
[0059] Referring now to FIGS. **5**A through **5**F, schematic, plan views are provided of particle separators **230** in accordance with various exemplary embodiments of the present disclosure. The exemplary particle separators **230** of FIGS. **5**A through **5**F may be incorporated into the cyclonic separator **202** described above with reference to FIGS. **2-3**B.
[0060] As shown in FIGS. **5**A-**5**F, the plurality of openings **236** may be one of several shapes and may be distributed along the particle separator **230** in one of several patterns. For clarity, the term “openings **236**” will be used collectively for openings of the particle separator **230** in general, and each of FIGS. **5**A-**5**B may use additional numerals to refer to the specific shapes and patterns of the openings **236** in the particular Figure.
[0061] FIG. **5**A shows circular openings **238** arranged in a lattice, i.e., an arrangement where each circular opening **238** is arranged in a rectangular grid, and each of the circular openings **238** is

substantially a same size. The lattice arrangement may be easier to manufacture than other arrangements because the spacing between each of the openings **236** is substantially even.

[0062] FIG. **5**B shows circular openings **240** arranged in the lattice and with decreasing sizes along the axial direction A**1**. In this arrangement, a first one **240**A of the plurality of openings **240** defined in the particle separator **230** at a first position in the axial direction A**1** has a size greater than a second one **240**B of the plurality of openings **240** defined in the particle separator **230** at a second position in the axial direction A**1**. In the example of FIG. **5**B, the openings **240** decrease in size eight times, illustrating openings **240**A, **240**B, **240**C, **240**D, **240**E, **240**E, **240**F, **240**G, and **240**H.

[0063] It will be appreciated, however, that in other exemplary embodiments the particle separator **230** may have a different number of sizes, such as two, four, six, or another number, and that the sizes may increase or decrease at different positions in the axial direction A**1**, including decreasing and increasing in an uneven or alternating pattern.

[0064] Particles that move through the larger openings, such as openings **240**A and **240**B, may be too large to pass through the smaller openings, such as **240**G and **240**H. The smaller openings thus inhibit movement of the particles back into the air flow in the center of the cyclonic separator **202**, forcing the air flowing with the particles through the second fluid outlet **214**.

[0065] FIG. **5**C shows circular openings **242** arranged in a staggered configuration, such that the openings **242** are not aligned with forward adjacent and aft adjacent openings **242** in the axial direction A**1**. The staggered configuration allows particles that may not pass through openings **242** at one axial position to pass through other openings **242** at a different axial position, increasing a likelihood that the particles pass through at least one of the openings **242** and, thus, through the second fluid outlet **214**.

[0066] FIG. **5**D shows polygonal openings **244**, specifically rectangular openings, arranged in a lattice. FIG. **5**E shows irregularly shaped openings **246**, such as a barbell shape. The polygonal and irregular shapes of the openings **244**, **246** may provide advantageous physical properties, such as a specific weight or stress distribution, while removing particles from the air flowing in the cyclonic separator **202**.

[0067] FIG. **5**F shows the particle separator **230** as a mesh, with the openings **248** formed between the intersections of the wires that form the mesh. The particle separator **230** may be formed of a prebuilt mesh with a specified opening size, reducing a total amount of manufacturing performed on the particle separator **230**. The mesh may also reduce overall weight of the particle separator **230** compared to a cylindrical tube with openings **236** machined therethrough, such as the openings **236**, **238**, **240**, **242**, **244**, and **246** as shown in FIGS. **5**A-**5**E.

[0068] It will be appreciated that the different patterns described herein may be modified, combined, or otherwise adapted to provide suitable particle removal from the air flow.

[0069] With reference to FIGS. **6**A-**6**E, a cross-sectional view of the particle separator **230** is shown. FIG. **6**A provides a view of a particle separator **230** with projections extending radially outward. FIG. **6**B provides a view of a particle separator **230** with projections extending radially inward. FIG. **6**C is a magnified view of one of the projections of the particle separator **230**. FIG. **6**D is a magnified view of another one of the projections of the particle separator **230**. FIG. **6**E is a magnified view of yet another one of the projections of the particle separator **230**. The exemplary particle separators **230** of FIGS. **6**A and **6**B may be configured in substantially the same manner as the exemplary particle separators **230** of FIGS. **2**-**5**F.

[0070] Each of the particle separators **230** depicted includes one or more projections **250** extending in a radial direction R**1** of a cooling circuit **200** including the respective particle separator **230** (see, e.g., FIGS. **3**A, **3**B) such that one of the openings **236** is defined through each projection **250**. The projection **250** is a tube or passage through which the particles move from the center of the housing **204** to the outer wall **228**. To assist in moving the particles from the center and to inhibit the particles from moving back into the center, the projection **250** defines an angle **252** with a centerline **254** of the housing **204**. The projection **250** changes trajectories of the particles to move outward in the radial direction R**1**, reducing or eliminating particle movement back into the center. More specifically, particles that move along the projection **250** may be propelled outward in the radial direction R**1** and forward in an axial direction Al of the cooling circuit **200** (see, e.g., FIGS. **3**A, **3**B), bouncing off of an outer wall **228** of the cooling circuit **200** back inward in the radial direction R**1**. Because the projection **250** is angled forward in the axial direction A**1**, the particles that bounce off of the outer wall **228** are less likely to move back down into the opening **236**, a trajectory that would include rearward motion in the axial direction A**1**. By providing momentum for the particles forward in the axial direction A**1**, fewer particles return to the center of the housing **204** and more particles are removed from the cyclonic separator **202**. The angle **252** may be an acute angle, i.e., less than 90 degrees, to achieve this trajectory-changing feature.

[0071] FIG. **6**A shows the projections **250** extending outward in the radial direction R**1** toward the outer wall **228** of the cooling circuit **200**. The projections **250** extending outward from the particle separator extend partway toward the outer wall **228** to direct particles thereto.

[0072] By contrast, FIG. **6**B shows the projections **250** extending inward in the radial direction R**1** away from the outer wall **228** of the cooling circuit **200**. The projections **250** receive particles from the center of the housing **204** and direct the particles toward the outer wall **228**.

[0073] Now referring to FIGS. **6**C-**6**E, the projections **250** may have different shapes than the straight projections **250** shown in FIGS. **6**A-**6**B. As shown in FIG. **6**C, a projection **250** may extend along a convex curved path **256**. The convex curved path **256** directs the particles in a downstream direction away from the particle separator **230**.

[0074] As shown in FIG. **6**D, a projection **250** may extend along a concave curved path **257**. The concave curved path **257** directs the particles radially away from the particle separator **230**.

[0075] As shown in FIG. **6**E, a projection **250** may extend along a serpentine path **258**. The serpentine path **258** directs the particles radially away and in a downstream direction away from the particle separator **230**.

[0076] It will be appreciated that the particle separator **230** may include projections **250** extending at different angles **252** and extending toward the outer wall **228**, away from the outer wall **228**, with different curved paths **256**, **257**, **258**, or combinations thereof, and that some or all of openings **236** of the particle separator **230** may extend through one of the projections **250**.

[0077] Now referring to FIG. **7**A, a cross-sectional view of another cyclonic separator **260** is shown. The cyclonic separator **260** of FIG. **7**A includes a particle separator **230** and a second particle separator **262**. The second particle separator **262** is disposed radially inward of the particle separator **230**. The second particle separator **262** includes a plurality of openings (not shown) that allow particles to pass therethrough. The openings of the second particle separator **262** may differ from the openings of the particle separator **230** to filter different sizes of particles. For example, the particle separator **230** may include openings having a first size, and the second particle separator **262** may include openings having a second size that is greater than the first size. In such a form, larger particles pass through the openings of the second particle separator **262** but are blocked from returning to the center of the cyclonic separator **260** by the smaller openings of the particle separator **230**.

[0078] Now referring to FIG. **7**B, a cross-sectional view of another cyclonic separator **270** is shown. The cyclonic separator **270** includes a particle separator **272** having an octagonal shape. The octagonal shape of the particle separator **272** allows for different air flow patterns in the cyclonic separator **270**. It will be appreciated that the particle separator **272** may have a different polygonal shape, such as a square shape, a triangular shape, a hexagonal shape, or a shape with a different number of sides.

[0079] With reference to FIG. **7**C, a cross-sectional view of another cyclonic separator **280** is shown. The cyclonic separator **280** includes a particle separator **282**. The particle separator **282** is disposed in the cyclonic separator **280** such that a center of the particle separator **282** is spaced away from a center of an outer wall **228** of the cyclonic separator **280**. That is, the particle separator **282** and the outer wall **228** are not concentric. By disposing the particle separator **282** off-center relative to the outer wall **228**, the particle separator **282** may filter particles that accumulate in specific sections of the cyclonic separator **280**. More specifically, based on the direction of the flow of cooling air **201** in the cyclonic separator **280**, particles may preferentially accumulate in specific regions. In order to filter the particles more readily, the particle separator **282** may be disposed off-center into the specific regions.

[0080] Now referring to FIG. **8**, another exemplary embodiment of the cyclonic separator **300** is shown. In particular, FIG. **8** provides a cross-sectional schematic view of the cyclonic separator **300**.

[0081] In the embodiment of FIG. **8**, the cyclonic separator **300** defines a radial direction R**2**, an axial direction A**2**, and a circumferential direction C**2**. The cyclonic separator **300** includes a housing **302**, and the housing **302** includes a fluid inlet **304**, a first fluid outlet **306**, a second fluid outlet **308**, a central body **310** along a centerline **312** of the cyclonic separator **300**, and an outer wall **314**. It will be appreciated that similarly named components of the cyclonic separator **300** perform similar functions to those in the cyclonic separator **202**, and the numerals used for the cyclonic separator **300** differ from those for the cyclonic separator **202** only for clarity.

[0082] The cyclonic separator **300** includes a particle separator **316** disposed between the central body **310** and the outer wall **314**. The central body **310** swirls the cooling air **201** from the fluid inlet **304** through the housing **302** about the centerline **312** to the first fluid outlet **306**. The swirling of the air flow causes particles to move through the particle separator **316** toward the outer wall **314** to the second fluid outlet **308**, and then out from the cyclonic separator **300**. Specifically, the particle separator **316** may be fixed to the first fluid outlet **306** such that the swirled cooling air **201** flowing around the central body **310** passes over or through the particle separator **316** before reaching the first fluid outlet **306**. The position of the particle separator **316** is determined to increase particle movement to the second fluid outlet **308**, removing the particles from the swirled air flow that exits the cyclonic separator **300** through the first fluid outlet **306**.

[0083] Notably, the cyclonic separator **300** may be positioned in a gas turbine engine at a similar location as the cyclonic separator **202** of the cooling circuit **200** of FIG. **2**. In such a manner, the cyclonic separator **300** may receive cooling air from a compressor section of the gas turbine engine through the fluid inlet **304** and may provide cooling air **201** to a turbine of a turbine section of the gas turbine engine **100** from the first fluid outlet **306**. The second fluid outlet **308** may exhaust the particle-laden air to an ambient location with an exit flow **216**.

[0084] The particle separator **316** may have a similar construction and may include one or more of the features described for the particle separator **230** in FIGS. **5**A-**7**C, including sizes and shapes of openings **236** and projections **250** that are suitable for removal of the particulate matter from the air flow. By including the central body **310** in the cyclonic separator **300**, the air flow swirls in a different manner than the cyclonic separator **202** of FIGS. **3**A-**3**B, which may be suitable for specific cooling applications.

[0085] As disclosed in the FIGS. and described above, the cyclonic separator swirls air in cyclic motion, applying centrifugal force on particulate matter in air flowing therethrough. The centrifugal forces push the particulate matter to a radial edge of the cyclonic separator through a particle separator that reduces or inhibits the particulate matter from flowing back into a center of the cyclonic separator. Upon moving through the particle separator, 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.

[0086] Further aspects are provided by the subject matter of the following clauses:

[0087] A cyclonic separator for a turbine cooling airflow of a gas turbine engine defines a centerline, an axial direction, a radial direction, and a circumferential direction. The cyclonic separator includes a housing comprising a first end, a second end, and an outer wall extending between the first end and the second end, a fluid inlet disposed at the first end of the housing, a first fluid outlet disposed at the second end of the housing opposing the first end in the axial direction, 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 particle separator disposed in the housing between the first end and the second end inward of the outer wall in the radial direction, the particle separator extending in the circumferential direction. The particle separator defines a plurality of openings extending in the radial direction toward the outer wall.

[0088] The cyclonic separator of the previous clause, wherein the housing further includes a central body, wherein the particle separator is disposed between the central body and the outer wall.

[0089] The cyclonic separator of any of the previous clauses, wherein the second fluid outlet defines an outlet passage in fluid communication with an exit flow, and wherein the plurality of openings of the particle separator are in fluid communication with the outlet passage.

[0090] The cyclonic separator of any of the previous clauses, wherein the particle separator extends from the first end of the housing to the second end of the housing.

[0091] The cyclonic separator of any of the previous clauses, wherein the plurality of openings includes a circular opening, an elliptical opening, a polygonal opening, or a combination thereof.

[0092] The cyclonic separator of any of the previous clauses, wherein the particle separator is a mesh.

[0093] The cyclonic separator of any of the previous clauses, wherein a first one of the plurality of openings defined in the particle separator at a first position in the axial direction has a size greater than a second one of the plurality of openings defined in the particle separator at a second position in the axial direction.

[0094] The cyclonic separator of any of the previous clauses, wherein the particle separator further comprises a projection extending in the radial direction, wherein at least one of the plurality of openings is defined through the projection.

[0095] The cyclonic separator of any of the previous clauses, wherein the projection defines an angle with the centerline that is less than 90 degrees.

[0096] The cyclonic separator of any of the previous clauses, wherein the gas turbine engine includes a turbine section including a turbine having a cooling passage, and wherein the first fluid outlet disposed at the second end of the housing is configured to be fluidly connected to the cooling passage of the turbine.

[0097] The cyclonic separator of any of the previous clauses, wherein the plurality of openings are evenly distributed around the particle separator in the circumferential direction.

[0098] The cyclonic separator of any of the previous clauses, wherein the plurality of openings are evenly distributed along the particle separator in the axial direction.

[0099] The cyclonic separator of any of the previous clauses, wherein the fluid inlet is disposed inward of the particle separator in the radial direction.

[0100] 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 defines an axial direction, a radial direction, and a circumferential direction. The cyclonic separator includes a housing comprising a first end, a second end, and an outer wall extending between the first end and the second end, a fluid inlet disposed at the first end of the housing and fluidly connected to the compressor section, a first fluid outlet disposed at the second end of the housing opposing the first end in the axial direction and fluidly connected to the turbine section, a second fluid outlet disposed in the outer wall downstream of the first end, the second fluid outlet extending outward at least partially in the radial direction relative to the outer wall and fluidly connected to an exit flow directed away from the turbine section, and a particle separator disposed in the housing between the first end and the second end inward of the outer wall in the radial direction, the particle separator extending in the circumferential direction. The particle

separator defines a plurality of openings extending in the radial direction toward the outer wall.
[0101] The gas turbine engine of any of the previous clauses, wherein the housing further includes a central body, wherein the particle separator is disposed between the central body and the outer wall.
[0102] The gas turbine engine of any of the previous clauses, wherein the plurality of openings includes a circular opening, an elliptical opening, a polygonal opening, or a combination thereof.
[0103] The gas turbine engine of any of the previous clauses, wherein the particle separator is a mesh.
[0104] The gas turbine engine of any of the previous clauses, wherein the particle separator further comprises a projection extending in the radial direction, wherein at least one of the plurality of openings is defined through the projection.
[0105] The gas turbine engine of any of the previous clauses, wherein the projection defines an angle with a centerline of the cyclonic separator that is less than 90 degrees.
[0106] The gas turbine engine of any of the previous clauses, 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.
[0107] 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.

Claims

1. A cyclonic separator for a turbine cooling airflow of a gas turbine engine, the cyclonic separator defining a centerline, an axial direction, a radial direction, and a circumferential direction, the cyclonic separator comprising: a housing comprising a first end, a second end opposing the first end in the axial direction, and an outer wall extending between the first end and the second end; a fluid inlet disposed at the first end of the housing; 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 particle separator disposed in the housing between the first end and the second end inward of the outer wall in the radial direction, the particle separator extending in the circumferential direction, wherein the particle separator defines a plurality of openings extending in the radial direction toward the outer wall.
2. The cyclonic separator of claim 1, wherein the housing further comprises a central body, wherein the particle separator is disposed between the central body and the outer wall.
3. The cyclonic separator of claim 1, wherein the second fluid outlet defines an outlet passage in fluid communication with an exit flow, and wherein the plurality of openings of the particle separator are in fluid communication with the outlet passage.
4. The cyclonic separator of claim 1, wherein the particle separator extends from the first end of the housing to the second end of the housing.
5. The cyclonic separator of claim 1, wherein the plurality of openings includes a circular opening, an elliptical opening, a polygonal opening, or a combination thereof.
6. The cyclonic separator of claim 1, wherein the particle separator is a mesh.
7. The cyclonic separator of claim 1, wherein a first one of the plurality of openings defined in the particle separator at a first position in the axial direction has a size greater than a second one of the

plurality of openings defined in the particle separator at a second position in the axial direction.
8. The cyclonic separator of claim 1, wherein the particle separator further comprises a projection extending in the radial direction, wherein at least one of the plurality of openings is defined through the projection.
9. The cyclonic separator of claim 8, wherein the projection defines an angle with the centerline that is less than 90 degrees.
10. The cyclonic separator of claim 1, wherein the gas turbine engine includes a turbine section comprising a turbine having a cooling passage, and wherein the first fluid outlet disposed at the second end of the housing is configured to be fluidly connected to the cooling passage of the turbine.
11. The cyclonic separator of claim 1, wherein the plurality of openings are evenly distributed around the particle separator in the circumferential direction.
12. The cyclonic separator of claim 1, wherein the plurality of openings are evenly distributed along the particle separator in the axial direction.
13. The cyclonic separator of claim 1, wherein the fluid inlet is disposed inward of the particle separator in the radial direction.
14. A gas turbine engine comprising: 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, a radial direction, and a circumferential direction, the cyclonic separator comprising: a housing comprising a first end, a second end opposing the first end in the axial direction, and an outer wall extending between the first end and the second end; a fluid inlet disposed at the first end of the housing and fluidly connected to the compressor section; a first fluid outlet disposed at the second end of the housing and fluidly connected to the turbine section; a second fluid outlet disposed in the outer wall downstream of the first end, the second fluid outlet extending outward at least partially in the radial direction relative to the outer wall and fluidly connected to an exit flow directed away from the turbine section; and a particle separator disposed in the housing between the first end and the second end inward of the outer wall in the radial direction, the particle separator extending in the circumferential direction, wherein the particle separator defines a plurality of openings extending in the radial direction toward the outer wall.
15. The gas turbine engine of claim 14, wherein the housing further comprises a central body, wherein the particle separator is disposed between the central body and the outer wall.
16. The gas turbine engine of claim 14, wherein the plurality of openings includes a circular opening, an elliptical opening, a polygonal opening, or a combination thereof.
17. The gas turbine engine of claim 14, wherein the particle separator is a mesh.
18. The gas turbine engine of claim 14, wherein the particle separator further comprises a projection extending in the radial direction, wherein at least one of the plurality of openings is defined through the projection.
19. The gas turbine engine of claim 18, wherein the projection defines an angle with a centerline of the cyclonic separator that is less than 90 degrees.
20. The gas turbine engine of claim 14, 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.