United States Patent	12392255
Kind Code	B2
Date of Patent	August 19, 2025
Inventor(s)	Drolet; Martin

Systems and methods for determining gas turbine engine operating margins

Abstract

A system for a gas turbine engine includes an engine control system. The engine control system includes a processor and a non-transitory memory storing instructions, which instructions when executed by the processor, cause the processor to: obtain a current engine installation configuration for the gas turbine engine and the aircraft, determine an expected normalized value of the engine parameter based on the current engine installation configuration and one or more of a normalized engine power (SHPN) of the gas turbine engine, an engine inlet temperature, an airspeed, or an altitude, determine a fully deteriorated engine (FDE) value of the engine parameter using the expected normalized value of the engine parameter, determine a current value of the engine parameter for the gas turbine engine, and determine the engine operating margin for the engine parameter based on the FDE value of the engine parameter and the current value of the engine parameter.

Inventors:	**Drolet; Martin (Saint-Amable, CA)**
Applicant:	**Pratt & Whitney Canada Corp.** (Longueuil, CA)
Family ID:	**1000008768143**
Assignee:	**Pratt & Whitney Canada Corp. (Longueuil, CA)**
Appl. No.:	**17/892776**
Filed:	**August 22, 2022**

Prior Publication Data

Document Identifier	Publication Date
US 20240060427 A1	Feb. 22, 2024

Publication Classification

Int. Cl.: F01D21/00 (20060101); **G07C5/08** (20060101)

U.S. Cl.:

CPC   **F01D21/003** (20130101); **G07C5/0808** (20130101); F05D2220/323 (20130101); F05D2260/80 (20130101)

Field of Classification Search

CPC: F05D (2260/80); F05D (2220/323)

References Cited

U.S. PATENT DOCUMENTS

Patent No.	Issued Date	Patentee Name	U.S. Cl.	CPC
6681558	12/2003	Orlando	N/A	N/A
8068997	12/2010	Ling	N/A	N/A
8117017	12/2011	Ellis	701/100	G05B 17/02
9726577	12/2016	Gordon	N/A	G01M 15/14
10956534	12/2020	Ling	N/A	N/A
11085321	12/2020	Ling	N/A	N/A
11702954	12/2022	Valois	415/1	F01D 21/003
2005/0261820	12/2004	Feeney	701/31.4	G07C 5/0816
2007/0220897	12/2006	Howlett	N/A	N/A
2008/0234994	12/2007	Goebel	N/A	N/A
2010/0204931	12/2009	Ling	702/41	G05B 23/0283
2010/0275575	12/2009	Brown	N/A	N/A
2016/0273379	12/2015	Soares, Jr.	N/A	N/A
2017/0175646	12/2016	Adibhatla	N/A	F02C 7/12
2018/0025557	12/2017	Steinert	701/99	G05B 23/0221
2019/0017409	12/2018	Yardibi	N/A	F02C 9/00
2019/0244443	12/2018	Steinert	N/A	N/A
2020/0284204	12/2019	Cafaro	N/A	N/A
2020/0398993	12/2019	Drolet	N/A	N/A
2021/0108578	12/2020	Darfeuil	N/A	B64D 31/02

FOREIGN PATENT DOCUMENTS

Patent No.	Application Date	Country	CPC
112173169	12/2020	CN	N/A

OTHER PUBLICATIONS

Dimitry Gorinevsky, Kevin Dittmar, Dinkar Mylaraswamy and Dinkar Mylaraswamy, "Model-Based Diagnostics for an Aircraft Auxiliary Power Unit," Proceedings of the 2002 IEEE International Conference on Control Applications Sep. 18-20, 2002* Glasgow, Scotland, U.K., (Year: 2002). cited by examiner

Vasileios E. Kyritsis and Pericles Pilidis, "An Analytical Approach for Gas Turbine Parameter Corrections," Proceedings of ASME Turbo Expo 2008: Power for Land, Sea and Air GT2008 Jun. 9-13, 2008, Berlin, Germany, GT2008-50716 (Year: 2008). cited by examiner

O'Brien, "RTO Technical Report 44 Performance Prediction and Simulation of Gas Turbine Engine Operation", Research and Technology Organisation, Apr. 1, 2022, pp. 1-357,

---

Primary Examiner: Olynick; David P.

Attorney, Agent or Firm: Getz Balich LLC

Background/Summary

TECHNICAL FIELD

(1) This disclosure relates generally to gas turbine engine operating margins, more particularly, to systems and methods for determining gas turbine engine operating margins.

BACKGROUND OF THE ART

(2) A gas turbine engine for an aircraft may be subject to various operational power checks to verify that the aircraft can satisfy minimum power requirements for a flight or operation. Various systems and methods are known in the art for verifying the operational power capability of a gas turbine engine. While these known systems and methods have various advantages, there is still room in the art for improvement.

SUMMARY

(3) It should be understood that any or all of the features or embodiments described herein can be used or combined in any combination with each and every other feature or embodiment described herein unless expressly noted otherwise.

(4) According to an aspect of the present disclosure, a system for determining an engine operating margin for an engine parameter of a gas turbine engine for an aircraft includes an engine control system. The engine control system includes a processor in communication with a non-transitory memory storing instructions, which instructions when executed by the processor, cause the processor to: obtain a current engine installation configuration for the gas turbine engine and the aircraft, determine an expected normalized value of the engine parameter based on the current engine installation configuration and one or more of a normalized engine power (SHPN) of the gas turbine engine, an engine inlet temperature, an airspeed, or an altitude, determine a fully deteriorated engine (FDE) value of the engine parameter using the expected normalized value of the engine parameter, determine a current value of the engine parameter for the gas turbine engine, and determine the engine operating margin for the engine parameter based on the FDE value of the engine parameter and the current value of the engine parameter.

(5) In any of the aspects or embodiments described above and herein, the instructions, when executed by the processor, may further cause the processor to determine if the engine operating margin decreases below a predetermined threshold margin value for gas turbine engine maintenance.

(6) In any of the aspects or embodiments described above and herein, the engine parameter may be an indicated turbine temperature (ITT).

(7) In any of the aspects or embodiments described above and herein, the engine parameter may be a compressor speed.

(8) In any of the aspects or embodiments described above and herein, the instructions, when executed by the processor, may further cause the processor to: calculate a current engine inlet pressure loss using an engine inlet pressure and an outside ambient pressure, compare the current engine inlet pressure loss to an expected nominal engine inlet pressure loss for the current engine

installation configuration to determine an inlet pressure loss correction factor, and apply the inlet pressure loss correction factor to the normalized engine power (SHPN).

(9) According to another aspect of the present disclosure, a method for determining an engine operating margin for an engine parameter of a gas turbine engine for an aircraft includes: identifying a current engine installation configuration for the gas turbine engine and the aircraft, determining an expected normalized value of the engine parameter based on the current engine installation configuration and one or more of a normalized engine power (SHPN) of the gas turbine engine, an engine inlet temperature, an airspeed, or an altitude, determining a fully deteriorated engine (FDE) value of the engine parameter using the expected normalized value of the engine parameter, determining a current value of the engine parameter for the gas turbine engine, and determining the engine operating margin for the engine parameter based on the FDE value of the engine parameter and the current value of the engine parameter.

(10) In any of the aspects or embodiments described above and herein, the engine parameter may be an indicated turbine temperature (ITT).

(11) In any of the aspects or embodiments described above and herein, the engine parameter may be a high-pressure compressor speed (NH).

(12) In any of the aspects or embodiments described above and herein, the method may further include identifying the engine operating margin has or has not decreased below a predetermined threshold margin value for gas turbine engine maintenance.

(13) In any of the aspects or embodiments described above and herein, the method may further include: determining a scaling factor based on SHPN, altitude, current ISA deviation, and the current engine installation configuration and applying the scaling factor to the expected normalized value of the engine parameter.

(14) In any of the aspects or embodiments described above and herein, the method may further include determining an accessory extraction load for the gas turbine engine, determining an accessory extraction load correction factor using the normalized engine power (SHPN), the altitude, and the accessory extraction load, adding the accessory extraction load correction factor to the expected normalized value of the engine parameter.

(15) In any of the aspects or embodiments described above and herein, the step of determining the current value of the engine parameter for the gas turbine engine may include measuring the engine parameter using one or more sensors of the gas turbine engine.

(16) In any of the aspects or embodiments described above and herein, the step of determining the current value of the engine parameter may include estimating the current value of the engine parameter using a computer-implemented model.

(17) In any of the aspects or embodiments described above and herein, the step of determining the FDE value of the engine parameter may include determining a deterioration correction factor for the FDE value. The deterioration correction factor may be based on one or more operational characteristics of a compressor of the gas turbine engine.

(18) According to another aspect of the present disclosure, a gas turbine engine includes an air inlet, a first rotational assembly, a second rotational assembly, an exhaust section, and an engine control system. The first rotational assembly includes a first shaft, a bladed first compressor rotor, and a bladed first turbine rotor. The first shaft interconnects the bladed first compressor rotor and the bladed first turbine rotor. The second rotational assembly includes a second shaft, a bladed second compressor rotor, and a bladed second turbine rotor. The second shaft interconnects the bladed second compressor rotor and the bladed second turbine rotor. The air inlet, the first rotational assembly, the second rotational assembly, and the exhaust section form a core flow path of the gas turbine engine. The engine control system includes a processor in communication with a non-transitory memory storing instructions, which instructions when executed by the processor, cause the processor to: obtain a current engine installation configuration for the gas turbine engine and the aircraft, determine a fully deteriorated engine (FDE) value of an engine parameter of the

gas turbine engine using the current engine installation configuration, determine a current value of the engine parameter for the gas turbine engine, and determine an engine operating margin for the engine parameter based on the FDE value of the engine parameter and the current value of the engine parameter.

(19) In any of the aspects or embodiments described above and herein, the instructions, when executed by the processor, may further cause the processor to determine an expected normalized value of the engine parameter based on the current engine installation configuration and one or more of a normalized engine power (SHPN) of the gas turbine engine, an engine inlet temperature, an airspeed, or an altitude.

(20) In any of the aspects or embodiments described above and herein, the engine control system may include a plurality of sensors.

(21) In any of the aspects or embodiments described above and herein, the plurality of sensors may include at least a speed sensor for the first rotational assembly and a torque sensor for the first rotational assembly.

(22) In any of the aspects or embodiments described above and herein, the current engine installation configuration may include an air inlet configuration.

(23) In any of the aspects or embodiments described above and herein, the current engine installation configuration may include an exhaust section configuration.

(24) The present disclosure, and all its aspects, embodiments and advantages associated therewith will become more readily apparent in view of the detailed description provided below, including the accompanying drawings.

Description

DESCRIPTION OF THE DRAWINGS

(1) FIG. **1** illustrates a perspective view of an exemplary aircraft including a gas turbine engine system, in accordance with one or more embodiments of the present disclosure.

(2) FIG. **2** illustrates a schematic view of a gas turbine engine system, in accordance with one or more embodiments of the present disclosure.

(3) FIG. **3** illustrates a flowchart depicting a method for determining an indicated turbine temperature (ITT) margin for a gas turbine engine, in accordance with one or more embodiments of the present disclosure.

(4) FIG. **4** illustrates a flowchart depicting a method for determining a high-pressure compressor speed (NH) margin for a gas turbine engine, in accordance with one or more embodiments of the present disclosure.

(5) FIG. **5** illustrates a flowchart depicting a method for using an engine operating margin to operate a gas turbine engine, in accordance with one or more embodiments of the present disclosure.

DETAILED DESCRIPTION

(6) FIG. **1** illustrates a perspective view of an exemplary aircraft **1000** including a gas turbine engine system **10**. The aircraft **1000** of FIG. **1** is configured as a rotorcraft (e.g., a helicopter), however, the present disclosure is also applicable to other aircraft configurations such as, but not limited to, fixed-wing aircraft.

(7) FIG. **2** schematically illustrates the gas turbine engine system **10**. The gas turbine engine system **10** of FIG. **2** includes a gas turbine engine **20** and an engine control system **22**. The gas turbine engine **20** of FIG. **2** is a multi-spool turboshaft gas turbine engine. However, while the following description and accompanying drawings may refer to the turboshaft gas turbine engine of FIG. **2** as an example, it should be understood that aspects of the present disclosure may be equally applicable to other types of gas turbine engines including, but not limited to, a turbofan gas turbine

engine, a turboprop gas turbine engine, a turbojet gas turbine engine, a propfan gas turbine engine, an open rotor gas turbine engine, an auxiliary power unit (APU), or the like. The gas turbine engine **20** of FIG. **2** includes an air inlet **24**, a compressor section **26**, a combustor section **28**, a turbine section **30**, and an exhaust section **32**. The compressor section **26** drives air from the air inlet **24** along a core flow path **34** for compression and communication into the combustor section **28**, expansion through the turbine section **30**, and exhaust from the gas turbine engine **20** via the exhaust section **32**.

(8) The gas turbine engine **20** of FIG. **2** includes a first rotational assembly **36** (e.g., a high-pressure spool) and a second rotational assembly **38** (e.g., a low-pressure spool), an engine static structure **40** (e.g., an engine case, a bearing compartment case, etc.), and an annular combustor **42**. It should be understood that "low pressure" and "high pressure" or variations thereof as used herein are relative terms indicating that the high pressure is greater than the low pressure. The first rotational assembly **36** and the second rotational assembly **38** are mounted for rotation about an axial centerline **44** (e.g., a rotational axis) of the gas turbine engine **20** relative to the engine static structure **40**.

(9) The first rotational assembly **36** includes a first shaft **46**, a bladed first compressor rotor **48** (e.g., of a high-pressure compressor of the compressor section **26**), and a bladed first turbine rotor **50** (e.g., of a high-pressure turbine of the turbine section **30**). The first shaft **46** interconnects the bladed first compressor rotor **48** and the bladed first turbine rotor **50**. The second rotational assembly **38** includes a second shaft **52**, a bladed second compressor rotor **54** (e.g., of a low-pressure compressor of the compressor section **26**), and a bladed second turbine rotor **56** (e.g., of a low-pressure turbine of the turbine section **30**). The second shaft **52** interconnects the bladed second compressor rotor **54** and the bladed second turbine rotor **56**. The second shaft **52** may additionally be connected to one or more rotational loads **58**, for example, directly or by one or more speed-reducing gear assemblies **60**. The combustor **42** of FIG. **2** is disposed between the bladed first compressor rotor **48** and the bladed first turbine rotor **50** along the core flow path **34**.

(10) In operation, airflow along the core flow path **34** is compressed by the bladed first compressor rotor **48** and the bladed second compressor rotor **54**, mixed and burned with fuel in the combustor **42**, and then expanded across the bladed first turbine rotor **50** and the bladed second turbine rotor **56**. The bladed first turbine rotor **50** and the bladed second turbine rotor **56** rotationally drive the first rotational assembly **36** and the second rotational assembly **38**, respectively, in response to the expansion of the combustion gases. The first shaft **46** and the second shaft **52** are concentric and rotate about the axial centerline **44**, which axial centerline **44** is collinear with respective rotational axes of the first shaft **46** and the second shaft **52**.

(11) The engine control system **22** of FIG. **2** includes a processor **62** and memory **64**. The memory **64** is in signal communication with the processor **62**. The processor **62** may include any type of computing device, computational circuit, or any type of process or processing circuit capable of executing a series of instructions that are stored in the memory **64**, thereby causing the processor **62** to perform or control one or more steps or other processes. The processor **62** may include multiple processors and/or multicore CPUs and may include any type of processor, such as a microprocessor, digital signal processor, co-processors, a micro-controller, a microcomputer, a central processing unit, a field programmable gate array, a programmable logic device, a state machine, logic circuitry, analog circuitry, digital circuitry, etc., and any combination thereof. The instructions stored in memory **64** may represent one or more algorithms for controlling the aspects of the gas turbine engine **20**, and the stored instructions are not limited to any particular form (e.g., program files, system data, buffers, drivers, utilities, system programs, etc.) provided they can be executed by the processor **62**. The memory **64** may be a non-transitory computer readable storage medium configured to store instructions that when executed by one or more processors, cause the one or more processors to perform or cause the performance of certain functions. The memory **64** may be a single memory device or a plurality of memory devices. A memory device may include a

storage area network, network attached storage, as well a disk drive, a read-only memory, random access memory, volatile memory, non-volatile memory, static memory, dynamic memory, flash memory, cache memory, and/or any device that stores digital information. One skilled in the art will appreciate, based on a review of this disclosure, that the implementation of the engine control system **22** may be achieved via the use of hardware, software, firmware, or any combination thereof. The engine control system **22** may also include input and output devices (e.g., keyboards, buttons, switches, touch screens, video monitors, sensor readouts, data ports, etc.) that enable the operator to input instructions, receive data, etc.

(12) The engine control system **22** may form or otherwise be part of an electronic engine controller (EEC) for the gas turbine engine **20**. The EEC may control operating parameters of the gas turbine engine **20** including, but not limited to, fuel flow, stator vane position, compressor air bleed valve position, etc. so as to control an engine power and/or thrust of the gas turbine engine **10**. In some embodiments, the EEC may be part of a full authority digital engine control (FADEC) system for the gas turbine engine **20**.

(13) The engine control system **22** receives data associated with operation of the gas turbine engine **20** and/or the aircraft **1000** (see FIG. **1**). The data may include operational parameters (e.g., pressure, temperature, rotation speed, torque, etc.) for the gas turbine engine **20**. The engine control system **22** may include and be in communication (e.g., signal communication) with one or more sensors **66** distributed throughout the gas turbine engine **20** and/or the aircraft **1000**. The sensors **66** may include, but are not limited to, one or more of the following: an engine inlet pressure (P1) sensor **66**A, an engine inlet temperature (T1) sensor **66**B, compressor pressure (P2.x) sensors **66**C at one or more compressor (e.g., a low-pressure compressor, a high-pressure compressor, etc.) stages, compressor temperature (T2.x) sensors **66**D at one or more compressor (e.g., a low-pressure compressor, a high-pressure compressor, etc.) stages, a compressor outlet pressure (P3) sensor **66**E, temperature (T4.x) sensors **66**F at one or more turbine (e.g., a low-pressure turbine, a high-pressure turbine, etc.) stages, a turbine exhaust temperature (T6) sensor **66**G, a rotation speed (NL/Np) sensor **66**H for the second shaft **52** (e.g., a low-pressure compressor speed sensor), a torque sensor **66**I for the second shaft **52**, a rotation speed (NH/Ng) sensor **66**J for the first shaft **46** (e.g., a high-pressure compressor speed sensor), an outside air temperature (OAT) sensor **66**K, and/or an outside ambient pressure (Pamb) sensor **66**L. The engine control system **22** may be configured to receive data from other sensors or equipment associated with the aircraft **1000** such as, but not limited to, altitude (e.g., measured or derived using outside ambient pressure (Pamb), RADAR, International Standard Atmosphere (ISA) pressure altitude, etc.), (e.g., calibrated airspeed (VCAS)), ISA temperature deviation (e.g., a difference between an actual temperature and the International Standard Atmosphere (ISA) temperature for a particular altitude), an accessory extraction load (e.g., a measure of bleed air, electricity, or other energy source supplied by a gas turbine engine to the aircraft **1000**), and/or an environmental control system (ECS) bleed extraction load (e.g., a measure of bleed air supplied by a gas turbine engine to an ECS of the aircraft **1000**). Additionally or alternatively, data associated with operation of the gas turbine engine **20** and/or the aircraft **1000** may be obtained from one or more data tables (e.g., data tables stored in the memory **64**), which data tables may include expected operational parameters associated with various operational conditions for the gas turbine engine **20** and/or the aircraft **1000**. Additionally or alternatively, data associated with operation of the gas turbine engine **20** and/or the aircraft **1000** may be derived or modeled by the engine control system **22**. For example, the engine control system **22** may include instructions which, when executed, allow the engine control system **22** to execute a model (e.g., a computer-implemented model) of one or more operational parameters of the gas turbine engine **20** and/or the aircraft **1000** in a virtual (e.g., digital) environment which closely represents the physical system (e.g., a component, assembly, system, etc. of a gas turbine engine) by accounting for factors such as, but not limited to, kinematics, static and dynamic behaviors, component surface characteristics, component geometry, shaft torque, engine power, pressure, temperature, altitude,

vibration, and the like. The engine control system **22** may include instructions which, when executed, cause one or more machine learning algorithms to estimate one or more operational parameters of the gas turbine engine **20** and/or the aircraft **1000**.

(14) Gas turbine engines may undergo periodical engine power assurance checks (EPAC) to verify that the gas turbine engine and/or the aircraft **1000** (see FIG. **1**) can satisfy the minimum power requirements for a planned flight or operation. The EPAC may be used to estimate one or more engine operating margins for one or more engine parameters the gas turbine engine. The available engine operating margins may provide an indication of the engine operational time and/or capability which is available before the gas turbine engine should undergo maintenance (e.g., a periodic overhaul). Conservative estimates of the engine operating margins may cause a gas turbine engine to be removed from service prematurely for maintenance, thereby preventing the gas turbine engine from achieving its expected engine Time Between Overhaul (TBO).

(15) Referring to FIGS. **2** and **3**, a Method **100** for determining an indicated turbine temperature (ITT) margin for a gas turbine engine (e.g., the gas turbine engine **20**) is provided. FIG. **3** illustrates a flowchart for the Method **100**. The Method **100** may be performed using the gas turbine engine **20** and engine control system **22**. For example, the processor **62** may execute instructions stored in memory **64**, thereby causing the engine control system **22** and/or its processor **62** to execute or otherwise control one or more steps of the Method **100**. However, while the Method **100** may be described herein with respect to the gas turbine engine **20** and/or the engine control system **22**, the present disclosure Method **100** is not limited to use with the gas turbine engine **20** and/or engine control system **22**. Unless otherwise noted herein, it should be understood that the steps of Method **100** are not required to be performed in the specific sequence in which they are discussed below and, in some embodiments, the steps of Method **100** may be performed separately or simultaneously. In addition, unless otherwise noted herein, it should be understood that various steps (e.g., correction factor steps) of the Method **100** may be optional and, thus, may not be essential for determining an ITT margin for a gas turbine engine.

(16) In Step **101**, a current engine power (SHP) for the gas turbine engine **20** may be obtained or otherwise determined. The current engine power (SHP) may be calculated, for example, using the rotation speed (NL/Np) of the second shaft **52** and the torque (e.g., measured torque) for the second shaft **52**.

(17) In Step **102**, the current engine power (SHP) may be normalized to the engine inlet pressure (P1, δ.sub.P1, where δ is a given pressure (e.g., P1) divided by a reference pressure (e.g., sea-level ISA static pressure)) and the engine inlet temperature (T1, Θ.sub.T1 where Θ is a given temperature (e.g., T1) divided by a reference temperature (e.g., sea-level static ISA temperature)) to obtain the current normalized engine power (SHPN). The current engine power (SHP) may alternatively be normalized using other operational parameters (e.g., other pressure and temperature parameters) of the gas turbine engine **20** such as, but not limited to, the outside ambient pressure (Pamb) and the outside air temperature (OAT).

(18) In Step **103**, a current engine installation configuration for the gas turbine engine **20** may be selected or otherwise determined. For example, a user may input current engine installation configuration characteristics of the gas turbine engine **20** to the engine control system **22**. Additionally or alternatively, current engine installation configuration characteristics of the gas turbine engine **20** may be stored in the memory **64**. The current engine installation configuration may include structural configurations or accessories of the gas turbine engine **20** and/or the aircraft **1000** (see FIG. **1**) which may be expected to affect an inlet pressure loss for the gas turbine engine **20** and, hence, may affect the ITT margin for the gas turbine engine **20**. Characteristics of the current engine installation configuration may include, but are not limited to, configurations of the air inlet **24** and/or the exhaust section **32** of the gas turbine engine **20** and/or the aircraft **1000**. Examples of the air inlet **24** and/or the exhaust section **32** configurations may include, but are not limited to, air inlet filters, air inlet inertial particle separators, air inlet foreign object debris (FOD)

screens, air inlet anti-icing and/or de-icing systems, exhaust emissions treatments systems, exhaust infra-red suppression systems, and the like. The engine installation configuration may include an installation configuration of the gas turbine engine **20** on the aircraft **1000**. The engine installation configuration may include features (e.g., structural features, accessories, etc.) of the aircraft **1000** on which or within which the gas turbine engine **20** may be installed.

(19) In Step **104**, a correction factor (DPCORR) for a current engine inlet pressure loss of the gas turbine engine **20** may be selected or otherwise determined. Determining the correction factor (DPCORR) may include calculating the current engine inlet pressure loss using the engine inlet pressure (P1) and the outside ambient pressure (Pamb). The current engine inlet pressure loss may be compared to an expected nominal engine inlet pressure loss value for the selected current engine installation configuration to determine the correction factor (DPCORR). The expected nominal engine inlet pressure loss value may be a function of altitude and airspeed (e.g., VCAS) for the selected current engine installation configuration.

(20) In Step **105**, a correction factor for the current normalized engine power (SHPN) may be selected or otherwise determined. The correction factor may be applied to the current normalized engine power to correct for variable inlet loss effects of the gas turbine engine **20**. The correction factor for the current normalized engine power (SHPN) may be determined, for example, using one or more data tables including the correction factor (DPCORR) vs. the current engine power (SHP) as a function of the selected current engine installation configuration.

(21) In Step **106**, an expected normalized ITT value (ITTN) may be selected or otherwise determined using the corrected current normalized engine power (SHPN), airspeed (e.g., VCAS), altitude, and the selected current engine installation configuration. Selecting or otherwise determining the expected normalized ITT value (ITTN) may include using one or more data tables including the expected normalized ITT value (ITTN) vs. the corrected normalized engine power (SHPN) as a function of the selected current engine installation configuration.

(22) In Step **107**, a scaling factor (KITTN) may be selected or otherwise determined using the corrected current normalized engine power (SHPN), altitude, current ISA Deviation, and the selected current engine installation configuration. The scaling factor (KITTN) may then be applied to the expected normalized ITT value (ITTN) obtained in Step **106**. The expected normalized ITT value (ITTN) of Step **106** may be selected or otherwise determined, for example, using International Standard Atmosphere (ISA) temperature values which may be different than the actual outside air temperature (OAT). The scaling factor (KITTN) may be used to compensate for differences between the ISA temperature and the actual outside air temperature (OAT).

(23) In Step **108**, an accessory extraction load (AGB ex_curr) may be obtained or otherwise determined for the gas turbine engine **20** and the aircraft **1000** (see FIG. **1**). The accessory extraction load (AGB ex_curr) may be represented as a value of power (e.g., horsepower (HP)). Obtaining the accessory extraction load (AGB ex_curr) may include measuring a current (e.g., a real time) value of the accessory extraction load (AGB ex_curr) for the aircraft **1000**. Alternatively, a value of the accessory extraction load (AGB ex_curr) may be estimated. The estimated accessory extraction load (AGB ex_curr) may be a fixed value. Alternatively, the accessory extraction load (AGB ex_curr) may be a function of one or more operational parameters of the gas turbine engine **20** and/or the aircraft **1000** such as, but not limited to, outside air temperature (OAT), altitude, normalized engine power (SHPN), etc. Alternatively, a zero (0) value may be assumed for the accessory extraction load (AGB ex_curr) to yield a more conservative value for the determined indicated turbine temperature (ITT) margin of the present disclosure Method **100**.

(24) In Step **109**, an expected normalized ITT value (ITTN) correction factor (e.g., a scalar factor) may be obtained or otherwise determined. The expected normalized ITT value (ITTN) correction factor may be a function of the current normalized engine power (SHPN) and altitude, multiplied by the accessory extraction load (AGB ex_curr). The expected normalized ITT value (ITTN) correction factor may be determined using one or more data tables and/or on-board engine models

(e.g., executed by the engine control system **22**) with various values of the accessory extraction load (AGB ex_curr) to estimate a sensitivity of the particular gas turbine engine **20** to accessory loads.

(25) In Step **110**, the expected normalized ITT value (ITTN) may be added to the expected normalized ITT value (ITTN) correction factor obtained in Steps **108** and/or **109**.

(26) In Step **111**, the environmental control system (ECS) bleed extraction load (ECS_bld) may be obtained or otherwise determined. Obtaining the environmental control system (ECS) bleed extraction load (ECS_bld) may include measuring a current (e.g., a real time) value of the environmental control system (ECS) bleed extraction load (ECS_bld) for the aircraft **1000**. Alternatively, a value of the environmental control system (ECS) bleed extraction load (ECS_bld) may be estimated. The estimated environmental control system (ECS) bleed extraction load (ECS_bld) may be a fixed value. Alternatively, the environmental control system (ECS) bleed extraction load (ECS_bld) may be a function of one or more operational parameters of the gas turbine engine **20** and/or the aircraft **1000** such as, but not limited to, outside air temperature (OAT), altitude, normalized engine power (SHPN), etc. Alternatively, a zero (0) value may be assumed for the environmental control system (ECS) bleed extraction load (ECS_bld) to yield a more conservative value for the determined indicated turbine temperature (ITT) margin of the present disclosure Method **100**.

(27) In Step **112**, an expected normalized ITT value (ITTN) correction factor (e.g., a scalar factor) may be obtained or otherwise determined. The expected normalized ITT value (ITTN) correction factor of Step **112** may be a function of the current normalized engine power (SHPN), altitude, and the outside air temperature (OAT) for the selected current engine installation configuration, which expected normalized ITT value (ITTN) correction factor may then be multiplied by the environmental control system (ECS) bleed extraction load (ECS_bld) obtained in Step **111**. The expected normalized ITT value (ITTN) correction factor may be determined using one or more data tables and/or on-board engine models (e.g., executed by the engine control system **22**) with various values of the bleed extraction load (ECS_bld) to estimate a sensitivity of the particular gas turbine engine **20** to bleed extraction loads.

(28) In Step **113**, the expected normalized ITT value (ITTN) correction factor obtained in Step **112** may be added to the expected normalized ITT value (ITTN) value.

(29) In Step **114**, a correction factor may be applied to the expected normalized ITT value (ITTN) to account for engine-to-engine and/or aircraft-to-aircraft variability in the expected normalized ITT value (ITTN) between different iterations of a new (e.g., as received) gas turbine engines and/or aircraft.

(30) In Step **115**, the expected normalized ITT value (ITTN) may be de-normalized using the Θ_{T1} value to obtain or otherwise determine an absolute ITT value expressed, for example, in absolute units such as, but not limited to Rankine (° R) or Kelvin (° K). The Θ_{T1} value may be modified by a factor (EXPITT) (e.g., $\Theta_{T1}\{$circumflex over ( )$\}$EXPITT) to account for empirical factors.

(31) In Step **116**, a correction factor (ITTCORR) may be applied to the ITT value obtained in Step **115** to account for inaccuracy in accessory extraction load (AGB ex_curr), environmental control system (ECS) bleed extraction load (ECS_bld), or other operational variable affects which may impact the ITT value.

(32) In Step **117**, the ITT value expressed in absolute units may be converted to relative units such as, but not limited to Fahrenheit (° F.) or Celsius (° C.) in preparation for calculating the ITT margin for the gas turbine engine **20**.

(33) In Step **118**, a correction factor (ITTCORRISA) may be applied to the ITT value to account for ambient temperature effects. The correction factor (ITTCORRISA) may provide additional temperature correction for the ITT value, for example, in addition to the expected normalized ITT value (ITTN) correction factor of Step **109**.

(34) In Step **119**, an engine ITT field margin may be added to the de-normalized ITT value to obtain or otherwise determine the Fully Deteriorated Engine (FDE) ITT value. The engine ITT field margin may represent an allowable increase in the de-normalized ITT value before the gas turbine engine **20** may need to undergo maintenance (e.g., a periodic overhaul).

(35) In Step **120**, an ITT deterioration correction factor may be applied to the FDE ITT value. The ITT deterioration correction factor may be a function of the ITT value (e.g., the ITT value obtained in Step **117**) and one or more operational characteristics of a compressor (e.g., a high-pressure compressor and/or a low-pressure compressor) of the gas turbine engine **20** such as, but not limited to fluid flow rate, rotor speed, pressure ratio, temperatures, and the like. The ITT deterioration correction factor may be added to the FDE ITT value to account for non-linear effects of engine deterioration on the FDE ITT value.

(36) In step **121**, the expected FDE ITT value may be obtained or otherwise determined based, for example, on the FDE ITT value obtained in Step **119** and optionally the ITT deterioration correction factor applied in Step **120**.

(37) In Step **122**, a current ITT value for the gas turbine engine **20** is obtained or otherwise determined. The current ITT value may be a temperature value of the core gas in the core flow path **34** downstream of the bladed first turbine rotor **50** (e.g., the high-pressure turbine outlet temperature) and, for example, the temperature value of the core gas in the core flow path **34** between the bladed first turbine rotor **50** and the bladed second turbine rotor **56**. The current ITT value may be obtained from direct measurements (e.g., using the temperature sensors **66**F), by estimating one or more operational parameters of the gas turbine engine **20** based on predetermined correlations with other known operational parameters, and/or by using on-board engine models (e.g., executed by the engine control system **22**) to estimate one or more operational parameters of the gas turbine engine **20**.

(38) In Step **123**, an available ITT margin is obtained or otherwise determined by subtracting the expected FDE ITT (e.g., obtained from Step **121**) from the current ITT value (e.g., obtained from Step **122**).

(39) Referring to FIGS. **2**, and **4**, a Method **200** for determining a compressor (e.g., high-pressure compressor) speed (NH) margin for a gas turbine engine (e.g., the gas turbine engine **20**) is provided. FIG. **4** illustrates a flowchart for the Method **200**. The Method **200** may be performed using the gas turbine engine **20** and engine control system **22**. For example, the processor **62** may execute instructions stored in memory **64**, thereby causing the engine control system **22** and/or its processor **62** to execute or otherwise control one or more steps of the Method **200**. However, while the Method **200** may be described herein with respect to the gas turbine engine **20** and/or the engine control system **22**, the present disclosure Method **200** is not limited to use with the gas turbine engine **20** and/or engine control system **22**. Unless otherwise noted herein, it should be understood that the steps of Method **200** are not required to be performed in the specific sequence in which they are discussed below and, in some embodiments, the steps of Method **200** may be performed separately or simultaneously. In addition, unless otherwise noted herein, it should be understood that various steps (e.g., correction factor steps) of the Method **200** may be optional and, thus, may not be essential for determining a compressor speed (NH) margin for a gas turbine engine.

(40) In Step **201**, a current engine power (SHP) for the gas turbine engine **20** may be obtained or otherwise determined. The current engine power (SHP) may be calculated, for example, using the rotation speed (NL/Np) of the second shaft **52** and the torque (e.g., measured torque) for the second shaft **52**.

(41) In Step **202**, the current engine power (SHP) may be normalized to the engine inlet pressure (P1, δ.sub.P1, where δ is a given pressure (e.g., P1) divided by a reference pressure (e.g., sea-level ISA static pressure)) and the engine inlet temperature (T1, Θ.sub.T1 where Θ is a given temperature (e.g., T1) divided by a reference temperature (e.g., sea-level static ISA temperature)) to

obtain the current normalized engine power (SHPN). The current engine power (SHP) may alternatively be normalized using other operational parameters (e.g., other pressure and temperature parameters) of the gas turbine engine **20** such as, but not limited to, the outside ambient pressure (Pamb) and the outside air temperature (OAT).

(42) In Step **203**, a current engine installation configuration for the gas turbine engine **20** may be selected or otherwise determined. For example, a user may input current engine installation configuration characteristics of the gas turbine engine **20** to the engine control system **22**. Additionally or alternatively, current engine installation configuration characteristics of the gas turbine engine **20** may be stored in the memory **64**. The current engine installation configuration may include structural configurations or accessories of the gas turbine engine **20** which may be expected to affect an inlet pressure loss for the gas turbine engine **20** and, hence, may affect the high-pressure compressor speed (NH) margin for the gas turbine engine **20**. Characteristics of the current engine installation configuration may include, but are not limited to, configurations of the air inlet **24** and/or the exhaust section **32** of the gas turbine engine **20**. Examples of the air inlet **24** and/or the exhaust section **32** configurations may include, but are not limited to, air inlet filters, air inlet inertial particle separators, air inlet foreign object debris (FOD) screens, air inlet anti-icing and/or de-icing systems, exhaust emissions treatments systems, exhaust infra-red suppression systems, and the like. The engine installation configuration may include an installation configuration of the gas turbine engine **20** on the aircraft **1000** (see FIG. **1**). The engine installation configuration may include features (e.g., structural features, accessories, etc.) of the aircraft **1000** on which or within which the gas turbine engine **20** may be installed.

(43) In Step **204**, a correction factor (DPCORR) for a current engine inlet pressure loss of the gas turbine engine **20** may be selected or otherwise determined. Determining the correction factor (DPCORR) may include calculating the current engine inlet pressure loss using the engine inlet pressure (P1) and the outside ambient pressure (Pamb). The current engine inlet pressure loss may be compared to an expected nominal engine inlet pressure loss value for the selected current engine installation configuration to determine the correction factor (DPCORR). The expected nominal engine inlet pressure loss value may be a function of altitude and airspeed (e.g., VCAS) for the selected current engine installation configuration.

(44) In Step **205**, a correction factor for the current normalized engine power (SHPN) may be selected or otherwise determined. The correction factor may be applied to the current normalized engine power to correct for variable inlet loss effects of the gas turbine engine **20**. The correction factor for the current normalized engine power (SHPN) may be determined, for example, using one or more data tables including the correction factor (DPCORR) vs. the current engine power (SHP) as a function of the selected current engine installation configuration.

(45) In Step **206**, an expected normalized high-pressure compressor speed (NHC1) may be selected or otherwise determined using the corrected current normalized engine power (SHPN), airspeed (e.g., VCAS), altitude, and the selected current engine installation configuration. Selecting or otherwise determining the expected normalized high-pressure compressor speed (NHC1) may include using one or more data tables including the expected normalized high-pressure compressor speed (NHC1) vs. the corrected normalized engine power (SHPN) as a function of the selected current engine installation configuration.

(46) In Step **207**, a scaling factor (KNHC1) may be selected or otherwise determined using the corrected current normalized engine power (SHPN), altitude, current ISA Deviation, and the selected current engine installation configuration. The scaling factor (KNHC1) may then be applied to the expected normalized high-pressure compressor speed (NHC1) obtained in Step **206**. The expected normalized high-pressure compressor speed (NHC1) may be selected or otherwise determined, for example, using International Standard Atmosphere (ISA) temperature values which may be different than the actual outside air temperature (OAT). The scaling factor (KNHC1) may be used to compensate for differences between the ISA temperature and the actual outside air

temperature (OAT).

(47) In Step **208**, an accessory extraction load (AGB ex_curr) may be obtained or otherwise determined for the gas turbine engine **20** and the aircraft **1000** (see FIG. **1**). The accessory extraction load (AGB ex_curr) may be represented as a value of power (e.g., horsepower (HP)). Obtaining the accessory extraction load (AGB ex_curr) may include measuring a current (e.g., a real time) value of the accessory extraction load (AGB ex_curr) for the aircraft **1000**. Alternatively, a value of the accessory extraction load (AGB ex_curr) may be estimated. The estimated accessory extraction load (AGB ex_curr) may be a fixed value. Alternatively, the accessory extraction load (AGB ex_curr) may be a function of one or more operational parameters of the gas turbine engine **20** and/or the aircraft **1000** such as, but not limited to, outside air temperature (OAT), altitude, normalized engine power (SHPN), etc. Alternatively, a zero (0) value may be assumed for the accessory extraction load (AGB ex_curr) to yield a more conservative value for the determined indicated turbine temperature (ITT) margin of the present disclosure Method **200**.

(48) In Step **209**, an expected normalized high-pressure compressor speed value (NHC1) correction factor (e.g., a scalar factor) may be obtained or otherwise determined. The expected normalized high-pressure compressor speed value (NHC1) correction factor may be a function of the current normalized engine power (SHPN) and altitude, multiplied by the accessory extraction load (AGB ex_curr). The expected normalized high-pressure compressor speed value (NHC1) correction factor may be determined using one or more data tables and/or on-board engine models (e.g., executed by the engine control system **22**) with various values of the accessory extraction load (AGB ex_curr) to estimate a sensitivity of the particular gas turbine engine **20** to accessory loads.

(49) In Step **210**, the expected normalized high-pressure compressor speed (NHC1) may be added to the expected normalized high-pressure compressor speed value (NHC1) correction factor obtained in Steps **208** and/or **209**.

(50) At step **211**, the environmental control system (ECS) bleed extraction load (ECS_bld) may be obtained or otherwise determined. Obtaining the environmental control system (ECS) bleed extraction load (ECS_bld) may include measuring a current (e.g., a real time) value of the environmental control system (ECS) bleed extraction load (ECS_bld) for the aircraft **1000** (see FIG. **1**). Alternatively, a value of the environmental control system (ECS) bleed extraction load (ECS_bld) may be estimated. The estimated environmental control system (ECS) bleed extraction load (ECS_bld) may be a fixed value. Alternatively, the environmental control system (ECS) bleed extraction load (ECS_bld) may be a function of one or more operational parameters of the gas turbine engine **20** and/or the aircraft **1000** such as, but not limited to, outside air temperature (OAT), altitude, normalized engine power (SHPN), etc. Alternatively, a zero (0) value may be assumed for the environmental control system (ECS) bleed extraction load (ECS_bld) to yield a more conservative value for the determined indicated turbine temperature (ITT) margin of the present disclosure Method **200**.

(51) In Step **212**, an expected normalized high-pressure compressor speed (NHC1) correction factor (e.g., a scalar factor) may be obtained or otherwise determined. The expected normalized high-pressure compressor speed (NHC1) correction factor of Step **212** may be a function of the current normalized engine power (SHPN), altitude, and the outside air temperature (OAT) for the selected current engine installation configuration, which expected normalized high-pressure compressor speed (NHC1) correction factor may then be multiplied by the environmental control system (ECS) bleed extraction load (ECS_bld) obtained in Step **211**. The expected normalized high-pressure compressor speed (NHC1) correction factor may be determined using one or more data tables and/or on-board engine models (e.g., executed by the engine control system **22**) with various values of the bleed extraction load (ECS_bld) to estimate a sensitivity of the particular gas turbine engine **20** to bleed extraction loads.

(52) In Step **213**, the expected normalized high-pressure compressor speed (NHC1) correction factor obtained in Step **212** may be added to the expected normalized high-pressure compressor

speed (NHC1).

(53) In Step **214**, the expected normalized high-pressure compressor speed (NHC1) may be de-normalized using the Θ.sub.T1 value to obtain or otherwise determine an absolute high-pressure compressor speed (NH) value expressed, for example, as a revolution-per-minute (RPM) value or as a percentage of a reference speed (e.g., a maximum rated speed for the high-pressure compressor). The Θ.sub.T1 value may be modified by a factor (EXPNH) (e.g., Θ.sub.T1{circumflex over (　)}EXPNH) to account for empirical factors.

(54) In Step **215**, an engine NH field margin may be added to the expected de-normalized high-pressure compressor speed (NH) value to obtain or otherwise determine the Fully Deteriorated Engine (FDE) high-pressure compressor speed (NH) value. The engine NH field margin may represent an allowable increase in the expected de-normalized high-pressure compressor speed (NH) value before the gas turbine engine **20** may need to undergo maintenance (e.g., a periodic overhaul).

(55) In Step **216**, an NH deterioration correction factor may be applied to the FDE high-pressure compressor speed (NH) value. The NH deterioration correction factor may be a function of a current indicated turbine temperature (ITT) value for the gas turbine engine **20** (see Step **122**) and compressor key characteristics and measurements such as, but not limited to fluid flow rate, rotor speed, pressure ratio, temperatures, and the like. The NH deterioration correction factor may be added to the FDE high-pressure compressor speed (NH) value to account for non-linear effects of engine deterioration on the FDE high-pressure compressor speed (NH) value.

(56) In Step **217**, an expected FDE high-pressure compressor speed (NH) value may be obtained or otherwise determined based, for example, on the FDE high-pressure compressor speed (NH) value obtained in Step **215** and optionally the NH deterioration correction factor applied in Step **216**.

(57) At Step **218**, a current high-pressure compressor speed (NH) value for the gas turbine engine **20** is obtained or otherwise determined. The current high-pressure compressor speed (NH) value may be obtained from direct measurements (e.g., using the sensors **66**), by estimating one or more operational parameters of the gas turbine engine **20** based on predetermined correlations with other known operational parameters, and/or by using on-board engine models (e.g., executed by the engine control system **22**) to estimate one or more operational parameters of the gas turbine engine **20**.

(58) At step **219**, an available high-pressure compressor speed (NH) margin is obtained or otherwise determined by subtracting the expected FDE high-pressure compressor speed (NH) value (e.g., obtained from Step **217**) from the current high-pressure compressor speed (NH) value (e.g., obtained from Step **218**).

(59) Referring to FIG. **5**, a Method **300** for using an engine operating margin (e.g., an available ITT margin or an available high-pressure compressor speed (NH) margin) to operate (e.g., control, manage, and/or maintain) a gas turbine engine (e.g., the gas turbine engine **20**) is provided. FIG. **5** illustrates a flowchart for the Method **300**. The Method **300** may be performed using the gas turbine engine **20** and engine control system **22**. For example, the processor **62** may execute instructions stored in memory **64**, thereby causing the engine control system **22** and/or its processor **62** to execute or otherwise control one or more steps of the Method **300**. However, while the Method **300** may be described herein with respect to the gas turbine engine **20** and/or the engine control system **22**, the present disclosure Method **300** is not limited to use with the gas turbine engine **20** and/or engine control system **22**. Unless otherwise noted herein, it should be understood that the steps of Method **300** are not required to be performed in the specific sequence in which they are discussed below and, in some embodiments, the steps of Method **300** may be performed separately or simultaneously.

(60) In Step **301**, the engine control system **22** may obtain or otherwise determine one or more engine operating margins (e.g., an available ITT margin or an available high-pressure compressor speed (NH) margin) for one or more engine parameters (e.g., ITT or high-pressure compressor

speed (NH)) the gas turbine engine **20** (see FIGS. **1** and **2**), for example, using the Method **100** and/or the Method **200**. In Step **302**, the engine control system **22** may cause the one or more engine operating margins to be displayed. For example, the engine operating margins may be displayed (e.g., on a computer screen, digital display, etc.) for a pilot and/or crew of an aircraft (e.g., the aircraft **1000**, see FIG. **1**) associated with the gas turbine engine **20**. For example, the engine operating margins may provide the pilot and/or crew with a live or substantially live indication of the available power for the gas turbine engine **20**. In Step **303**, at least one of the engine operating margins may be compared to a predetermined threshold operating margin value. If the engine operating margin decreases below the predetermined threshold operating margin value, the engine control system **22** may flag (e.g., identify) the gas turbine engine **20** for scheduling and/or performance of maintenance. The engine control system **22** may provide a maintenance notification to a pilot, crew, and/or maintenance personnel for an associated aircraft for the gas turbine engine **20**.

(61) It is noted that various connections are set forth between elements in the preceding description and in the drawings. It is noted that these connections are general and, unless specified otherwise, may be direct or indirect and that this specification is not intended to be limiting in this respect. A coupling between two or more entities may refer to a direct connection or an indirect connection. An indirect connection may incorporate one or more intervening entities. It is further noted that various method or process steps for embodiments of the present disclosure are described in the following description and drawings. The description may present the method and/or process steps as a particular sequence. However, to the extent that the method or process does not rely on the particular order of steps set forth herein, the method or process should not be limited to the particular sequence of steps described. As one of ordinary skill in the art would appreciate, other sequences of steps may be possible. Therefore, the particular order of the steps set forth in the description should not be construed as a limitation.

(62) Furthermore, no element, component, or method step in the present disclosure is intended to be dedicated to the public regardless of whether the element, component, or method step is explicitly recited in the claims. No claim element herein is to be construed under the provisions of 35 U.S.C. 112(f) unless the element is expressly recited using the phrase "means for." As used herein, the terms "comprises", "comprising", or any other variation thereof, are intended to cover a non-exclusive inclusion, such that a process, method, article, or apparatus that comprises a list of elements does not include only those elements but may include other elements not expressly listed or inherent to such process, method, article, or apparatus.

(63) While various aspects of the present disclosure have been disclosed, it will be apparent to those of ordinary skill in the art that many more embodiments and implementations are possible within the scope of the present disclosure. For example, the present disclosure as described herein includes several aspects and embodiments that include particular features. Although these particular features may be described individually, it is within the scope of the present disclosure that some or all of these features may be combined with any one of the aspects and remain within the scope of the present disclosure. References to "various embodiments," "one embodiment," "an embodiment," "an example embodiment," etc., indicate that the embodiment described may include a particular feature, structure, or characteristic, but every embodiment may not necessarily include the particular feature, structure, or characteristic. Moreover, such phrases are not necessarily referring to the same embodiment. Further, when a particular feature, structure, or characteristic is described in connection with an embodiment, it is submitted that it is within the knowledge of one skilled in the art to effect such feature, structure, or characteristic in connection with other embodiments whether or not explicitly described. Accordingly, the present disclosure is not to be restricted except in light of the attached claims and their equivalents.

Claims

1. A system for determining an engine operating margin for an engine parameter of a gas turbine engine for an aircraft, the system comprising: an engine control system including a processor in communication with a non-transitory memory storing instructions, which instructions when executed by the processor, cause the processor to: obtain a current engine installation configuration for the gas turbine engine and the aircraft; determine an expected normalized value of the engine parameter based on the current engine installation configuration and one or more of a normalized engine power (SHPN) of the gas turbine engine, an engine inlet temperature, an airspeed, or an altitude; determine a fully deteriorated engine (FDE) value of the engine parameter using the expected normalized value of the engine parameter; determine a current value of the engine parameter for the gas turbine engine; and determine the engine operating margin for the engine parameter based on the FDE value of the engine parameter and the current value of the engine parameter; determine a scaling factor based on SHPN, altitude, current ISA deviation, and the current engine installation configuration; and apply the scaling factor to the expected normalized value of the engine parameter.

2. The system of claim 1, wherein the instructions, when executed by the processor, further cause the processor to determine if the engine operating margin decreases below a predetermined threshold margin value for gas turbine engine maintenance.

3. The system of claim 1, wherein the engine parameter is an indicated turbine temperature (ITT).

4. The system of claim 1, wherein the engine parameter is a compressor speed.

5. The system of claim 1, wherein the instructions, when executed by the processor, further cause the processor to: calculate a current engine inlet pressure loss using an engine inlet pressure and an outside ambient pressure; compare the current engine inlet pressure loss to an expected nominal engine inlet pressure loss for the current engine installation configuration to determine an inlet pressure loss correction factor; and apply the inlet pressure loss correction factor to the normalized engine power (SHPN).

6. A method for determining an engine operating margin for an engine parameter of a gas turbine engine for an aircraft, the method comprising: identifying a current engine installation configuration for the gas turbine engine and the aircraft; determining an expected normalized value of the engine parameter based on the current engine installation configuration and one or more of a normalized engine power (SHPN) of the gas turbine engine, an engine inlet temperature, an airspeed, or an altitude; determining a fully deteriorated engine (FDE) value of the engine parameter using the expected normalized value of the engine parameter; determining a current value of the engine parameter for the gas turbine engine; and determining the engine operating margin for the engine parameter based on the FDE value of the engine parameter and the current value of the engine parameter; determining a scaling factor based on SHPN, altitude, current ISA deviation, and the current engine installation configuration; and applying the scaling factor to the expected normalized value of the engine parameter.

7. The method of claim 6, wherein the engine parameter is an indicated turbine temperature (ITT).

8. The method of claim 6, wherein the engine parameter is a high-pressure compressor speed (NH).

9. The method of claim 6, further comprising identifying the engine operating margin decreasing below a predetermined threshold margin value for gas turbine engine maintenance.

10. The method of claim 6, further comprising: determining an accessory extraction load for the gas turbine engine; determining an accessory extraction load correction factor using the normalized engine power (SHPN), the altitude, and the accessory extraction load; and adding the accessory extraction load correction factor to the expected normalized value of the engine parameter.

11. The method of claim 6, wherein the step of determining the current value of the engine parameter for the gas turbine engine includes measuring the engine parameter using one or more

sensors of the gas turbine engine.

12. The method of claim 6, wherein the step of determining the current value of the engine parameter includes estimating the current value of the engine parameter using a computer-implemented model.

13. The method of claim 6, wherein the step of determining the FDE value of the engine parameter includes determining a deterioration correction factor for the FDE value, the deterioration correction factor based on one or more operational characteristics of a compressor of the gas turbine engine.

14. A gas turbine engine for an aircraft, the gas turbine engine comprising: an air inlet; a first rotational assembly including a first shaft, a bladed first compressor rotor, and a bladed first turbine rotor, the first shaft interconnecting the bladed first compressor rotor and the bladed first turbine rotor; a second rotational assembly include a second shaft, a bladed second compressor rotor, and a bladed second turbine rotor, the second shaft interconnecting the bladed second compressor rotor and the bladed second turbine rotor; an exhaust section, wherein air inlet, the first rotational assembly, the second rotational assembly, and the exhaust section form a core flow path of the gas turbine engine; and an engine control system including a processor in communication with a non-transitory memory storing instructions, which instructions when executed by the processor, cause the processor to: obtain a current engine installation configuration for the gas turbine engine and the aircraft; determine an expected normalized value of the engine parameter based on the current engine installation configuration and one or more of a normalized engine power (SHPN) of the gas turbine engine, an engine inlet temperature, an airspeed, or an altitude; determine a fully deteriorated engine (FDE) value of an engine parameter of the gas turbine engine using the current engine installation configuration; determine a current value of the engine parameter for the gas turbine engine; and determine an engine operating margin for the engine parameter based on the FDE value of the engine parameter and the current value of the engine parameter; determine a scaling factor based on one or more of SHPN, altitude, current ISA deviation, and the current engine installation configuration; and apply the scaling factor to the expected normalized value of the engine parameter.

15. The gas turbine engine of claim 14, wherein the step of determining the FDE value further includes determining the FDE value using the current engine configuration and the expected normalized value of the engine parameter.

16. The gas turbine engine of claim 14, wherein the engine control system includes a plurality of sensors.

17. The gas turbine engine of claim 16, wherein the plurality of sensors includes at least a speed sensor for the first rotational assembly and a torque sensor for the first rotational assembly.

18. The gas turbine engine of claim 14, wherein the current engine installation configuration includes an air inlet configuration.

19. The gas turbine engine of claim 14, wherein the current engine installation configuration includes an exhaust section configuration.