

TITLE**ENGINE COOLING SYSEYEM****FIELD**

The present disclosure relates to an engine cooling system and an engine cooling
5 method for cooling gas paths in an engine core of a gas turbine engine of a stationary
aircraft.

BACKGROUND

Gas turbine engine powered aircraft require maintenance between flights. The
engines ingest debris such as sand, dust, soot and carbon during use and the
10 accumulation of this debris can detrimentally affect engine performance and cause
components to wear. Engine maintenance therefore typically requires periodic engine
cleaning.

It is critical for the efficiency of an airline to minimise the time that is needed to
safely complete that maintenance. The longer the aircraft is on the ground undergoing
15 maintenance, the less the aircraft is generating revenue. Performing maintenance in small
groundings between flights can be difficult due to the engine temperature being too hot.

Cleaning a gas turbine engine, especially air passages within an engine core of
the gas turbine engine, can be a difficult operation that typically involves passing water,
sprays, mists or vapours through the engine core. The cleaning operation generally follows
20 a flight so the engines need to be cool enough to be safely and effectively cleaned. It
sometimes requires temporarily removing the gas turbine engines from the wings of the
aircraft. It is usually a time consuming and costly operation that requires specialised
equipment and specialist technicians and can present health and safety risks. During the
operation, which typically involves cooling and then cleaning two or four engines, the
25 engines and the aircraft are not available for use, which is costly for the airline that owns
or leases the aircraft, and any delays can be especially so.

Certain methods are known for cooling gas turbine engines in situ prior to any
engine cleaning. While engines can be cooled by spraying water through them doing this
before the engine is at least semi-cooled can damage engine components, especially high
30 pressure compressor blades and high pressure turbine blades that can remain very hot for
several hours after the engine has been shut down.

Existing engine cooling systems generally require two or more qualified engineers
to operate them. This is typically the case when the engine's starter motor needs to be
activated as part of the engine cooling procedure.

35 There is a need to provide an engine cooling system that overcomes at least some

of the aforementioned problems or at least provides a useful alternative to known engine cooling systems.

SUMMARY

In a first aspect, there is provided an engine cooling system for cleaning gas paths
5 in an engine core of a gas turbine engine of a stationary aircraft, the gas turbine engine
having a core exhaust nozzle. The engine cooling system comprises: an air pump; a core
exhaust nozzle engaging collar configured to detachably seal over the core exhaust
nozzle of the gas turbine engine; an air pipe that connects the core exhaust nozzle
engaging collar to the air pump; and a first temperature sensor configured to measure an
10 ambient air temperature (T_A); a second temperature sensor that is located in or adjacent
the core exhaust nozzle and configured to measure an engine core exiting temperature
(T_R); and a controller configured: (a) to calculate an engine core temperature (T_E) from the
engine core exiting temperature (T_R) and the ambient air temperature (T_A); and (b) to
activate the air pump to draw air through the engine core to cool the gas paths within the
15 engine core until the engine core temperature (T_E) equals a predetermined engine target
temperature (T_T).

In some embodiments, the air pump is configured to respond to signals provided
by the controller, which is in communication with the first temperature sensor and the
second temperature sensor.

20 In some embodiments, the air pump is configured to expel the air that it has drawn
through the gas paths of the engine core back into the atmosphere.

In some embodiments, the core exhaust nozzle engaging collar is configured to
collect air that is drawn through the gas paths of the engine core when the air pump is
activated and to allow the air to pass through the air pipe and into the air pump.

25 In some embodiments, the first temperature sensor is housed with the air pump,
on or incorporated into the core exhaust nozzle engaging collar, or on or incorporated into
the air intake.

In some embodiments, the second temperature sensor is located in or adjacent
the core exhaust nozzle.

30 In some embodiments, the first temperature sensor and/or the second temperature
sensor is a thermocouple.

In some embodiments, the controller is housed with the air pump.

In some embodiments, the controller is a programmable logic controller that is
accessed by a human-machine interface.

35 In some embodiments, at least one of the air pump, the core exhaust nozzle
engaging collar, the air pipe, the first temperature sensor, the second temperature and the
controller form part of an engine cleaning system for cleaning the gas paths in the engine

core of the gas turbine engine.

In a second aspect, there is provided a method of cooling gas paths in an engine core of a gas turbine engine of a stationary aircraft. The method comprises the steps of: measuring an ambient air temperature (T_A); measuring an engine core exiting
5 temperature (T_R); calculating an engine core temperature (T_E) from the engine core exiting temperature (T_R) and the ambient air temperature (T_A); activating an air pump to draw air through the engine core via a core exhaust nozzle engaging collar and an air pipe to cool the gas paths within the engine core; and deactivating the air pump when the engine core temperature (T_E) equals a predetermined engine target temperature (T_T).

10 In some embodiments, the ambient air temperature (T_A) is measured by a first temperature sensor that is housed with the air pump, on or incorporated into the core exhaust nozzle engaging collar, or on or incorporated into the air intake.

In some embodiments, the engine core exiting temperature (T_R) is measured by a second temperature sensor that is located in or adjacent the core exhaust nozzle.

15 In some embodiments, the engine core temperature (T_E) is calculated by an algorithm as a single synthesised representative engine temperature.

In some embodiments, the air pump is activated by the controller in response to the measurements made by the first temperature sensor and the second temperature sensor.

20 In a third aspect, there is provided a gas turbine engine including an engine core that has been cooled using the engine cooling system of the first aspect or the method of the second aspect.

The term "ambient air temperature (T_A)" as used herein means the temperature of the ambient air. The ambient air temperature will typically depend on the temperature and
25 other climatic conditions if the engine is in the open air or the temperature and perhaps other conditions within a hangar or other building where the engine may be present during maintenance. The ambient air temperature will typically be from -10 °C to 50 °C.

The term "engine core temperature (T_E)" as used herein represents the temperature of the engine core of the engine that is to be cooled using the engine cooling
30 system and engine cooling method of the present disclosure. The temperature will typically vary depending on the specific location in the engine core however for present purposes the engine core temperature (T_E) is a single synthesised representative engine temperature that is calculated by an algorithm. During the cooling operation the algorithm may use a) measured ambient temperatures entering the engine, and b) measured
35 exhausted heated air temperatures, exiting the engine to then calculate engine core temperature (T_E). The engine core temperature will typically fall with time after engine shutdown as the engine cools passively and will typically fall with time as the engine is

cooled actively using the engine cooling system and engine cooling method of the present disclosure. The engine core temperature will also depend on the gas turbine concerned but will typically be about 150 to 200 °C immediately after engine shut down and fall over time to the ambient air temperature or lower.

5 The term “engine core exiting temperature (T_R)” as used herein means the temperature of the air on exit from the engine core of the engine, e.g. from the core exhaust nozzle.

 The term “engine target temperature (T_T)” as used herein is a selected target temperature for the engine core. In operation the air pump of the engine cooling system of
10 the present disclosure automatically draws air through the engine core until the engine core temperature (T_E) equals the engine target temperature (T_T).

 The terms “low pressure turbine” and “low pressure compressor” as used herein may be taken to mean the lowest pressure turbine stages and lowest pressure compressor stages (i.e. not including the fan 23) respectively and/or the turbine and
15 compressor stages that are connected together by the interconnecting shaft 26 with the lowest rotational speed in the engine (i.e. not including the gearbox output shaft that drives the fan 23). In some literature, the “low pressure turbine” and “low pressure compressor” referred to herein may alternatively be known as the “intermediate pressure turbine” and “intermediate pressure compressor”. Where such alternative nomenclature is
20 used, the fan 23 may be referred to as a first, or lowest pressure, compression stage.

 The terms “vapourise” and “vapourising” as used herein refer to the formation of a mist that includes droplets of a liquid suspended in a gas.

 The term “configured to” as used herein is at least as restrictive as the term “adapted to” and requires actual design intention to perform the specified function rather
25 than mere physical capability of performing such a function.

 The skilled person will appreciate that except where mutually exclusive, a feature or parameter described in relation to any one of the above aspects may be applied to any other aspect. Furthermore, except where mutually exclusive, any feature or parameter described herein may be applied to any aspect and/or combined with any other feature or
30 parameter described herein.

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments will now be described by way of example only with reference to the accompanying drawings, which are purely schematic and not to scale, and in which:

FIG. 1 is a schematic sectional side view of a gas turbine engine.

35 FIG. 2 is a schematic side view of an engine cooling system of the present disclosure.

FIG. 3 is a flowchart of the engine cooling method of the present disclosure.

FIG. 4 is a schematic side view of an engine cleaning system that incorporates the engine cooling system of the present disclosure.

The following table lists the reference numerals used in the drawings with the features to which they refer:

5

Ref no.	Feature	Figure
9	Principal rotational axis (of engine)	1
10	Gas turbine engine	1 2 4
10a	Upstream end of gas turbine engine	2 4
10b	Downstream end of gas turbine engine	2 4
11	Engine core	1 4
11a	Upstream end of engine core	4
11b	Downstream end of engine core	4
12	Air intake	1 2 4
14	Low pressure compressor (LPC)	1
15	High pressure compressor (HPC)	1
16	Combustion equipment	1
17	High pressure turbine (HPT)	1
18	Bypass exhaust nozzle	1 2
19	Low pressure turbine (LPT)	1
20	Core exhaust nozzle	1 2
21	Nacelle	1 4
22	Bypass duct	1 4
23	Fan	1 4
26	Shaft	1
27	Shaft	1
30	Epicyclic gearbox	1
50	Engine cooling system	2
52	Pylon	2
55	Air pump	2
60	Core exhaust nozzle engaging collar	2
65	Air pipe	2
70	First temperature sensor	2
75	Second temperature sensor	2
80	Controller	2
90	Engine cooling method	3
91	Step	3
92	Step	3
93	Step	3
94	Step	3
95	Step	3
100	Engine cleaning system	4

102	Source of an engine cleaning liquid	4
104	Engine cleaning liquid	4
106	Engine cleaning mist forming unit	4
108	Delivery device	4
110	Pump	4
112	Engine cleaning mist collector	4
114	Engine cleaning mist	4
116	Condensing chamber	4
118	Gas paths through the engine core	4
120	Conduit	4
121	Tooling	4
A	Core air flow	1
B	Bypass air flow	1
T _A	Ambient air temperature	2
T _E	Engine core temperature	2
T _R	Core engine exiting temperature	2
T _T	Engine target temperature	-

DETAILED DESCRIPTION

The present disclosure provides an engine cooling system and method for cooling gas paths in an engine core of a gas turbine engine of a stationary aircraft.

- 5 As introduced in the Background section, aero gas turbine engines typically need to be sufficiently cool before they can be cleaned to remove various types of debris that can accumulate during flights. The engines are most conveniently and economically cleaned whilst on wing and typically actively cooled for safe and timely cleaning and other maintenance so the aircraft can be ready for the next flight as soon as practically possible.
- 10 Such cooling is often carried out by dry motoring the engine, i.e. using a starter motor for the engine but without fuel, or sometimes by using external tooling. When dry motoring an engine a suitably licensed engineer is generally required to operate the engine's starter motor from the cockpit multiple times until the desired temperature to begin cleaning the engine is reached. This can involve a prolonged period of time as the starter motor can
- 15 only run in short bursts between long cool down periods.

- When using external tooling, air extraction tooling or air conditioning tooling is typically attached to the engine exhaust, e.g. the core exhaust nozzle or the bypass exhaust nozzle. Control of the engine's temperature (and whether it has reached the desired temperature) is typically achieved by once again placing a suitably licensed
- 20 engineer in the cockpit of the aircraft. That is because conventionally the engine's temperature sensors can only be read in the cockpit. Once the desired temperature is reached the engineer in the cockpit then must communicate by some means to the

engineer who is operating the cooling system, near the engine. Therefore the cooling process prior to any engine cleaning is reliant on the availability of at least two suitably licensed engineers, access to the cockpit and radio, telephone or sign communication from an engineer in the cockpit to an engineer who can operate the engine cooling
5 system. The engine colling system and the method of the present disclosure removes any requirement for an engineer to be in the cockpit and in some embodiments both engine cooling and engine cleaning can be automatically controlled.

In broad terms the engine cooling system of the present disclosure for cooling gas paths in an engine core of a gas turbine engine of a stationary aircraft comprises an air
10 pump, a core exhaust nozzle engaging collar, an air pipe, a first temperature sensor, a second temperature sensor, and a controller.

The gas turbine engine can be any gas turbine engine, particularly an aero gas turbine engine. While the present disclosure illustrates the engine cooling system cooling a turbofan aero engine it could also be used to cool turboprop aero engines or other gas
15 turbine engines.

The gas turbine engine has an engine core, which typically houses a compressor module, combustor equipment, and a turbine module through which define a variety of gas paths through the engine core of the gas turbine engine.

The air pump is used to draw air through the gas paths of the engine core and can
20 take any suitable form for that purpose. The air pump works in conjunction with the core exhaust nozzle engaging collar that is configured to detachably seal over the core exhaust nozzle of the gas turbine engine and the air pipe that connects the core exhaust nozzle engaging collar to the air pump so that air from the atmosphere is drawn into and through the engine before being collected in the core exhaust nozzle engaging collar and further
25 drawn through the air pipe and into the air pump. The drawing of air from the atmosphere though the gas paths of the engine core serves to cool the gas paths.

The air pump is configured to respond to signals provided by the controller which is in communication with the first temperature sensor and the second temperature sensor.

The controller can take any form and be provided in any location that is suitable for
30 its purpose. In some embodiments the controller is a programmable logic controller (PLC) that is accessed by a human-machine interface (HMI). The HMI may display parameters for the operator and receive inputs from the operator. In some embodiments the controller is housed with the air pump. In some embodiments the HMI is housed within a handheld unit for operating the engine cooling system. Such a handheld unit may for example be
35 linked to the PLC via Bluetooth® or Wi-Fi technologies.

The first temperature sensor is configured to measure an ambient air temperature (T_A). The first temperature sensor can take any form and be provided in any location that

is suitable for its purpose. In some embodiments the first temperature sensor is a thermocouple. In some embodiments the first temperature sensor is housed with the air pump, on or incorporated into the core exhaust nozzle engaging collar, or on or incorporated into the air intake.

5 The second temperature sensor is configured to measure an engine core exiting temperature (T_R). The second temperature sensor can take any form and be provided in any location that is suitable for its purpose. In some embodiments the first temperature sensor is a thermocouple. In some embodiments the second temperature sensor is located in or adjacent the core exhaust nozzle.

10 The controller is configured: (a) to calculate an engine core temperature (T_E) from the engine core exiting temperature (T_R) and the ambient air temperature (T_A); and (b) to activate the air pump to draw air through the engine core to cool the gas paths within the engine core until the engine core temperature (T_E) equals a predetermined engine target temperature (T_T).

15 The engine core temperature (T_E) can be calculated from the engine core exiting temperature (T_R) and the ambient air temperature (T_A) in any suitable manner. For example, a Weighted Average Calculation may be used, where an "average" of the ambient air temperature and engine temperature are taken, but instead of giving them equal weighting, a multiplication factor is applied to each of them in order to add greater
20 influence to one part of the equation. The value of these multiplication factors may be calculated from on engine testing; e.g. applying the formula $T_R = (\alpha T_A + \beta T_E)/2$, i.e. in an ordinary "average" calculation α and β would both be equal to 1, therefore giving both the ambient temperature T_A and the engine temperature T_E equal influence over the rig temperature T_R . However, when cooling engines it is known that, due to the thermal mass
25 of the engine, the engine temperature T_E is a larger influence on the rig temperature T_R than the ambient air temperature T_A . Therefore $\beta > \alpha$, and α and β may also be bespoke to each engine that is cooled, i.e. the values of α and β may change between engines, e.g. from a TRENT® XWB engine to a smaller TRENT® 700 engine, the smaller engine having a lower thermal mass and therefore its influence on rig temperature T_R would be
30 lower.

 The engine cooling system and the engine cooling method of the present disclosure can be usefully applied to various known methods for cleaning engines. One such suitable engine cleaning system is that developed by the Applicant and described in United States patent application US 2021/0108537 A1 discloses an engine cleaning
35 system for cleaning an engine core of a gas turbine engine and a method of cleaning an engine core of a gas turbine engine. The engine cleaning system includes an engine cleaning mist forming unit that vapourises an engine cleaning fluid to form an engine

cleaning mist and a pump that draws the engine cleaning mist through the engine core to clean the gas paths within the engine core.

In contrast to the procedure for operating the engine cleaning system of US 2021/0108537 A1, no engineer needs to be in the cockpit of the aircraft to cool the engine using the engine cooling system of the present disclosure. A single engineer connects the exhaust nozzle engaging collar to the core exhaust nozzle of the gas turbine engine and air pump to draw air through the gas paths of the engine core of the engine. The cleaning cooling system determines and records the engine core exiting temperature (T_R) and the ambient air temperature (T_A). The engine cooling system uses an algorithm to calculate the engine core temperature (T_E) from the engine core exiting temperature (T_R) and the ambient air temperature (T_A). The air pump draws air through the engine core to cool the gas paths within the engine core until the engine core temperature (T_E) equals a predetermined engine target temperature (T_T).

The cleaning cooling system can be incorporated with an engine cleaning system such as the engine cleaning system of US 2021/0108537 A1 to similarly automate the engine cleaning function so that the engine can be both cooled and by a single engineer.

Aspects and embodiments of the present disclosure will now be discussed with reference to the accompanying figures. Further aspects and embodiments will be apparent to those skilled in the art.

FIG. 1 illustrates a gas turbine engine 10 having a principal rotational axis 9. The engine 10 comprises an air intake 12 and a propulsive fan 23 that generates two airflows: a core airflow A and a bypass airflow B. The gas turbine engine 10 comprises a core 11 that receives the core airflow A. The engine core 11 comprises, in axial flow series, a low pressure compressor 14, a high pressure compressor 15, combustion equipment 16, a high pressure turbine 17, a low pressure turbine 19 and a core exhaust nozzle 20. A nacelle 21 surrounds the gas turbine engine 10 and defines a bypass duct 22 and a bypass exhaust nozzle 18. The bypass airflow B flows through the bypass duct 22. The fan 23 is attached to and driven by the low pressure turbine 19 via a shaft 26 and an epicyclic gearbox 30.

In use, the core airflow A is accelerated and compressed by the low pressure compressor 14 and directed into the high pressure compressor 15 where further compression takes place. The compressed air exhausted from the high pressure compressor 15 is directed into the combustion equipment 16 where it is mixed with fuel and the mixture is combusted. The resultant hot combustion products then expand through, and thereby drive, the high pressure and low pressure turbines 17, 19 before being exhausted through the core exhaust nozzle 20 to provide some propulsive thrust. The high pressure turbine 17 drives the high pressure compressor 15 by a suitable

interconnecting shaft 27. The fan 23 generally provides the majority of the propulsive thrust. The epicyclic gearbox 30 is a reduction gearbox.

FIG. 2 schematically depicts an engine cooling system of the present disclosure for cooling the gas paths in an engine core of a gas turbine engine, e.g. the gas turbine engine of FIG. 1.

As mentioned above, on wing aero gas turbine engines have to be actively cooled before they can be safely cleaned or otherwise maintained. The engine cooling system of the present enables this operation to be performed by a single engineer.

FIG. 2 is a schematic side view of a gas turbine engine 10 and an engine cooling system 50 for cooling the gas paths of that gas turbine engine. The gas turbine engine 10 has an upstream end 10a through which air is drawn into the engine when the engine is in operation and a downstream end 10b through which air is propelled out on the engine when the engine is in operation. The gas turbine engine 10 is attached to an aircraft (not shown) via a pylon 52. Also shown is the air intake 12 at the upstream end 10a of the engine and the bypass exhaust nozzle 18 and the core exhaust nozzle at the downstream end 10b of the engine.

The engine cooling system 50 has an air pump 55, a core exhaust nozzle engaging collar 60, an air pipe 65, a first temperature sensor 70, a second temperature sensor 75, and a controller 80.

The core exhaust nozzle engaging collar 60 is configured to detachably seal over the core exhaust nozzle 20 of the gas turbine engine 10. It is connected to the air pump 55 by the air pipe 65. When the air pump 55 is activated, it draws air from the atmosphere into and through the air intake 12 of the engine, through the gas paths within the engine core 11 of the engine, through the core exhaust nozzle engaging collar 60, through the air pipe 65 and into the air pump 55. The drawing of air from the atmosphere through the gas paths of the engine core serves to cool them. The air received by the air pump 55 is expelled from the air pump back into the atmosphere.

The air pump 55 is operated in response to signals from the controller 80, which is in communication with the first temperature sensor 70 and the second temperature sensor 75.

The first temperature sensor 70 is configured to measure an ambient air temperature (T_A). In the embodiment depicted in FIG. 2 the first temperature sensor 70 is housed with the air pump 55.

The second temperature sensor 75 is configured to measure an engine core exiting temperature (T_R). In the embodiment depicted in FIG. 2 the second temperature sensor 75 is located adjacent the core exhaust nozzle 20 and configured to measure an engine core exiting temperature (T_R).

The controller (80) is configured: (a) to calculate an engine core temperature (T_E) from the engine core exiting temperature (T_R) and the ambient air temperature (T_A); and (b) to activate the air pump (55) to draw air through the engine core (11) to cool the gas paths within the engine core until the engine core temperature (T_E) equals a
5 predetermined engine target temperature (T_T). In the embodiment depicted in FIG. 2 the controller 80 is housed with the air pump 55.

As explained above, the engine cooling system of present disclosure measures current ambient temperature (T_A). With the air pump running the engine cooling system then measures the temperature of air coming out of the engine, i.e. the engine core
10 exiting temperature (T_R).

The engine core temperature (T_E) is a single synthesised representative engine temperature that is calculated from the engine core exiting temperature (T_R) and the ambient air temperature (T_A) by an algorithm.

When applied to a control system, a predetermined engine target temperature (T_T)
15 can be set. The air pump 55 automatically pumps air through the engine cooling the gas paths in the engine core until the calculated engine core temperature (T_E) equals the predetermined engine target temperature (T_T). Once the predetermined engine target temperature (T_T) has been achieved the air pump 55 is deactivated and the engine cooling system automatically stops.

20 Automating the engine cooling system in this way enables the engine cooling system to be safely and efficiently operated by a single engineer. It removes the requirement for a trained engineer to be present in the cockpit of the aircraft while its engines are cooled.

FIG. 3 is a flowchart of the engine cooling method for cooling gas paths in an
25 engine core of a gas turbine engine of a stationary aircraft of the present disclosure. In broad terms the method 90 comprises five steps 91-95.

The first step (91) involves measuring an ambient air temperature (T_A). This can be measured using any suitable method, e.g. based on readings taken from the first temperature sensor (70) that is suitably located for the purpose.

30 The second step (92) involves measuring an engine core exiting temperature (T_R). This can be measured using any suitable method, e.g. based on readings taken from the second temperature sensor (75) that is suitably located for the purpose.

The third step (93) involves calculating an engine core temperature (T_E) from the engine core exiting temperature (T_R) and the ambient air temperature (T_A). This can be
35 calculated using any suitable method, e.g. using an algorithm.

The fourth step (94) involves activating an air pump to draw air through the engine core via a core exhaust nozzle engaging collar (60) and an air pipe (65) to cool the gas

paths within the engine core (11). The air pump can be activated using any suitable method, e.g. controlled by the controller (80).

The fifth step (95) involves deactivating the air pump (55) when the engine core temperature (T_E) equals a predetermined engine target temperature (T_T). The air pump
5 can be deactivated using any suitable method, e.g. controlled by the controller (80).

The method (90) of the present disclosure may not require a specialist technician to operate the gas turbine engine. Since the starter motor is not used, cleaning of the gas turbine engine is not impacted by a cool down period of the starter motor. This may lower operational costs and reduce process time. There may be less health and safety risks as
10 the gas turbine engine is not operational during cleaning. Cleaning can occur in situ while the gas turbine engine is mounted on the aircraft. Cleaning may also be more robust to weather conditions.

FIG. 4 shows the engine cooling system 50 of the present disclosure incorporated within a cleaning system 100 for cleaning gas paths in an engine core of a gas turbine
15 engine, e.g. the gas turbine engine of FIG. 1.

The cleaning system 100 includes a source 102 of an engine cleaning liquid 104, an engine cleaning mist forming unit 106, at least one delivery device 108, a pump 110, and a mist collecting arrangement 112.

The source 102 may include one or more tanks or vessels that can store the
20 engine cleaning liquid 104. The engine cleaning liquid 104 may be a mixture of water and a detergent. In some cases, the detergent may be biodegradable. In an arrangement, the source 102 may include components to generate the engine cleaning liquid 104, such as a water tank, a detergent tank and a mixer for mixing detergent and water in order to generate the engine cleaning liquid 104. In some embodiments, the source 102 may
25 optionally store an anti-freeze. The source 102 may include an anti-freeze tank for storing the anti-freeze. The anti-freeze may be mixed with the engine cleaning liquid 104. The source 102 may include additional components, such as one or more valves, pipes, seals, filters, fluid connectors, fluid pump etc.

In some embodiments, the source 102 may pressurise the engine cleaning liquid
30 104. For example, the fluid pump of the source 102 may pressurise the engine cleaning liquid 104 to supply the engine cleaning liquid 104 in pressurised state. In some embodiments, the source 102 may optionally include a heating element to heat the engine cleaning liquid 104. Further, a composition of the engine cleaning liquid 104 may be changed based on a specific stage during cleaning. For example, the source 102 may
35 supply water without any detergent for rinsing. In such cases, the engine cleaning liquid 104 may be substantially free of any detergent.

The engine cleaning mist forming unit 106 vapourises the engine cleaning liquid

104 to form an engine cleaning mist 114. The engine cleaning mist forming unit 106 is in fluid communication with the source 102 for receiving the engine cleaning liquid 104. The engine cleaning mist 114 may include droplets of the engine cleaning liquid 104 suspended in a gas, such as air. The engine cleaning mist 114 and the gas may form an aerosol.

The engine cleaning mist forming unit 106 may use different mechanisms to vapourise the engine cleaning liquid 104 to form the engine cleaning mist 114. The engine cleaning mist forming unit 106 further delivers the engine cleaning mist 114 into the engine core 11 of the gas turbine engine 10.

The at least one delivery device 108 is configured to deliver the engine cleaning liquid 104 to the engine cleaning mist forming unit 106. In the embodiment shown in Figure 2, the cleaning system 100 has a single delivery device 108. However, the cleaning system 100 may include two or more delivery devices 108 based on application requirements.

The pump 110 is configured to draw the engine cleaning mist 114 through the engine core 11 to clean the gas paths within the engine core. The pump 110 may also be used without the cleaning mist to cool the engine prior to cleaning and/or to dry the engine after cleaning.

The engine cleaning mist collector 112 has a condensing chamber 116 that is accessed via a conduit 120 that is detachably connectable to the core exhaust nozzle 20 by a tooling 121. The engine cleaning mist collector 112 is configured to collect the engine cleaning mist 114 that has passed through the engine core 11 and condensed in the condensing chamber 116.

As shown in FIG. 4, the gas turbine engine 100 has an air intake 12, a propulsive fan 23 and an engine core 11. The engine core 11 includes, in axial flow series, a low pressure compressor, a high pressure compressor, combustion equipment, a high pressure turbine, a low pressure turbine and a core exhaust nozzle 20. A nacelle 21 surrounds the gas turbine engine 10 and defines a bypass duct 22 and a bypass exhaust nozzle 18. The nacelle 21 may be supported on a body of an aircraft by one or more pylons, e.g. on a wing of the aircraft by the one or more of such pylons. The engine core 11 has an upstream end 11a that is proximal to the low pressure compressor and a downstream end 11b that is proximal to the core exhaust nozzle 20. The gas turbine engine 10 has an upstream end 10a that is proximal to the air intake 12 and a downstream end 10b that is proximal to the bypass exhaust nozzle 18. The propulsive fan 23 generates a core airflow (A) and a bypass airflow (B).

When the gas turbine engine 10 is in operation, the propulsive fan 23 generates a core airflow (A) through the engine core 11 and a bypass airflow (B) through the bypass

duct 22. The core airflow is accelerated and compressed by the low pressure compressor and directed into the high pressure compressor where further compression takes place.

The compressed air exhausted from the high pressure compressor is directed into the combustion equipment where it is mixed with fuel and the mixture is combusted. The resultant hot combustion products then expand through, and thereby drive, the high pressure and low pressure turbines before being exhausted through the core exhaust nozzle 20 to provide some propulsive thrust. In FIG. 2 gas paths 118 schematically indicate the passageways through the core airflow flows through the engine core 11 during operation. These gas paths 118 are cleaned using the cleaning system of the present disclosure.

In the embodiment of the cleaning system 100 shown in FIG. 2 for cleaning the gas paths 118 in the engine core 11 of the gas turbine engine 10 the engine cleaning mist forming unit 106 and a single delivery device 108 to which it is attached are inserted into the bypass exhaust nozzle 18 and through the bypass duct 22 of the gas turbine engine 10. The engine cleaning mist forming unit 106 is then directed into the engine core 11. In other embodiments the engine cleaning mist forming unit 106 and the single delivery device 108 are inserted into the air intake 12 and the engine cleaning mist forming unit 106 is then directed into the engine core 11. The former arrangement is typically preferred on a health and safety basis as it can avoid any interaction with the fan. It can also enable the engine to be cleaned without stopping the fan.

The delivery device 108 can include one or more conduits configured to receive a flow of the engine cleaning liquid 104 from the source 102 and deliver the flow of the engine cleaning liquid 104 to the engine cleaning mist forming unit 106. In some embodiments, the delivery device 108 may receive the engine cleaning liquid 104 in a pressurised state. The delivery device 108 delivers the pressurised engine cleaning liquid 104 to the engine cleaning mist forming unit 106. An end of the delivery device 108 is in fluid communication with the source 102 and receives the engine cleaning liquid 104. An opposite end of the delivery device 108 delivers the engine cleaning liquid 104 to the mist forming unit 106. The delivery device 108 may include a flexible conduit (e.g. a hose), a rigid conduit (e.g. a pipe), or a combination thereof. The one or more conduits of the delivery device 108 may be made of a fluid impermeable material to substantially prevent any leakage of the engine cleaning liquid 104. The delivery device 108 may further include various components, such as fluid connectors, pipe fittings, adapters etc. The delivery device 108 may include one or more bends in order to deliver the engine cleaning liquid 104 to the engine cleaning mist forming unit 106. The delivery device 108 may be specific to an engine geometry, which might correspond to a single type (e.g. model) of gas turbine engines or a family of gas turbine engines.

The engine cooling system of the present disclosure can be incorporated into the engine cleaning method described above by providing the core exhaust nozzle engaging collar 60 as the tooling 121, using the conduit 120 as the air pipe 65, using the pump 110 as the air pump 65, and providing the first temperature sensor 70, the second temperature
5 75 and the controller 80 in suitable locations for their respective functions. In the embodiment shown in FIG. 4, the first temperature sensor 70 and the controller 80 are housed with the pump 110 and the second temperature sensor is located adjacent the core exhaust nozzle.

The cleaning system of US 2021/0108537 A1 requires two qualified engineers to
10 operate it. One of the engineers is required to sit in the cockpit of the aircraft powered by the engines to be cleaned to read the engine temperature prior to any washing of the engines and determine they sufficiently cool to be safely washed. This is because engine thermocouples can typically only be read from the cockpit of the aircraft. The suitable engine temperature for washing temperature depends on the engine concerned but is
15 typically from 50 °C to 100 °C. Having established it is safe to wash the engines, the engineer in the cockpit informs the other engineer, typically by mobile phone, to connect the air conduit to the core exhaust nozzle of the first engine and activate the cooling fan of the cleaning system to draw air through the gas paths of the engine core and to commence washing.

20 Requiring an engineer to be placed in the cockpit is an onerous use of a highly trained individual. The engine cleaning system and engine cleaning method of the present disclosure avoids that requirement.

Like the engine cooling system 50 and the engine cooling method of the present disclosure, the engine cleaning system 100 can be operated by a single engineer. Since
25 the starter motor is not used, cleaning of the gas turbine engine is not impacted by a cool down period of the starter motor. This may lower operational costs and reduce process time.

Various examples have been described, each of which comprise various combinations of features. It will be appreciated by those skilled in the art that, except
30 where clearly mutually exclusive, any of the features may be employed separately or in combination with any other features and the invention extends to and includes all combinations and sub-combinations of one or more features described herein.

CLAIMS

1. An engine cooling system (50) for cooling gas paths in an engine core (11) of a gas turbine engine (10) of a stationary aircraft, the gas turbine engine having a core exhaust nozzle (20), the engine cooling system (50) comprising:
- 5 an air pump (55);
a core exhaust nozzle engaging collar (60) configured to detachably seal over the core exhaust nozzle (20) of the gas turbine engine (10);
an air pipe (65) that connects the core exhaust nozzle engaging collar (60) to the air pump (55); and
- 10 a first temperature sensor (70) configured to measure an ambient air temperature (T_A);
a second temperature sensor (75) that is located in or adjacent the core exhaust nozzle (20) and configured to measure an engine core exiting temperature (T_R); and
15 a controller (80) configured:
(a) to calculate an engine core temperature (T_E) from the engine core exiting temperature (T_R) and the ambient air temperature (T_A); and
(b) to activate the air pump (55) to draw air through the engine core (11) to cool the gas paths within the engine core until the engine core temperature (T_E) equals a
20 predetermined engine target temperature (T_T).
2. The engine cooling system (50) according to claim 1, wherein the air pump (55) is configured to respond to signals provided by the controller (80), which is in communication with the first temperature sensor (70) and the second temperature sensor (75).
- 25 3. The engine cooling system (50) according to claim 1 or 2, wherein the air pump (55) is configured to expel the air that it has drawn through the gas paths of the engine core (11) back into the atmosphere.
- 30 4. The engine cooling system (50) according to any preceding claim, wherein the core exhaust nozzle engaging collar (60) is configured to collect air that is drawn through the gas paths of the engine core (11) when the air pump (55) is activated and to allow the air to pass through the air pipe (65) and into the air pump (55).
- 35 5. The engine cooling system (50) according to any preceding claim, wherein the first temperature sensor (70) is housed with the air pump (55), on or incorporated into the core exhaust nozzle engaging collar (60), or on or incorporated into the air intake (12).

6. The engine cooling system (50) according to any preceding claim, wherein the second temperature sensor (75) is located in or adjacent the core exhaust nozzle (20).
7. The engine cooling system (50) according to any preceding claim, wherein the first temperature sensor (70) and/or the second temperature sensor (75) is a thermocouple.
8. The engine cooling system (50) according to any preceding claim, wherein the controller (80) is housed with the air pump (55).
9. The engine cooling system (50) according to any preceding claim, wherein the controller (80) is a programmable logic controller that is accessed by a human-machine interface.
10. The engine cooling system (50) according to any preceding claim, wherein at least one of the air pump (55), the core exhaust nozzle engaging collar (60), the air pipe (65), the first temperature sensor (70), the second temperature (75) and the controller (80) form part of an engine cleaning system for cleaning the gas paths in the engine core (11) of the gas turbine engine (10).
11. An engine cooling method for cooling gas paths in an engine core (11) of a gas turbine engine (10) of a stationary aircraft, the engine cooling method comprising the steps of:
- measuring an ambient air temperature (T_A) (91);
 - measuring an engine core exiting temperature (T_R) (92);
 - calculating an engine core temperature (T_E) from the engine core exiting temperature (T_R) and the ambient air temperature (T_A) (93);
 - activating an air pump (55) to draw air through the engine core (11) via a core exhaust nozzle engaging collar (60) and an air pipe (65) to cool the gas paths within the engine core (94); and
 - deactivating the air pump (55) when the engine core temperature (T_E) equals a predetermined engine target temperature (T_T) (95).
12. The engine cooling method of claim 11, wherein the ambient air temperature (T_A) is measured by a first temperature sensor (70) that is housed with the air pump (55), on or incorporated into the core exhaust nozzle engaging collar (60), or on or incorporated into the air intake (12).

13. The engine cooling method of claim 11 or 12, wherein the engine core exiting temperature (T_R) is measured by a second temperature sensor (75) that is located in or adjacent the core exhaust nozzle (20).
- 5 14. The engine cooling method of any one of claims 11 to 13, wherein the engine core temperature (T_E) is calculated by an algorithm as a single synthesised representative engine temperature.
- 10 15. The engine cooling method of any one of claims 11 to 14, wherein the air pump (55) is activated by the controller (80) in response to the measurements made by the first temperature sensor (70) and the second temperature sensor (75).