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Goyette et al.

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(54) **PROPULSOR BLADE IMAGING ASSEMBLY
FOR AN AIRCRAFT PROPULSION SYSTEM**

2260/80; F05D 2270/8041; H04N 23/56;
H04N 7/188; G01B 5/205

See application file for complete search history.

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(57) **ABSTRACT**

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An assembly for an aircraft propulsion system includes a propulsor section, an imaging device, a plurality of light sources, and a controller. The propulsor section includes a propulsor. The propulsor includes a plurality of propulsor blades. The imaging device is disposed in the propulsor section. The imaging device includes a camera. The plurality of light sources are disposed in the propulsor section. The controller includes a processor in communication with a non-transitory memory storing instructions, which instructions when executed by the processor, cause the processor to: control the plurality of light sources to direct light to the plurality of propulsor blades, control the camera to capture image data of each propulsor blade of the plurality of propulsor blades, and identify a presence or an absence of damage for each propulsor blade of the plurality of propulsor blades using the image data.

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(51) **Int. Cl.**

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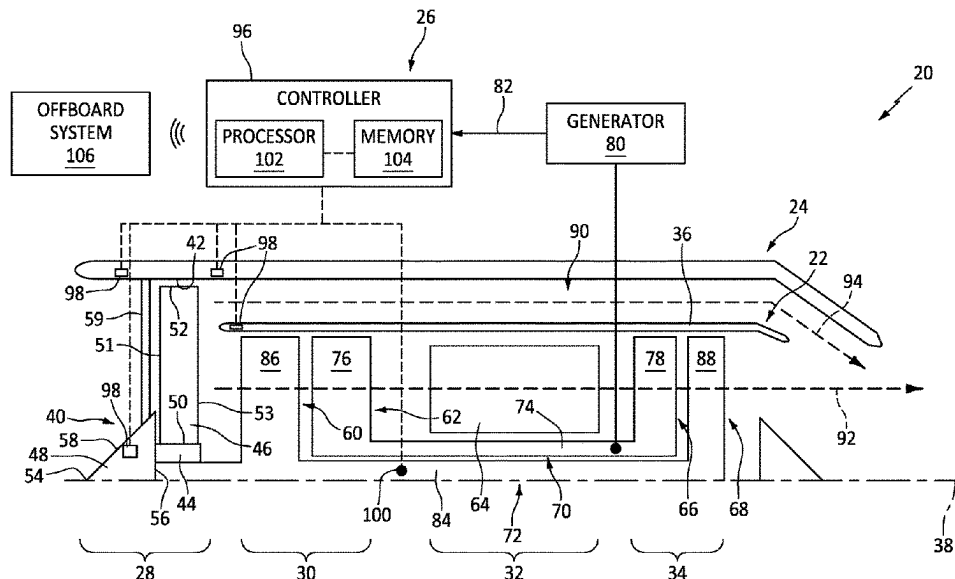
(52) **U.S. Cl.**

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(2013.01); **H04N 23/56** (2023.01); **F05D**
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F05D 2260/83; F05D 2220/36; F05D

20 Claims, 6 Drawing Sheets



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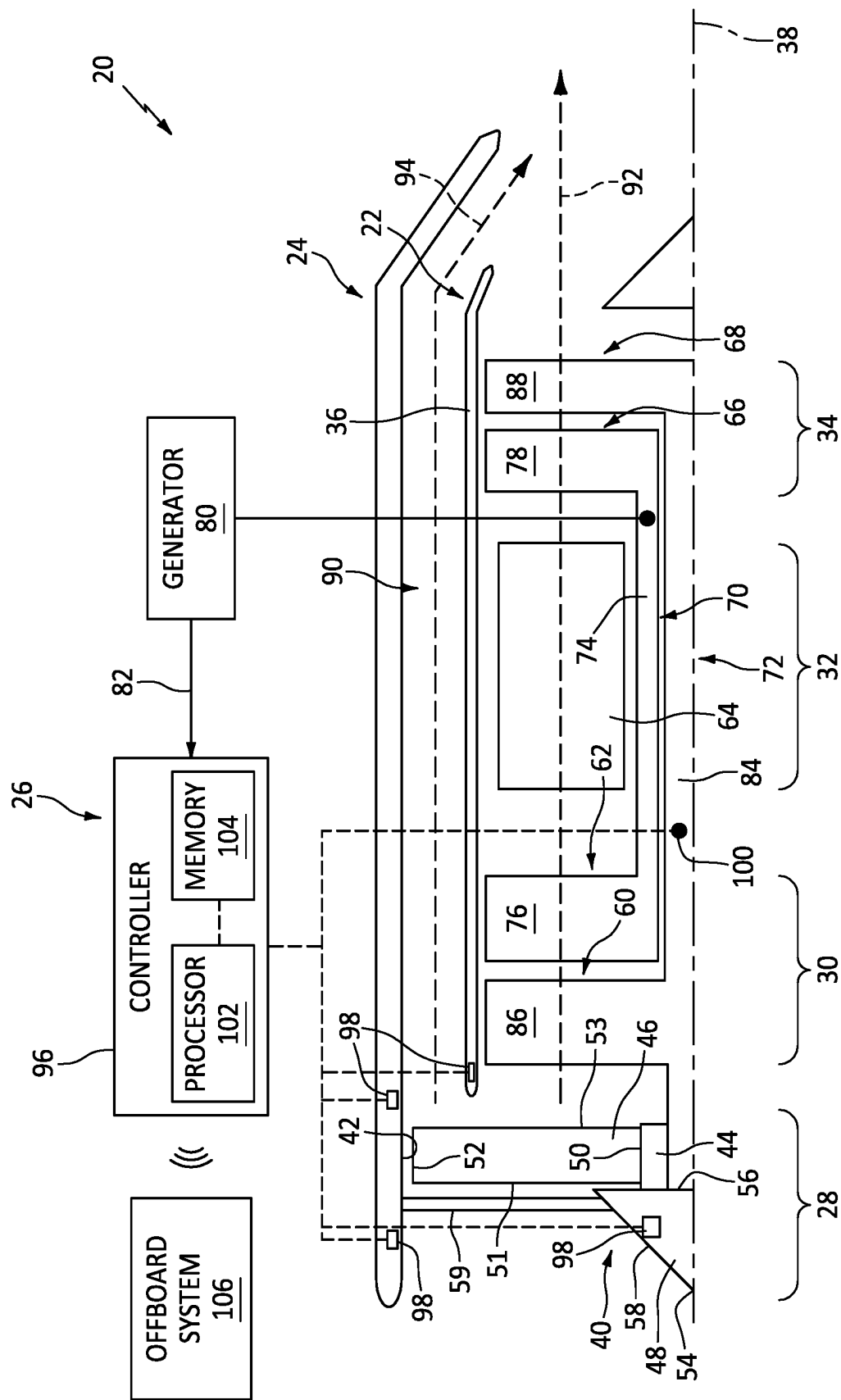


FIG. 1

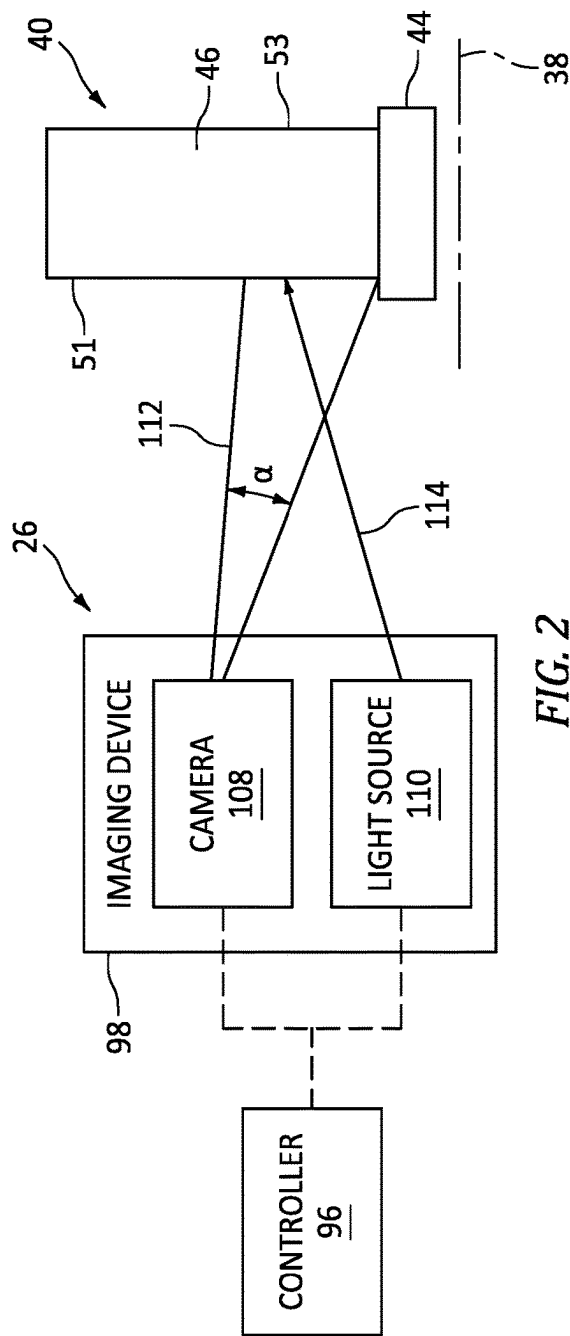


FIG. 2

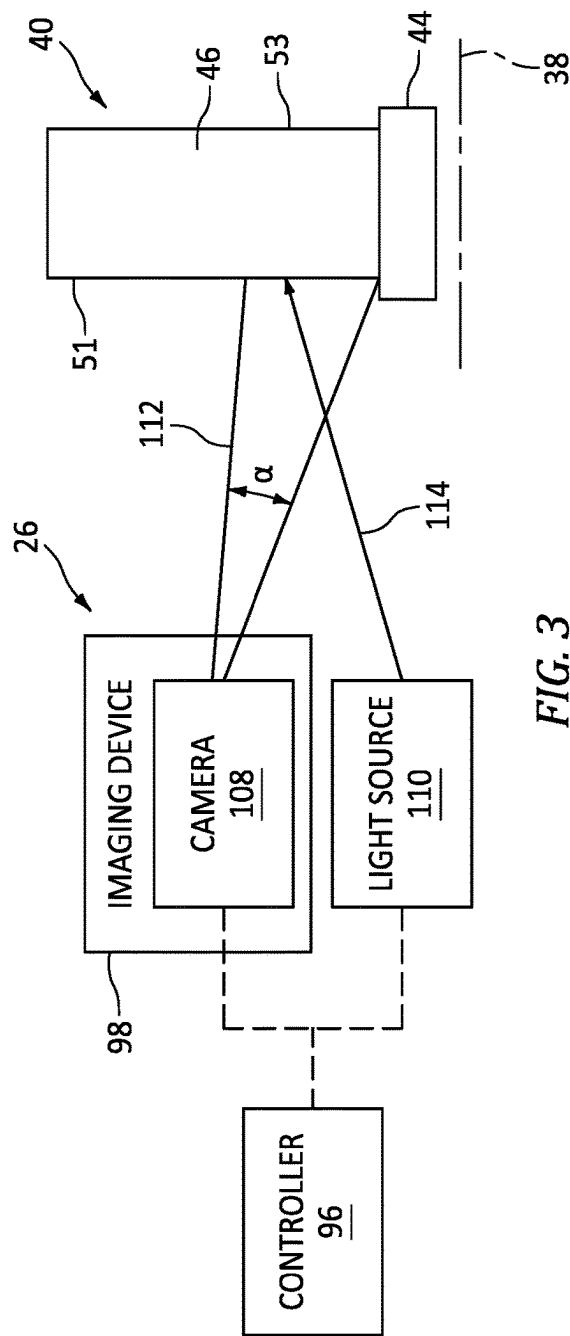


FIG. 3

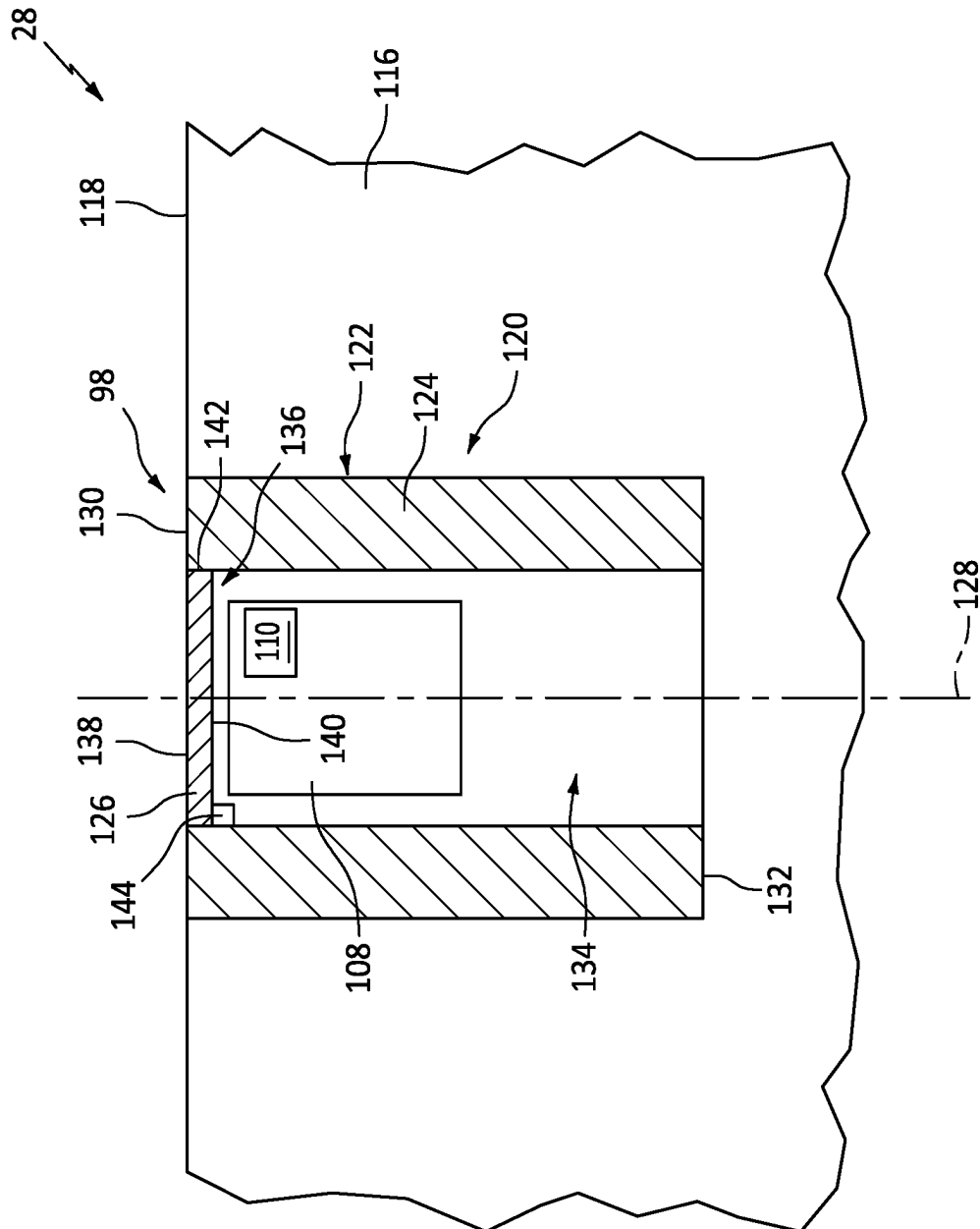


FIG. 4

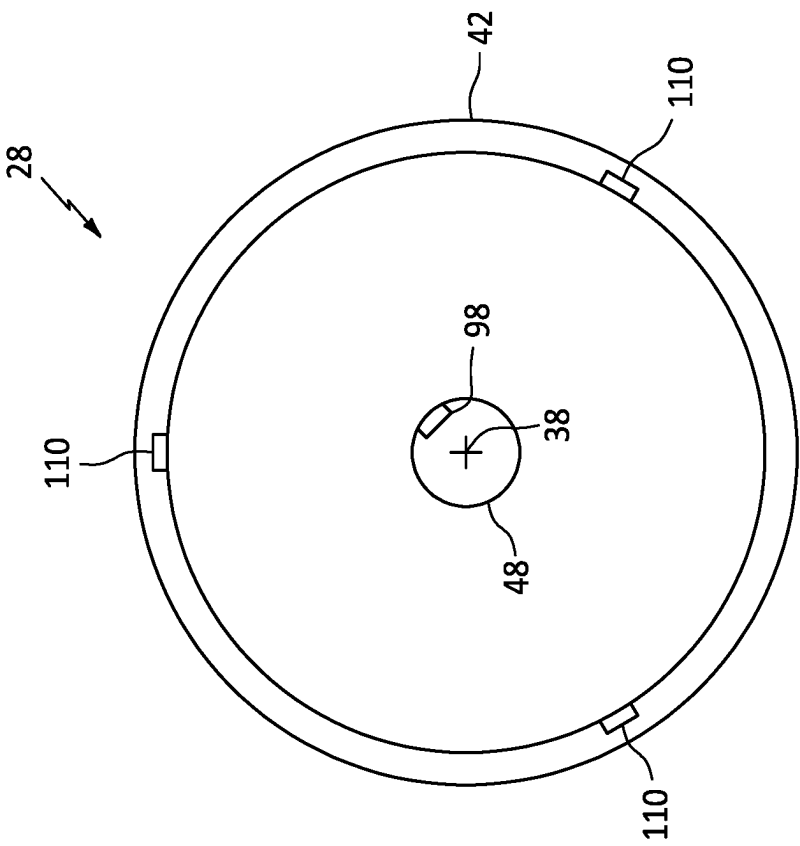


FIG. 5

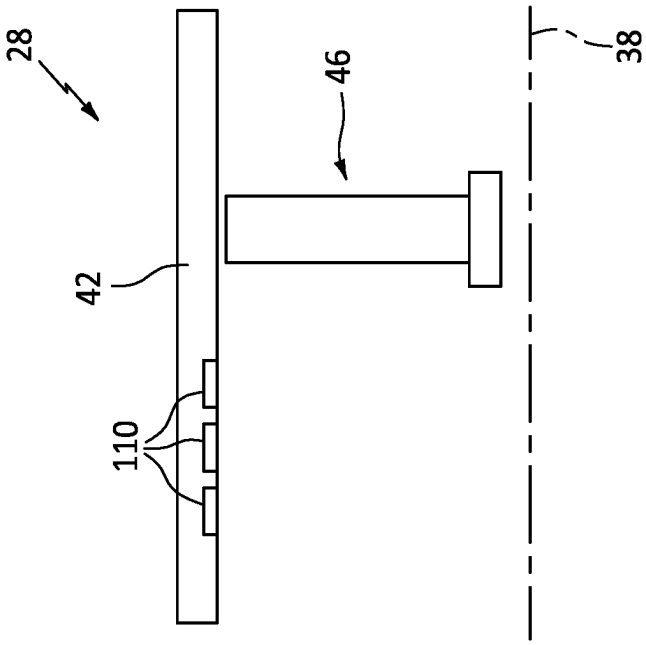
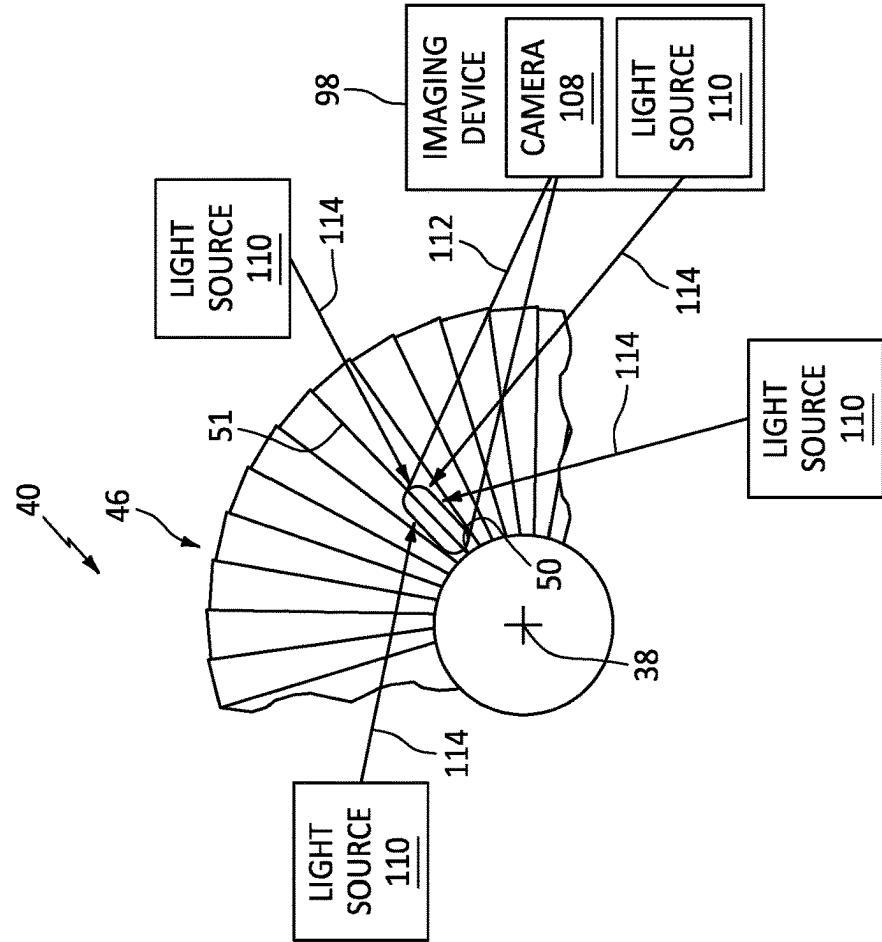
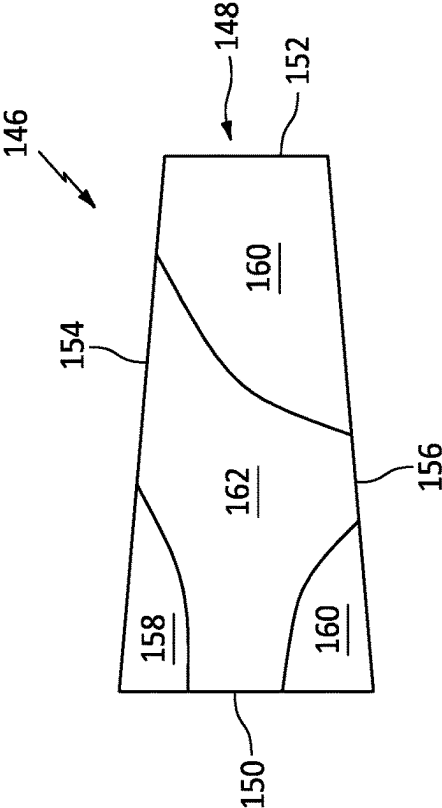


FIG. 6



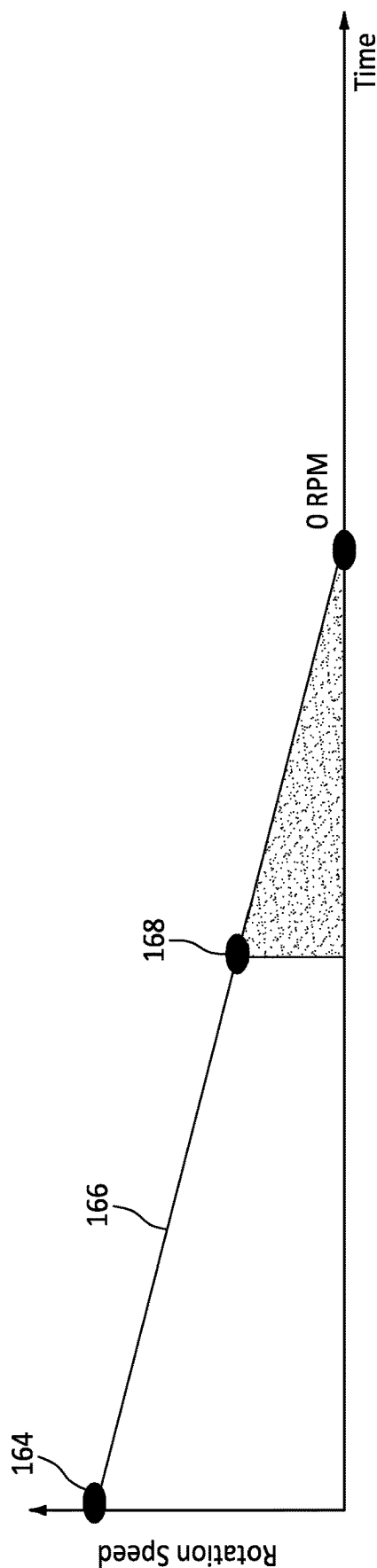


FIG. 9

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PROPULSOR BLADE IMAGING ASSEMBLY FOR AN AIRCRAFT PROPULSION SYSTEM

BACKGROUND

1. Technical Field

The present disclosure relates to aircraft propulsion systems and, more particularly, to imaging assemblies for in situ inspection of propulsor blades for aircraft propulsion systems.

2. Background Information

Propulsion systems for aircraft may include rotational equipment, such as propulsors or other rotational equipment components, which may be susceptible to foreign object damage (FOD). Various systems and methods for inspecting rotational equipment components for FOD are known in the art. While these known systems and methods have various advantages, there is still room in the art for improvement. There is a need in the art, therefore, for improved systems and methods for identifying damage to propulsors and other rotational equipment for aircraft propulsion systems.

SUMMARY

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

According to an aspect of the present disclosure, an assembly for an aircraft propulsion system includes a propulsor section for the aircraft propulsion system, an imaging device, a plurality of light sources, and a controller. The propulsor section includes a propulsor. The propulsor includes a plurality of propulsor blades configured for rotation about a rotational axis of the aircraft propulsion system. The imaging device is disposed in the propulsor section. The imaging device includes a camera. The plurality of light sources are disposed in the propulsor section. The controller is connected in signal communication with the imaging device and the plurality of light sources. The controller includes a processor in communication with a non-transitory memory storing instructions, which instructions when executed by the processor, cause the processor to: control the plurality of light sources to direct light to the plurality of propulsor blades, control the camera to capture image data of each propulsor blade of the plurality of propulsor blades as the plurality of propulsor blades rotate about the rotational axis, and identify a presence or an absence of damage for each propulsor blade of the plurality of propulsor blades using the image data.

In any of the aspects or embodiments described above and herein, the plurality of light sources may include a first light source and a second light source. The first light source may be disposed at a first circumferential position. The second light source may be disposed at a second circumferential position different than the first circumferential position.

In any of the aspects or embodiments described above and herein, the plurality of light sources may include a first light source and a second light source. The first light source may be disposed at a first axial position. The second light source may be disposed at a second axial position different than the first axial position.

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In any of the aspects or embodiments described above and herein, the instructions, when executed by the processor, may further cause the processor to control the plurality of light sources to establish a first lighting combination of the plurality of light sources and a second lighting combination of the plurality of light sources. The second lighting combination may be different than the first lighting combination.

In any of the aspects or embodiments described above and herein, the plurality of light sources may include a first light source. In the first lighting combination the first light source may be energized and in the second lighting combination the first light source may be deenergized.

In any of the aspects or embodiments described above and herein, the instructions, when executed by the processor, may further cause the processor to control the camera to capture image data of each propulsor blade of the plurality of propulsor blades for both the first lighting combination and the second lighting combination.

In any of the aspects or embodiments described above and herein, the instructions, when executed by the processor, may further cause the processor to identify the presence or the absence of damage for each propulsor blade of the plurality of propulsor blades by determining a damage probability for each propulsor blade of the plurality of propulsor blades using the image data captured by the camera for both the first lighting combination and the second lighting combination.

In any of the aspects or embodiments described above and herein, the instructions, when executed by the processor, may further cause the processor to identify the presence or the absence of damage for each propulsor blade of the plurality of propulsor blades by comparing the damage probability for each propulsor blade of the plurality of propulsor blades to a damage probability threshold.

In any of the aspects or embodiments described above and herein, the propulsor further may include a nose cone disposed axially adjacent the plurality of propulsor blades. The nose cone may be rotationally fixed relative to the rotational axis. The plurality of light sources may include a first light source. The first light source may be disposed on the nose cone.

In any of the aspects or embodiments described above and herein, the propulsor section may further include a propulsor case extending circumferentially about the rotational axis and circumscribing the plurality of propulsor blades. The plurality of light sources may include a first light source. The first light source may be disposed on the propulsor case.

In any of the aspects or embodiments described above and herein, each propulsor blade of the plurality of propulsor blades may include a root end, a tip end, a leading edge, and a trailing edge. The leading edge and the trailing edge may extend radially between and to the root end and the tip end. Each light source of the plurality of light sources may be configured to direct light to a same portion of a radial span of each propulsor blade of the plurality of propulsor blades as the plurality of propulsor blades rotate about the rotational axis.

In any of the aspects or embodiments described above and herein, the same portion may include the leading edge at the root end.

In any of the aspects or embodiments described above and herein, the instructions, when executed by the processor, may further cause the processor to initiate the capture of the image data by controlling the camera to capture the image data based on a measured rotation speed of the propulsor about the rotational axis.

In any of the aspects or embodiments described above and herein, the instructions, when executed by the processor, may further cause the processor to transmit to an offboard system an indication of identification of the presence of damage to at least one propulsor blade of the plurality of propulsor blades.

According to another aspect of the present disclosure, a method for inspecting a plurality of propulsor blades for an aircraft propulsion system is provided. The method includes rotating the plurality of propulsor blades about a rotational axis, controlling a plurality of light sources to direct light to the plurality of propulsor blades, controlling a camera to capture image data of each propulsor blade of the plurality of propulsor blades as the plurality of propulsor blades rotate about the rotational axis, and identify a presence or an absence of damage for each propulsor blade of the plurality of propulsor blades using the image data.

In any of the aspects or embodiments described above and herein, controlling the plurality of light sources to direct light to the plurality of propulsor blades may include controlling the plurality of light sources to establish a first lighting combination of the plurality of light sources and a second lighting combination of the plurality of light sources. The second lighting combination may be different than the first lighting combination.

In any of the aspects or embodiments described above and herein, controlling the camera to capture image data of each propulsor blade of the plurality of propulsor blades may include: controlling the camera to capture image data of each propulsor blade of the plurality of propulsor blades for the first lighting combination and controlling the camera to capture image data of each propulsor blade of the plurality of propulsor blades subsequent to controlling the camera to capture image data of each propulsor blade of the plurality of propulsor blades for the first lighting combination.

In any of the aspects or embodiments described above and herein, controlling the plurality of light sources to establish the first lighting combination and the second lighting combination may include: controlling the plurality of light sources to establish the first lighting combination for a first rotational position of the plurality of propulsor blades and controlling the plurality of light sources to establish the second lighting combination for a second rotational position of the plurality of propulsor blades. The second rotational position may be different than the first rotational position.

According to another aspect of the present disclosure, a propulsion system for an aircraft includes a gas turbine engine and an imaging assembly. The gas turbine engine includes a rotational assembly and a propulsor. The rotational assembly includes a shaft rotatable about a rotational axis. The propulsor includes a plurality of propulsor blades. Each propulsor blade of the plurality of propulsor blades includes a root end, a tip end, a leading edge, and a trailing edge. The leading edge and the trailing edge extend radially between and to the root end and the tip end. The imaging assembly includes a camera, a plurality of light sources, and a controller. The camera is configured to capture image data of the leading edge of each propulsor blade of the plurality of propulsor blades as the plurality of propulsor blades rotate about the rotational axis. The camera has a fixed field-of-view. Each light source of the plurality of light sources is configured to direct light to the leading edge of each propulsor blade of the plurality of propulsor blades as the plurality of propulsor blades rotate about the rotational axis. The controller is connected in signal communication with the camera and each light source of the plurality of light

sources. The controller includes a processor in communication with a non-transitory memory storing instructions, which instructions when executed by the processor, cause the processor to: identify a presence or an absence of damage for each propulsor blade of the plurality of propulsor blades using the image data from the camera.

In any of the aspects or embodiments described above and herein, the plurality of light sources may include a first light source and a second light source. The first light source may be disposed at a first circumferential position. The second light source may be disposed at a second circumferential position different than the first circumferential position.

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

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates a schematic side, cutaway view of an aircraft propulsion system, in accordance with one or more embodiments of the present disclosure.

FIG. 2 illustrates a block diagram of a propulsor blade imaging assembly for an aircraft propulsion system, in accordance with one or more embodiments of the present disclosure.

FIG. 3 illustrates a block diagram of another propulsor blade imaging assembly for an aircraft propulsion system, in accordance with one or more embodiments of the present disclosure.

FIG. 4 illustrates a side, cutaway view of an imaging device for a propulsor blade imaging assembly, in accordance with one or more embodiments of the present disclosure.

FIG. 5 illustrates a schematic front, cutaway view of an aircraft propulsion system with a propulsor blade imaging assembly, in accordance with one or more embodiments of the present disclosure.

FIG. 6 illustrates a schematic side, cutaway view of an aircraft propulsion system with another propulsor blade imaging assembly, in accordance with one or more embodiments of the present disclosure.

FIG. 7 illustrates a schematic front, cutaway view of an aircraft propulsion system propulsor and a propulsor blade imaging assembly, in accordance with one or more embodiments of the present disclosure.

FIG. 8 illustrates exemplary image data for a portion of a propulsor blade, in accordance with one or more embodiments of the present disclosure.

FIG. 9 illustrates an exemplary graph of an aircraft propulsion system propulsor rotation speed during an engine shutdown, in accordance with one or more embodiments of the present disclosure.

DETAILED DESCRIPTION

FIG. 1 schematically illustrates a side, cutaway view of a propulsion system 20 configured for an aircraft. The aircraft propulsion system 20 of FIG. 1 includes a gas turbine engine 22, a nacelle 24, and an imaging assembly 26.

The gas turbine engine 22 of FIG. 1 is configured as a multi-spool turbopropulsor gas turbine engine. The gas turbine engine 22 of FIG. 1 includes a propulsor section 28, a compressor section 30, a combustor section 32, a turbine section 34, and an engine static structure 36. The present disclosure, however, is not limited to the particular gas turbine engine 22 configuration of FIG. 1. For example,

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aspects of the present disclosure may also be applicable to propulsion system gas turbine engines having single-spool and three-spool configurations.

The gas turbine engine 22 sections 28, 30, 32, and 34, of FIG. 1 are arranged sequentially along an axial centerline 38 (e.g., a rotational axis) of the gas turbine engine 22. The engine static structure 36 may include, for example, one or more engine cases for the gas turbine engine 22. The engine static structure 36 may additionally include cowlings, bearing assemblies, or other structural components of the gas turbine engine 22. The engine static structure 36 and its components house, structurally support, and/or rotationally support components of the engine sections 28, 30, 32, and 34.

The propulsor section 28 includes a propulsor 40 (e.g., a fan, an open rotor propulsor, etc.) The propulsor section 28 may additionally include a propulsor case 42 (e.g., a fan case). The propulsor 40 includes a propulsor disk 44, a plurality of propulsor blades 46, and a nose cone 48. The propulsor disk 44 is configured as an annular body. For example, the propulsor disk 44 extends circumferentially about (e.g., completely around) the axial centerline 38. Each of the plurality of propulsor blades 46 includes a root end 50 and a tip end 52. The root end 50 is mounted to the propulsor disk 44. Each of the plurality of propulsor blades 46 extends radially outward from the root end 50 to the tip end 52. Each of the plurality of propulsor blades 46 further includes a leading edge 51 (e.g., an axially forward edge) and a trailing edge 53 (e.g., an axially aft edge). Each of the plurality of propulsor blades 46 extends between and to the leading edge 51 and the trailing edge 53. Each of the leading edge 51 and the trailing edge 53 extend between and to the root end 50 and the tip end 52. The plurality of propulsor blades 46 are circumferentially distributed about the propulsor disk 44.

The nose cone 48 forms an aerodynamic structure of the propulsor 40 axially adjacent the propulsor disk 44. For example, the nose cone 48 may be disposed upstream of (e.g., axially forward of) the propulsor disk 44. The nose cone 48 extends (e.g., axially extends) between and to a leading end 54 of the nose cone 48 and a trailing end 56 of the nose cone 48. The leading end 54 is disposed upstream of (e.g., axially forward of) the trailing end 56. The trailing end 56 is disposed at (e.g., on, adjacent, or proximate) the propulsor disk 44. The nose cone 48 forms an exterior surface 58 extending between and to the leading end 54 and the trailing end 56. The exterior surface 58 is configured with a conical shape which radially diverges in a direction from the leading end 54 to the trailing end 56. The nose cone 48 may be rotatable about the axial centerline 38 (with the propulsor disk 44) or the nose cone 48 may be rotationally fixed relative to the axial centerline 38. For example, the nose cone 48 of FIG. 1 is rotationally fixed relative to the axial centerline 38. In other words, the propulsor disk 44 and the plurality of propulsor blades 46 may rotate about the axial centerline 38 while the nose cone 48 remains rotationally fixed relative to the axial centerline 38. The propulsor 40 may include one or more struts 59, vanes, or other structural components for supporting the nose cone 48 (e.g., for mounting the nose cone 48 to the propulsor case 42); however, the present disclosure is not limited to any particular mounting configuration for the nose cone 48. The propulsor case 42 extends circumferentially about (e.g., completely around) the axial centerline 38. The propulsor case 42 radially circumscribes the plurality of propulsor blades 46. The propulsor case 42 may be formed by or otherwise disposed at the nacelle 24.

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The compressor section 30 may include a low-pressure compressor (LPC) 60 and a high-pressure compressor (HPC) 62. The combustor section 32 includes a combustor 64 (e.g., an annular combustor) forming a combustion chamber. The turbine section 34 may include a high-pressure turbine (HPT) 66 a low-pressure turbine (LPT) 68.

The gas turbine engine 22 sections 28, 30, 32, 34 form a first rotational assembly 70 (e.g., a high-pressure spool) and a second rotational assembly 72 (e.g., a low-pressure spool) of the gas turbine engine 22. The first rotational assembly 70 and the second rotational assembly 72 of FIG. 1 are mounted for rotation about the axial centerline 38 relative to the engine static structure 36. Alternatively, the first rotational assembly 70 and the second rotational assembly 72 may each be mounted for rotation about different respective rotational axes.

The first rotational assembly 70 includes a first shaft 74, a bladed first compressor rotor 76 for the high-pressure compressor 62, and a bladed first turbine rotor 78 for the high-pressure turbine 66. The first shaft 74 interconnects the bladed first compressor rotor 76 and the bladed first turbine rotor 78. The first rotational assembly 70 may further include one or more engine accessories connected in rotational communication with the first shaft 74. For example, the first rotational assembly 70 of FIG. 1 includes a generator 80 connected in rotational communication with the first shaft 74. The generator 80 may be directly mechanically coupled to the first shaft 74. Alternatively, the generator 80 may be indirectly mechanically coupled to the first shaft 74, for example, by an accessory gear assembly (not shown) configured to rotationally drive the generator 80 at a reduced rotational speed relative to the first shaft 74. Rotation of the first shaft 74 drives rotation of the generator 80 causing the generator 80 to generate electrical power for electrical loads (e.g., electronic control systems, electric motors, lighting systems, etc.) of the propulsion system 20 and/or an aircraft on which the propulsion system 20 is installed. For example, the generator 80 may direct electrical power 82 to all or a portion of the imaging assembly 26. While engine accessories, such as the generator 80, are described above as components of the first rotational assembly 70, the engine accessories (e.g., the generator 80) may alternatively be components of the second rotational assembly 72 and may be mechanically coupled to and driven by the second rotational assembly 72 in a similar manner.

The second rotational assembly 72 includes a second shaft 84, a bladed second compressor rotor 86 for the low-pressure compressor 60, and a bladed second turbine rotor 88 for the low-pressure turbine 68. The second shaft 84 interconnects the bladed second compressor rotor 86 and the bladed second turbine rotor 88. The second shaft 84 may be directly or indirectly connected to the propulsor 40 (e.g., the propulsor disk 44) to drive rotation of the propulsor 40. For example, the second shaft 84 may be connected to the propulsor 40 by one or more speed-reducing gear assemblies (not shown) to drive the propulsor 40 at a reduced rotational speed relative to the second shaft 84.

The nacelle 24 forms an exterior aerodynamic housing for the propulsion system 20. The nacelle 24 of FIG. 1 extends circumferentially about (e.g., completely around) the axial centerline 38 and surrounds the gas turbine engine 22. The nacelle 24 surrounds and forms an annular bypass duct 90 between (e.g., radially between) the nacelle 24 and the engine static structure 36 (e.g., a core cowling).

During operation of the gas turbine engine 22 of FIG. 1, ambient air enters the gas turbine engine 22 through the propulsor section 28 and is directed into a core flow path 92

and a bypass flow path **94** by rotation of the propulsor **40**. The core flow path **92** extends generally axially along the axial centerline **38** in the gas turbine engine **22**. For example, the core flow path **92** extends axially through the gas turbine engine **22** sections **30**, **32**, and **34** of FIG. 1. The air in the core flow path **92** may be referred to as “core air.” The core air is compressed by the bladed second compressor rotor **86** and the bladed first compressor rotor **76** and directed into the combustion chamber of the combustor **64**. Fuel is injected into the combustion chamber and mixed with the compressed core air to form a fuel-air mixture. This fuel-air mixture is ignited and combustion products thereof, which may be referred to as “core combustion gas,” flow through and sequentially cause the bladed first turbine rotor **78** and the bladed second turbine rotor **88** to rotate. The rotation of the bladed first turbine rotor **78** and the bladed second turbine rotor **88** respectively drive rotation of the first rotational assembly **70** and the second rotational assembly **72**. Rotation of the second rotational assembly **72** further drives rotation of the propulsor **40**, as discussed above. The air in the bypass flow path **94** is directed through the bypass duct **90**. The air in the bypass flow path **94** may be referred to as “bypass air.”

The imaging assembly **26** of FIG. 1 includes a controller **96** and one or more imaging devices **98**. The imaging assembly **26** may additionally include a shaft speed sensor **100**.

The controller **96** is connected in signal communication with the imaging device(s) **98** to perform the functions described herein. The controller **96** includes a processor **102** and memory **104**. The memory **104** is connected in signal communication with the processor **102**. The processor **102** may include any type of computing device, computational circuit, processor(s), CPU, computer, or the like capable of executing a series of instructions that are stored in the memory **104**. Instructions can be directly executable or can be used to develop executable instructions. For example, instructions can be realized as executable or non-executable machine code or as instructions in a high-level language that can be compiled to produce executable or non-executable machine code. Further, instructions also can be realized as or can include data. Computer-executable instructions also can be organized in any format, including routines, subroutines, programs, data structures, objects, modules, applications, applets, functions, etc. The instructions may include an operating system, and/or executable software modules such as program files, system data, buffers, drivers, utilities, and the like. The executable instructions may apply to any functionality described herein to enable the imaging assembly **26** to accomplish the same algorithmically and/or by coordination of imaging assembly **26** components. The memory **104** may include a single memory device or a plurality of memory devices, for example, a computer-readable storage device that can be read, written, or otherwise accessed by a general purpose or special purpose computing device, including any processing electronics, and/or processing circuitry capable of executing instructions. The present disclosure is not limited to any particular type of configuration for the memory **104**, which may be non-transitory, and may include read-only memory, random access memory, volatile memory, non-volatile memory, static memory, dynamic memory, flash memory, cache memory, volatile or non-volatile semiconductor memory, optical disk storage, magnetic disk storage, magnetic tape, other magnetic storage devices, or any other medium capable of storing one or more instructions, and/or any device that stores digital information. The memory **104** may

be directly or indirectly electronically integrated with the controller **96**. The controller **96** may include, or may be in communication with, an input device that enables a user to enter data and/or instructions, and may include, or be in communication with, an output device configured, for example to display information (e.g., a visual display or a printer), or to transfer data, etc. Communications between the controller **96** and other components, such as other components of the imaging assembly **26**, may be via a hardwire connection or via a wireless connection. A person of skill in the art will recognize that portions of the controller **96** may assume various forms (e.g., digital signal processor, analog device, etc.) capable of performing the functions described herein.

The controller **96** may form or otherwise be part of an electronic engine controller (EEC) for the gas turbine engine **22**. The EEC may control operating parameters of the gas turbine engine **22** including, but not limited to, fuel flow to the combustor **64**, stator vane position (e.g., variable compressor inlet guide vane (IGV) position), compressor air bleed valve position, etc. so as to control an engine power and/or thrust of the gas turbine engine **22**. In some embodiments, the EEC may be part of a full authority digital engine control (FADEC) system for the gas turbine engine **22**.

The shaft speed sensor **100** may be connected in signal communication with the controller **96**, as shown in FIG. 1. The shaft speed sensor **100** of FIG. 1 is positioned at (e.g., on, adjacent, or proximate) the second shaft **84**. The shaft speed sensor **100** is configured to measure a rotation speed of the second rotational assembly **72** (e.g., the second shaft **84**) and generate an output signal proportional to the measured rotation speed.

The controller **96** may be configured for wireless communication with one or more offboard systems **106** (e.g., an electronic system which is external to both the propulsion system **20** and an aircraft on which the propulsion system **20** is installed). As will be discussed in further detail, the controller **96** may transmit image data and/or other operational data collected from the propulsion system **20** (e.g., from the imaging device **98**) to the offboard system(s) **106** for remote monitoring and/or analysis of propulsion system **20** health. For example, the offboard system(s) **106** may allow maintenance personnel to remotely monitor and/or analyze the health of the propulsion system **20** (e.g., the plurality of propulsor blades **46**). The offboard system(s) **106** may include, for example, a ground station, a near-wing maintenance computer, and/or any other device with which the controller **96** may establish one-way or two-way wireless communication. Wireless communication may be implemented by a variety of technologies such as, but not limited to, Wi-Fi (e.g., radio wireless local area networking based on IEEE 802.11 or other applicable standards), cellular networks, satellite communication, and/or other wireless communication technologies known in the art. Wireless communication between the controller **96** and the offboard system(s) **106** may be direct or indirect. For example, the controller **96** may directly wirelessly communicate with the offboard system(s) **106**. Alternatively, for example, the controller **96** may indirectly wirelessly communicate with the offboard system(s) **106** using one or more intermediate systems or components (e.g., communication systems) of the propulsion system **20** and/or an aircraft on which the propulsion system **20** is installed. It should be understood, of course, that wired communication systems may be used in addition to or as an alternative to wireless communication systems.

FIGS. 2 and 3 illustrate block diagrams of the imaging assembly 26 including the imaging device 98 and the controller 96. FIGS. 2 and 3 further illustrate a portion of the propulsor 40. The imaging device 98 of FIGS. 2 and 3 includes at least one camera 108. The imaging assembly 26 may further include one or more light sources 110, which light sources 110 may be formed by the imaging device 98 or may be independent of (e.g., separate from) the imaging device 98. The imaging device 98 may include more than one camera 108 and/or more than one light source 110. The imaging assembly 26 may additionally or alternatively include one or more light sources 110 which are discrete from the imaging device 98. For example, the one or more light sources 110 may be positioned independent of the imaging device 98.

The camera 108 is configured to capture image data of the plurality of propulsor blades 46 as the plurality of propulsor blades 46 rotate with the propulsor disk 44 about the axial centerline 38, and subsequently transmit the capture image data to the controller 96. The camera 108 of FIGS. 2 and 3 is configured to capture image data for at least a portion of each of the plurality of propulsor blades 46. The term "image data" may refer to the data (e.g., computer-readable data) representing an image (e.g., a single instance of a captured image) captured by the camera 108. For example, the camera 108 of FIGS. 2 and 3 is configured to capture image data of a portion of the plurality of propulsor blades 46 (e.g., each of the plurality of propulsor blades 46) at and including the leading edge 51 as the plurality of propulsor blades 46 pass through a focused field-of-view (schematically illustrated in FIG. 4 as field-of-view 112 having a field-of-view angle α) of the camera 108. For further example, the camera 108 of FIGS. 2 and 3 is configured to capture image data of a radial portion (e.g., only a radial portion) of the plurality of propulsor blades 46 as the plurality of propulsor blades 46 pass through the field-of-view 112 of the camera 108. The field-of-view 112 may the camera 108 may be a fixed field-of-view 112. In other words, the focused field-of-view 112 of the camera 108 may not move, and the camera 108 may capture the image data for each propulsor blade of the plurality of propulsor blades 46 as each propulsor blade moves through the field-of-view 112. The camera 108 may alternatively be configured for zooming, refocusing, or otherwise varying the field-of-view 112. The camera 108 may be configured as any image capture device such as, but not limited to, an imaging device or image sensor capable of capturing two-dimensional (2D) still images or video images.

The camera 108 has a shutter speed, which shutter speed is representative of a length of time in which a digital image sensor of the camera 108 is exposed to light (e.g., while capturing the image data). The particular shutter speed for the camera 108 may correspond to a rotation speed range of the propulsor 40 at which the camera 108 may be used to capture image data (e.g., clear and unblurred image data) of the plurality of propulsor blades 46. For example, a faster shutter speed of the camera 108 may facilitate the capture of suitable image data of the plurality of propulsor blades 46 for greater rotation speeds of the propulsor 40. The present disclosure, however, is not limited to any particular shutter speed for the camera 108, and there are a number of conventional systems and methods for reducing or eliminating image blurring for a moving object. The camera 108 may additionally be configured with a polarizing filter and/or other optical filters to reduce glare, improve contrast for image features of interest, and/or to otherwise improve image data quality.

The light source 110 is configured to direct light (schematically illustrated in FIGS. 2 and 3 using light vector 114 indicating a direction of the light) toward the plurality of propulsor blades 46 to facilitate the capture of image data of the plurality of propulsor blades 46 by the camera 108. The light source 110 may have any suitable lighting configuration (e.g., a light emitting diode (LED)) conventionally known in the art. As shown in FIG. 2, the light source 110 may be positioned at (e.g., on, adjacent, or proximate) the imaging device 98, for example, on or adjacent the camera 108. Alternatively, as shown in FIG. 3, the light source 110 may be positioned in a discrete location of the propulsor section 28 separated from the camera 108. The light source 110 may additionally be configured with a diffusing filter, a polarizing filter, and/or other optical filters. The use of a diffusing filter for the light source 110 may facilitate a reduction in glare for the camera 108. The use of a polarizing filter (e.g., a circular or a linear polarizing filter) may improve contrast for image features of interest, as captured by the camera 108.

FIG. 4 schematically illustrates a side, cutaway view of an exemplary configuration of the imaging device 98 and a structural body 116 of the propulsor section 28 (see FIG. 1). The imaging device 98 is disposed in or otherwise mounted to the structural body 116. The structural body 116 may be include or otherwise be formed by a fixed structure of the propulsor section 28 such as, but not limited to, the propulsor case 42, the nose cone 48, the engine static structure 36, or one of the struts 59 (see FIG. 1). The structural body 116 forms an outer air flow surface 118, which outer air flow surface 118 forms a portion of an air flow path through the propulsor section 28 and into the core flow path 92 and/or the bypass flow path 94 (see FIG. 1). The structural body 116 of FIG. 4 forms a recess 120 at and through the air flow surface 118. The imaging device 98 of FIG. 4 is disposed in the recess 120. It should be understood, however, that the present disclosure is not limited to the particular imaging device 98 configuration of FIG. 4. For example, the present disclosure imaging assembly 26 may include any imaging device 98 (e.g., including the camera 108) disposed in or in proximity to the propulsor section 28.

The imaging device 98 of FIG. 4 includes a housing 122 as well as the camera 108 and the light source 110. The housing 122 of FIG. 4 includes a housing body 124 and a cover 126. The housing body 124 extends about (e.g., completely around) an axial centerline 128 of the housing 122. The housing body 124 may be configured as an annular or cylindrical body extending circumferentially about the axial centerline 128, however, the present disclosure is not limited to any particular shape of the housing body 124. The housing body 124 extends (e.g., axially extends) between and to a first axial end 130 of the housing body 124 and a second axial end 132 of the housing body 124. The housing body 124 surrounds and forms a cavity 134 of the housing 122. The cavity 134 extends along the axial centerline 128 and is disposed between the first axial end 130 and the second axial end 132. The housing body 124 forms an opening 136 of the cavity 134 at the first axial end 130. The opening 136 is disposed coincident with the axial centerline 128 at (e.g., on, adjacent, or proximate) the outer air flow surface 118. As shown in FIG. 4, the first axial end 130 may form a portion of the outer air flow surface 118 (e.g., the first axial end 130 may be disposed coincident with the outer air flow surface 118 formed by the structural body 116).

The cover 126 is disposed at (e.g., on, adjacent, or proximate) the first axial end 130. The cover 126 includes an outer side 138, an inner side 140, and a perimeter side 142.

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The outer side 138 is disposed opposite the inner side 140. The perimeter side 142 extends about (e.g., completely around) the cover 126. The perimeter side 142 extends between and to the outer side 138 and the inner side 140. The cover 126 is selectively positionable between a stowed position and a deployed position. The cover 126 of FIG. 4 is illustrated in the stowed position. In the stowed position, the cover 126 is disposed in the opening 136. For example, in the stowed position, the cover 126 obstructs the opening 136 to separate the cavity 134 from the air flow path through the propulsor section 28 (see FIG. 1). In the stowed position, the outer side 138 may form a portion of the outer air flow surface 118 (e.g., the outer side 138 may be disposed coincident with the outer air flow surface 118 formed by the structural body 116). In the stowed position, the inner side 140 may form a portion of the cavity 134 and may face the camera 108. In the stowed position, the perimeter side 142 may be disposed at (e.g., on, adjacent, or proximate) the housing body 124. The cover 126 may be pivotably mounted to the housing body 124 such that the cover 126 may pivot between the stowed position and the deployed position. For example, the cover 126 may be pivotably mounted to the housing body 124 by a hinge 144. The imaging device 98 may include an actuation assembly (not shown) configured to pivot the cover 126 between the stowed position and the deployed position. The present disclosure is not limited to any particular actuation assembly for the imaging device 98.

The camera 108 of FIG. 4 is positioned in the cavity 134. The light source 110 of FIG. 4 is positioned on the camera 108; however, the present disclosure is not limited to this particular configuration of the light source 110 with the camera 108. The camera 108 may be configured to move relative to the housing body 124. For example, the camera 108 (e.g., and the attached light source 110) may be configured for axial translation along the axial centerline 128. The camera 108 may be movable such that the camera 108 is disposed in the cavity 134 with the cover 126 in the stowed position and at least a portion of the camera 108 is disposed outside the cavity 134 with the cover 126 in the deployed position.

Referring to FIGS. 5 and 6, the light sources 110 may be disposed at one or more positions in the propulsor section 28. The light sources 110 may be disposed at (e.g., on, adjacent, or proximate) the propulsor case 42. For example, the light sources 110 may be disposed on the propulsor case 42 upstream of (e.g., axially forward of) the plurality of propulsor blades 46 and/or downstream of (e.g., axially aft of) the plurality of propulsor blades 46. The light sources 110 may additionally or alternatively be disposed at (e.g., on, adjacent, or proximate) the nose cone 48. The light sources 110 may additionally or alternatively be disposed at (e.g., on, adjacent, or proximate) the engine static structure 36.

FIG. 5 illustrates a front, cutaway view of the propulsor section 28 including a plurality of the light sources 110. As shown in FIG. 5, the light sources 110 may be disposed at different circumferential positions in the propulsor section 28. The light sources 110 may be circumferentially distributed about the propulsor case 42 and/or the nose cone 48. For example, each of the light sources 110 may be disposed at a circumferential position which is different than one other light source 110, more than one other light source 110, and/or each other light source 110.

FIG. 6 illustrates a side, cutaway view of the propulsor section 28 including a plurality of the light sources 110. As shown in FIG. 6, the light sources 110 may be axially distributed in the propulsor section 28 (e.g., along the

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propulsor case 42). For example, each of the light sources 110 may be disposed at an axial position which is different than one other light source 110, more than one other light source 110, and/or each other light source 110. The present disclosure, however, is not limited to any particular location of the light sources 110 in the propulsor section 28.

FIG. 7 illustrates an exemplary configuration of the imaging system 26 relative to a portion of the propulsor 40 and its plurality of propulsor blades 46. The imaging device 98 of FIG. 7 includes the camera 108 disposed with its field-of-view 112 directed to a portion (e.g., a radial portion) of the leading edge 51. For example, the camera 108 is configured to capture image data associated with a radial portion of the leading edge 51 of each of the plurality of propulsor blades 46 at (e.g., on, adjacent, or proximate) the root end 50. As the plurality of propulsor blades 46 rotates about the axial centerline 38, the radial portion of the leading edge 51 of each of the plurality of propulsor blades 46 at (e.g., on, adjacent, or proximate) the root end 50 passes through the field-of-view 112 of the camera 108 of FIG. 7. Each light source 110 of FIG. 7 has a different position in the propulsor section 28 relative to each other light source 110. Each light source 110 of FIG. 7 is configured to direct the respective light 114 toward the portion of the plurality of propulsor blades 46 for which the camera 108 is configured to capture image data. In other words, each light source 110 of FIG. 7 directs the respective light 114 toward the portion of the plurality of propulsor blades 46 from a different direction.

During operation of the propulsion system 20 and its gas turbine engine 22 (e.g., during flight), the plurality of propulsor blades 46 may be exposed to foreign objects (e.g., birds, dirt, rocks, loose mechanical fasteners, etc.) which may enter the propulsor section 28 and collide with one or more of the plurality of propulsor blades 46. As a result, one or more of the plurality of propulsor blades 46 may be damaged (e.g., foreign object damage or "FOD"). For example, one or more of the plurality of propulsor blades 46 may include nicks, dents, scratches, tears, and the like caused by a foreign object. Propulsor blades, such as the plurality of propulsor blades 46, which experience foreign object damage may exhibit an increased likelihood of material failure. Inner radial portions of propulsor blades (e.g., at the root end 50) may experience greater steady stress and vibratory stress relative to other portions of the propulsor blades and these inner radial portions may, therefore, be more susceptible to material failure resulting from foreign object damage.

To identify the presence of foreign object damage on propulsor blades, the propulsor blades may be periodically inspected. This inspection process may conventionally be performed manually by an inspector directly visually observing the propulsor blades and feeling the propulsor blades to identify foreign object damage. While this may be a reliable method for identifying foreign object damage, it can require a considerable amount of time, during which time the propulsion system 20 and its gas turbine engine 22 may not be operated. Moreover, this manual inspection process may present an increased likelihood of inspection tools and/or maintenance materials being left inside the gas turbine engine, where they may subsequently be ingested by the gas turbine engine contributing to the risk of foreign object damage.

In operation of the imaging assembly 26, the imaging device 98 (e.g., the camera(s) 108) captures image data of the plurality of propulsor blades 46 and transmits the image data to the controller 96. The memory 104 includes instructions which, when executed by the controller 96 and/or its

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processor 102, cause the controller 96 and/or its processor 102 to identify the presence or absence of damage (e.g., foreign object damage) for the plurality of propulsor blades 46. Using the image data, the controller 96 may identify a probability that the plurality of propulsor blades 46 or one or more of the plurality of propulsor blades 46 includes damage. The controller 96 may identify damage to the plurality of propulsor blades 46 or one or more of the plurality of propulsor blades 46 if the determined probability exceeds a damage probability threshold. The damage probability threshold may be a predetermined value (e.g., a user input). The instructions may include, for example, a machine learning algorithm to identify the presence of damage or otherwise determine a probability of damage using the image data from the cameras 108. The machine learning algorithm may be trained using historical image data of propulsor blades, which historical image data may include flagged (e.g., manually identified) propulsor blade damage. Alternatively, the instructions may cause the controller 96 to compare the image data from the cameras 108 to reference image data which is representative of the plurality of propulsor blades 46. The controller 96 may compare the image data from the cameras 108 to the reference image data to identify differences which may be indicative of the presence of damage for the plurality of propulsor blades 46. The present disclosure, however, is not limited to any particular algorithm or process for identifying damage using the image data from the cameras 108.

The controller 96 may control the imaging device 98 (e.g., the camera(s) 108) to capture the image data for the plurality of propulsor blades 46 as the plurality of propulsor blades 46 rotate about the axial centerline 38. For example, the memory 104 may include instructions which, when executed by the controller 96 and/or its processor 102, cause the controller 96 to control the imaging device 98 to capture the image data for the plurality of propulsor blades 46. The controller 96 may control each camera 108 to capture image data for each propulsor blade of the plurality of propulsor blades 46 as each propulsor blade passes through the respective field-of-view 112 for each camera 108. The controller 96 may control each camera 108 to capture more than one instance of image data for each propulsor blade of the plurality of propulsor blades 46 as each propulsor blade passes through the respective field-of-view 112 for each camera 108.

We have observed that the identification of damage using image data may be complicated by a number of factors influencing quality characteristics of the captured image data. Light scatter from surfaces of propulsor blades as they rotate may impact the usability of captured image data for identifying the presence of damage to the propulsor blades. For example, light (e.g., ambient light and/or artificial light) may reflect from propulsor blade surfaces in various directions relative to a camera positioned to capture image data for the propulsor blades. A position of a camera relative to the propulsor blades may impact the light reflected from propulsor blades surfaces toward the camera, which light is captured by the camera to form the image data. The collected image data may be representative of portions of the propulsor blades which are suitable for identifying the presence of propulsor blade damage. However, the collected image data may also be representative of portions of the propulsor blades which are unsuitable for identifying the presence of propulsor blade damage. For example, portions of the propulsor blades in the image data may be overexposed (e.g.,

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too much light for identifying propulsor blade damage) or underexposed (e.g., too little light for identifying propulsor blade damage).

FIG. 8 illustrates exemplary propulsor blade image data 146 which is representative of a portion (e.g., a side) of a propulsor blade 148 including a root end 150, a tip end 152, a leading edge 154, and a trailing edge 156. The propulsor blade image data 146 includes lighting characteristics which vary along the portion of the propulsor blade 148. For example, the propulsor blade image data 146 includes overexposed sections 158 of the propulsor blade 148, dark sections 160 of the propulsor blade 148, and nominal sections 162 (e.g., suitable for identifying propulsor blade damage) of the propulsor blade 148. The overexposed sections 158, the dark sections 160, and/or the nominal sections 162 may be present along various portions of the image data 146 for the propulsor blade 148 including along the leading edge 154.

Because propulsor blade image data may be captured while the propulsor blades are rotating, reflection of light from the propulsor blades towards a camera may be continuously changing while the camera is capturing propulsor blade image data, thereby causing overexposed portions and dark portions of the propulsor blade image data to shift as well. The suitability of propulsor blade image data for identifying the presence of propulsor blade damage may also be impacted by the damage itself. For example, different propulsor blade damage shapes (e.g., a spherical recess, a conical recess, a scratch, etc.) may exhibit different light reflection characteristics. The suitability of propulsor blade image data for identifying the presence of propulsor blade damage may also be impacted by the shape and material of the propulsor blades. Propulsor blades may include complex shapes and curvatures which may cause directions of light reflection from propulsor blades surfaces to vary significantly along the propulsor blades. Propulsor blade material surface characteristics (e.g., grain structures, reflectance, gloss, etc.) may also influence the reflection of light by propulsor blade surfaces.

The light sources 110 (see, e.g., FIG. 7) may be operated to facilitate identification of the presence or the absence of damage to the plurality of propulsor blades 46 using the image data by improving the lighting characteristics and visibility of portions of the plurality of propulsor blades 46 in the captured image data. For example, the memory 104 may include instructions which, when executed by the controller 96 and/or its processor 102, cause the controller 96 and/or its processor 102 to control (e.g., energize, deenergize, and/or establish a brightness level) the light sources 110 to control lighting characteristics of a portion or portions of the plurality of propulsor blades 46 which pass through respective fields-of-view 112 of one or more of the cameras 108. The controller 96 may control the light sources 110 to illuminate (e.g., direct the light 114 toward) one or more portions of the plurality of propulsor blades 46 as the one or more cameras 108 capture the image data for the plurality of propulsor blades 46. The use of the light sources 110 having different positions in the propulsor section 28 to direct light 114 to the plurality of propulsor blades 46 from different perspectives may facilitate an increase in the likelihood of identifying propulsor blade damage as well as a decrease in a likelihood of false positives (e.g., damage which is identified but not actually present on the plurality of propulsor blades 46).

The controller 96 may control the light sources 110 as a unit, such that all of the light sources 110 are energized or deenergized together. Alternatively, the controller 96 may

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control the light sources 110 independently, such that each light source 110 may be energized or deenergized independent of each other light source 110. For example, the controller 96 may control the light sources 110 to establish various combinations of the light sources 110 in respective energized and deenergized conditions. As an example, for a configuration of the imaging assembly 26 having three light sources 110 (e.g., a first light source, a second light source, and a third light source), the controller 96 may control the light sources 110 to independently energize, deenergize, control a color (e.g., spectrum), and/or control a brightness level of each of the light sources 110 to establish one or more lighting combinations. A first lighting combination may be established by the controller 96, for example, by energizing the first light source and the second light source and deenergizing the third light source. A second lighting combination may be established by the controller 96, for example, by energizing the second light source and the third light source and deenergizing the first light source. The present disclosure, of course, is not limited to any particular number of the light sources 110 or any particular combination or number of combinations of the light sources 110.

The controller 96 may control the light sources 110 to establish different lighting combinations as the camera(s) 108 collect image data of the plurality of propulsor blades 46 during rotation of the propulsor blades 46. For example, the controller 96 may control the light sources 110 to establish a first lighting combination of the light sources 110 as the camera(s) 108 captures image data for each of the plurality of propulsor blades 46. The controller 96 may then control the light sources 110 to establish a second lighting combination of the light sources 110 (e.g., different than the first lighting combination of the light sources 110) as the camera(s) 108 again captures image data for each of the plurality of propulsor blades 46. The capture of image data for the plurality of propulsor blades 46 may be performed using any number of different lighting combinations of the light sources 110. The controller 96 may alternatively control the light sources 110 to establish different lighting combinations based, for example, on a predetermined amount of time, a predetermined number of rotations of the propulsor 40, etc.

The controller 96 may alternatively control the light sources 110 to establish different lighting combinations based on a rotational position of the propulsor 40 (e.g., the plurality of propulsor blades 46). As each propulsor blade of the plurality of propulsor blades 46 passes through the field(s)-of-view 112 of the camera(s) 108, the camera(s) 108 may capture multiple instances of image data for the particular propulsor blade, with each instance of the image data captured at a different rotational position of the propulsor 40 (e.g., the camera(s) 108 may sequentially capture instances of image data of each propulsor blade as each propulsor blade passes through the field(s)-of-view 112). For each propulsor blade of the plurality of propulsor blades 46, the controller 96 may control the light sources 110 to establish different lighting combinations at different rotational positions of the propulsor 40. Accordingly, the controller 96 may facilitate improved lighting of the plurality of propulsor blades 46 as the plurality of propulsor blades 46 move relative to the camera(s) 108. Establishing different lighting combinations based on the rotational position of the propulsor 40 may facilitate the capture of image data for the plurality of propulsor blades 46 in a shorter period of time, for example, in comparison to a process for capturing the image data of the plurality of propulsor blades 46 for a first lighting combination, capturing the image data of the plu-

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ality of propulsor blades 46 for a second lighting combination, etc. However, the non-zero energization and deenergization time for lighting devices (e.g., LEDs) may mean that this process may be performed for relatively lower propulsor rotation speeds, for example, relative to a process for capturing the image data of the plurality of propulsor blades 46 for a first lighting combination, capturing the image data of the plurality of propulsor blades 46 for a second lighting combination, etc.

The selection of lighting combinations for facilitating improved identification of the presence or the absence of damage for the plurality of propulsor blades 46 using the image data may be based on a number of factors including, but not limited to propulsor blade shape and material, camera positions relative to the propulsor blades, light source characteristics such as positions relative to the propulsor blades, propulsor rotation speed, ambient lighting, etc. Routine experimentation, simulation, and/or analysis may be performed by a person of ordinary skill in the art to determine suitable lighting combinations for the capture of propulsor blade image data in accordance with and as informed by one or more aspects of the present disclosure.

The controller 96 may identify damage for a particular propulsor blade of the plurality of propulsor blades 46 based on an indication of the damage in the image data from the camera(s) 108. The controller 96 may identify the presence or the absence of damage to the plurality of propulsor blades 46 based on image data captured by the camera(s) 108 during different lighting combinations (e.g., both a first lighting combination and a second different lighting combination). For example, the controller 96 may identify a probability that the plurality of propulsor blades 46 or one or more of the plurality of propulsor blades 46 includes damage using image data captured by the camera(s) 108 during different lighting combinations.

The controller 96 may control the imaging device 98 to initiate capture of the image data based on a measured or otherwise determined rotation speed of the propulsor 40. For example, the controller 96 may control the imaging device 98 based on the output signal of the shaft speed sensor 100, which output signal may be representative of the rotation speed of the propulsor 40. For embodiments of the gas turbine engine 22 in which the propulsor 40 may be driven by the second shaft 84 via a speed-reducing gear assembly, the rotation speed of the propulsor 40 may be determined by the controller 96 based on a known speed-reduction ratio of the speed-reducing gear assembly. The controller 96 may control the imaging device 98 to capture the image data for the plurality of propulsor blades 46 when the rotation speed of the propulsor 40 is less than or equal to a rotation speed threshold value (e.g., a predetermined rotation speed value). The rotation speed threshold value may be representative of a rotation speed of the propulsor 40 at or below which the camera(s) 108 may capture image data of the plurality of propulsor blades 46 which is suitable for the controller 96 to identify the presence or absence of damage (e.g., foreign object damage) for the plurality of propulsor blades 46, for example, based on the shutter speed for each camera 108.

The controller 96 may control the imaging device 98 to capture the image data for the plurality of propulsor blades 46 subsequent to shutdown of the propulsion system 20 and/or its gas turbine engine 22 (e.g., when fuel is no longer being supplied to the combustor 64 to drive rotation of the rotational assemblies 70, 72). In other words, the propulsion system 20 may be understood to be in a shutdown condition when the propulsion system 20 is no longer expending energy (e.g., fuel, stored battery energy, etc.) to drive

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rotation of the propulsor 40 (e.g., using the rotational assemblies 70, 72). FIG. 9 illustrates a graph of propulsor 40 rotation speed vs. time following shutdown of the gas turbine engine 22. A shutdown 164 of the gas turbine engine 22 may occur at Time 0, as shown in FIG. 9. A rotation speed 166 of the propulsor 40 (e.g., based on measurement of the second shaft 84 rotation speed) will gradually decrease toward zero (0) revolutions per minute (RPM) subsequent to the shutdown 164. For ease of understanding, the slope of the rotation speed 166 in FIG. 9 is illustrated as being substantially linear, however, the present disclosure should not be understood to be limited in this regard. The controller 96 may control the imaging device 98 to capture the image data for the plurality of propulsor blades 46 when the rotation speed 166 of the propulsor 40 is less than or equal to a rotation speed threshold value 168. As shown in FIG. 9, the rotation speed threshold value 168 is a rotation speed value greater than zero (0) RPM. The rotation speed threshold value 168 may be less than an initial rotation speed 166 of the propulsor 40 at the shutdown 164. The rotation speed threshold value 168 may be selected such that the captured image data of the plurality of propulsor blades 46 is suitable for analysis by the controller 96, as described above, but provides sufficient time for the capture of the image data of each of the plurality of propulsor blades 46 prior to the propulsor 40 reaching a rotationally stationary condition (e.g., the rotation speed 166 at or approximately at zero (0) RPM). In some embodiments of the propulsion system 20, the imaging assembly 26 or components (e.g., the imaging device 98) of the imaging assembly 26 may receive electrical power from the generator 80 (see FIG. 1). Following the shutdown 164, rotation of the first rotational assembly 70 and the second rotational assembly 72 may gradually decrease to a point at which the generator 80 may no longer be capable of suitably generating electrical power for the imaging assembly 26 or components (e.g., the imaging device 98) of the imaging assembly 26. Accordingly, the rotation speed threshold value 168 may be selected to provide sufficient time for the capture of the image data of each of the plurality of propulsor blades 46 prior to a loss of electrical power by the imaging assembly 26 or components (e.g., the imaging device 98) of the imaging assembly 26. Routine experimentation, simulation, and/or analysis may be performed by a person of ordinary skill in the art to determine suitable a rotation speed threshold value(s) in accordance with and as informed by one or more aspects of the present disclosure. The process for capturing the image data for the plurality of propulsor blades 46 following the shutdown 164, as described above, may generally be performed with the propulsion system 20 in a grounded condition (e.g., with the aircraft on which the propulsion system 20 is installed being on the ground). For example, the controller 96 may initiate the capture of the image data following an aircraft landing procedure, where the gas turbine engine 22 is shutdown during or following aircraft transit on the ground (e.g., taxiing).

The controller 96 may transmit the image data and/or an indication of the identified presence or absence of damage for the plurality of propulsor blades 46 to the offboard system(s) 106. For example, the controller 96 may transmit data to the offboard system(s) 106 indicating that one or more of the plurality of propulsor blades 46 has been identified as being damaged. Receipt of the damage-indicative data by the offboard system(s) 106 may facilitate the scheduling and/or performing of inspections and/or repair for the plurality of propulsor blades 46 (e.g., the damaged one or more propulsor blades of the plurality of propulsor

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blades 46). Accordingly, aspects of the present disclosure may facilitate a reduction or elimination of periodic manual inspections of the plurality of propulsor blades 46, and inspections and repairs may instead be performed based on in situ identification of damage to the plurality of propulsor blades 46 as identified by the imaging assembly 26.

While the principles of the disclosure have been described above in connection with specific apparatuses and methods, it is to be clearly understood that this description is made only by way of example and not as limitation on the scope of the disclosure. Specific details are given in the above description to provide a thorough understanding of the embodiments. However, it is understood that the embodiments may be practiced without these specific details.

It is noted that the embodiments may be described as a process which is depicted as a flowchart, a flow diagram, a block diagram, etc. Although any one of these structures may describe the operations as a sequential process, many of the operations can be performed in parallel or concurrently. In addition, the order of the operations may be rearranged. A process may correspond to a method, a function, a procedure, a subroutine, a subprogram, etc.

The singular forms “a,” “an,” and “the” refer to one or more than one, unless the context clearly dictates otherwise. For example, the term “comprising a specimen” includes single or plural specimens and is considered equivalent to the phrase “comprising at least one specimen.” The term “or” refers to a single element of stated alternative elements or a combination of two or more elements unless the context clearly indicates otherwise. As used herein, “comprises” means “includes.” Thus, “comprising A or B,” means “including A or B, or A and B,” without excluding additional elements.

It is noted that various connections are set forth between elements in the present description and drawings (the contents of which are included in this disclosure by way of reference). It is noted that these connections are general and, unless specified otherwise, may be direct or indirect and that this specification is not intended to be limiting in this respect. Any reference to attached, fixed, connected or the like may include permanent, removable, temporary, partial, full and/or any other possible attachment option.

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

While various inventive aspects, concepts and features of the disclosures may be described and illustrated herein as embodied in combination in the exemplary embodiments, these various aspects, concepts, and features may be used in many alternative embodiments, either individually or in various combinations and sub-combinations thereof. Unless expressly excluded herein all such combinations and sub-combinations are intended to be in the scope of the present application. Still further, while various alternative embodiments as to the various aspects, concepts, and features of the disclosures—such as alternative materials, structures, configurations, methods, devices, and components, and so on—

may be described herein, such descriptions are not intended to be a complete or exhaustive list of available alternative embodiments, whether presently known or later developed. Those skilled in the art may readily adopt one or more of the inventive aspects, concepts, or features into additional embodiments and uses in the scope of the present application even if such embodiments are not expressly disclosed herein. For example, in the exemplary embodiments described above in the Detailed Description portion of the present specification, elements may be described as individual units and shown as independent of one another to facilitate the description. In alternative embodiments, such elements may be configured as combined elements.

The invention claimed is:

1. An assembly for an aircraft propulsion system, the assembly comprising:

a propulsor section for the aircraft propulsion system, the propulsor section including a propulsor and a propulsor case, the propulsor including a plurality of propulsor blades configured for rotation about a rotational axis of the aircraft propulsion system, and the propulsor further including a nose cone disposed axially adjacent the plurality of propulsor blades, the nose cone and the propulsor case rotationally fixed relative to the rotational axis;

an imaging device disposed in the propulsor section, the imaging device including a camera;

a plurality of light sources disposed in the propulsor section including a light source disposed on the propulsor case and a light source disposed on the nose cone; and

a controller connected in signal communication with the imaging device and the plurality of light sources, the controller including a processor in communication with a non-transitory memory storing instructions, which instructions when executed by the processor, cause the processor to:

control each of the plurality of light sources to direct light to the plurality of propulsor blades;

control the camera to capture image data of each propulsor blade of the plurality of propulsor blades as the plurality of propulsor blades rotate about the rotational axis; and

identify a presence or an absence of damage for each propulsor blade of the plurality of propulsor blades using the image data.

2. The assembly of claim 1, wherein the plurality of light sources includes a first light source and a second light source, the first light source is disposed at a first circumferential position, and the second light source is disposed at a second circumferential position different than the first circumferential position.

3. The assembly of claim 1, wherein the plurality of light sources includes a first light source and a second light source, the first light source is disposed at a first axial position, and the second light source is disposed at a second axial position different than the first axial position.

4. The assembly of claim 1, wherein the instructions, when executed by the processor, further cause the processor to control the plurality of light sources to establish a first lighting combination of the plurality of light sources and a second lighting combination of the plurality of light sources, the second lighting combination different than the first lighting combination.

5. The assembly of claim 4, wherein:

the plurality of light sources includes a first light source; and

in the first lighting combination the first light source is energized and in the second lighting combination the first light source is deenergized.

6. The assembly of claim 4, wherein the instructions, when executed by the processor, further cause the processor to control the camera to capture image data of each propulsor blade of the plurality of propulsor blades for both the first lighting combination and the second lighting combination.

7. The assembly of claim 6, wherein the instructions, when executed by the processor, further cause the processor to identify the presence or the absence of damage for each propulsor blade of the plurality of propulsor blades by determining a damage probability for each propulsor blade of the plurality of propulsor blades using the image data captured by the camera for both the first lighting combination and the second lighting combination.

8. The assembly of claim 7, wherein the instructions, when executed by the processor, further cause the processor to identify the presence or the absence of damage for each propulsor blade of the plurality of propulsor blades by comparing the damage probability for each propulsor blade of the plurality of propulsor blades to a damage probability threshold.

9. The assembly of claim 1, wherein: the plurality of light sources includes a first light source, the first light source disposed on an engine static structure of the aircraft propulsion system.

10. The assembly of claim 1, the propulsor case extending circumferentially about the rotational axis and circumscribing the plurality of propulsor blades.

11. The assembly of claim 1, wherein:

each propulsor blade of the plurality of propulsor blades includes a root end, a tip end, a leading edge, and a trailing edge, the leading edge and the trailing edge extending radially between and to the root end and the tip end; and

a group of the plurality of light sources is configured to direct light to a same portion of a radial span of each propulsor blade of the plurality of propulsor blades as the plurality of propulsor blades rotate about the rotational axis.

12. The assembly of claim 11, wherein the same portion includes the leading edge at the root end.

13. The assembly of claim 1, wherein the instructions, when executed by the processor, further cause the processor to initiate the capture of the image data by controlling the camera to capture the image data based on a measured rotation speed of the propulsor about the rotational axis.

14. The assembly of claim 1, wherein the instructions, when executed by the processor, further cause the processor to transmit to an offboard system an indication of identification of the presence of damage to at least one propulsor blade of the plurality of propulsor blades.

15. The assembly of claim 1, wherein the propulsor section comprises a structural body, the structural body forming an outer air flow surface, the outer air flow surface forming a portion of an air flow path through the propulsor section, and the structural body forming a recess at and through the outer air flow surface, and wherein the imaging device is disposed in the recess.

16. The assembly of claim 1, wherein the imaging device further includes a housing body and a cover, and the cover is pivotally mounted to the housing body.

17. A method for inspecting a plurality of propulsor blades of a propulsor section for an aircraft propulsion system, the propulsor section including a propulsor case, a propulsor including the plurality of propulsor blades and a nose cone

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disposed axially adjacent the plurality of propulsor blades, the nose cone and the propulsor case rotationally fixed relative to a rotational axis of the aircraft propulsion system, the method comprising:

- rotating the plurality of propulsor blades about the rotational axis; 5
- controlling each of a plurality of light sources to direct light to the plurality of propulsor blades, the plurality of light sources including a light source disposed on the propulsor case and a light source disposed on the nose cone; 10
- controlling a camera to capture image data of each propulsor blade of the plurality of propulsor blades as the plurality of propulsor blades rotate about the rotational axis; and 15
- identifying a presence or an absence of damage for each propulsor blade of the plurality of propulsor blades using the image data.

18. The method of claim 17, wherein controlling the plurality of light sources to direct light to the plurality of propulsor blades includes controlling the plurality of light sources to establish a first lighting combination of the plurality of light sources and a second lighting combination of the plurality of light sources, the second lighting combination different than the first lighting combination. 20

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19. The method of claim 18, wherein controlling the camera to capture image data of each propulsor blade of the plurality of propulsor blades includes:

- controlling the camera to capture image data of each propulsor blade of the plurality of propulsor blades for the first lighting combination; and
- controlling the camera to capture image data of each propulsor blade of the plurality of propulsor blades for the second lighting combination subsequent to controlling the camera to capture image data of each propulsor blade of the plurality of propulsor blades for the first lighting combination.

20. The method of claim 18, wherein controlling the plurality of light sources to establish the first lighting combination and the second lighting combination includes: controlling the plurality of light sources to establish the first lighting combination for a first rotational position of the plurality of propulsor blades; and controlling the plurality of light sources to establish the second lighting combination for a second rotational position of the plurality of propulsor blades, the second rotational position different than the first rotational position.

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