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Inventor(s) Natarajan; Avinash et al.

METHODS AND APPARATUS TO IMPROVE FAN OPERABILITY CONTROL USING SMART MATERIALS

Abstract

Systems, apparatus, articles of manufacture, and methods are disclosed to improve fan operability control using smart materials. An engine comprising an engine surface in an airflow path, a sensor positioned on the engine surface, and a smart-material-based feature positioned on the engine surface, the smart-material-based feature triggered to modify the airflow path when the sensor outputs an indication of a detected deviation from a reference value of an operating parameter of the engine.

Inventors: **Natarajan; Avinash (Bengaluru, IN), Tatiparthi; Vishnu Vardhan Venkata (Bengaluru, IN), Ganiger; Ravindra Shankar (Bengaluru, IN), G; Nagashiresha (Bengaluru, IN), Mathur; Prateek (Chennai, IN), Kuropatwa; Michal Tomasz (Warsaw, PL), Sibbach; Arthur W. (Boxford, MA)**

Applicant: **General Electric Company** (Evendale, OH); **General Electric Company Polska sp. z o.o.** (Warsaw, PL)

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Background/Summary

RELATED APPLICATION [0001] This patent arises from a continuation of U.S. patent application Ser. No. 18/350,496 (now U.S. Pat. No. ______), filed on Jul. 11, 2023. U.S. patent application Ser. No. 18/350,496 is hereby incorporated herein by reference in its entirety. Priority to U.S. patent application Ser. No. 18/350,496 is hereby claimed.

FIELD OF THE DISCLOSURE
[0002] This disclosure relates generally to gas turbine engines and, more particularly, to methods and apparatus to improve air flow in a gas turbine engine.
BACKGROUND
[0003] In recent years, some engine designs use nacelles with shortened inlets to save size, weight, etc. However, nacelles with shortened inlets typically experience inlet distortion at the fan due to insufficient space in front of the fan to align the air flow.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
[0004] FIG. **1** is a schematic cross-sectional view of an example gas turbine engine in which examples disclosed herein may be implemented.
[0005] FIG. **2** is a close-up, schematic, cross-sectional view of a forward end of the example gas turbine engine of FIG. **1** including a plurality of smart-material-based features on a fan casing.
[0006] FIG. **3** is a close-up, schematic, cross-sectional view of a forward end of the example gas turbine engine of FIG. **1** including a plurality of smart-material-based features on a fan blade.
[0007] FIG. **4** is a close-up, schematic, cross-sectional view of a forward end of the example gas turbine engine of FIG. **1** including a plurality of smart-material-based features on an inlet guide vane.
[0008] FIG. **5**A is a close-up, schematic, cross-sectional view of a rear end of the example gas turbine engine of FIG. **1** including a plurality of smart-material-based features on a nozzle.
[0009] FIG. **5**B is a cross-sectional view of the inlet guide vane of FIG. **4** including a plurality of smart-material-based features.
[0010] FIG. **6** is a schematic cross-sectional view of an example unducted gas turbine engine in which examples disclosed herein may be implemented.
[0011] FIG. **7**A is a close-up, schematic, cross-sectional view of a forward end of the example unducted gas turbine engine of FIG. **6** including a plurality of smart-material-based features on an exit guide vane.
[0012] FIG. **7**B is a close-up, schematic, cross-sectional view of a forward end of the example unducted gas turbine engine of FIG. **6** including a plurality of smart-material-based features on a fan blade.
[0013] FIG. **8** is a close-up, schematic, cross-sectional view of a rear end of the example unducted gas turbine engine of FIG. **6** including a plurality of smart-material-based features on a third-stream nozzle.
[0014] FIG. **9**A is a close-up, schematic, cross-sectional view of a forward end of the example gas

turbine engine of FIG. **1** including a plurality of smart-material-based features implemented as serrations on a fan casing and fan blade.
[0015] FIG. **9**B is a close-up view of a first implementation of the example serrations of FIG. **9**A.
[0016] FIG. **9**C is a close-up view of a second implementation of the example serrations of FIG. **9**A.
[0017] FIG. **9**D is a close-up view of a third implementation of the example serrations of FIG. **9**A.
[0018] FIG. **10** is a close-up, schematic, cross-sectional view of a forward end of the example gas turbine engine of FIG. **1** including a plurality of active vortex generators on a fan casing and fan blade.
[0019] FIG. **11** is an illustration of an implementation of the example plurality of the active vortex generators of FIG. **10** on a wing.
[0020] FIG. **12**A is an illustration of a deactivated position of the example active vortex generator of FIG. **10** using a spring.
[0021] FIG. **12**B is an illustration of an activated position of the example active vortex generator of FIG. **10** using the spring.
[0022] FIG. **13**A is an illustration of a deactivated position of the example active vortex generator of FIG. **10** using a smart material actuator.
[0023] FIG. **13**B is an illustration of an activated position of the example active vortex generator of FIG. **10** using the smart material actuator.
[0024] FIG. **13**C is a close-up, schematic, cross-sectional view of the example active vortex generator of FIG. **13**A.
[0025] FIG. **13**D is an example arrangement of the example plurality of the active vortex generators of FIG. **13**A on the wing of FIG. **11**.
[0026] FIG. **14** is a block diagram of an example full authority digital engine control circuitry.
[0027] FIGS. **15** and **16** are flowcharts representative of example machine readable instructions and/or example operations that may be executed, instantiated, and/or performed by example programmable circuitry to implement the example full authority digital engine control circuitry of FIG. **14**.
[0028] FIG. **17** is a block diagram of an example processing platform including programmable circuitry structured to execute, instantiate, and/or perform the example machine readable instructions and/or perform the example operations of FIGS. **15** and **16** to implement the example full authority digital engine control circuitry of FIG. **14**.
[0029] In general, the same reference numbers will be used throughout the drawing(s) and accompanying written description to refer to the same or like parts. The figures are not necessarily to scale. Instead, the thickness of the layers or regions may be enlarged in the drawings. Although the figures show layers and regions with clean lines and boundaries, some or all of these lines and/or boundaries may be idealized. In reality, the boundaries and/or lines may be unobservable, blended, and/or irregular.

DETAILED DESCRIPTION

[0030] In the following detailed description, reference is made to the accompanying drawings that form a part hereof, and in which is shown by way of illustration specific examples that may be practiced. These examples are described in sufficient detail to enable one skilled in the art to practice the subject matter, and it is to be understood that other examples may be utilized. The following detailed description is, therefore, provided to describe example implementations and not to be taken limiting on the scope of the subject matter described in this disclosure. Certain features from different aspects of the following description may be combined to form yet new aspects of the subject matter discussed below.
[0031] As used in this disclosure, stating that any part (e.g., a layer, film, area, region, or plate) is in any way on (e.g., positioned on, located on, disposed on, or formed on, etc.) another part, indicates that the referenced part is either in contact with the other part, or that the referenced part is above

the other part with one or more intermediate part(s) located therebetween.

[0032] As used herein, connection references (e.g., attached, coupled, connected, and joined) may include intermediate members between the elements referenced by the connection reference and/or relative movement between those elements unless otherwise indicated. As such, connection references do not necessarily infer that two elements are directly connected and/or in fixed relation to each other. As used herein, stating that any part is in “contact” with another part is defined to mean that there is no intermediate part between the two parts.

[0033] “Including” and “comprising” (and all forms and tenses thereof) are used herein to be open ended terms. Thus, whenever a claim employs any form of “include” or “comprise” (e.g., comprises, includes, comprising, including, having, etc.) as a preamble or within a claim recitation of any kind, it is to be understood that additional elements, terms, etc., may be present without falling outside the scope of the corresponding claim or recitation. As used herein, when the phrase “at least” is used as the transition term in, for example, a preamble of a claim, it is open-ended in the same manner as the term “comprising” and “including” are open ended. The term “and/or” when used, for example, in a form such as A, B, and/or C refers to any combination or subset of A, B, C such as (1) A alone, (2) B alone, (3) C alone, (4) A with B, (5) A with C, (6) B with C, or (7) A with B and with C. As used herein in the context of describing structures, components, items, objects and/or things, the phrase “at least one of A and B” is intended to refer to implementations including any of (1) at least one A, (2) at least one B, or (3) at least one A and at least one B. Similarly, as used herein in the context of describing structures, components, items, objects and/or things, the phrase “at least one of A or B” is intended to refer to implementations including any of (1) at least one A, (2) at least one B, or (3) at least one A and at least one B. As used herein in the context of describing the performance or execution of processes, instructions, actions, activities and/or steps, the phrase “at least one of A and B” is intended to refer to implementations including any of (1) at least one A, (2) at least one B, or (3) at least one A and at least one B. Similarly, as used herein in the context of describing the performance or execution of processes, instructions, actions, activities and/or steps, the phrase “at least one of A or B” is intended to refer to implementations including any of (1) at least one A, (2) at least one B, or (3) at least one A and at least one B.

[0034] As used herein, singular references (e.g., “a”, “an”, “first”, “second”, etc.) do not exclude a plurality. The term “a” or “an” object, as used herein, refers to one or more of that object. The terms “a” (or “an”), “one or more”, and “at least one” are used interchangeably herein. Furthermore, although individually listed, a plurality of means, elements, or actions may be implemented by, e.g., the same entity or object. Additionally, although individual features may be included in different examples or claims, these may possibly be combined, and the inclusion in different examples or claims does not imply that a combination of features is not feasible and/or advantageous.

[0035] Unless specifically stated otherwise, descriptors such as “first,” “second,” “third,” etc., are used herein without imputing or otherwise indicating any meaning of priority, physical order, arrangement in a list, and/or ordering in any way, but are merely used as labels and/or arbitrary names to distinguish elements for ease of understanding the disclosed examples. In some examples, the descriptor “first” may be used to refer to an element in the detailed description, while the same element may be referred to in a claim with a different descriptor such as “second” or “third.” In such instances, it should be understood that such descriptors are used merely for identifying those elements distinctly within the context of the discussion (e.g., within a claim) in which the elements might, for example, otherwise share a same name.

[0036] As used herein, “approximately” and “about” modify their subjects/values to recognize the potential presence of variations that occur in real world applications. For example, “approximately” and “about” may modify dimensions that may not be exact due to manufacturing tolerances and/or other real world imperfections as will be understood by persons of ordinary skill in the art. For

example, “approximately” and “about” may indicate such dimensions may be within a tolerance range of +/−10% unless otherwise specified in the below description.
[0037] As used herein, the phrase “in communication,” including variations thereof, encompasses direct communication and/or indirect communication through one or more intermediary components, and does not require direct physical (e.g., wired) communication and/or constant communication, but rather additionally includes selective communication at periodic intervals, scheduled intervals, aperiodic intervals, and/or one-time events.
[0038] As used herein, “programmable circuitry” is defined to include (i) one or more special purpose electrical circuits (e.g., an application specific circuit (ASIC)) structured to perform specific operation(s) and including one or more semiconductor-based logic devices (e.g., electrical hardware implemented by one or more transistors), and/or (ii) one or more general purpose semiconductor-based electrical circuits programmable with instructions to perform specific functions(s) and/or operation(s) and including one or more semiconductor-based logic devices (e.g., electrical hardware implemented by one or more transistors). Examples of programmable circuitry include programmable microprocessors such as Central Processor Units (CPUs) that may execute first instructions to perform one or more operations and/or functions, Field Programmable Gate Arrays (FPGAs) that may be programmed with second instructions to cause configuration and/or structuring of the FPGAs to instantiate one or more operations and/or functions corresponding to the first instructions, Graphics Processor Units (GPUs) that may execute first instructions to perform one or more operations and/or functions, Digital Signal Processors (DSPs) that may execute first instructions to perform one or more operations and/or functions, XPUs, Network Processing Units (NPUs) one or more microcontrollers that may execute first instructions to perform one or more operations and/or functions and/or integrated circuits such as Application Specific Integrated Circuits (ASICs). For example, an XPU may be implemented by a heterogeneous computing system including multiple types of programmable circuitry (e.g., one or more FPGAs, one or more CPUs, one or more GPUs, one or more NPUs, one or more DSPs, etc., and/or any combination(s) thereof), and orchestration technology (e.g., application programming interface(s) (API(s)) that may assign computing task(s) to whichever one(s) of the multiple types of programmable circuitry is/are suited and available to perform the computing task(s).
[0039] As used herein integrated circuit/circuitry is defined as one or more semiconductor packages containing one or more circuit elements such as transistors, capacitors, inductors, resistors, current paths, diodes, etc. For example an integrated circuit may be implemented as one or more of an ASIC, an FPGA, a chip, a microchip, programmable circuitry, a semiconductor substrate coupling multiple circuit elements, a system on chip (SoC), etc.
[0040] During the operation of gas turbine engines, engine systems experience blade flutter or stall due disturbances in a flowpath of air, shortened nacelles, different air streams, and other factors. Some engine designs use nacelles with shortened inlets to save size, weight, etc. However, nacelles with shortened inlets typically experience inlet distortion at the fan due to insufficient space in front of the fan to align the air flow. Blade flutter is introduced when there are disturbances in the air flow across and/or around an air foil or other aircraft surface. An aircraft that is attempting to take-off or land in a crosswind situation is likely to experience blade flutter due to the disturbances in the air flow created by the cross winds. Likewise, blade flutter can occur when there are two different air streams with different velocities or pressures mixing together. This can occur at an engine nozzle, where two different airflow paths converge. Certain examples, employ smart materials to minimize or otherwise reduce blade flutter or stall depending on engine pressure, speed, vibration data and other operating parameters. For example, smart materials can be embedded in a fan casing, fan blade and/or inlet cone.
[0041] Sensors that monitor engine pressure, vibration, speed data, and/or other operating parameters can be mounted on a fan hub and/or the fan casing behind a rotor, for example. Deviation from a reference value or range for one or more operating parameters activates smart

materials to mitigate blade flutter and inlet distortion caused by an incoming air flow by changing a direction of the air flow. Smart materials are materials made of substances such as a shape memory alloy, a bi-metal material, a graphene-based element, or a composite foam, etc., that may be activated to, for example, extend an active vortex generator or create serrations on the engine by exposure to electricity, electromagnetic waves, microwaves, graphene-based heating elements, etc. Smart materials can create serrations on the fan casing and/or dendritic features on the fan blade, for example, and are adapted to mitigate inlet distortion, blade flutter and/or bend or tip clearance issues. For instance, smart materials made of graphene-based heating elements, bi-metallics, composite metal foams, and/or shape memory alloy are activated using electromagnetic (EM) waves (e.g., laser, ultraviolet (UV), infrared, etc.) and/or microwaves to produce quick and effective heating.

[0042] Serrations are made of different shapes, such as criss-cross, scallop-like, or saw-like shapes, that protrude and create turbulence to the flow. In some examples, a dendritic (e.g., leaf-like) structure with branches can span across a fan blade. Furthermore, branches connect leading edge and trailing edge or radial passages from blade root to blade tip. A larger dendritic pattern may include one or more axial ply and/or criss-cross patterns.

[0043] In some examples, activation of smart materials can occur at a local area to counter detrimental changes (e.g., bend, dent, flutter) in a particular area. In other examples, activation of smart materials extends across an entire surface (e.g., an interior surface (also referred to herein as an inner surface, indicative of a surface facing inward toward a center of the engine) of a fan casing, an exterior surface (also referred to herein as an outer surface, indicative of a surface facing outward away from a center of an engine) of a fan blade, an interior surface of a nozzle, an exterior surface of a nozzle, a surface of an inlet guide vane, a surface of an exit guide vane, etc.).

[0044] An example smart-material-based feature includes a retractable active vortex generator with one or more bi-metal material or shape memory alloy (SMA) actuators, as known as smart material actuators. Such retractable active vortex generators can be positioned on a fan casing and/or inlet nose cone of an engine to create turbulence to mitigate cross wind conditions. Local activation of smart materials on the fan blade and/or other structure (e.g., fan casing, inlet guide vane, etc.), using smart materials (e.g., materials made of shape memory alloy, bi-metal material, etc.) at a certain angle of attack to change the surface features of the blade, creates a turbulence and avoids boundary layer separation, which mitigates inlet distortion. Smart material activation is placed inside the casing using graphene heating elements which are then activated or otherwise triggered using electromagnetic waves (EM waves such as laser, ultraviolet (UV), infrared, etc.) and microwaves.

[0045] In operation, effects such as fan flutter, fan blade denting, and/or non-optimal tip clearance are mitigated by activating a given segment or local area of the blade to counter the damage induced in the form of bending, denting, and/or blade flutter. Mitigating elements such as smart materials can be applied to a ducted fan and/or an open rotor architecture on various structures.

[0046] FIG. **1** is a schematic cross-sectional view of an example gas turbine engine in which examples disclosed herein may be implemented. Particularly, for the example of FIG. **1**, the gas turbine engine is a high-bypass turbofan jet engine **10**, referred to herein as “turbofan engine **10**”. The turbofan engine **10** has a ducted or closed-rotor design. As shown in FIG. **1**, the turbofan engine **10** defines an axial direction A (extending parallel to a longitudinal axis **12** provided for reference), a radial direction R, and a circumferential direction. In general, the turbofan engine **10** includes a fan section **14** and a turbomachine **16** disposed downstream from the fan section **14**.

[0047] The turbomachine **16** depicted generally includes a substantially outer casing **18** that defines an annular inlet **20**. The outer casing **18** encases, in serial flow relationship, a compressor section including a booster or low pressure (LP) compressor **22** and a high pressure (HP) compressor **24**; a combustion section **26**; a turbine section including a high pressure (HP) turbine **28** and a low pressure (LP) turbine **30**; and a nozzle **32**. A high pressure (HP) shaft **34** drivingly connects the HP turbine **28** to the HP compressor **24**. A low pressure (LP) shaft **36** drivingly connects the LP turbine **30** to the LP compressor **22**. The LP turbine **30** may also be referred to as a “drive turbine”.

[0048] In FIG. **1**, the fan section **14** includes a fan **38** having a plurality of fan blades **40** coupled to a disk **42** in a spaced apart manner. More specifically, the fan section **14** includes the fan **38**, housing a single stage of fan blades **40**. As depicted, the fan blades **40** extend outwardly from disk **42** generally along the radial direction R. Each of the fan blades **40** is rotatable relative to the disk **42** about a pitch axis P by virtue of the fan blades **40** being operatively coupled to an actuation member **44** configured to collectively vary the pitch of the fan blades **40** in unison. The fan **38** is mechanically coupled to and rotatable with the LP turbine **30**, or drive turbine. More specifically, the fan blades **40**, disk **42**, and actuation member **44** are together rotatable about the longitudinal axis **12** by LP shaft **36** in a “direct drive” configuration. Accordingly, the fan **38** is coupled with the LP turbine **30** in a manner such that the fan **38** is rotatable by the LP turbine **30** at the same rotational speed as the LP turbine **30**.

[0049] Referring still to FIG. **1**, the disk **42** is covered by rotatable front hub **48** aerodynamically contoured to promote an airflow through the plurality of fan blades **40**. Additionally, the fan section **14** includes a fan casing **50** that circumferentially surrounds the plurality of fan blades **40** of the fan **38** and/or at least a portion of the turbomachine **16**. More specifically, the fan casing **50** includes an inner wall **52** and a downstream section **54** of the inner wall **52** of the fan casing **50** extends over an outer portion of the turbomachine **16** so as to define a bypass airflow passage **56** therebetween. Additionally, for the example depicted, the fan casing **50** is supported relative to the turbomachine **16** by a plurality of circumferentially spaced outlet guide vanes **55**.

[0050] During operation of the turbofan engine **10**, a volume of air **58** enters the turbofan engine **10** through an associated inlet **60** of the fan casing **50** and/or fan section **14**. As the volume of air **58** passes across the fan blades **40**, a first portion of the air **58** as indicated by arrows is directed or routed into the bypass airflow passage **56** and a second portion of the air **58** as indicated by arrow is directed or routed into the LP compressor **22**. The pressure of the second portion of air **64** is then increased as it is routed through the high pressure (HP) compressor **24** and into the combustion section **26**, where it is mixed with fuel and burned to provide combustion gases **66**.

[0051] The combustion gases **66** are routed through the nozzle **32** of the turbomachine **16** to provide propulsive thrust. Simultaneously, the pressure of the first portion of air **62** is substantially increased as the first portion of air **62** is routed through the bypass airflow passage **56** before it is exhausted from a fan nozzle exhaust section **76** of the turbofan engine **10**, also providing propulsive thrust. The HP turbine **28**, the LP turbine **30**, and the nozzle **32** at least partially define a hot gas path **78** for routing the combustion gases **66** through the turbomachine **16**.

[0052] It should be appreciated, however, that the turbofan engine **10** depicted in FIG. **1** and described above is by way of example only, and that in other examples, the turbofan engine **10** may have any other configuration. In other examples, the turbomachine **16** may include any other number of compressors, turbines, and/or shaft or spools. Additionally, the turbofan engine **10** may not include each of the features described herein, or alternatively, may include one or more features not described herein. For example, in other examples, the fan **38** may not be a variable pitch fan. Additionally, although described as a “turbofan” gas turbine engine, in other examples the gas turbine engine may instead be configured as any other ducted gas turbine engine. In some examples, the turbofan engine **10** may be a two-stream engine or three-stream engine. In some examples, the turbofan engine **10** may or may not include the inlet guide vane **100**.

[0053] As will be appreciated, operating the turbofan engine **10** may ordinarily lead to blade flutter and/or stall due to a flowpath of air. To mitigate the blade flutter and/or stall of the turbofan engine **10** due to the flowpath of air, smart-material-based-features are utilized on various portions of the turbofan engine **10**.

[0054] FIG. **2** is a close-up, schematic, cross-sectional view of a forward end of the example gas turbine engine of FIG. **1** including a plurality of smart-material-based features **220** on a fan casing

50. The turbofan engine **10** depicted generally includes smart-material-based features **220** that are placed on the fan casing **50**. The smart-material-based features **220** may include at least one of a shape memory alloy, a bi-metal material, a graphene-based element, or a composite foam. The smart-material-based features **220** may include active vortex generators which are retractable. The smart-material-based features **220** may create at least one of a serration or a bump on at least one of the inner surface of the fan casing **50**. The smart-material-based features may activate the active vortex generator when a smart material actuator **226** receives the signal to activate.

[0055] In certain examples, the turbofan engine **10** includes a sensor **222** (e.g., a pressure sensor, a vibration sensor, a speed sensor, etc.) which monitors an operating parameter of the turbofan engine **10** for a deviation from a reference value of an operating parameter. The operating parameter may include at least one of engine pressure, engine vibration, or engine speed. The turbofan engine **10** includes a controller **224** and the smart material actuator **226**, the controller **224** sending a signal to the smart material actuator **226** to activate the smart-material-based features **220** when the sensor **222** outputs an indication of the deviation from the reference value of the operating parameter of the engine that has been detected by the sensor **222**. The indication is a signal reflecting a detected deviation from the reference value of the operating parameter of the engine. The sensor **222** sends a signal to the controller **224** when the sensor **222** outputs the indication of the deviation from the reference value of the operating parameter of the engine. Once the smart-material-based feature is activated, the blade flutter and/or stall of the turbofan engine **10** due to the flowpath of air will mitigate or stop.

[0056] FIG. **3** is a close-up, schematic, cross-sectional view of a forward end of the example gas turbine engine of FIG. **1** including a plurality of smart-material-based features **220** positioned on the fan blades **40**. As shown in the example of FIG. **3**, the smart-material-based features **220** are arranged in a spaced-apart configuration (e.g., between 0.1 and 2.0 inches) on the exterior surface of the fan blades **40**. In some examples, activation of the smart-material-based features **220** can occur at a local area to counter detrimental changes (e.g., bend, dent, flutter) in a particular area. The smart-material-based features **220** include at least one of a shape memory alloy, a bi-metal material, a graphene-based element, or a composite foam. The smart material actuator **226** activates the smart-material-based features **220** using at least one of electricity, electromagnetic waves, microwaves, or a graphene-based heating element.

[0057] FIG. **4** is a close-up, schematic, cross-sectional view of a forward end of the example gas turbine engine of FIG. **1** including a plurality of smart-material-based features **220** positioned on the inlet guide vane **100**. As shown in the example of FIG. **4**, the smart-material-based features **220** are arranged in a spaced-apart configuration (e.g., between 0.1 and 2.0 inches) on the inlet guide vane **100**. The space-apart configuration of the smart-material-based features **220** on the inlet guide vane **100** helps move the air flow through the engine and correlates with a certain amount of air flow that moves through the engine.

[0058] FIG. **5**A is a close-up, schematic, cross-sectional view of a rear end of the example gas turbine engine of FIG. **1** including a plurality of the smart-material-based features **220** on the nozzle **32**. As shown in FIG. **1**, the turbofan engine **10** defines the longitudinal axis **12** and the nozzle **32**. The turbofan engine **10** depicted in FIG. **5**A includes smart-material-based features **220** that are placed on the nozzle **32**. The smart-material-based features **220** on the nozzle **32** activate and help with the air flowing through the turbofan engine **10**. As air flows through the rear end of the turbofan engine **10**, the smart-material-based features **220** on the nozzle **32** mitigate blade flutter and inlet distortion caused by incoming air flow by changing the air flow.

[0059] FIG. **5**B is a cross-sectional view of the inlet guide vane **100** of FIG. **4** including a plurality of the smart-material-based features **220**. As is depicted in FIG. **5**B, the inlet guide vane **100** is configured generally as an airfoil having a pressure side **120** and an opposite suction side **122**, extending between the leading edge **108** and the trailing edge **110**. Air **58** flows in an airflow direction **129** through the inlet **60** of the fan casing **50**. The cross-sectional view of the inlet guide vane **100** of the example gas turbine engine of FIG. **1** generally includes smart-material-based features **220** that are placed on the inlet guide vane **100**.

[0060] FIGS. **1-5**B illustrate example closed-rotor or ducted engine configurations able to benefit from placement of the smart-material-based features **220**. FIGS. **6-8** illustrate example open-rotor or unducted engine configurations that can also benefit from placement of the smart-material-based features **220**.

[0061] There are multiple engine configurations, such as an unducted gas turbine engine, where smart-material-based features can be placed. FIG. **6** is a schematic cross-sectional view of an unducted gas turbine engine **600** in which examples disclosed herein may be implemented. The unducted gas turbine engine **600** defines an axial direction A, a radial direction R, and a circumferential direction C. Moreover, the unducted gas turbine engine **600** defines an axial centerline or longitudinal axis **612** that extends along the axial direction A. The unducted gas turbine engine **600** extends between a forward end **614** and an aft end **616**, e.g., along the axial direction A.

[0062] The unducted gas turbine engine **600** includes a core engine **618** and a fan section **650** positioned upstream thereof. Generally, the core engine **618** includes, in serial flow order, a compressor section, a combustion section, a turbine section, and an exhaust section. Particularly, as shown in FIG. **6**, the core engine **618** includes an engine core **620** and a core cowl **622** that annularly surrounds the engine core **620**. The engine core **620** and core cowl **622** define a core inlet **624**. Pressurized air stream flows downstream to a combustor **630** where fuel is injected into the pressurized air stream and ignited to raise the temperature and energy level of the pressurized air.

[0063] The high energy combustion products flow from the combustor **630** downstream to a high pressure turbine **632**. The high pressure turbine **632** drives the high pressure compressor **628** through a first shaft or high pressure (HP) shaft **636**. The high energy combustion products then flow to a low pressure turbine **634**. A low pressure (LP) shaft **638** is coaxial with the HP shaft **636** in this example. After driving each the high pressure turbine **632** and the low pressure turbine **634**, the combustion products exit the core engine **618** through a nozzle **640** to produce propulsive thrust. The nozzle **640** can be a third-stream nozzle or a core exhaust nozzle depending on the engine configuration. Accordingly, the core engine **618** defines a core flowpath or core duct **642** that extends between the core inlet **624** and the nozzle **640**.

[0064] The fan section **650** includes a primary fan **652**. For the example of FIG. **6**, the primary fan **652** is an open rotor or unducted primary fan **652**. However, in other examples, the primary fan **652** may be ducted, e.g., by a fan casing **50** (FIG. **1**) or nacelle circumferentially surrounding the primary fan **652**. As depicted, the primary fan **652** includes an array of fan blades **654** (only one shown in FIG. **6**). The fan blades **654** are rotatable, e.g., about the longitudinal axis **612**. As noted above, the primary fan **652** is drivingly coupled with the low pressure turbine **634** via the LP shaft **638**. The primary fan **652** can be directly coupled with the LP shaft **638**, e.g., in a direct-drive configuration. Optionally, as shown in FIG. **6**, the primary fan **652** can be coupled with the LP shaft **638** via a speed reduction gearbox **655**, e.g., in an indirect-drive or geared-drive configuration.

[0065] Moreover, the fan blades **654** can be arranged in equal spacing around the longitudinal axis **612**. Each of the fan blades **654** has a root and a tip and a span defined therebetween. Each of the fan blades **654** defines a central blade axis **656**. For this example, each of the fan blades **654** of the primary fan **652** is rotatable about their respective central blade axes **656**, e.g., in unison with one another. One or more actuators **658** can be controlled to pitch the fan blades **654** about their respective central blade axes **656**. However, in other examples, each of the fan blades **654** may be fixed or unable to be pitched about its central blade axis **656**.

[0066] The fan section **650** further includes an exit guide vane **660** that includes fan guide vanes **662** (only one shown in FIG. **6**) disposed around the longitudinal axis **612**. Each of the fan guide vanes **662** defines a central blade axis **664**. The fan guide vanes **662** are mounted to a fan cowl **670**.

[0067] The fan cowl **670** annularly encases at least a portion of the core cowl **622** and is generally positioned outward of the core cowl **622** along the radial direction R. Particularly, a downstream section of the fan cowl **670** extends over a forward portion of the core cowl **622** to define a fan flowpath or fan duct **672**. Incoming air may enter through the fan duct **672** through a fan duct inlet **676** and may exit through a fan exhaust nozzle **678** to produce propulsive thrust. The fan duct **672** is an annular duct positioned generally outward of the core duct **642** along the radial direction R. The fan cowl **670** and the core cowl **622** are connected together and supported by a plurality of substantially radially-extending, circumferentially-spaced struts **674** (only one shown in FIG. **6**). The struts **674** may each be aerodynamically contoured to direct air flowing thereby.

[0068] The unducted gas turbine engine **600** also defines or includes an inlet duct **680**. The inlet duct **680** extends between an engine inlet **682** and the core inlet **624**/fan duct inlet **676**. Air flowing downstream along the inlet duct **680** is split, not necessarily evenly, into the core duct **642** and the fan duct **672** by a nose of a splitter **644** of the core cowl **622**. In various examples, it will be appreciated that the unducted gas turbine engine **600** includes a ratio of a quantity of the fan guide vanes **662** to a quantity of fan blades **654** that could be less than, equal to, or greater than 1:1.

[0069] With reference to FIG. **6**, operation of the unducted gas turbine engine **600** may be summarized in the following manner. During operation, an initial or incoming airflow passes through the fan blades **654** of the primary fan **652** and splits into a first airflow and a second airflow. The first airflow bypasses the engine inlet **682** and flows generally along the axial direction A outward of the fan cowl **670** along the radial direction R. The first airflow accelerated by the fan blades **654** passes through the fan guide vanes **662** and continues downstream thereafter to produce a primary propulsion stream or first thrust stream S**1**. The second airflow flowing downstream through the inlet duct **680** flows through low pressure compressor blades **692** of a first stage of a low pressure compressor **690** and is consequently compressed. The second airflow flowing downstream of the first stage of the low pressure compressor **690** is split by the splitter **644** located at the forward end of the core cowl **622**. The air flows generally along the axial direction A through the fan duct **672** and is ultimately exhausted from the fan duct **672** through the fan exhaust nozzle **678** to produce a third thrust stream S**3**. A “third stream” or third thrust stream S**3** as used herein means a secondary air stream capable of increasing fluid energy to produce a minority of total propulsion system thrust.

[0070] Although the unducted gas turbine engine **600** has been described and illustrated in FIG. **6** as representing an example three-stream gas turbine engine operable to produce first thrust stream S**1**, second thrust stream S**2**, and third thrust stream S**3**, it will be appreciated that the aspects of the present disclosure may apply to three-stream gas turbine engines having other configurations such as having one stream or two streams. One stream engines produce the first thrust stream S**1**. Two stream engines produce the first thrust stream S**1** and the second thrust stream S**2**. Three stream engines produce the first thrust stream S**1**, the second thrust stream S**2**, and the third thrust stream S**3**.

[0071] FIGS. **7**A, **7**B, and **8** are close-up, schematic, cross-sectional views of a forward end of the unducted gas turbine engine **600** of FIG. **6** including a plurality of the smart-material-based features **220** on the exit guide vane **660**, on the array of fan blades **654**, and on the nozzle **640**, respectively. The smart-material-based features **220** on the exit guide vane **660**, on the array of fan blades **654**, and on the nozzle **640** are adapted to mitigate inlet distortion, blade flutter, and/or bend and/or tip clearance issues. The smart-material-based features **220** create, when activated by the smart material actuator **226**, at least one of a serration or a bump on at least one of the exit guide vane **660**, on the array of fan blades **654**, and on the nozzle **640**. In some examples, activation of smart-material-based features **220** can occur at a local area to counter detrimental changes (e.g., bend, dent, flutter) in a particular area.

[0072] The smart-material-based features **220** include at least one of a shape memory alloy, a bi-metal material, a graphene-based element, or a composite foam. The smart material actuator **226** activates the smart-material-based features **220** using at least one of electricity, electromagnetic waves, microwaves, or a graphene-based heating element. The unducted gas turbine engine **600** includes the sensor **222** which monitors an operating parameter of the unducted gas turbine engine **600** for a deviation from a reference value of an operating parameter. The operating parameter may include at least one of engine pressure, engine vibration, or engine speed, for example. The unducted gas turbine engine **600** includes the controller **224** and the smart material actuator **226**, the controller **224** sending a signal to the smart material actuator **226** to activate the smart-material-based feature(s) **220** when the sensor **222** outputs an indication of the deviation from the reference value of the operating parameter of the engine. The sensor **222** sends a signal to the controller **224** when the sensor **222** outputs the indication of the deviation from the reference value of the operating parameter of the engine. In operation, as airflows through the engine and the sensor **222** senses a deviation from the operating reference values, the smart-material-based features **220** are activated to counter detrimental changes (e.g., bend, dent, flutter).

[0073] FIG. **9**A is a close-up, schematic, cross-sectional view of a forward end of the example gas turbine engine of FIG. **1** including a plurality of the smart-material-based features **220** implemented as serrations on a fan casing **904** and fan blade **902**. A turbofan engine **900** has smart-material-based features **906** on fan casing **904** and/or fan blade **902** are adapted to mitigate inlet distortion, blade flutter or bend or tip clearance issues. The smart-material-based features **906** create, when activated, at least one of a serration or a bump on at least one of the inner surface of the fan casing **904**, an exterior surface of the fan blade **902**, the inner surface of the nozzle, the outer surface of the nozzle, or the inlet guide vane when the smart material actuator **226** receives the signal to activate. In some examples, activation of smart-material-based features **906** can occur at a local area to counter detrimental changes (e.g., bend, dent, flutter) in a particular area. The smart-material-based features **906** includes at least one of a shape memory alloy, a bi-metal material, a graphene-based element, or a composite foam. The smart material actuator **226** activates the smart-material-based features **906** using at least one of electricity, electromagnetic waves, microwaves, or a graphene-based heating element.

[0074] The turbofan engine **900** includes the sensor **222** which monitors an operating parameter of the turbofan engine for a deviation from a reference value of an operating parameter. The operating parameter may include at least one of engine pressure, engine vibration, or engine speed. The turbofan engine **900** includes the controller **224** and the smart material actuator **226**, the controller **224** sending a signal to the smart material actuator **226** to activate the smart-material-based feature when the sensor **222** outputs the indication of the deviation from the reference value of the operating parameter of the engine. The sensor **222** sends a signal to the controller **224** when the sensor **222** outputs the indication of the deviation from the reference value of the operating parameter of the engine.

[0075] FIG. **9**B is a close-up view of a first implementation of the example serrations of FIG. **9**A. A serration pattern **910** shows a straight-line pattern. In some examples, serrations can be a different pattern. Serrations are made of different shapes that protrude and create turbulence to the flow. In some examples, activation of smart materials to create the serration pattern **910** can occur at a local area to counter detrimental changes (e.g., bend, dent, flutter) in a particular area. In other examples, activation of smart materials to create the serration pattern **910** extends across an entire surface (e.g., an interior surface of a fan casing, an exterior surface of a fan blade, a surface of an inlet guide vane, etc.).

[0076] FIG. **9**C is a close-up view of a second implementation of the example serrations of FIG. **9**A. A serration pattern **912** shows a criss-cross pattern. In some examples, serrations can be a different pattern. Serrations are made of different shapes that protrude and create turbulence to the flow. In some examples, activation of smart materials to create the serration pattern **912** can occur at a local area to counter detrimental changes (e.g., bend, dent, flutter) in a particular area. In other examples, activation of smart materials to create the serration pattern **912** extends across an entire surface (e.g., an interior surface of a fan casing, an exterior surface of a fan blade, a surface of an inlet guide vane, etc.).

[0077] FIG. **9**D is a close-up view of a third implementation of the example serrations of FIG. **9**A. A serration pattern **914** shows a wavy pattern. In some examples, serrations can be a different pattern. Serrations are made of different shapes that protrude and create turbulence to the flow. In some examples, activation of smart materials to create the serration pattern **914** can occur at a local area to counter detrimental changes (e.g., bend, dent, flutter) in a particular area. In other examples, activation of smart materials to create the serration pattern **914** extends across an entire surface (e.g., an interior surface of a fan casing, an exterior surface of a fan blade, a surface of an inlet guide vane, etc.).

[0078] FIG. **10** is a close-up, schematic, cross-sectional view of a forward end of the example gas turbine engine of FIG. **1** including a plurality of active vortex generators **1006** on a fan casing **1004** and fan blade **1002**. A turbofan engine **900** has active vortex generators **1006** on fan casing **1004** and/or fan blade **1002** are adapted to mitigate inlet distortion, blade flutter or bend or tip clearance issues. The active vortex generators **1006** is a smart-material-based feature. The active vortex generators **1006** are retractable. The smart material actuator **226** activates a smart-material-based feature using at least one of electricity, electromagnetic waves, microwaves, or a graphene-based heating element. The smart-material-based feature includes at least one of a shape memory alloy, a bi-metal material, a graphene-based element, or a composite foam. The turbofan engine **900** includes the sensor **222** which monitors an operating parameter of the turbofan engine for a deviation from a reference value of an operating parameter. The operating parameter may include at least one of engine pressure, engine vibration, or engine speed. The turbofan engine **900** includes the controller **224** and the smart material actuator **226**, the controller **224** sending a signal to the smart material actuator **226** to activate the smart-material-based feature when the sensor **222** outputs the indication of the deviation from the reference value of the operating parameter of the engine. The sensor **222** sends a signal to the controller **224** when the sensor **222** outputs the indication of the deviation from the reference value of the operating parameter of the engine.

[0079] FIG. **11** is an illustration of an implementation of the example plurality of the active vortex generators **1006** of FIG. **10** on a wing **1105**. Before active vortex generators **1006** are activated, there is smooth airflow on a surface such as the wing **1105** of a commercial airplane. As smooth airflow continues, the boundary layer begins to separate. Subsequently, the wing **1105** stalls. On the other hand, after active vortex generators **1006** are activated, there is vortex airflow on the wing **1105**. As vortex airflow continues, the boundary layer is energized by vortices. Subsequently, the boundary layer remains attached, and the wing **1105** does not stall. As shown, the wing **1105** has a certain angle of attack (AoA). A first AoA **1120** of the wing **1105** has the smallest angle and a second AoA **1122** of the wing **1105** has an angle larger than the first AoA **1120** but smaller than a third AoA **1124** of the wing **1105**. The third AoA **1124** of the wing **1105** has the largest angle compared to the first AoA **1120** and the second AoA **1122**. When the first AoA **1120** of the wing **1105** is small or the second AoA **1122** of the wing **1105** is relatively larger than the first AoA **1120**, the airflow is attached to the wing **1105**, regardless of the active vortex generators **1006** being utilized. However, when the AoA increases (above a threshold value) to the third AoA **1124** of the wing **1105**, the airflow separates from the wing **1105** before the active vortex generators **1006** are utilized, resulting in the wing **1105** stalling. After the active vortex generators **1006** are activated, airstream reattachment results when the wing **1105** operates under the third AoA **1124**. Consequently, the AoA, causing the wing **1105** to stall, is increased for configuration with the active vortex generators **1006** being activated when the wing **1105** operates under a large AoA and the surface is smooth, causing low drag forces, when the wing **1105** operates under a small AoA.

[0080] FIG. **12**A is an illustration of a deactivated position of the example active vortex generator **1006** of FIG. **10** using a spring **1202**. In the deactivated position of the example active vortex generator **1006**, a spring **1202** is attached to a shape memory alloy (SMA) actuator **1204**. The SMA actuator **1204** is an example of the smart material actuator **226**, as described above. The spring

1202 does not move and the SMA actuator **1204** does not actuate during a deactivated position of the example active vortex generator **1006**.

[0081] FIG. **12**B is an illustration of an activated position of the example active vortex generator **1006** of FIG. **10** using a spring **1202**. In the activated position of the example active vortex generator **1006**, the spring **1202** is attached to the SMA actuator **1204**. The spring **1202** moves when the SMA actuator **1204** activates during an activated position of the example active vortex generator **1006**.

[0082] FIGS. **13**A and **13**B illustrate a deactivated position and an activated position, respectively, of the example active vortex generator **1006** of FIG. **10**. FIG. **13**A is an illustration of a deactivated position of the example active vortex generator **1006** of FIG. **10** using the smart material actuator **226**. FIG. **13**A shows an electric terminal **1302**, a sealing layer **1304**, a SMA layer **1306**, and a base plate **1308**. In some examples, the SMA layer **1306** may be wires or metal other than the base plate **1308**. In a deactivated position, the air flow does not cause the smart material actuator **226** shaped to the active vortex generator **1006** to activate. In some examples, the smart material actuator **226** may be bimetallic-based or SMA-based. FIG. **13**B is an illustration of an activated position of the example active vortex generator **1006** of FIG. **10** using the smart material actuator **226**. FIG. **13**B shows the electric terminal **1302**, the sealing layer **1304**, the SMA layer **1306**, and the base plate **1308**. In an activated position, the air flow causes the smart material actuator **226** shaped to the active vortex generator **1006** to activate by bending.

[0083] FIG. **13**C is a close-up, schematic, cross-sectional view of the example active vortex generator **1006** of FIG. **13**A. FIG. **13**C shows the SMA layer **1306** and the base plate **1308**. When air flows across the base plate **1308**, the air impacts the activated SMA layer **1306**, which distorts or otherwise adjusts the air flow to mitigate blade futter and/or wing stall. FIG. **13**D is an example arrangement of the example plurality of the active vortex generators **1006** of FIG. **13**A on the wing **1105** of FIG. **11**. Air flows through the plurality of the active vortex generators **1006** on the wing **1105** to mitigate blade flutter and/or stall, as shown in FIG. **13**D.

[0084] FIG. **14** illustrates a block diagram of an example full authority digital engine control (FADEC) circuitry **1402**. In the illustrated example of FIG. **14**, the example full authority digital engine control circuitry **1402** includes example monitoring circuitry **1404**, example activator circuitry **1406**, and example controller circuitry **1408**.

[0085] In operation, and as described in further detail below, the example monitoring circuitry **1404** monitors the operating parameters, the example activator circuitry **1406** activates the smart-material-based features **220**, and the example controller circuitry **1408** controls the smart-material-based features **220**.

[0086] In FIG. **14**, the example monitoring circuitry **1404** monitors operating parameters. Operating parameters may include, but are not limited to, at least one of engine pressure, engine vibration, or engine speed. The example monitoring circuitry **1404** monitors the operating parameters by checking against reference values of the operating parameters. If there is a deviation from the reference values of the operating parameters, it may represent an engine not operating to its standard performance. In some examples, engine speed is typically measured as a percent (0-100%) of redline speed for each spool of the engine. In some examples, typical pressures are atmospheric pressure (P**0**) at about 2-16 PSIA and compressor discharge pressure (P**3**) at about 15 PSIA with engine off up to about 1000 PSIA in operation at takeoff conditions. In some examples, vibrations typically refer to 1/revolution of a given spool or the blade passing frequencies of a given rotor.

[0087] When there is a deviation from the reference values of the operating parameters, the example activator circuitry **1406** activates the smart-material-based features **220**. As described above, smart-material-based features **220** may include, but are not limited to, active vortex generators. The smart-material-based features **220** mitigate effects from an engine with deviations from its reference values of the operating parameters. The smart-material-based features **220** includes at least one of a shape memory alloy, a bi-metal material, a graphene-based element, or a composite foam. The example activator circuitry **1406** sends a signal to the smart material actuator **226** to activate the smart-material-based features **220** using at least one of electricity, electromagnetic waves, microwaves, or a graphene-based heating element. In some examples, activation of smart-material-based features **220** can occur at a local area (rather than the entire surface of the relevant part) to counter detrimental changes (e.g., bend, dent, flutter) in a particular area.

[0088] In some examples, after the example activator circuitry **1406** activates the smart-material-based features **220**, the example controller circuitry **1408** may determine whether to adjust the smart-material-based features **220**. For example, if the smart-material-based feature is to be adjusted, the example controller circuitry **1408** determines an adjustment percentage and adjusts the smart-material-based features **220** based on that percentage. For example, if the smart-material-based features **220** need to be adjusted slightly, such as by 3%, to mitigate the blade flutter of the engine, the example controller circuitry **1408** adjusts the smart-material-based features **220** by that percentage.

[0089] After the example activator circuitry **1406** activates the smart-material-based features **220**, the example controller circuitry **1408** checks if the engine is still operating. If the engine is still in operation, the example controller circuitry **1408** sends a signal to the example monitoring circuitry **1404** to continue monitoring the operating parameters for a deviation from the reference values. If the engine is no longer operating, the example controller circuitry **1408** deactivates the smart-material-based features **220**.

[0090] FIG. **14** is a block diagram of an example implementation of the example full authority digital engine control circuitry **1402** to improve fan operability control using smart materials. The example full authority digital engine control circuitry **1402** of FIG. **14** may be instantiated (e.g., creating an instance of, bring into being for any length of time, materialize, implement, etc.) by programmable circuitry such as a Central Processor Unit (CPU) executing first instructions. Additionally or alternatively, the example full authority digital engine control circuitry **1402** of FIG. **14** may be instantiated (e.g., creating an instance of, bring into being for any length of time, materialize, implement, etc.) by (i) an Application Specific Integrated Circuit (ASIC) and/or (ii) a FPGA structured and/or configured in response to execution of second instructions to perform operations corresponding to the first instructions. It should be understood that some or all of the circuitry of FIG. **14** may, thus, be instantiated at the same or different times. Some or all of the circuitry of FIG. **14** may be instantiated, for example, in one or more threads executing concurrently on hardware and/or in series on hardware. Moreover, in some examples, some or all of the circuitry of FIG. **14** may be implemented by microprocessor circuitry executing instructions and/or FPGA circuitry performing operations to implement one or more virtual machines and/or containers.

[0091] In some examples, the example monitoring circuitry **1404** is instantiated by programmable circuitry executing example monitoring circuitry **1404** instructions and/or configured to perform operations such as those represented by the flowcharts of FIGS. **15** and **16**. In some examples, the example activator circuitry **1406** is instantiated by programmable circuitry executing example activator circuitry **1406** instructions and/or configured to perform operations such as those represented by the flowcharts of FIGS. **15** and **16**. In some examples, the example controller circuitry **1408** is instantiated by programmable circuitry executing example controller circuitry **1408** instructions and/or configured to perform operations such as those represented by the flowcharts of FIGS. **15** and **16**.

[0092] In some examples, the example monitoring circuitry **1404** apparatus includes means for monitoring the operating parameters, the example activator circuitry **1406** apparatus includes means for activating the smart-material-based features **220**, and the example controller circuitry **1408** apparatus includes means for controlling the smart-material-based features **220**. For example,

the means for monitoring the operating parameters, activating the smart-material-based features **220**, and controlling the smart-material-based features **220** may be implemented by the example monitoring circuitry **1404**, the example activator circuitry **1406**, and the example controller circuitry **1408**, respectively. In some examples, the aforementioned circuitry may be instantiated by programmable circuitry such as the example programmable circuitry **1712** of FIG. **17**. Additionally or alternatively, the aforementioned circuitry may be instantiated by any other combination of hardware, software, and/or firmware. For example, the aforementioned circuitry may be implemented by at least one or more hardware circuits (e.g., processor circuitry, discrete and/or integrated analog and/or digital circuitry, an FPGA, an ASIC, an XPU, a comparator, an operational-amplifier (op-amp), a logic circuit, etc.) configured and/or structured to execute some or all of the machine readable instructions and/or to perform some or all of the operations corresponding to the machine readable instructions without executing software or firmware, but other structures are likewise appropriate.
[0093] While an example manner of implementing the example full authority digital engine control circuitry **1402** of FIG. **14** is illustrated in FIG. **14**, one or more of the elements, processes, and/or devices illustrated in FIG. **14** may be combined, divided, re-arranged, omitted, eliminated, and/or implemented in any other way. Further, the example monitoring circuitry **1404**, the example activator circuitry **1406**, the example controller circuitry **1408**, and/or, more generally, the example full authority digital engine control circuitry **1402** of FIG. **14**, may be implemented by hardware alone or by hardware in combination with software and/or firmware. Thus, for example, any of the example monitoring circuitry **1404**, the example activator circuitry **1406**, the example controller circuitry **1408**, and/or, more generally, the example full authority digital engine control circuitry **1402**, could be implemented by programmable circuitry in combination with machine readable instructions (e.g., firmware or software), processor circuitry, analog circuit(s), digital circuit(s), logic circuit(s), programmable processor(s), programmable microcontroller(s), graphics processing unit(s) (GPU(s)), digital signal processor(s) (DSP(s)), ASIC(s), programmable logic device(s) (PLD(s)), and/or field programmable logic device(s) (FPLD(s)) such as FPGAs. Further still, the example full authority digital engine control circuitry **1402** of FIG. **14** may include one or more elements, processes, and/or devices in addition to, or instead of, those illustrated in FIG. **14**, and/or may include more than one of any or all of the illustrated elements, processes and devices.
[0094] Flowcharts representative of example machine readable instructions, which may be executed by programmable circuitry to implement and/or instantiate the example full authority digital engine control circuitry **1402** of FIG. **14** and/or representative of example operations which may be performed by programmable circuitry to implement and/or instantiate the example full authority digital engine control circuitry **1402** of FIG. **14**, are shown in FIGS. **15** and **16**. In some examples, the machine readable instructions cause an operation, a task, etc., to be carried out and/or performed in an automated manner in the real world. As used herein, “automated” means without human involvement.
[0095] The program may be embodied in instructions (e.g., software and/or firmware) stored on one or more non-transitory computer readable and/or machine readable storage medium such as cache memory, a magnetic-storage device or disk (e.g., a floppy disk, a Hard Disk Drive (HDD), etc.), an optical-storage device or disk (e.g., a Blu-ray disk, a Compact Disk (CD), a Digital Versatile Disk (DVD), etc.), a Redundant Array of Independent Disks (RAID), a register, ROM, a solid-state drive (SSD), SSD memory, non-volatile memory (e.g., electrically erasable programmable read-only memory (EEPROM), flash memory, etc.), volatile memory (e.g., Random Access Memory (RAM) of any type, etc.), and/or any other storage device or storage disk. The instructions of the non-transitory computer readable and/or machine readable medium may program and/or be executed by programmable circuitry located in one or more hardware devices, but the entire program and/or parts thereof could alternatively be executed and/or instantiated by one or more hardware devices other than the programmable circuitry and/or embodied in dedicated

hardware. The machine readable instructions may be distributed across multiple hardware devices and/or executed by two or more hardware devices (e.g., a server and a client hardware device). For example, the client hardware device may be implemented by an endpoint client hardware device (e.g., a hardware device associated with a human and/or machine user) or an intermediate client hardware device gateway (e.g., a radio access network (RAN)) that may facilitate communication between a server and an endpoint client hardware device. Similarly, the non-transitory computer readable storage medium may include one or more mediums. Further, although the example program is described with reference to the flowcharts illustrated in FIGS. **15** and **16**, many other methods of implementing the example full authority digital engine control circuitry **1402** may alternatively be used. For example, the order of execution of the blocks of the flowcharts may be changed, and/or some of the blocks described may be changed, eliminated, or combined. Additionally or alternatively, any or all of the blocks of the flow chart may be implemented by one or more hardware circuits (e.g., processor circuitry, discrete and/or integrated analog and/or digital circuitry, an FPGA, an ASIC, a comparator, an operational-amplifier (op-amp), a logic circuit, etc.) structured to perform the corresponding operation without executing software or firmware. The programmable circuitry may be distributed in different network locations and/or local to one or more hardware devices (e.g., a single-core processor (e.g., a single core CPU), a multi-core processor (e.g., a multi-core CPU, an XPU, etc.)). For example, the programmable circuitry may be a CPU and/or an FPGA located in the same package (e.g., the same integrated circuit (IC) package or in two or more separate housings), one or more processors in a single machine, multiple processors distributed across multiple servers of a server rack, multiple processors distributed across one or more server racks, etc., and/or any combination(s) thereof.

[0096] The machine readable instructions described herein may be stored in one or more of a compressed format, an encrypted format, a fragmented format, a compiled format, an executable format, a packaged format, etc. Machine readable instructions as described herein may be stored as data (e.g., computer-readable data, machine-readable data, one or more bits (e.g., one or more computer-readable bits, one or more machine-readable bits, etc.), a bitstream (e.g., a computer-readable bitstream, a machine-readable bitstream, etc.), etc.) or a data structure (e.g., as portion(s) of instructions, code, representations of code, etc.) that may be utilized to create, manufacture, and/or produce machine executable instructions. For example, the machine readable instructions may be fragmented and stored on one or more storage devices, disks and/or computing devices (e.g., servers) located at the same or different locations of a network or collection of networks (e.g., in the cloud, in edge devices, etc.). The machine readable instructions may require one or more of installation, modification, adaptation, updating, combining, supplementing, configuring, decryption, decompression, unpacking, distribution, reassignment, compilation, etc., in order to make them directly readable, interpretable, and/or executable by a computing device and/or other machine. For example, the machine readable instructions may be stored in multiple parts, which are individually compressed, encrypted, and/or stored on separate computing devices, wherein the parts when decrypted, decompressed, and/or combined form a set of computer-executable and/or machine executable instructions that implement one or more functions and/or operations that may together form a program such as that described herein.

[0097] In another example, the machine readable instructions may be stored in a state in which they may be read by programmable circuitry, but require addition of a library (e.g., a dynamic link library (DLL)), a software development kit (SDK), an application programming interface (API), etc., in order to execute the machine-readable instructions on a particular computing device or other device. In another example, the machine readable instructions may need to be configured (e.g., settings stored, data input, network addresses recorded, etc.) before the machine readable instructions and/or the corresponding program(s) can be executed in whole or in part. Thus, machine readable, computer readable and/or machine readable media, as used herein, may include instructions and/or program(s) regardless of the particular format or state of the machine readable instructions and/or program(s).

[0098] The machine readable instructions described herein can be represented by any past, present, or future instruction language, scripting language, programming language, etc. For example, the machine readable instructions may be represented using any of the following languages: C, C++, Java, C#, Perl, Python, JavaScript, HyperText Markup Language (HTML), Structured Query Language (SQL), Swift, etc.

[0099] As mentioned above, the example operations of FIGS. **15** and **16** may be implemented using executable instructions (e.g., computer readable and/or machine readable instructions) stored on one or more non-transitory computer readable and/or machine readable media. As used herein, the terms non-transitory computer readable medium, non-transitory computer readable storage medium, non-transitory machine readable medium, and/or non-transitory machine readable storage medium are expressly defined to include any type of computer readable storage device and/or storage disk and to exclude propagating signals and to exclude transmission media. Examples of such non-transitory computer readable medium, non-transitory computer readable storage medium, non-transitory machine readable medium, and/or non-transitory machine readable storage medium include optical storage devices, magnetic storage devices, an HDD, a flash memory, a read-only memory (ROM), a CD, a DVD, a cache, a RAM of any type, a register, and/or any other storage device or storage disk in which information is stored for any duration (e.g., for extended time periods, permanently, for brief instances, for temporarily buffering, and/or for caching of the information). As used herein, the terms “non-transitory computer readable storage device” and “non-transitory machine readable storage device” are defined to include any physical (mechanical, magnetic and/or electrical) hardware to retain information for a time period, but to exclude propagating signals and to exclude transmission media. Examples of non-transitory computer readable storage devices and/or non-transitory machine readable storage devices include random access memory of any type, read only memory of any type, solid state memory, flash memory, optical discs, magnetic disks, disk drives, and/or redundant array of independent disks (RAID) systems. As used herein, the term “device” refers to physical structure such as mechanical and/or electrical equipment, hardware, and/or circuitry that may or may not be configured by computer readable instructions, machine readable instructions, etc., and/or manufactured to execute computer-readable instructions, machine-readable instructions, etc.

[0100] FIG. **15** is a flowchart representative of example machine readable instructions and/or example operations **1500** that may be executed, instantiated, and/or performed by programmable circuitry to improve fan operability control using smart materials. The example machine-readable instructions and/or the example operations **1500** of FIG. **15** begin at block **1502**, at which the example monitoring circuitry **1404** monitors operating parameters. Operating parameters may include, but are not limited to, at least one of engine pressure, engine vibration, or engine speed. The example monitoring circuitry **1404** monitors the operating parameters by checking against reference values of the operating parameters.

[0101] At block **1504**, the example monitoring circuitry **1404** determines if there is a deviation from the reference values of the operating parameters. For example, a deviation from the reference values of the operating parameters may represent that an engine not operating to its standard performance. If there is no deviation from the reference values, then the process returns to block **1502**. If there is a deviation from the reference values, then the process proceeds to block **1506**.

[0102] At block **1506**, the example activator circuitry **1406** activates the smart-material-based features **220** to mitigate blade flutter and/or stall by changing the air flow. As described above, smart-material-based features **220** may include, but are not limited to, active vortex generators. The smart-material-based features **220** mitigate effects from an engine with deviations from its reference values of the operating parameters. The example activator circuitry **1406** sends a signal to the smart material actuator **226** to activate the smart-material-based features **220** using at least one of electricity, electromagnetic waves, microwaves, or a graphene-based heating element. In some examples, activation of smart-material-based features **220** can occur at a local area to counter detrimental changes (e.g., bend, dent, flutter) in a particular area. Air flow is changed to counter the detrimental changes when the smart-material-based features **220** are activated.

[0103] At block **1508**, the example controller circuitry **1408** determines if the engine is still in operating to further determine whether to continue monitoring the operating parameters or deactivate the smart-material-based features **220**. If the engine is still in operation, the process returns to block **1502** where the example monitoring circuitry **1404** monitors the operating parameters. If the engine is not still in operation, the process proceeds to block **1510**.

[0104] At block **1510**, the example controller circuitry **1408** deactivates the smart-material-based features **220** based on the operation status of the engine. After the smart-material-based features **220** are deactivated, fan operability control is improved using the smart-material-based features **220** by mitigating blade flutter and/or stall.

[0105] Turning to FIG. **16**, which is a flowchart representative of example machine readable instructions and/or example operations **1600** that may be executed, instantiated, and/or performed by programmable circuitry to improve fan operability control using smart materials and describes in more detail the adjustment of the smart-material-based features **220** based on the adjustment percentage. At block **1602**, the example monitoring circuitry **1404** monitors operating parameters. Operating parameters may include, but are not limited to, at least one of engine pressure, engine vibration, or engine speed. The example monitoring circuitry **1404** monitors the operating parameters by checking against reference values of the operating parameters.

[0106] At block **1604**, the example monitoring circuitry **1404** determines if there is a deviation from the reference values of the operating parameters. For example, a deviation from the reference values of the operating parameters may represent that an engine not operating to its standard performance. If there is no deviation from the reference values, then the process returns to block **1602**. If there is a deviation from the reference values, then the process proceeds to block **1606**.

[0107] At block **1606**, the example activator circuitry **1406** activates the smart-material-based features **220** to mitigate blade flutter and/or stall by changing the air flow. As described above, smart-material-based features **220** may include, but are not limited to, active vortex generators. The smart-material-based features **220** mitigate effects from an engine with deviations from its reference values of the operating parameters. The example activator circuitry **1406** sends a signal to the smart material actuator **226** to activate the smart-material-based features **220** using at least one of electricity, electromagnetic waves, microwaves, or a graphene-based heating element. In some examples, activation of smart-material-based features **220** can occur at a local area to counter detrimental changes (e.g., bend, dent, flutter) in a particular area. Air flow is changed to counter the detrimental changes when the smart-material-based features **220** are activated.

[0108] At block **1608**, the example controller circuitry **1408** determines whether to adjust the smart-material-based features **220** based on the adjustment percentage to mitigate the blade flutter and/or stall more effectively. If the smart-material-based feature is to be adjusted, the process proceeds to block **1610**. If the smart-material-based feature is not to be adjusted, the process proceeds to block **1614**.

[0109] At block **1610**, the example controller circuitry **1408** determines an adjustment percentage to mitigate the blade flutter and/or stall more effectively. For example, if the example controller circuitry **1408** determines that the smart-material-based features **220** need to be adjusted slightly, such as by 3%, to mitigate the blade flutter, the example controller circuitry **1408** adjusts the smart-material-based features **220** by that percentage, as described at block **1612**.

[0110] At block **1612**, the example controller circuitry **1408** adjusts the smart-material-based features **220** based on the determined percentage. Mitigation of the blade flutter may be more effective with an adjustment of smart-material-based features **220**.

[0111] At block **1614**, the example controller circuitry **1408** the example controller circuitry **1408** determines if the engine is still in operating to further determine whether to continue monitoring the operating parameters or deactivate the smart-material-based features **220**. If the engine is still in operation, the process returns to block **1602**. If the engine is not still in operation, the process proceeds to block **1616**.

[0112] At block **1616**, the example controller circuitry **1408** deactivates the smart-material-based features **220**. After the smart-material-based features **220** are deactivated, fan operability control is improved using the smart-material-based features **220** by mitigating blade flutter and/or stall (block **1610**).

[0113] FIG. **17** is a block diagram of an example programmable circuitry platform **1700** structured to execute and/or instantiate the example machine-readable instructions and/or the example operations of FIGS. **15** and **16** to implement the example full authority digital engine control circuitry **1402** of FIG. **14**. The programmable circuitry platform **1700** can be, for example, a server, a personal computer, a workstation, a self-learning machine (e.g., a neural network), a mobile device (e.g., a cell phone, a smart phone, a tablet such as an iPad™), a personal digital assistant (PDA), an Internet appliance, or any other type of computing and/or electronic device.

[0114] The programmable circuitry platform **1700** of the illustrated example includes programmable circuitry **1712**. The programmable circuitry **1712** of the illustrated example is hardware. For example, the programmable circuitry **1712** can be implemented by one or more integrated circuits, logic circuits, FPGAs, microprocessors, CPUs, GPUs, DSPs, and/or microcontrollers from any desired family or manufacturer. The programmable circuitry **1712** may be implemented by one or more semiconductor based (e.g., silicon based) devices. In this example, the programmable circuitry **1712** implements the example monitoring circuitry **1404**, the example activator circuitry **1406**, and the example controller circuitry **1408**.

[0115] The programmable circuitry **1712** of the illustrated example includes a local memory **1713** (e.g., a cache, registers, etc.). The programmable circuitry **1712** of the illustrated example is in communication with main memory **1714**, **1716**, which includes a volatile memory **1714** and a non-volatile memory **1716**, by a bus **1718**. The volatile memory **1714** may be implemented by Synchronous Dynamic Random Access Memory (SDRAM), Dynamic Random Access Memory (DRAM), RAMBUS® Dynamic Random Access Memory (RDRAM®), and/or any other type of RAM device. The non-volatile memory **1716** may be implemented by flash memory and/or any other desired type of memory device. Access to the main memory **1714**, **1716** of the illustrated example is controlled by a memory controller **1717**. In some examples, the memory controller **1717** may be implemented by one or more integrated circuits, logic circuits, microcontrollers from any desired family or manufacturer, or any other type of circuitry to manage the flow of data going to and from the main memory **1714**, **1716**.

[0116] The programmable circuitry platform **1700** of the illustrated example also includes interface circuitry **1720**. The interface circuitry **1720** may be implemented by hardware in accordance with any type of interface standard, such as an Ethernet interface, a universal serial bus (USB) interface, a Bluetooth® interface, a near field communication (NFC) interface, a Peripheral Component Interconnect (PCI) interface, and/or a Peripheral Component Interconnect Express (PCIe) interface.

[0117] In the illustrated example, one or more input devices **1722** are connected to the interface circuitry **1720**. The input device(s) **1722** permit(s) a user (e.g., a human user, a machine user, etc.) to enter data and/or commands into the programmable circuitry **1712**. The input device(s) **1722** can be implemented by, for example, an audio sensor, a microphone, a camera (still or video), a keyboard, a button, a mouse, a touchscreen, a trackpad, a trackball, an isopoint device, and/or a voice recognition system.

[0118] One or more output devices **1724** are also connected to the interface circuitry **1720** of the illustrated example. The output device(s) **1724** can be implemented, for example, by display devices (e.g., a light emitting diode (LED), an organic light emitting diode (OLED), a liquid crystal display (LCD), a cathode ray tube (CRT) display, an in-place switching (IPS) display, a touchscreen, etc.), a tactile output device, a printer, and/or speaker. The interface circuitry **1720** of the illustrated example, thus, typically includes a graphics driver card, a graphics driver chip, and/or graphics processor circuitry such as a GPU.

[0119] The interface circuitry **1720** of the illustrated example also includes a communication device such as a transmitter, a receiver, a transceiver, a modem, a residential gateway, a wireless access point, and/or a network interface to facilitate exchange of data with external machines (e.g., computing devices of any kind) by a network **1726**. The communication can be by, for example, an Ethernet connection, a digital subscriber line (DSL) connection, a telephone line connection, a coaxial cable system, a satellite system, a beyond-line-of-sight wireless system, a line-of-sight wireless system, a cellular telephone system, an optical connection, etc.

[0120] The programmable circuitry platform **1700** of the illustrated example also includes one or more mass storage discs or devices **1728** to store firmware, software, and/or data. Examples of such mass storage discs or devices **1728** include magnetic storage devices (e.g., floppy disk, drives, HDDs, etc.), optical storage devices (e.g., Blu-ray disks, CDs, DVDs, etc.), RAID systems, and/or solid-state storage discs or devices such as flash memory devices and/or SSDs.

[0121] The machine readable instructions **1732**, which may be implemented by the machine readable instructions of FIGS. **15** and **16**, may be stored in the mass storage device **1728**, in the volatile memory **1714**, in the non-volatile memory **1716**, and/or on at least one non-transitory computer readable storage medium such as a CD or DVD which may be removable.

[0122] From the foregoing, it will be appreciated that example systems, apparatus, articles of manufacture, and methods have been disclosed that improve fan operability control using smart materials. Disclosed systems, apparatus, articles of manufacture, and methods improve the efficiency of using a computing device by mitigating fan flutter, fan blade denting, and/or non-optimal tip clearance. Disclosed systems, apparatus, articles of manufacture, and methods are accordingly directed to one or more improvement(s) in the operation of a machine such as a computer or other electronic and/or mechanical device.

[0123] Example methods, apparatus, systems, and articles of manufacture to improve fan operability control using smart materials are disclosed herein. Further examples and combinations thereof include the following:

[0124] An engine comprising an engine surface in an airflow path, a sensor positioned on the engine surface, and a smart-material-based feature positioned on the engine surface, the smart-material-based feature triggered to modify the airflow path when the sensor outputs an indication of a detected deviation from a reference value of an operating parameter of the engine.

[0125] The engine of any preceding clause, wherein the engine surface includes at least one of an inner surface of a fan casing, an outer surface of a fan blade, an inner surface of a nozzle, an outer surface of the nozzle, an inlet guide vane, or an exit guide vane.

[0126] The engine of any preceding clause, wherein the engine is ducted, and further including a plurality of smart-material-based features on a plurality of engine surfaces including the inner surface of the fan casing, the outer surface of the fan blade, the inner surface of the nozzle, and the outer surface of the nozzle.

[0127] The engine of any preceding clause, wherein the engine further includes at least one of the plurality of smart-material-based features on the inlet guide vane.

[0128] The engine of any preceding clause, wherein the engine is unducted, and further including a plurality of smart-material-based features on a plurality of engine surfaces including the outer surface of the fan blade, the inner surface of the nozzle, and the outer surface of the nozzle.

[0129] The engine of any preceding clause, wherein the engine is a one-stream engine, a two-stream engine, or a three-stream engine.

[0130] The engine of any preceding clause, wherein the smart-material-based feature includes at least one of a shape memory alloy, a bi-metal material, a graphene-based element, or a composite foam.

[0131] The engine of any preceding clause, wherein the operating parameter includes at least one of engine pressure, engine vibration, or engine speed.

[0132] The engine of any preceding clause, wherein the smart-material-based feature deactivates when the engine is not in operation.

[0133] The engine of any preceding clause, wherein the smart-material-based feature adjusts by an adjustment percentage.

[0134] The engine of any preceding clause, wherein the smart-material-based feature includes an active vortex generator.

[0135] The engine of any preceding clause, wherein the active vortex generator is retractable.

[0136] The engine of any preceding clause, further including a controller and a smart material actuator, the controller sending a signal to the smart material actuator to activate the smart-material-based feature when the sensor outputs the indication of the deviation from the reference value of the operating parameter.

[0137] The engine of any preceding clause, wherein the sensor sends the signal to the controller when the sensor outputs the indication of the deviation from the reference value of the operating parameter.

[0138] The engine of any preceding clause, wherein the smart material actuator activates the smart-material-based feature using at least one of electricity, electromagnetic waves, microwaves, or a graphene-based heating element.

[0139] The engine of any preceding clause, wherein the smart-material-based feature creates at least one of a serration or a bump on the engine surface when the smart material actuator receives the signal to activate.

[0140] The engine of any preceding clause, wherein the smart material actuator activates the smart-material-based feature to create the at least one of the serration or the bump at a local area of the engine surface.

[0141] A non-transitory machine readable storage medium comprising instructions to cause programmable circuitry to at least monitor an operating parameter of an engine, activate a smart-material-based feature when a sensor outputs an indication of a detected deviation from a reference value of the operating parameter, and control the smart-material-based feature triggered to modify an airflow path of the engine.

[0142] The non-transitory machine readable storage medium of any preceding clause, wherein the operating parameter includes at least one of engine pressure, engine vibration, or engine speed.

[0143] The non-transitory machine readable storage medium of any preceding clause, wherein the sensor sends a signal to a controller when the sensor outputs the indication of the deviation from the reference value of the operating parameter.

[0144] The non-transitory machine readable storage medium of any preceding clause, wherein the controller sends a signal to a smart material actuator to activate the smart-material-based feature.

[0145] The non-transitory machine readable storage medium of any preceding clause, wherein the smart-material-based feature creates at least one of a serration or a bump on an engine surface when the smart material actuator receives the signal to activate.

[0146] A turbofan engine comprising a fan casing having an inner surface, the inner surface defining a flowpath, a fan blade in the flowpath, a nozzle having an inner surface and an outer surface, and a smart-material-based feature positioned in the flowpath on at least one of the inner surface of the fan casing, an exterior surface of the fan blade, the inner surface of the nozzle, or the outer surface of the nozzle, the smart-material-based feature to, when actuated, modify a flow of air in the flowpath.

[0147] The turbofan engine of any preceding clause, wherein the turbofan engine is a two-stream turbofan engine or a three-stream turbofan engine.

[0148] The turbofan engine of any preceding clause, wherein the smart-material-based feature includes at least one of a shape memory alloy, a bi-metal material, a graphene-based element, or a composite foam.

[0149] The turbofan engine of any preceding clause, further including an inlet guide vane, wherein the smart-material-based feature is positioned in the flowpath on the inlet guide vane.
[0150] The turbofan engine of any preceding clause, further including a sensor, the sensor monitoring an operating parameter of the turbofan engine for a deviation from a reference value of an operating parameter.
[0151] The turbofan engine of any preceding clause, wherein the operating parameter includes at least one of engine pressure, engine vibration, or engine speed.
[0152] The turbofan engine of any preceding clause, wherein the smart-material-based feature includes an active vortex generator.
[0153] The turbofan engine of any preceding clause, wherein the active vortex generator is retractable.
[0154] The turbofan engine of any preceding clause, further including a controller and a smart material actuator, the controller sending a signal to the smart material actuator to activate the smart-material-based feature when the sensor monitors the deviation from the reference value of the operating parameter.
[0155] The turbofan engine of any preceding clause, wherein the sensor sends a signal to the controller when the sensor monitors the deviation from the reference value of the operating parameter.
[0156] The turbofan engine of any preceding clause, wherein the smart material actuator activates the smart-material-based feature using at least one of electricity, electromagnetic waves, microwaves, or a graphene-based heating element.
[0157] The turbofan engine of any preceding clause, wherein the smart-material-based feature creates at least one of a serration or a bump on at least one of the inner surface of the fan casing, the exterior surface of the fan blade, the inner surface of the nozzle, the outer surface of the nozzle, or the inlet guide vane when the smart material actuator receives the signal to activate.
[0158] The turbofan engine of any preceding clause, wherein the smart-material-based feature activates the active vortex generator when the smart material actuator receives the signal to activate.
[0159] An unducted gas turbine engine comprising a fan blade having an exterior surface in a flowpath, a nozzle having an inner surface and an outer surface, and a smart-material-based feature positioned in the flowpath on at least one of the exterior surface of the fan blade, the inner surface of the nozzle, or the outer surface of nozzle, the smart-material-based feature to, when actuated, modify a flow of air in the flowpath.
[0160] The unducted gas turbine engine of any preceding clause, wherein the unducted gas turbine engine is a two-stream gas turbine engine or a three-stream gas turbine engine.
[0161] The unducted gas turbine engine of any preceding clause, wherein the smart-material-based feature includes at least one of a shape memory alloy, a bi-metal material, a graphene-based element, or a composite foam.
[0162] The unducted gas turbine engine of any preceding clause, further including an exit guide vane, wherein the smart-material-based feature is positioned in the flowpath on at least one of the exit guide vane.
[0163] The unducted gas turbine engine of any preceding clause, wherein the smart-material-based feature includes an active vortex generator.
[0164] The unducted gas turbine engine of any preceding clause, wherein the active vortex generator is retractable.
[0165] The unducted gas turbine engine of any preceding clause, further including a sensor, the sensor monitoring an operating parameter of the unducted gas turbine engine for a deviation from a reference value of an operating parameter.
[0166] The unducted gas turbine engine of any preceding clause, wherein the operating parameter includes at least one of engine pressure, engine vibration, or engine speed.

[0167] The unducted gas turbine engine of any preceding clause, further including a controller and a smart material actuator, the controller sending a signal to the smart material actuator to activate the smart-material-based feature when the sensor monitors the deviation from the reference value of the operating parameter.
[0168] The unducted gas turbine engine of any preceding clause, wherein the sensor sends a signal to the controller when the sensor monitors the deviation from the reference value of the operating parameter.
[0169] The unducted gas turbine engine of any preceding clause, wherein the smart material actuator activates the smart-material-based feature using at least one of electricity, electromagnetic waves, microwaves, or a graphene-based heating element.
[0170] The unducted gas turbine engine of any preceding clause, wherein the smart-material-based feature creates at least one of a serration or a bump on at least one of exterior surface of the fan blade, at least one of exit guide vane, or at least one of the inner surface or outer surface of the nozzle when the smart material actuator receives the signal to activate.
[0171] The unducted gas turbine engine of any preceding clause, wherein the smart-material-based feature activates the active vortex generator when the smart material actuator receives the signal to activate.
[0172] A turbofan engine comprising a fan casing having an inner surface, the inner surface defining a flowpath, a fan blade in the flowpath, a nozzle having an inner surface and an outer surface, an inlet guide vane, and a smart-material-based feature positioned in the flowpath on at least one of the inner surface of the fan casing, an exterior surface of the fan blade, the inner surface of the nozzle, the outer surface of the nozzle, or the inlet guide vane, the smart-material-based feature to, when actuated, modify a flow of air in the flowpath.
[0173] The turbofan engine of any preceding clause, wherein the turbofan engine is a two-stream turbofan engine or a three-stream turbofan engine.
[0174] The following claims are hereby incorporated into this Detailed Description by this reference. Although certain example systems, apparatus, articles of manufacture, and methods have been disclosed herein, the scope of coverage of this patent is not limited thereto. On the contrary, this patent covers all systems, apparatus, articles of manufacture, and methods fairly falling within the scope of the claims of this patent.

Claims

1. A non-transitory machine-readable storage medium comprising instructions to cause programmable circuitry to at least: determine whether an engine is in operation; monitor an operating parameter of the engine when the engine is determined to be in operation; and adjust a smart-material-based feature based on a deviation from a reference value for the operating parameter of the engine, the deviation determined from the monitoring of the operating parameter, wherein the smart-material-based feature is positioned on a surface of the engine to modify, when adjusted, an airflow path to mitigate blade flutter when the engine is in operation.
2. The non-transitory machine-readable storage medium of claim 1, wherein to adjust the smart-material-based feature based on the deviation from the reference value for the operating parameter of the engine includes to cause the programmable circuitry to: determine an adjustment percentage to mitigate the operating parameter, wherein the adjustment percentage is based on the operating parameter; and adjust the smart-material-based feature based on the adjustment percentage to mitigate the operating parameter.
3. The non-transitory machine-readable storage medium of claim 1, wherein to monitor the operating parameter of the engine includes to cause the programmable circuitry to determine the deviation from the reference value for the operating parameter of the engine.
4. The non-transitory machine-readable storage medium of claim 1, further including to cause the

programmable circuitry to deactivate the smart-material-based feature based on a determination that the engine is not in operation.
5. The non-transitory machine-readable storage medium of claim 1, further including to cause the programmable circuitry to monitor the operating parameter of the engine based on a determination that the engine is in operation after adjustment of the smart-material-based feature.
6. The non-transitory machine-readable storage medium of claim 1, wherein the operating parameter includes at least one of engine pressure, engine vibration, or engine speed.
7. The non-transitory machine-readable storage medium of claim 1, wherein the smart-material-based feature includes at least one of a shape memory alloy, a bi-metal material, a graphene-based element, a composite foam, and/or an active vortex generator.
8. An apparatus for adjusting a smart-material-based feature of a turbine engine, comprising: interface circuitry; machine-readable instructions; one or more processors configured to execute the machine-readable instructions to: determine whether the turbine engine is in operation; monitor an operating parameter of the turbine engine when the turbine engine is determined to be in operation; and adjust the smart-material-based feature based on a deviation from a reference value for the operating parameter of the turbine engine, the deviation determined from the monitoring of the operating parameter, wherein the smart-material-based feature is positioned on a surface of the turbine engine to modify, when adjusted, an airflow path to mitigate blade flutter when the turbine engine is in operation.
9. The apparatus of claim 8, wherein to adjust the smart-material-based feature based on the deviation from the reference value for the operating parameter of the turbine engine includes to cause the one or more processors to: determine an adjustment percentage to mitigate the operating parameter, wherein the adjustment percentage is based on the operating parameter; and adjust the smart-material-based feature based on the adjustment percentage to mitigate the operating parameter.
10. The apparatus of claim 8, wherein to monitor the operating parameter of the turbine engine includes to cause the one or more processors to determine the deviation from the reference value for the operating parameter of the turbine engine.
11. The apparatus of claim 8, wherein the machine-readable instructions include to cause the one or more processors to deactivate the smart-material-based feature based on a determination that the turbine engine is not in operation.
12. The apparatus of claim 8, wherein the machine-readable instructions include to cause the one or more processors to monitor the operating parameter of the turbine engine based on a determination that the turbine engine is in operation after the adjustment of the smart-material-based feature.
13. The apparatus of claim 8, wherein the operating parameter includes at least one of engine pressure, engine vibration, or engine speed.
14. The apparatus of claim 8, wherein the smart-material-based feature includes at least one of a shape memory alloy, a bi-metal material, a graphene-based element, a composite foam, and/or an active vortex generator.
15. A method for adjusting a smart-material-based feature of a turbine engine, comprising: determining whether the turbine engine is in operation; monitoring an operating parameter of the turbine engine when the turbine engine is determined to be in operation; and adjusting the smart-material-based feature based on a deviation from a reference value for the operating parameter of the turbine engine, the deviation determined from the monitoring of the operating parameter, wherein the smart-material-based feature is positioned on a surface of the turbine engine to modify, when adjusted, an airflow path to mitigate blade flutter when the turbine engine is in operation.
16. The method of claim 15, wherein adjusting the smart-material-based feature based on the deviation from the reference value for the operating parameter of the turbine engine includes: determining an adjustment percentage to mitigate the operating parameter, wherein the adjustment percentage is based on the operating parameter; and adjusting the smart-material-based feature

based on the adjustment percentage to mitigate the operating parameter.

17. The method of claim 15, wherein monitoring the operating parameter of the turbine engine includes determining the deviation from the reference value for the operating parameter of the turbine engine.

18. The method of claim 15, further includes deactivating the smart-material-based feature based on a determination that the turbine engine is not in operation.

19. The method of claim 15, further includes monitoring the operating parameter of the turbine engine based on a determination that the turbine engine is in operation after the adjustment of the smart-material-based feature.

20. The method of claim 15, wherein the operating parameter includes at least one of engine pressure, engine vibration, or engine speed.