SUMMARY

Foam material is introduced at the gas-path entry of turbine equipment while off-line. The foam will coat and contact the internal surfaces, scrubbing, removing, and carrying fouling material away from equipment.

In an aspect, the present disclosure refers to a method for scheduling a foam cleaning of a gas turbine engine, comprising:

quantifying a range of improvement to an operational parameter of a family of gas turbine engines achievable by foam cleaning of a member of the family;

operating a specific engine of the family;

measuring the performance of the specific engine during said operating;

determining that the specific engine should be foam cleaned; and

scheduling a foam cleaning of the specific engine.

In an aspect, the present disclosure refers to a method for providing a foamed liquid cleaning agent to a gas turbine engine, comprising:

operating a gas turbine engine;

measuring the performance of the gas turbine engine during said operating;

determining that the gas turbine engine should be foam washed based on the measured performance;

operating a source of a liquid cleaning agent, a liquid pump, and a source of pressurized gas;

mixing pressurized gas with pressurized liquid and creating a supply of foam;

streaming the supply of foam into the gas turbine engine.

One example of the present disclosure pertains to an apparatus for foaming a cleaning agent. Some examples include a housing defining an internal flowpath having first, second, and third flow portions, a gas inlet, a liquid inlet for the cleaning agent, and a foam outlet. The first flow portion includes a gas plenum that is adapted and configured for receiving gas under pressure from the gas inlet and including a plurality of apertures, the plenum and the interior of the housing forming a mixing region that provides a first foam of the liquid and the gas. The second flow portion receives the first foam and flows the first foam past a foam growth matrix adapted and configured to provide surface area for attachment and merging of the cells. The third flow portion flows the second foam through a foam structuring member downstream of either the first portion or the second portion adapted and configured to reduce the size of at least some of the cells. It is understood that yet other examples of the present disclosure contemplate a housing having only a first portion; or a first and second portion; or only a first and third portion in various other nucleation devices.

Another example of the present disclosure pertains to a method for foaming a liquid cleaning agent. Some examples include mixing the liquid cleaning agent and a pressurized gas to form a first foam. Other examples include flowing the first foam over a member or matrix and increasing the size of the cells of the first foam to form a second foam. Yet other examples include flowing the second foam through a

structure such as a mesh or one or more apertured plates and decreasing the size of the cells of the second foam to form a third foam.

Yet another example of the present disclosure pertains to a system for providing an air-foamed liquid cleaning agent. Other examples include an air pump or pressurized gas reservoir providing air or gas at pressure higher than ambient pressure, and a liquid pump providing the liquid at pressure. Still other examples include a nucleation device receiving pressurized air, a liquid inlet receiving pressurized liquid, and a foam outlet, the nucleation device turbulently mixing the pressurized air and the liquid to create a foam. Yet other examples include a nozzle receiving the foam through a foam conduit, the internal passageways of the nozzle and the conduit being adapted and configured to not increase the turbulence of the foam, the nozzle being adapted and configured to deliver a low velocity stream of foam.

Still another example pertains to a method for providing an air-foamed liquid cleaning agent to the inlet of a jet engine installed on an airplane. Some examples include providing a source of a pressurized liquid cleaning agent, an air pump, a turbulent mixing chamber, and a non-atomizing supply aperture. Other examples include mixing pressurized air with pressurized liquid in the mixing chamber and creating a supply of foam. Still other examples include streaming the supply of foam into the installed engine either through the inlet or through various tubing attached to the engine from the aperture.

Yet another example of the present disclosure pertains to an apparatus for foaming a water soluble liquid cleaning agent. Some examples include means for mixing a pressurized gas with a flowing water soluble liquid to create a foam. Other

examples include means for growing the size of the cells of the foam created by said mixing means and means for reducing the size of the grown cells.

In various examples of the disclosure, the effluent after a cleaning operation is collected and evaluated. This evaluation can include an on-site analysis of the content of the effluent, including whether or not particular metals or compounds are present in the effluent. Based on the results of this evaluation, a decision is made as to whether or not further cleaning is appropriate.

Still further examples of the present disclosure pertain to a method in which the effect of a cleaning operation is assessed, and that assessment is used to evaluate the terms of a contract. As one example, the contract may pertain to the terms of the engine warranty provided by the engine manufacturer to the operator or owner of the aircraft. In still further examples the assessment may be used to evaluate the terms of a contract pertaining to the engine cleaning operation itself. In yet further examples the assessment of the cleaning effect on the engine may be used to evaluate the engine relative to establish FFA maintenance standards for that engine.

In one example, the assessment method includes operating an engine in a commercial flight environment for more than about one month. It is anticipated that in some examples this operation can include multiple flights per day, and usage of the aircraft for up to seven days per week. The method further includes operating the used engine and establishing a baseline characteristic. In some examples, the baseline characteristic can be specific fuel consumption at a particular level of thrust, engine pressure ratio, or rotor speed. In some alternatives, the method includes correcting this baseline data for ambient atmospheric characteristics. In yet other examples, the

baseline parameter could be the elapsed time for the start of an engine from zero rpm up to idle speed. In still further examples, the baseline assessment of the used engine includes the assessment of engine start time in the following manner: performing a first start of an engine; shutting down the engine; motoring the engine on the starter (without the combustion of fuel) for a predetermined period of time; and after the motoring, performing a second engine start, and using the second engine start time as the baseline start time.

The method further includes cleaning the engine. This cleaning of the engine may include one or more successive cleaning cycles. After the engine is cleaned, the baseline test method is repeated. This second test results (of the cleaned engine) are compared to the baseline test results (of the used engine, as received); and the changes in engine characteristics are assessed against a contractual guarantee. As one example, the operator of the cleaning equipment may have offered contractual terms to the owner or operator of the aircraft with regards to the improvement to be made by the cleaning method. In still further examples, the delta improvement provided by the cleaning method (or alternatively, the test results of the cleaned engine considered by itself) can be compared to a contractual guarantee between the manufacturer of the engine (or the facility that performed the previous overhaul of the engine, or the licensee of the engine) to assess whether or not the cleaned engine meets those contractual terms.

In still further examples, there is a cleaning method in which a baseline test is performed on a used engine; the engine is cleaned; and the baseline test is performed a

second time. The comparison of the baseline test to the clean engine test can be used for any reason.

In yet other examples, the cleaning method includes a procedure in which the engine is operated in a cleaning cycle, and that cleaning cycle (or a different cleaning cycle), is subsequently applied to the engine. Preferably, the cleaning chemicals are provided to the engine at relatively low rotational speeds, and preferably less than about one-half the typical idle speed for that engine.

In still further examples, such as in those engines supported substantially vertically, the cleaning chemical can be applied to the engine when the engine is static (i.e., zero rpm). After applying a sufficient amount of chemicals, the engine can then be rotated at any speed, and the cleaning chemicals subsequently flushed.

Yet other examples of the present disclosure pertain to methods for cleaning an engine that include manipulation of the temperature of the cleaning chemicals and/or manipulation of the temperature of the engine that is being cleaned. In one example, the cleaning system includes a heater that is adapted and configured to heat the cleaning chemicals prior to the creation of a cleaning foam. In still further examples, the method includes a heater for heating the air being used to create the foam with the cleaning liquids. In still further examples, the cleaning apparatus includes one or more air blowers that provide a source of heated ambient air (similar to “alligator” space heaters used at construction sites). These hot air blowers can be positioned at the inlet of the engine, and the engine can be motored (i.e., rotated on the starter, without combustion of fuel) for either a predetermined period of time (which may be based on ambient conditions), or motored until thermocouples or other temperature

measurement devices in the engine hot section have reached a predetermined temperature. In still further examples, the temperature of the engine prior to the introduction of the cleaning foam can be raised by starting the engine and operating the engine at idle conditions for a predetermined period of time, and subsequently shut down the engine prior to introduction of the cleaning foam. In still further examples, the engine can be motored after the shutdown from idle and before the introduction of chemicals to further achieve a consistent baseline temperature condition prior to introduction of the foam. Still further examples of the present disclosure contemplate any combination of preheated liquid chemicals, preheated compressed air used for foaming, externally heated engines, and engines made “warm” by one or more recent periods of operation.

In still further examples of the present disclosure, the cleaning foam can be heated by providing a heating element within the device used to mix and create the cleaning foam.

It will be appreciated that the various apparatus and methods described in this summary section, as well as elsewhere in this application, can be expressed as a large number of different combinations and subcombinations. All such useful, novel, and inventive combinations and subcombinations are contemplated herein, it being recognized that the explicit expression of each of these combinations is unnecessary.