US012394179B2

(12) **United States Patent**
Tong et al.

(10) **Patent No.: US 12,394,179 B2**
(45) **Date of Patent: Aug. 19, 2025**

(54) **PERFORMING VANE CLASSIFICATION FOR TURBINE ENGINES USING STRUCTURED LIGHT THREE-DIMENSIONAL (3D) SCANS**

(71) Applicant: **RTX Corporation**, Farmington, CT (US)

(72) Inventors: **Kun Tong**, West Hartford, CT (US); **Tracy A. Propheter-Hinckley**, Rocky Hill, CT (US); **Venumadhava Ponnala**, East Hampton, CT (US); **Andres Diaz Alvarado**, Humacao, PR (US)

(73) Assignee: **RTX CORPORATION**, Farmington, CT (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 354 days.

(21) Appl. No.: **17/877,712**

(22) Filed: **Jul. 29, 2022**

(65) **Prior Publication Data**

US 2024/0037909 A1 Feb. 1, 2024

(51) **Int. Cl.**

G06V 10/764	(2022.01)
F01D 9/02	(2006.01)
G06T 7/521	(2017.01)
G06T 17/20	(2006.01)

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

CPC ***G06V 10/764*** (2022.01); ***F01D 9/02*** (2013.01); ***G06T 7/521*** (2017.01); ***G06T 17/20*** (2013.01); *F05D 2220/323* (2013.01); *F05D 2240/12* (2013.01); *F05D 2250/20* (2013.01);

(Continued)

(58) **Field of Classification Search**

CPC F05D 2250/20

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

8,578,581	B2 *	11/2013	Bellerose	G05B 19/4097 29/557
9,704,293	B2 *	7/2017	Date	G06T 17/205
9,733,195	B2	8/2017	Colletti	

(Continued)

FOREIGN PATENT DOCUMENTS

CN	105737762	B	3/2018
CN	105333855	B	10/2018

(Continued)

OTHER PUBLICATIONS

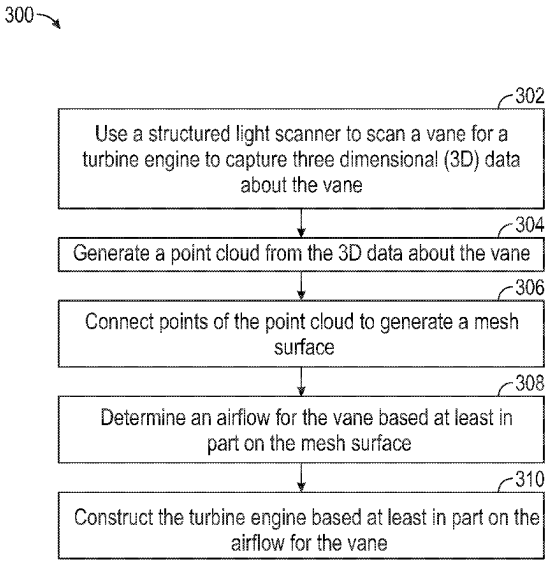
EP Search Report dated Jul. 19, 2023; EP Application No. 23175879.8; 12 pages.

Primary Examiner — Courtney D Heinle
Assistant Examiner — Danielle M. Christensen
(74) *Attorney, Agent, or Firm* — CANTOR COLBURN LLP

(57) **ABSTRACT**

An example method for vane classification includes scanning, using a structured light scanner, a vane for a turbine engine to capture three-dimensional (3D) data about the vane. The method further includes generating a point cloud from the 3D data about the vane. The method further includes connecting, using a processing system, points of the point cloud to generate a mesh surface. The method further includes determining, using the processing system, an airflow for an airfoil of the vane based at least in part on the mesh surface. The method further includes constructing the turbine engine based at least in part on the airflow for the airfoil of the vane without reference to an adjacent airfoil of the vane.

15 Claims, 9 Drawing Sheets



(52) **U.S. Cl.**
CPC *G06T 2207/10028* (2013.01); *G06T 2207/30164* (2013.01)

(56) **References Cited**

U.S. PATENT DOCUMENTS

10,024,760	B2	7/2018	Bojappa et al.	
10,295,436	B2	5/2019	Conner et al.	
11,003,806	B2 *	5/2021	Burkett	G06F 30/17
11,250,189	B1	2/2022	Clark et al.	
2019/0391559	A1	12/2019	Auxier et al.	
2020/0173936	A1	6/2020	Vöhringer et al.	

FOREIGN PATENT DOCUMENTS

CN	111612768	A	9/2020
EP	1760427	A2	3/2007
EP	3168808	A1	5/2017
EP	3192978	A2	7/2017
EP	3591173	A1	1/2020
WO	2014052209	A1	4/2014

* cited by examiner

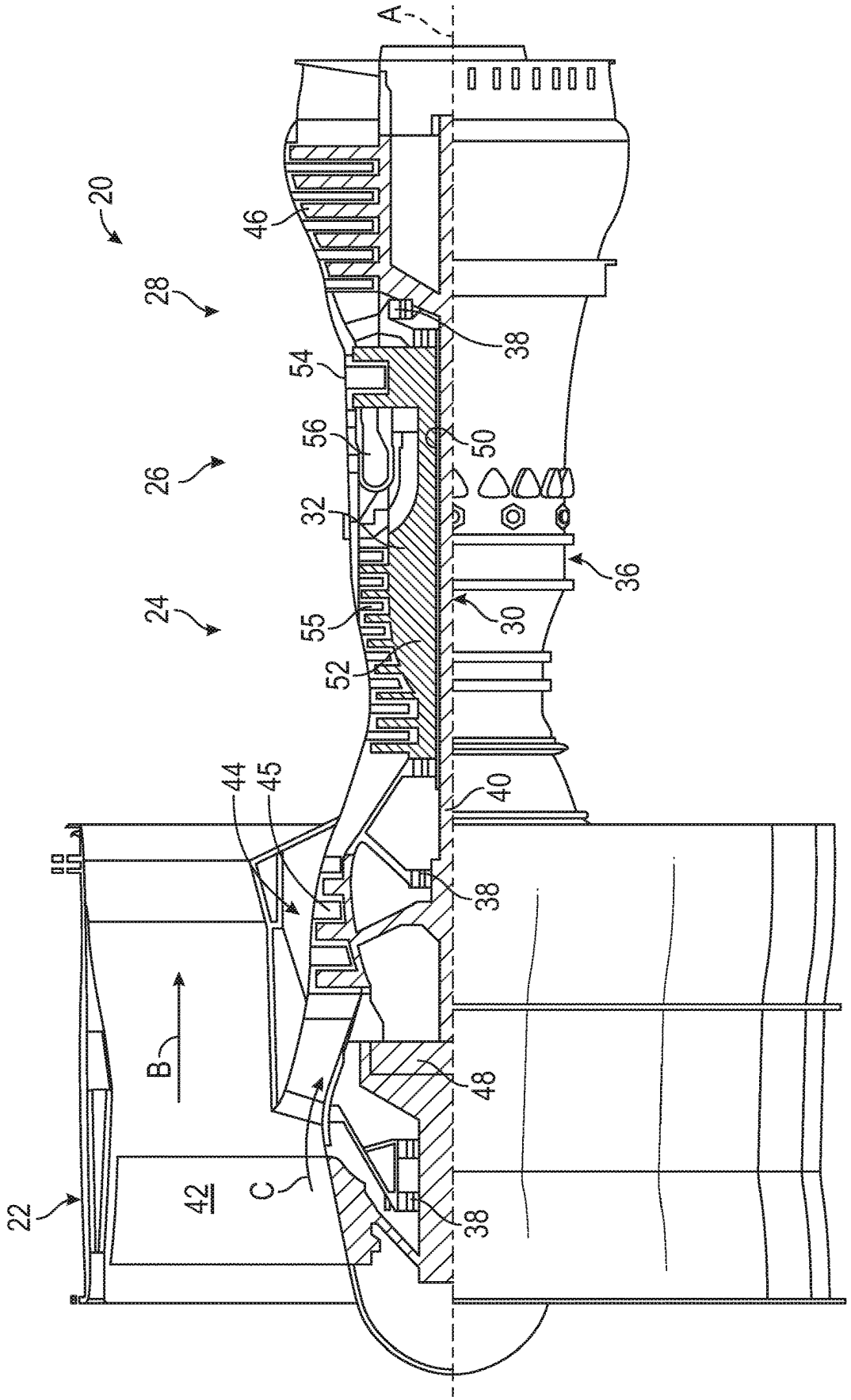


FIG. 1

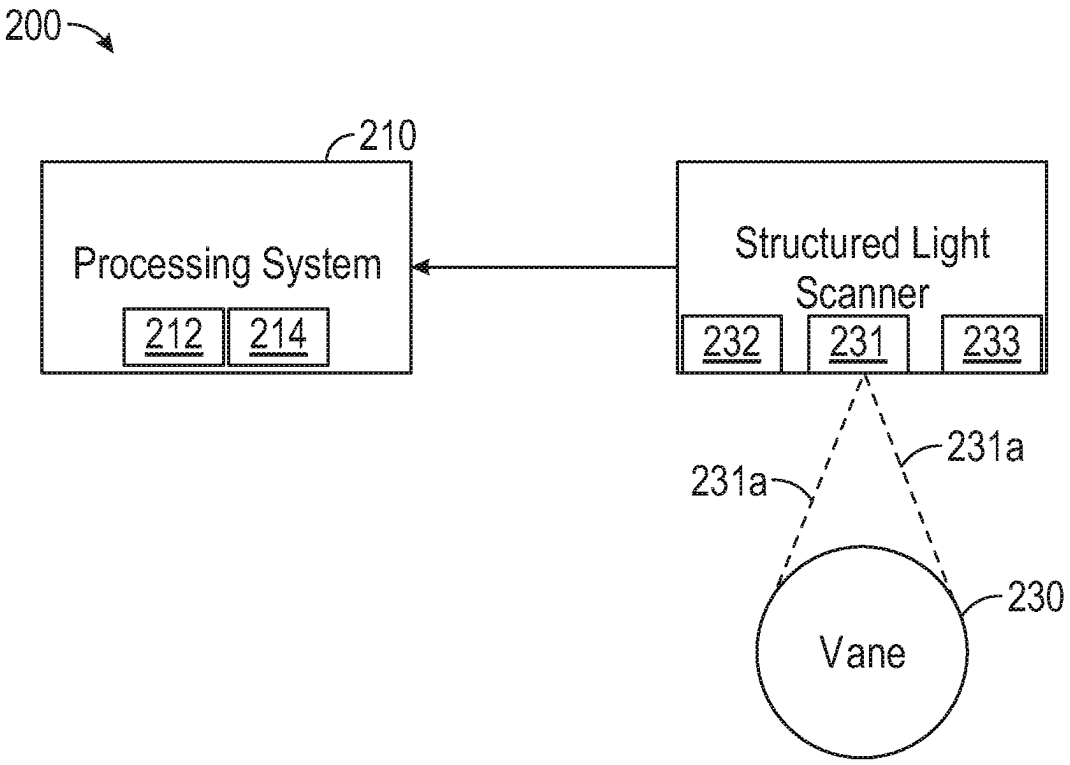

200
210
Processing System
212
214
Structured Light Scanner
232
231
233
231a
231a
230
Vane

FIG. 2A

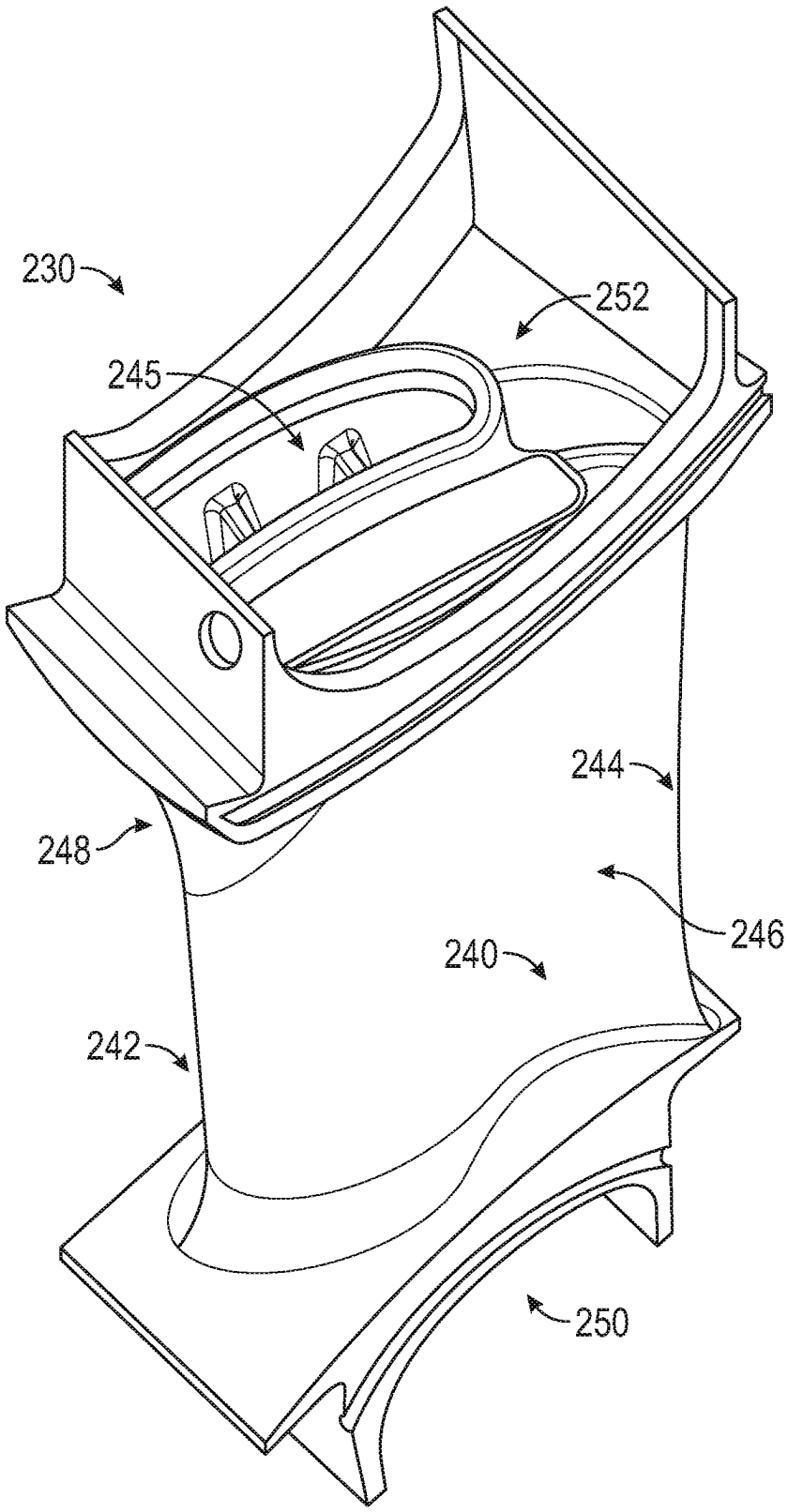


FIG. 2B

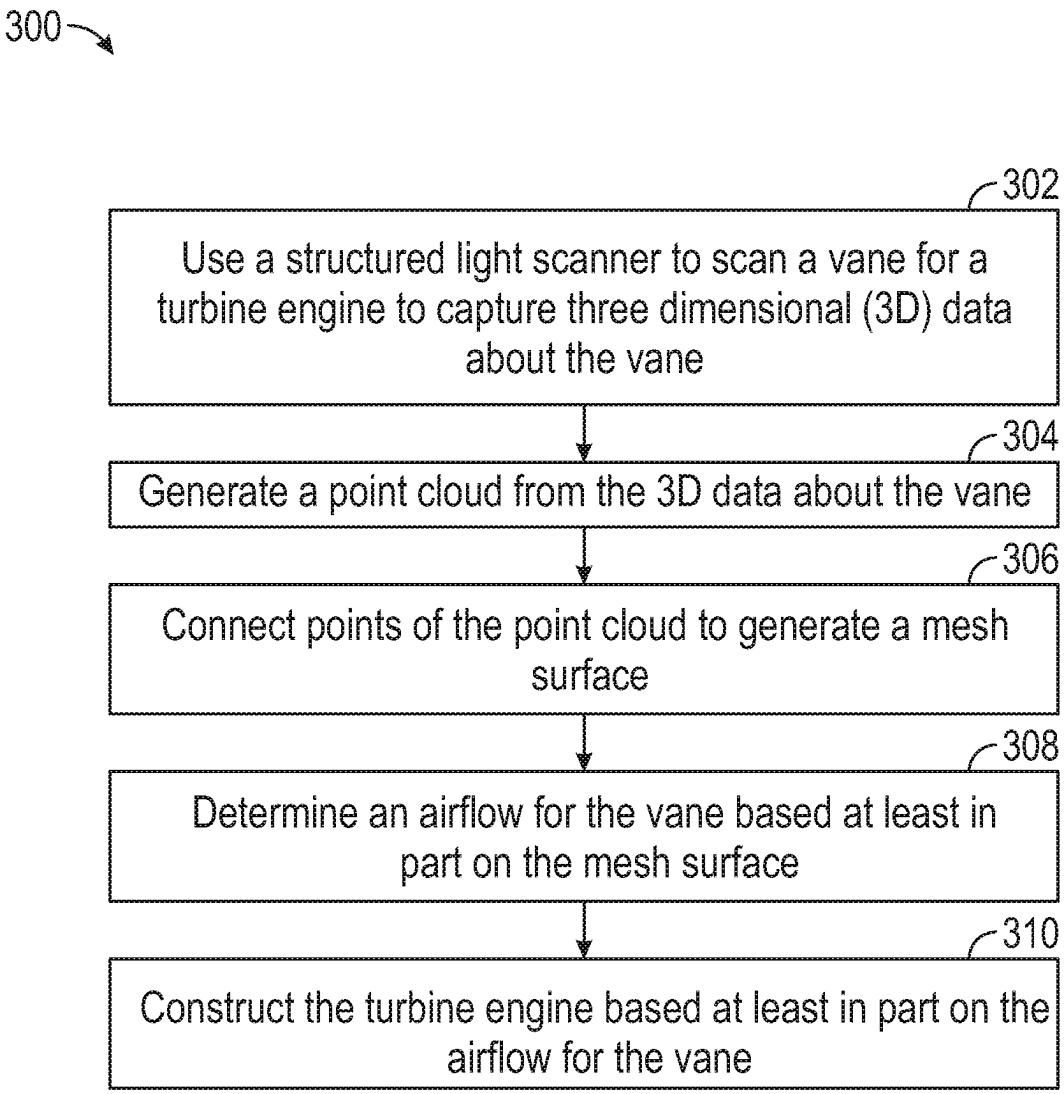

300
302
Use a structured light scanner to scan a vane for a turbine engine to capture three dimensional (3D) data about the vane
304
Generate a point cloud from the 3D data about the vane
306
Connect points of the point cloud to generate a mesh surface
308
Determine an airflow for the vane based at least in part on the mesh surface
310
Construct the turbine engine based at least in part on the airflow for the vane

FIG. 3

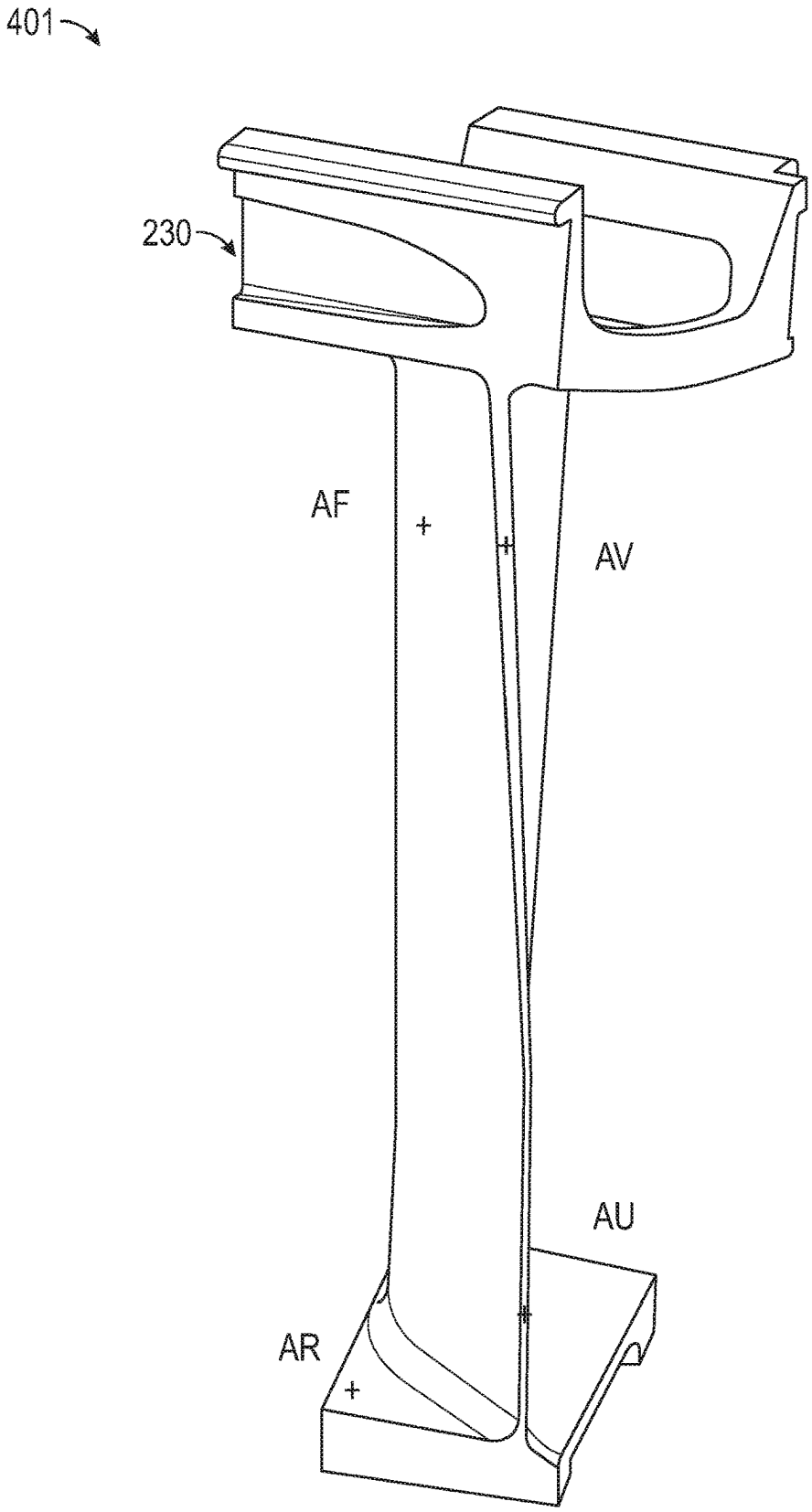


FIG. 4A

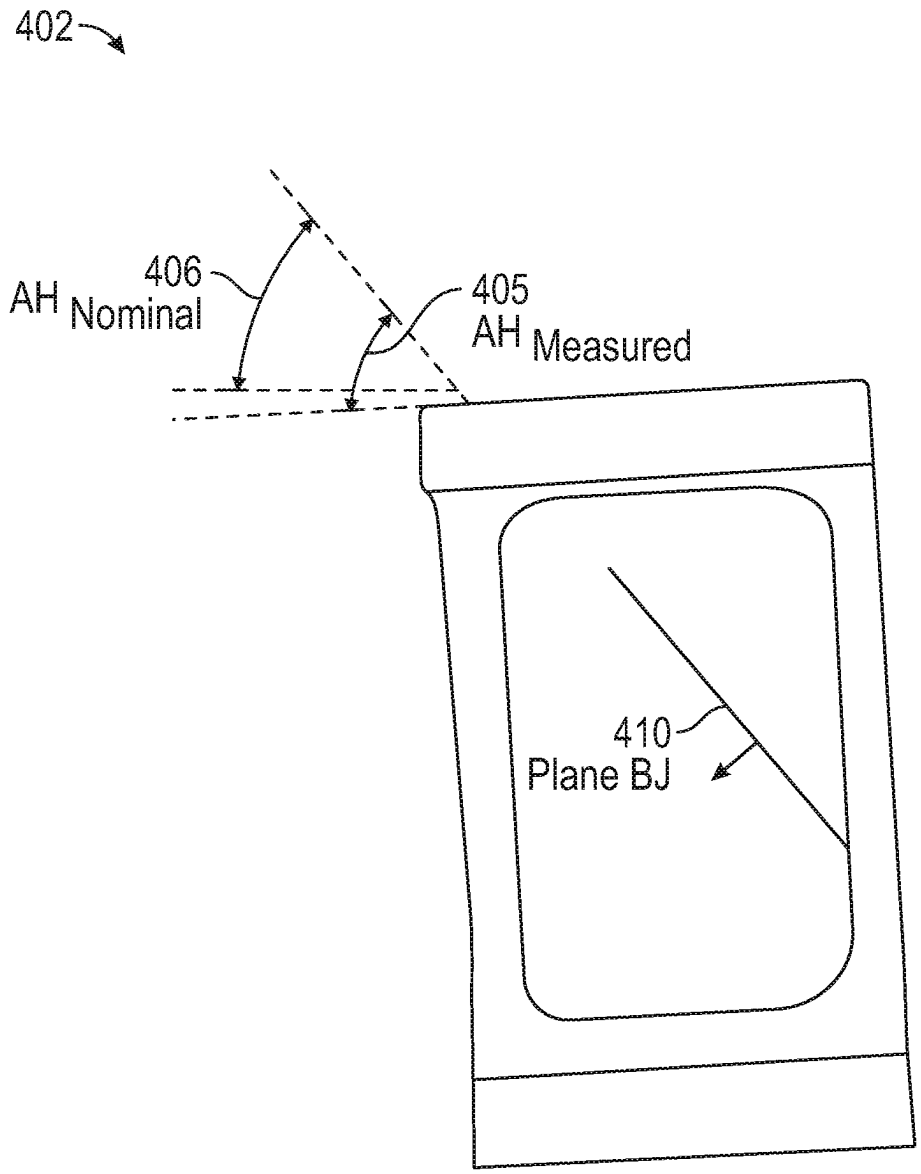


FIG. 4B

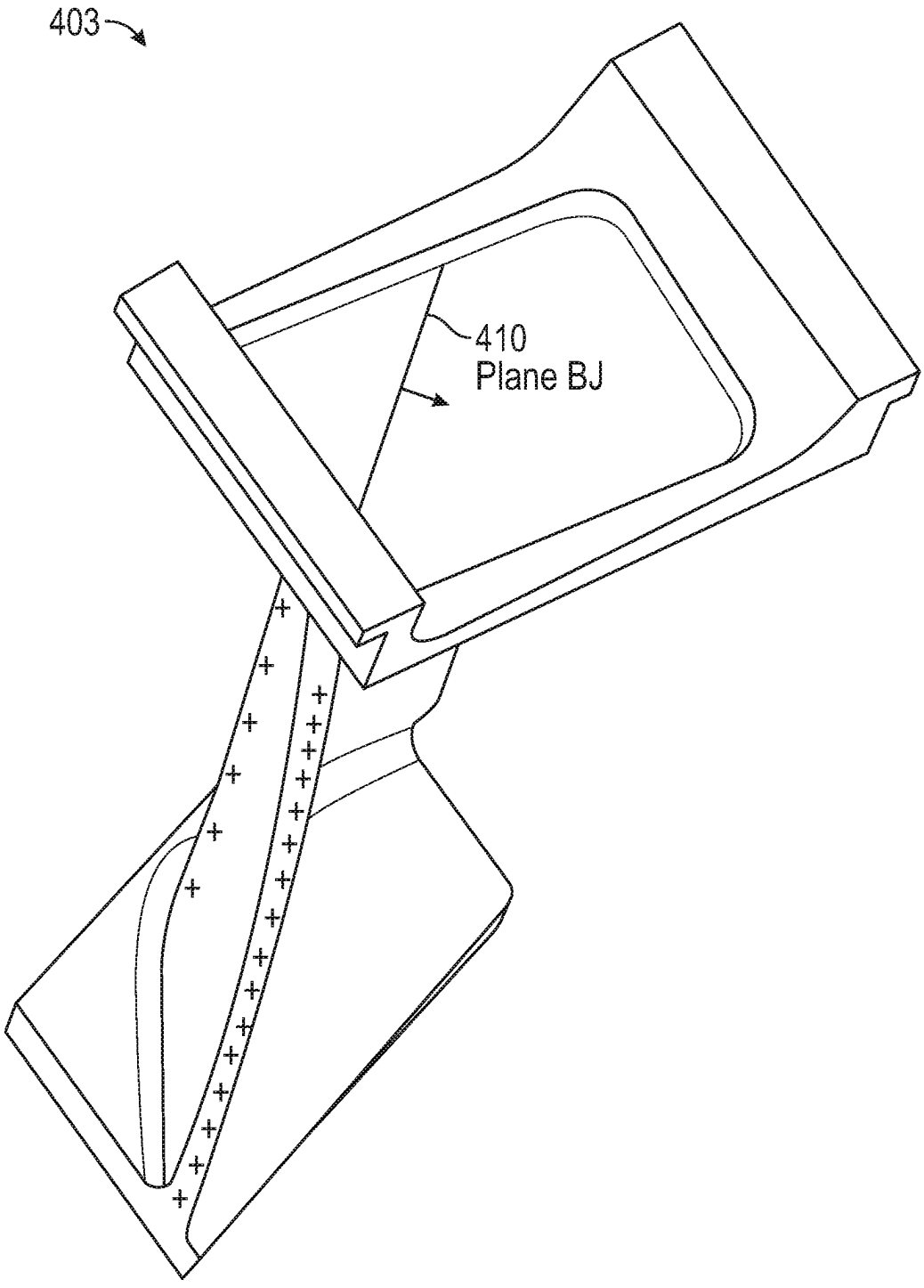


FIG. 4C

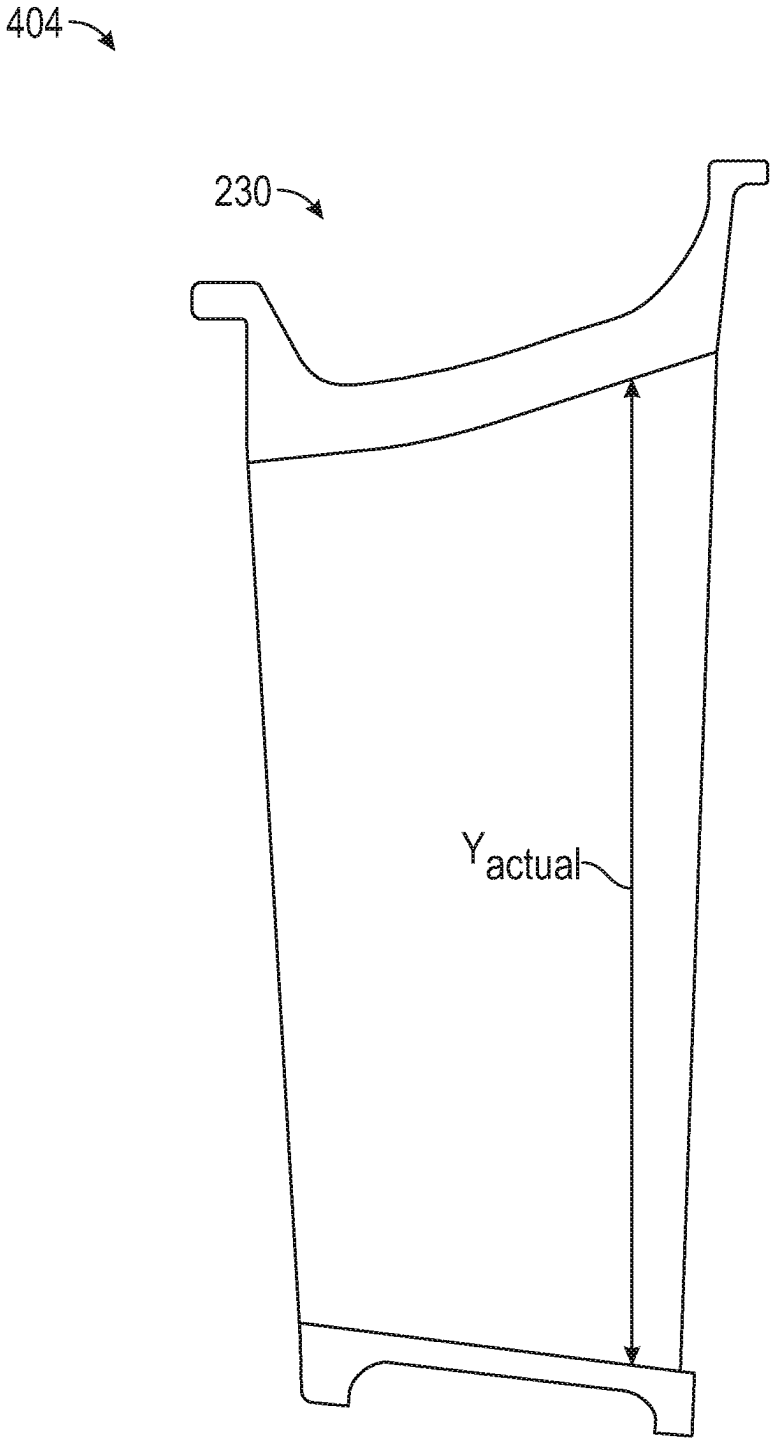


FIG. 4D

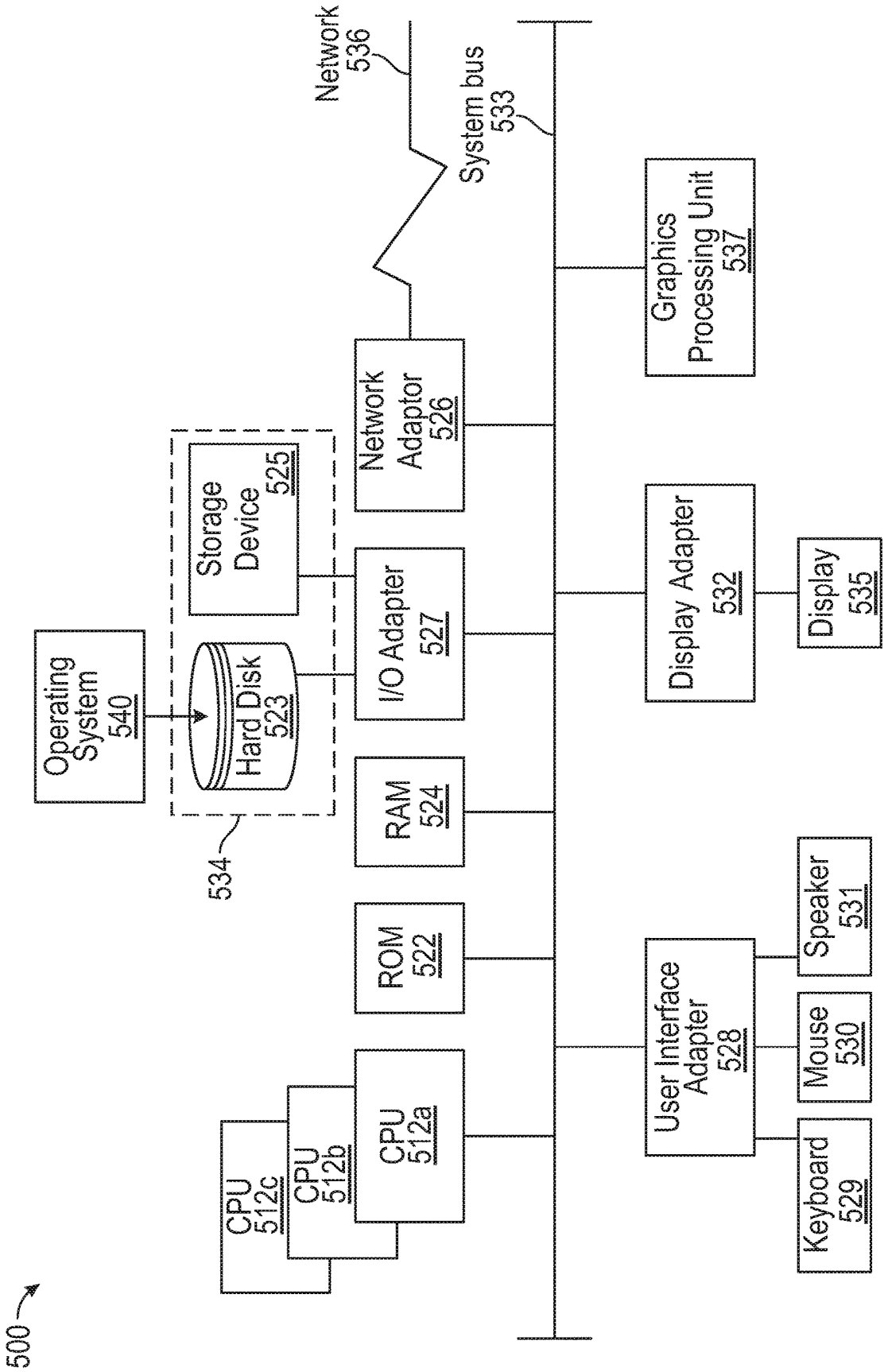

500
CPU 512c
CPU 512b
CPU 512a
ROM 522
RAM 524
I/O Adapter 527
Network Adaptor 526
Graphics Processing Unit 537
Display Adapter 532
Display 535
User Interface Adapter 528
Speaker 531
Mouse 530
Keyboard 529
534
Storage Device 525
Hard Disk 523
Operating System 540
System bus 533
Network 536

FIG. 5

PERFORMING VANE CLASSIFICATION FOR TURBINE ENGINES USING STRUCTURED LIGHT THREE-DIMENSIONAL (3D) SCANS

STATEMENT OF FEDERAL SUPPORT

This invention was made with Government support under Contract FA8626-21-D-0001, Order FA8626-21-F-0033 awarded by the United States Air Force. The Government has certain rights in this invention.

BACKGROUND

The subject matter disclosed herein generally relates to vane classification for turbine engines.

Turbine engines, such as gas turbine engines and hybrid electric turbine engines, use vanes to direct air within the engines. Turbine vanes direct and meter the hot combustion gasses onto turbine blades which spin to create rotational motion that is transferred to other turbine components such as a fan and/or compressor to create thrust and/or power. The direction and the amount of hot gas flow presented to a blade from the preceding vane can be directly correlated to the efficiency by which rotational energy can be extracted from the hot gas path flow. It is therefore useful to analyze vanes based on their airflow characteristics.

BRIEF DESCRIPTION

In one exemplary embodiment, a computer-implemented method for vane classification is provided. The method includes scanning, using a structured light scanner, a vane for a turbine engine to capture three-dimensional (3D) data about the vane. The method further includes generating a point cloud from the 3D data about the vane. The method further includes connecting, using a processing system, points of the point cloud to generate a mesh surface. The method further includes determining, using the processing system, an airflow for an airfoil of the vane based at least in part on the mesh surface. The method further includes constructing the turbine engine based at least in part on the airflow for the airfoil of the vane without reference to an adjacent airfoil of the vane.

In addition to one or more of the features described herein, or as an alternative, further embodiments of the method may include that the structured light scanner is a blue light structured light scanner.

In addition to one or more of the features described herein, or as an alternative, further embodiments of the method may include that the mesh surface is a triangle mesh.

In addition to one or more of the features described herein, or as an alternative, further embodiments of the method may include that the mesh surface is a polygon mesh.

In addition to one or more of the features described herein, or as an alternative, further embodiments of the method may include that the airflow is determined based at least in part on an amount of air flow blockage of the vane.

In addition to one or more of the features described herein, or as an alternative, further embodiments of the method may include that the airflow is determined based at least in part on a rotational angle of the vane.

In addition to one or more of the features described herein, or as an alternative, further embodiments of the method may include that constructing the turbine engine is further based at least in part on the airflow of a plurality of other airfoils.

In another exemplary embodiment a system includes a structured light scanner to scan a vane for a turbine engine to capture three-dimensional (3D) data about an airfoil of the vane. The system further includes a processing system. The processing system includes a memory having computer readable instructions and a processing device for executing the computer readable instructions. The computer readable instructions control the processing device to perform operations for vane classification. The operations include generating a point cloud from the 3D data about the airfoil of the vane. The operations further include connecting points of the point cloud to generate a mesh surface. The operations further include determining an airflow for the airfoil of the vane based at least in part on the mesh surface. The operations further include causing the turbine engine to be constructed based at least in part on the airflow for the airfoil for the vane without reference to an adjacent airfoil of the vane.

In addition to one or more of the features described herein, or as an alternative, further embodiments of the system may include that the structured light scanner is a blue light structured light scanner.

In addition to one or more of the features described herein, or as an alternative, further embodiments of the system may include that the mesh surface is a triangle mesh.

In addition to one or more of the features described herein, or as an alternative, further embodiments of the system may include that the mesh surface is a polygon mesh.

In addition to one or more of the features described herein, or as an alternative, further embodiments of the system may include that the airflow is determined based at least in part on an amount of air flow blockage of the vane.

In addition to one or more of the features described herein, or as an alternative, further embodiments of the system may include that the airflow is determined based at least in part on a rotational angle of the vane.

In addition to one or more of the features described herein, or as an alternative, further embodiments of the system may include that constructing the turbine engine is further based at least in part on the airflow of a plurality of other vanes.

In addition to one or more of the features described herein, or as an alternative, further embodiments of the system may include that the structured light scanner scans a gas path of the turbine engine for a window height, wherein determining the airflow for the airfoil of the vane is based at least in part on the window height.

In yet another exemplary embodiment a computer program product includes a computer readable storage medium having program instructions embodied therewith, the program instructions executable by a processor to cause the processor to perform operations. The operations include receiving, from a structured light scanner, three-dimensional (3D) data about an airfoil and a gas path of a vane for a turbine engine. The operations further include generating a point cloud from the 3D data about the airfoil and the gas path of the vane. The operations further include connecting, using a processing system, points of the point cloud to generate a mesh surface. The operations further include determining, using the processing system, an airflow for the airfoil of the vane based at least in part on the mesh surface. The operations further include causing the turbine engine to be constructed based at least in part on the airflow for the airfoil of the vane without reference to an adjacent airfoil of the vane.

In addition to one or more of the features described herein, or as an alternative, further embodiments of the

computer program product may include that the structured light scanner is a blue light structured light scanner.

In addition to one or more of the features described herein, or as an alternative, further embodiments of the computer program product may include that the mesh surface is a polygon mesh.

In addition to one or more of the features described herein, or as an alternative, further embodiments of the computer program product may include that the airflow is determined based at least in part on an amount of air flow blockage of the vane.

In addition to one or more of the features described herein, or as an alternative, further embodiments of the computer program product may include that the airflow is determined based at least in part on a rotational angle of the vane.

The above features and advantages, and other features and advantages, of the disclosure are readily apparent from the following detailed description when taken in connection with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

The following descriptions should not be considered limiting in any way. With reference to the accompanying drawings, like elements are numbered alike:

FIG. **1** is a partial cross-sectional illustration of a gas turbine engine, in accordance with an embodiment of the disclosure;

FIG. **2**A is a block diagram of a system for performing vane classification according to one or more embodiments described herein;

FIG. **2**B depicts a vane according to one or more embodiments described herein;

FIG. **3** is a flow diagram of a method for performing vane classification according to one or more embodiments described herein;

FIGS. **4**A-**4**D depict representations of the vane of FIG. **2** according to one or more embodiments described herein; and

FIG. **5** is a block diagram of a processing system for implementing one or more embodiments described herein.

DETAILED DESCRIPTION

A detailed description of one or more embodiments of the disclosed apparatus and method are presented herein by way of exemplification and not limitation with reference to the Figures.

FIG. **1** schematically illustrates a gas turbine engine **20**. The gas turbine engine **20** is disclosed herein as a two-spool turbofan that generally incorporates a fan section **22**, a compressor section **24**, a combustor section **26** and a turbine section **28**. The fan section **22** drives air along a bypass flow path B in a bypass duct, while the compressor section **24** drives air along a core flow path C for compression and communication into the combustor section **26** then expansion through the turbine section **28**. Although depicted as a two-spool turbofan gas turbine engine in the disclosed non-limiting embodiment, it should be understood that the concepts described herein are not limited to use with two-spool turbofans as the teachings may be applied to other types of turbine engines including three-spool architectures.

The exemplary engine **20** generally includes a low speed spool **30** and a high speed spool **32** mounted for rotation about an engine central longitudinal axis A relative to an engine static structure **36** via several bearing systems **38**. It should be understood that various bearing systems **38** at various locations may alternatively or additionally be provided, and the location of bearing systems **38** may be varied as appropriate to the application.

The low speed spool **30** generally includes an inner shaft **40** that interconnects a fan **42**, a low pressure compressor **44** and a low pressure turbine **46**. The inner shaft **40** is connected to the fan **42** through a speed change mechanism, which in exemplary gas turbine engine **20** is illustrated as a geared architecture **48** to drive the fan **42** at a lower speed than the low speed spool **30**. The high speed spool **32** includes an outer shaft **50** that interconnects a high pressure compressor **52** and high pressure turbine **54**. A combustor **56** is arranged in exemplary gas turbine **20** between the high pressure compressor **52** and the high pressure turbine **54**. An engine static structure **36** is arranged generally between the high pressure turbine **54** and the low pressure turbine **46**. The engine static structure **36** further supports bearing systems **38** in the turbine section **28**. The inner shaft **40** and the outer shaft **50** are concentric and rotate via bearing systems **38** about the engine central longitudinal axis A which is collinear with their longitudinal axes.

The core airflow is compressed by the low pressure compressor **44** then the high pressure compressor **52**, mixed and burned with fuel in the combustor **56**, then expanded over the high pressure turbine **54** and low pressure turbine **46**. In some embodiments, stator vanes **45** in the low pressure compressor **44** and stator vanes **55** in the high pressure compressor **52** may be adjustable during operation of the gas turbine engine **20** to support various operating conditions. In other embodiments, the stator vanes **45**, **55** may be held in a fixed position. The turbines **46**, **54** rotationally drive the respective low speed spool **30** and high speed spool **32** in response to the expansion. It will be appreciated that each of the positions of the fan section **22**, compressor section **24**, combustor section **26**, turbine section **28**, and fan drive gear system **48** may be varied. For example, gear system **48** may be located aft of combustor section **26** or even aft of turbine section **28**, and fan section **22** may be positioned forward or aft of the location of gear system **48**.

The engine **20** in one example is a high-bypass geared aircraft engine. In a further example, the engine **20** bypass ratio is greater than about six (6), with an example embodiment being greater than about ten (10), the geared architecture **48** is an epicyclic gear train, such as a planetary gear system or other gear system, with a gear reduction ratio of greater than about 2.3 and the low pressure turbine **46** has a pressure ratio that is greater than about five. In one disclosed embodiment, the engine **20** bypass ratio is greater than about ten (10:1), the fan diameter is significantly larger than that of the low pressure compressor **44**, and the low pressure turbine **46** has a pressure ratio that is greater than about five 5:1. Low pressure turbine **46** pressure ratio is pressure measured prior to inlet of low pressure turbine **46** as related to the pressure at the outlet of the low pressure turbine **46** prior to an exhaust nozzle. The geared architecture **48** may be an epicycle gear train, such as a planetary gear system or other gear system, with a gear reduction ratio of greater than about 2.3:1. It should be understood, however, that the above parameters are only exemplary of one embodiment of a geared architecture engine and that the present disclosure is applicable to other gas turbine engines including direct drive turbofans.

A significant amount of thrust is provided by the bypass flow B due to the high bypass ratio. The fan section **22** of the engine **20** is designed for a particular flight condition—

typically cruise at about 0.8 Mach and about 35,000 feet (10,688 meters). The flight condition of 0.8 Mach and 35,000 ft (10,688 meters), with the engine at its best fuel consumption—also known as "bucket cruise Thrust Specific Fuel Consumption ('TSFCT')"—is the industry standard parameter of lbm of fuel being burned divided by lbf of thrust the engine produces at that minimum point. "Low fan pressure ratio" is the pressure ratio across the fan blade alone, without a Fan Exit Guide Vane ("FEGV") system. The low fan pressure ratio as disclosed herein according to one non-limiting embodiment is less than about 1.45. "Low corrected fan tip speed" is the actual fan tip speed in ft/sec divided by an industry standard temperature correction of $[(\text{Tram} \circ \text{R})/(518.7^\circ \text{R})]^{0.5}$. The "Low corrected fan tip speed" as disclosed herein according to one non-limiting embodiment is less than about 1150 ft/second (350.5 m/sec).

While the example of FIG. **1** illustrates one example of the gas turbine engine **20**, it will be understood that any number of spools, inclusion or omission of the gear system **48**, and/or other elements and subsystems are contemplated. Further, rotor systems described herein can be used in a variety of applications and need not be limited to gas turbine engines for aircraft applications. For example, rotor systems can be included in power generation systems, which may be ground-based as a fixed position or mobile system, and other such applications.

As described, the gas turbine engine **20** can include one or more vanes, such as the stator vanes **45**, **55**, guide inlet vanes, fan exit guide vanes, compressor vanes, turbine vanes, and/or the like, including combinations and/or multiples thereof. When the vanes are being manufactured, it may be desirable to perform vane classification to determine an airflow for each vane. Each vane, even of the same design, can be different in terms of airflow due to variations in manufacturing, materials, etc. It is useful to analyze each vane when assembling a gas turbine engine to determine how each vane's airflow contributes to the airflow of a full ring of vanes at a given stage of the turbine. This analysis eliminates vanes that are out of tolerance in terms of airflow.

The aerodynamic efficiency of a turbine is dependent on how efficiently energy can be extracted from combustion gasses by the turbine blades. For turbine blades to efficiently extract energy from those gasses, the amount and direction of combustion gas flow onto the blades should be within prescribed tolerances. These two parameters, amount and direction of flow, are determined by the aerodynamic shape of turbine vanes. It is therefore useful to analyze vanes based on their airflow characteristics. The analysis of the amount of flow is further described herein and may be referred to as "vane classification." A conventional approach to vane classification includes performing unique part specific hard gage classification. However, hard gage classification is difficult to maintain and needs periodic calibration to perform accurately due to the delicate nature of the system used. Another conventional approach to vane classification includes using a coordinate measuring machine (CMM). However, CMM vane classification requires unique part specific fixtures, complex programming, and only returns discrete points on the surface of the vane. Moreover, conventional techniques tend to analyze vane assemblies (that is, assemblies of multiple vanes) as a whole and not on an individual airfoil-by-airfoil basis.

One or more embodiments described herein address these and other shortcomings by providing for performing vane classification using structured light three-dimensional (3D) scans. A structured light 3D scanner is used to measure the 3D shape of an object (e.g., a vane) by projecting a light pattern onto surfaces of the object and then capturing one or more images of the object while the light pattern is projected on to the object. Stitching images taken from different orientations enables a full 3D geometry to be captured according to one or more embodiments. The results are a collection of 3D points, referred to as "scans." The scans can be digitally aligned to a model, such as a computer aided design (CAD) model. According to one or more embodiments described herein, virtual touch edges and touch disks on the structured light scan can be used to simulate hard gage pins to identify surface high points, which can be used to extract dimensions for vane classification.

According to one or more embodiments described herein, a structured light scanner captures geometry of a vane as a 3D point cloud. Dimensions can be extracted from the 3D point cloud by digital analysis, which can then be used to perform vane classification. The full 3D geometry provides for identification of high points on a surface of a vane more accurately than single point CMM approaches. The 3D data of the point cloud also provides for analysis with different datum schemes for engineering investigations.

FIG. **2** is a block diagram of a system **200** for performing vane classification according to one or more embodiments described herein. The system **200** includes a processing system **210** (e.g., the processing system **500** of FIG. **5**) and a structured light scanner **220**. The structured light scanner **220** can be any suitable device for projecting a light pattern onto a surface of an object to be scanned, such as a vane **230** of a turbine engine (e.g., the gas turbine engine **20**). For example, the structured light scanner **220** can include a projector **231** to project a structured light pattern **231***a* onto the vane **230**. The structured light scanner **220** can also include cameras **232**, **233** to capture images of the vane **230** while the structured light pattern **231***a* is being projected onto the vane **230**. According to an example, the structured light scanner **220** is a blue light scanner, although other types of structured light scanners can be implemented in accordance with one or more embodiments described herein.

The processing system **210** receives data about the vane **230** from the structured light scanner **220**. According to an example, the structured light scanner **220** can use the images from the cameras **232**, **233** to generate 3D data. According to another example, the processing system **210** receives the images from the structured light scanner **220** and uses those images to generate the 3D data. The processing system **210** can use the 3D data to generate a mesh surface and determine an airflow for the vane using the mesh surface.

The features and functionality of the system **200** can be implemented, for example, as instructions stored on a computer-readable storage medium, as hardware modules, as special-purpose hardware (e.g., application specific hardware, application specific integrated circuits (ASICs), application specific special processors (ASSPs), field programmable gate arrays (FPGAs), as embedded controllers, hardwired circuitry, etc.), or as some combination or combinations of these and/or the like. According to aspects of the present disclosure, the features and functionality described herein can be a combination of hardware and programming. The programming can be processor executable instructions stored on a tangible memory, and the hardware can include a processing device **212** (e.g., one or more of processing devices **521** of FIG. **5** and/or the like) for executing those instructions. Thus a system memory **214** (e.g., the random access memory **524** of FIG. **5**, the read only memory **522** of FIG. **5**, and/or the like, including combinations and/or multiples thereof) can store program instructions that when executed by the processing device **212** implement the

engines described herein. Other engines can also be utilized to include other features and functionality described in other examples herein.

FIG. **2**B depicts the vane **230** according to one or more embodiments described herein. Particularly, the vane **230** is turbine vane featuring an airfoil **240** having a leading edge **242**, a trailing edge **244**, a pressure side **246**, and a suction side **248**. The vane **230** also includes an inner diameter platform **250** and an outer diameter platform **252**. This particular embodiment features both an airfoil core **254** which renders the airfoil hollow and a platform core (not shown). In addition, though this figure features only an outer diameter core, the same principles can be used on the inner platform. Also note that this example features a singlet design, namely one airfoil per inner and outer platform segments. However, one or more embodiments described herein can be used on vane segments with a multiplicity of airfoils.

FIG. **3** is a flow diagram of a method **300** for performing vane classification according to one or more embodiments described herein. The method **300** can be performed using any suitable system and/or device. For example, the method **300** can be performed using the processing system **210** of FIG. **2**, the processing system **500** of FIG. **5**, and/or the like, including combinations and/or multiples thereof. The method **300** is now described with reference to the components of FIG. **2**, but is not so limited.

At block **302**, the structured light scanner **220** scans the vane **230** of a turbine engine (e.g., the gas turbine engine **20**) to capture 3D data about the vane **230**. At block **304**, a point cloud is generated from the 3D data about the vane **230**. As described herein, the structured light scanner **220** and/or the processing system **210** can generate the point cloud from the 3D data. At block **306**, the processing system **210** connects points of the point cloud to generate a mesh surface. The mesh surface can be generated using a triangle mesh, a polygon mesh, and/or another suitable mesh, including combinations and/or multiples thereof.

At block **308**, the processing system **210** determines an airflow for an airfoil (e.g., the airfoil **240**) of the vane **230** using the mesh surface from block **306**. The mesh surface provides for the processing system **210** to take measurements off the mesh surface to determine airflow of a single airfoil of the vane **230** then determine flow responsibility of that airfoil of the vane **230** to determine the airflow of that airfoil. This provides for measuring a single airfoil without reference to an adjacent airfoil. Techniques for determining the airflow for the vane **230** can include using a rectangular differential equation, a Simpson's Rule (also referred to as Simpson's ⅓ Rule), a trapezoidal rule, and/or the like, including combinations and/or multiples thereof. According to one or more embodiments described herein, the airflow is determined based at least in part on an amount of air flow blockage of the vane. According to one or more embodiments described herein, the airflow is determined based at least in part on a rotational angle of the vane. An example equation for determining the airflow is given as follows:

$$FA = SA_{SectorArea} - \text{Blockage} + \Delta RFA + X_{translated\ from\ \Delta Y}$$

where FA is the airflow, $SA_{SectorArea}$ is the total area responsible for one sector of a ring of airfoils where a portion of that sector is blocked by the airfoil and the other is not blocked, Blockage is the thickness of the airfoil along the direction of flow, ΔRFA is the change in flow area due to a change in angular direction of the airfoil relative to an engine holding point, and $X_{tranlatedfrom\Delta Y}$ is the Change in the flow area due to the change in distance between the inner and outer diameter platforms.

At block **310**, a turbine engine (e.g., the gas turbine engine **20**) is constructed based at least in part on the airflow for the vane. For example, if the airflow for the vane indicates that the vane is out of tolerance or otherwise unsuitable for inclusion in the turbine engine (e.g., if the airflow fails to satisfy a threshold), the vane may be discarded or not used in a particular turbine engine, even though it may be suitable for another turbine engine. For example, for some engine programs, vanes are selected, sorted, and intermixed such that their combined air flow meets the airflow requirement for the engine. In some other engine programs, airflow of vanes are measured and used to alter future vanes being manufactured (e.g., adjust an aspect of vanes produced in a next batch of vanes) until the vanes produced create a flow area within a specific tolerance allowing the vanes to be fully interchangeable with other vanes made using the same tolerances. According to one or more embodiments described herein, the vane can be selected based on the airflow of other vanes included in the gas turbine engine. Or for example, vanes can be selected that have similar airflow.

It should be appreciated that the method **300** can be used to evaluate a single airfoil at a time. That is, a single vane is scanned, and each airfoil is analyzed individually for airflow.

Additional processes also may be included, and it should be understood that the process depicted in FIG. **3** represents an illustration, and that other processes may be added or existing processes may be removed, modified, or rearranged without departing from the scope of the present disclosure.

FIGS. **4**A-**4**D depict representations **401**-**404** of the vane **230** according to one or more embodiments described herein. The representations **401**-**404** represent scans of the vane **230** according to one or more embodiments described herein. In FIG. **4**A, the representation **401** shows a six-point nest alignment to establish a nominal average flow direction ("BJ"). In FIG. **4**B, the representation **402** shows a measured angle **405** and a nominal angle **406**. The "nominal" angle **406** represents an as designed angle AH while the "actual" measured angle **405** represent the measured angle "AH." A deviation value "dev" represents the deviation or difference between the measured and nominal angles **405**, **406**. That is, the deviation value, or difference between the measured and nominal angles **405**, **406**, equals how the airfoil (e.g., the airfoil **240**) as rotated relative to how the vane **230** will sit in the engine. In FIG. **4**C, the representation **403** shows how gage points for the flow direction of nominal airflow are used to extract the thickness of the airfoil in the direction of flow. The plane **410** represents the average flow direction. Gauge points (not shown) perpendicular to the direction of flow can be used to measure the blockage of the airfoil. The number of points can be equal, or not, and the number of points can be in coplanar pairs, or not, depending on the differential method used to calculate the blockage area. In FIG. **4**D, the representation **404** shows how to measure Y_{actual}, which is a height of the airfoil as shown. The "nominal" value represents the design intent height, while the "actual" represents the measured height of the actual airfoil.

One or more embodiments described herein reduce/eliminate the infrastructure for hard gage or CMM vane calculation approaches. For example, for the techniques described herein, the vane is simply positioned, scanned, and then the processing system **210** determines airflow for the vane as described. Moreover, one or more examples described herein can scan an entire surface of a vane to get a high

point, so if a choke point is not where it says it should be, a true flow area for that vane can be determined. By constructing a turbine engine using vanes classified using one or more embodiments described herein, the turbine engine is improved. Specifically, using vanes with known airflows means turbine engines can be constructed more closely to design specifications, thus improving the engine efficiency.

One or more embodiments described herein eliminate the CMM fixture requirement, provide for multiple part alignments compared to CMM single/fixtured alignment, provide for visualization of Aberrant geometry (e.g., crocked trailing edge due to hot or cold forming), provide for automated high point detection compared to CMM single point measurements, and/or the like, including combinations and/or multiples thereof.

It is understood that one or more embodiments described herein is capable of being implemented in conjunction with any other type of computing environment now known or later developed. For example, FIG. **5** depicts a block diagram of a processing system **500** for implementing the techniques described herein. In accordance with one or more embodiments described herein, the processing system **500** is an example of a cloud computing node of a cloud computing system. In examples, processing system **500** has one or more central processing units ("processors" or "processing resources" or "processing devices") **521***a*, **521***b*, **521***c*, etc. (collectively or generically referred to as processor(s) **521** and/or as processing device(s)). In aspects of the present disclosure, each processor **521** can include a reduced instruction set computer (RISC) microprocessor. Processors **521** are coupled to system memory (e.g., random access memory (RAM) **524**) and various other components via a system bus **533**. Read only memory (ROM) **522** is coupled to system bus **533** and may include a basic input/output system (BIOS), which controls certain basic functions of processing system **500**.

Further depicted are an input/output (I/O) adapter **527** and a network adapter **526** coupled to system bus **533**. I/O adapter **527** may be a small computer system interface (SCSI) adapter that communicates with a hard disk **523** and/or a storage device **525** or any other similar component. I/O adapter **527**, hard disk **523**, and storage device **525** are collectively referred to herein as mass storage **534**. Operating system **540** for execution on processing system **500** may be stored in mass storage **534**. The network adapter **526** interconnects system bus **533** with an outside network **536** enabling processing system **500** to communicate with other such systems.

A display **535** (e.g., a display monitor) is connected to system bus **533** by display adapter **532**, which may include a graphics adapter to improve the performance of graphics intensive applications and a video controller. In one aspect of the present disclosure, adapters **526**, **527**, and/or **532** may be connected to one or more I/O busses that are connected to system bus **533** via an intermediate bus bridge (not shown). Suitable I/O buses for connecting peripheral devices such as hard disk controllers, network adapters, and graphics adapters typically include common protocols, such as the Peripheral Component Interconnect (PCI). Additional input/output devices are shown as connected to system bus **533** via user interface adapter **528** and display adapter **532**. A keyboard **529**, mouse **530**, and speaker **531** may be interconnected to system bus **533** via user interface adapter **528**, which may include, for example, a Super I/O chip integrating multiple device adapters into a single integrated circuit.

In some aspects of the present disclosure, processing system **500** includes a graphics processing unit **537**. Graphics processing unit **537** is a specialized electronic circuit designed to manipulate and alter memory to accelerate the creation of images in a frame buffer intended for output to a display. In general, graphics processing unit **537** is very efficient at manipulating computer graphics and image processing, and has a highly parallel structure that makes it more effective than general-purpose CPUs for algorithms where processing of large blocks of data is done in parallel.

Thus, as configured herein, processing system **500** includes processing capability in the form of processors **521**, storage capability including system memory (e.g., RAM **524**), and mass storage **534**, input means such as keyboard **529** and mouse **530**, and output capability including speaker **531** and display **535**. In some aspects of the present disclosure, a portion of system memory (e.g., RAM **524**) and mass storage **534** collectively store the operating system **540** to coordinate the functions of the various components shown in processing system **500**.

The term "about" is intended to include the degree of error associated with measurement of the particular quantity based upon the equipment available at the time of filing the application.

The terminology used herein is for the purpose of describing particular embodiments only and is not intended to be limiting of the present disclosure. As used herein, the singular forms "a", "an" and "the" are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will be further understood that the terms "comprises" and/or "comprising," when used in this specification, specify the presence of stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, element components, and/or groups thereof.

While the present disclosure has been described with reference to an exemplary embodiment or embodiments, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted for elements thereof without departing from the scope of the present disclosure. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the present disclosure without departing from the essential scope thereof. Therefore, it is intended that the present disclosure not be limited to the particular embodiment disclosed as the best mode contemplated for carrying out this present disclosure, but that the present disclosure will include all embodiments falling within the scope of the claims.

What is claimed is:

1. A method for vane classification comprising:

scanning, using a structured light scanner, a vane having a singlet design including a single airfoil for a turbine engine to capture three-dimensional (3D) data about the vane,

generating a point cloud from the 3D data corresponding to the scanned vane;

connecting, using a processing system, points of the point cloud to generate a vane mesh surface of the scanned vane and an airfoil mesh surface;

determining, using the processing system, an airflow for the single airfoil without reference to an adjacent airfoil based at least in part on the vane mesh surface; and

optimizing the airflow of the turbine engine based on the airflow of the single airfoil,

wherein determining the airflow for the single airfoil includes measuring the airflow of the single airfoil based on the vane mesh surface without reference to an adjacent airfoil, and wherein the airflow is determined based at least in part on an amount of air flow blockage of corresponding to the scanned vane, and

wherein the turbine engine including at least one produced airflow is constructed based at least in part on the airflow for the single airfoil.

2. The method of claim **1**, wherein the structured light scanner is a blue light structured light scanner.

3. The method of claim **1**, wherein the mesh surface is a triangle mesh.

4. The method of claim **1**, wherein the mesh surface is a polygon mesh.

5. The method of claim **1**, wherein the airflow is determined based at least in part on a rotational angle of the scanned vane.

6. A system comprising:

a structured light scanner to scan a vane having a singlet design including a single airfoil for a turbine engine, the scan configured to capture three-dimensional (3D) data about the single airfoil of the vane; and

a processing system comprising:

a memory comprising computer readable instructions; and

a processing device for executing the computer readable instructions, the computer readable instructions controlling the processing device to perform operations for vane classification comprising:

generating a point cloud from the 3D data corresponding to the airfoil of the vane;

connecting points of the point cloud to generate a vane mesh surface;

determining, using the processing system, an airflow for the single airfoil with without reference to an adjacent airfoil based at least in part on the vane mesh surface; and

optimizing the airflow of the turbine engine based on the airflow of the single airfoil,

wherein determining the airflow for the single airfoil includes measuring the airflow of the single airfoil based on the vane mesh surface without reference to an adjacent airfoil, and wherein the airflow is determined based at least in part on an amount of air flow blockage of corresponding to the scanned vane, and

wherein the turbine engine is constructed based at least in part on the airflow determined according to the single airfoil.

7. The system of claim **6**, wherein the structured light scanner is a blue light structured light scanner.

8. The system of claim **6**, wherein the mesh surface is a triangle mesh.

9. The system of claim **6**, wherein the mesh surface is a polygon mesh.

10. The system of claim **6**, wherein the airflow is determined based at least in part on a rotational angle of the vane.

11. The system of claim **6**, wherein the structured light scanner scans a gas path of the turbine engine for a window height, wherein determining the airflow for the airfoil of the vane is based at least in part on the window height.

12. A computer program product comprising a computer readable storage medium having program instructions embodied therewith, the program instructions executable by a processor to cause the processor to perform operations comprising:

receiving, from a structured light scanner, three-dimensional (3D) data about a vane and a gas path for the vane, the vane having a singlet design including a single airfoil for a turbine engine,

generating a point cloud from the 3D data corresponding to the airfoil and the gas path of the vane;

connecting, using a processing system, points of the point cloud to generate a vane mesh surface;

determining, using the processing system, an airflow for the single airfoil without reference to an adjacent airfoil based at least in part on the vane mesh surface; and

optimizing the airflow of the turbine engine based on the airflow of the single airfoil,

wherein determining the airflow for the single airfoil includes measuring the airflow of the single airfoil based on the vane mesh surface without reference to an adjacent airfoil, and wherein the airflow is determined based at least in part on an amount of air flow blockage of corresponding to the scanned vane, and

wherein the turbine engine including at least one produced airflow is constructed based at least in part on the airflow for the single airfoil.

13. The computer program product of claim **12**, wherein the structured light scanner is a blue light structured light scanner.

14. The computer program product of claim **12**, wherein the mesh surface is a polygon mesh.

15. The computer program product of claim **12**, wherein the airflow is determined based at least in part on a rotational angle of the vane.

* * * * *