US009884370B2

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

(10) **Patent No.: US 9,884,370 B2**
(45) **Date of Patent: Feb. 6, 2018**

(54) **SYSTEM FOR FORMING PERFORATIONS IN A BARREL SECTION**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 72 days.

(21) Appl. No.: **15/155,018**

(22) Filed: **May 15, 2016**

(65) **Prior Publication Data**

US 2016/0256935 A1 Sep. 8, 2016

Related U.S. Application Data

(62) Division of application No. 14/012,243, filed on Aug. 28, 2013, now Pat. No. 9,370,827.

(51) **Int. Cl.**
B23B 39/14 (2006.01)
B23B 39/24 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC ***B23B 39/24*** (2013.01); ***B23B 39/14*** (2013.01); ***B23B 39/20*** (2013.01); ***B25J 11/005*** (2013.01); ***B64D 33/02*** (2013.01); ***F02C 7/045*** (2013.01); *B23B 2215/04* (2013.01); *B23B 2226/27* (2013.01); *B23B 2270/16* (2013.01);
(Continued)

(58) **Field of Classification Search**
CPC B23B 39/14; B23B 39/24; Y10T 408/38
See application file for complete search history.

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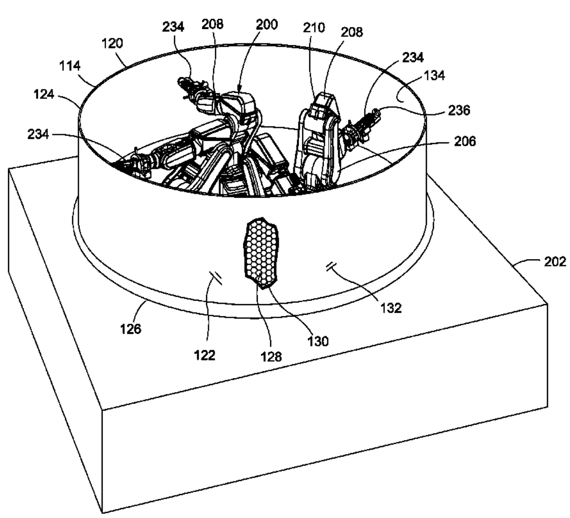
Primary Examiner — James Sanders

(57) **ABSTRACT**

A drilling system may include a plurality of robotic drilling units. Each one of the robotic drilling units may include a drill end effector positioned inside a barrel section. The barrel section may be configured as a composite sandwich structure having an inner face sheet. The robotic drilling units maybe operable in synchronized movement with one another to drill a plurality of perforations into the inner face sheet using the drill end effectors in a manner providing a predetermined percent-open-area of the inner face sheet.

14 Claims, 12 Drawing Sheets



(51) **Int. Cl.**

B23B 39/20	(2006.01)
B25J 11/00	(2006.01)
B64D 33/02	(2006.01)
F02C 7/045	(2006.01)

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

CPC *B23B 2270/20* (2013.01); *B23B 2270/32* (2013.01); *B64D 2033/0206* (2013.01); *B64D 2033/0286* (2013.01); *Y10T 408/03* (2015.01); *Y10T 408/38* (2015.01)

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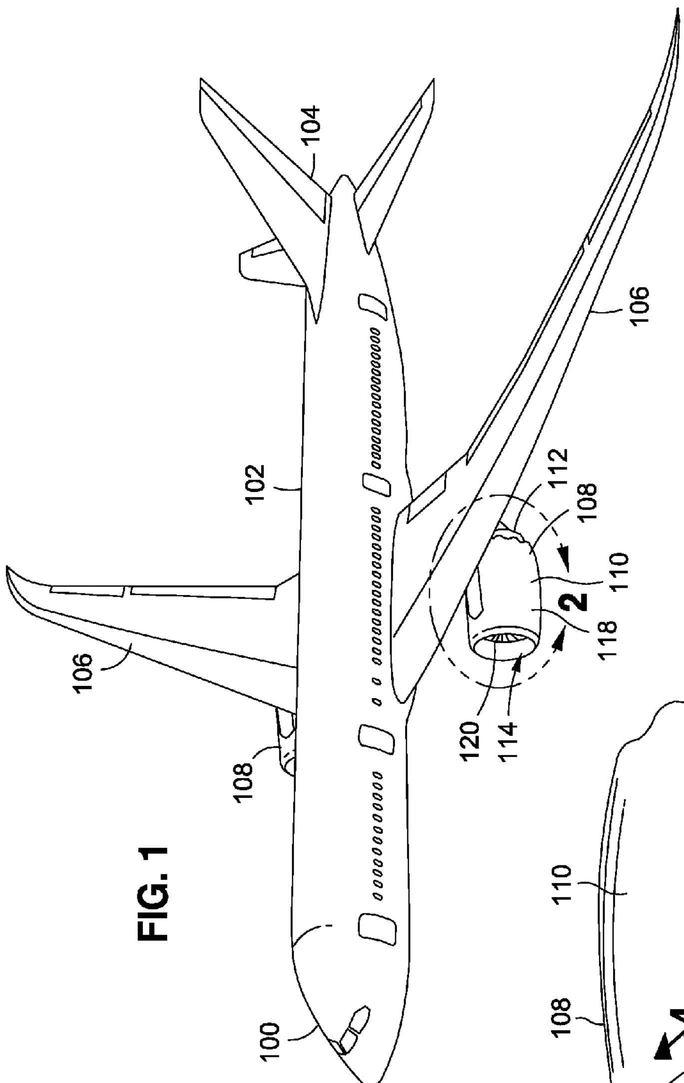

104
106
102
112
108
110
2
118
120
114
106
108
100

FIG. 1

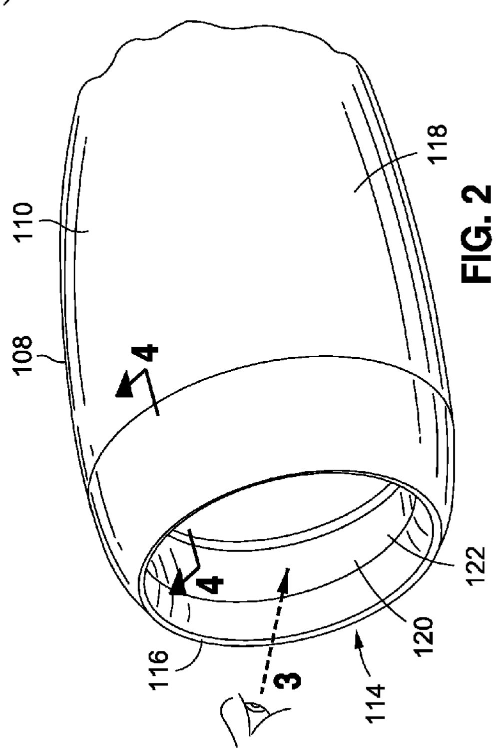
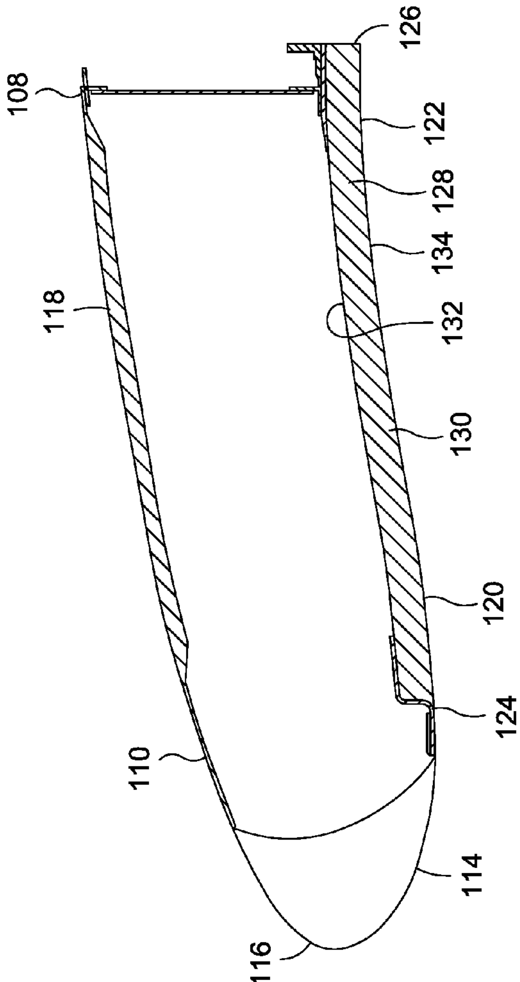

118
110
108
4
4
122
120
116
3
114

FIG. 2


108
126
122
128
134
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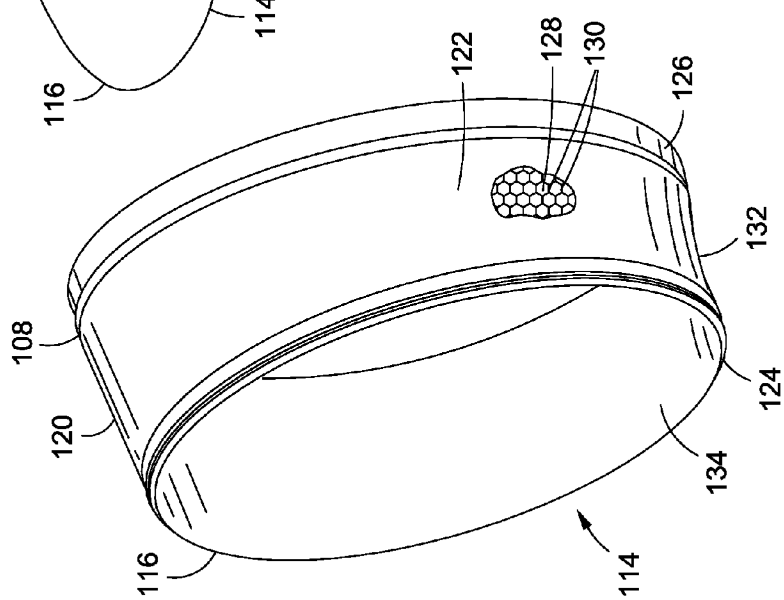
118
130
120
124
110
114
116

FIG. 4


122
128
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126
132
108
120
124
134
116
114

FIG. 3

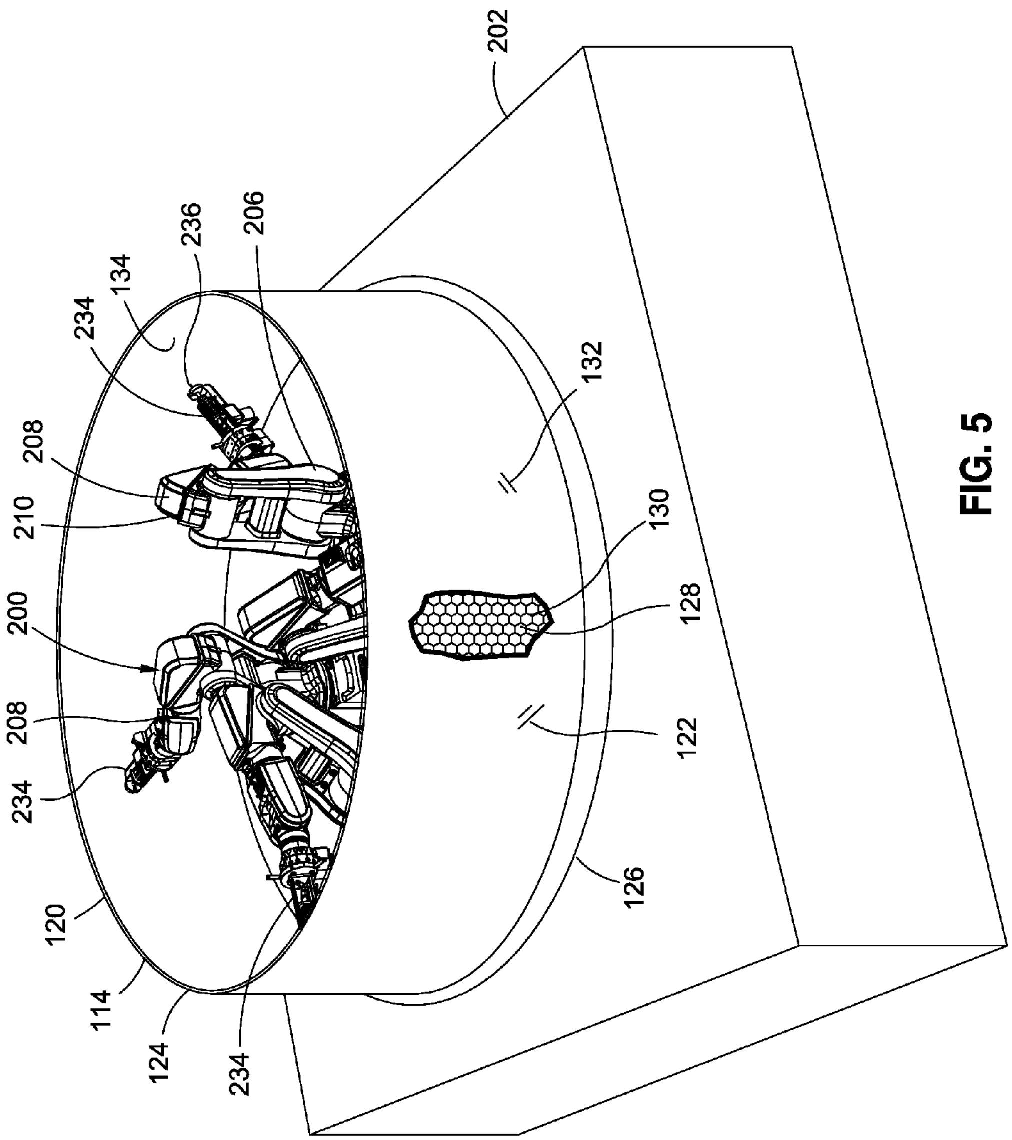
202
236
206
134
234
132
208
210
130
128
200
122
208
234
126
120
114
124
234

FIG. 5

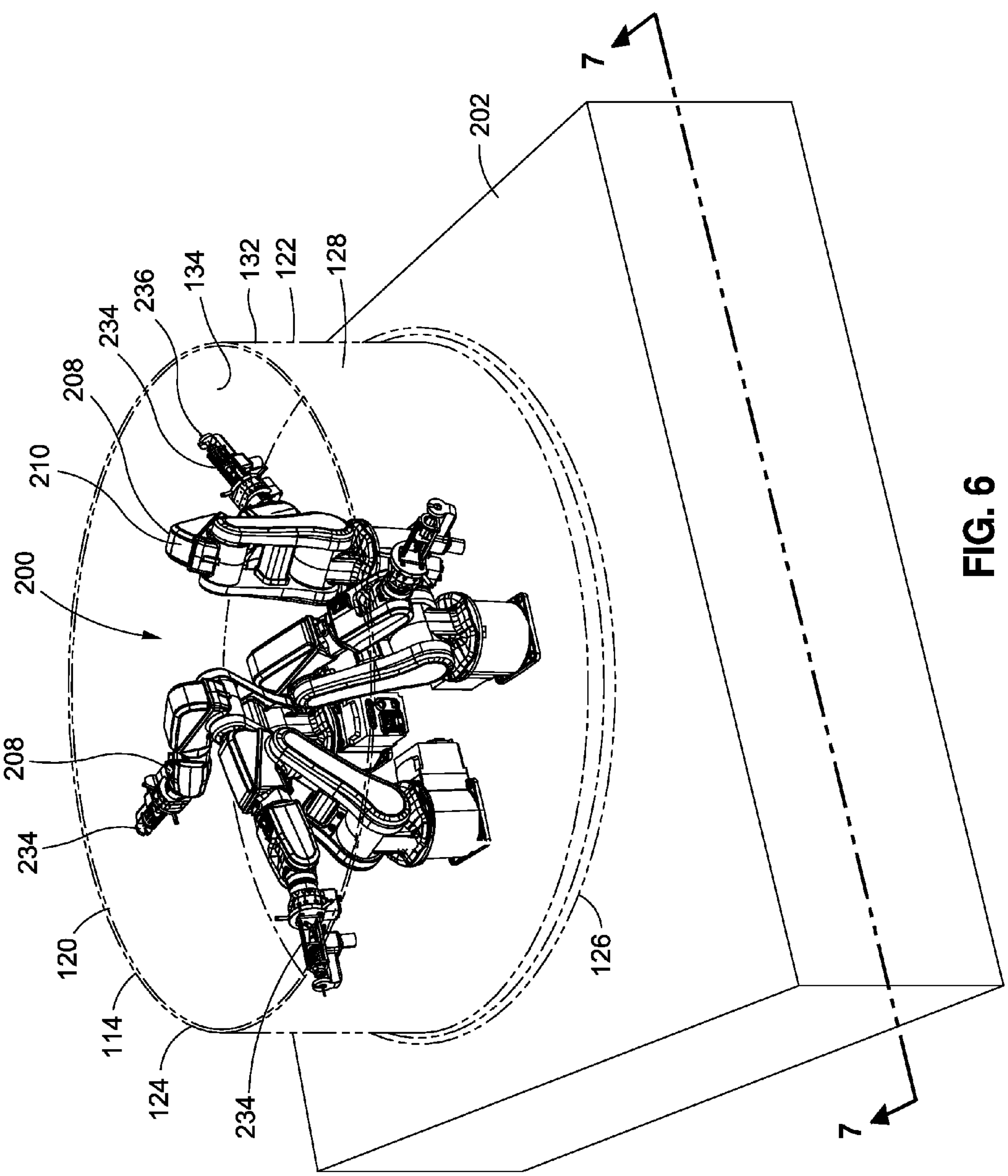
7
202
128
122
132
134
236
234
208
210
200
208
234
120
114
124
234
126
7

FIG. 6

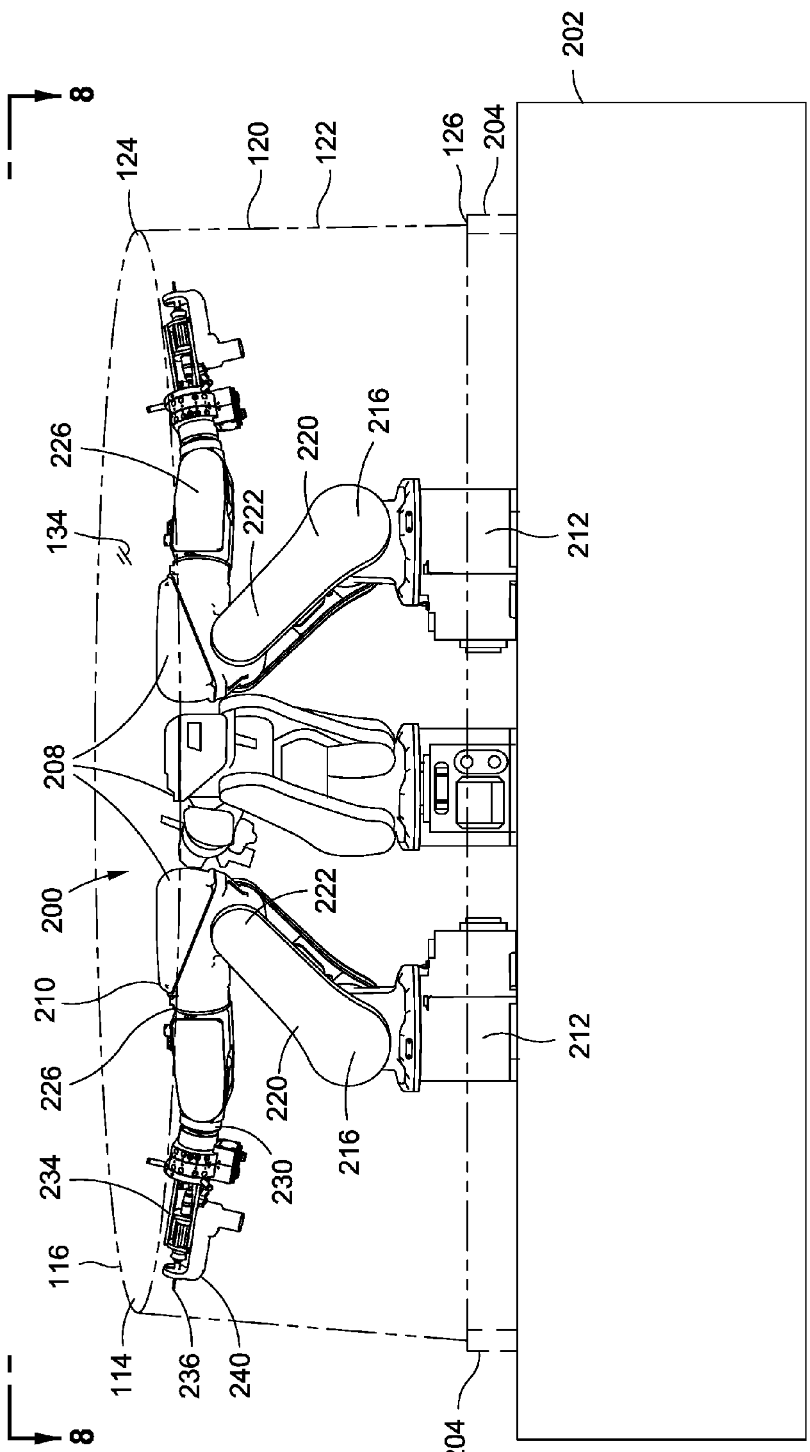
8
124
120
122
126
204
202
226
134
222
220
216
212
208
200
222
210
226
220
216
212
230
234
116
114
236
240
204
8

FIG. 7

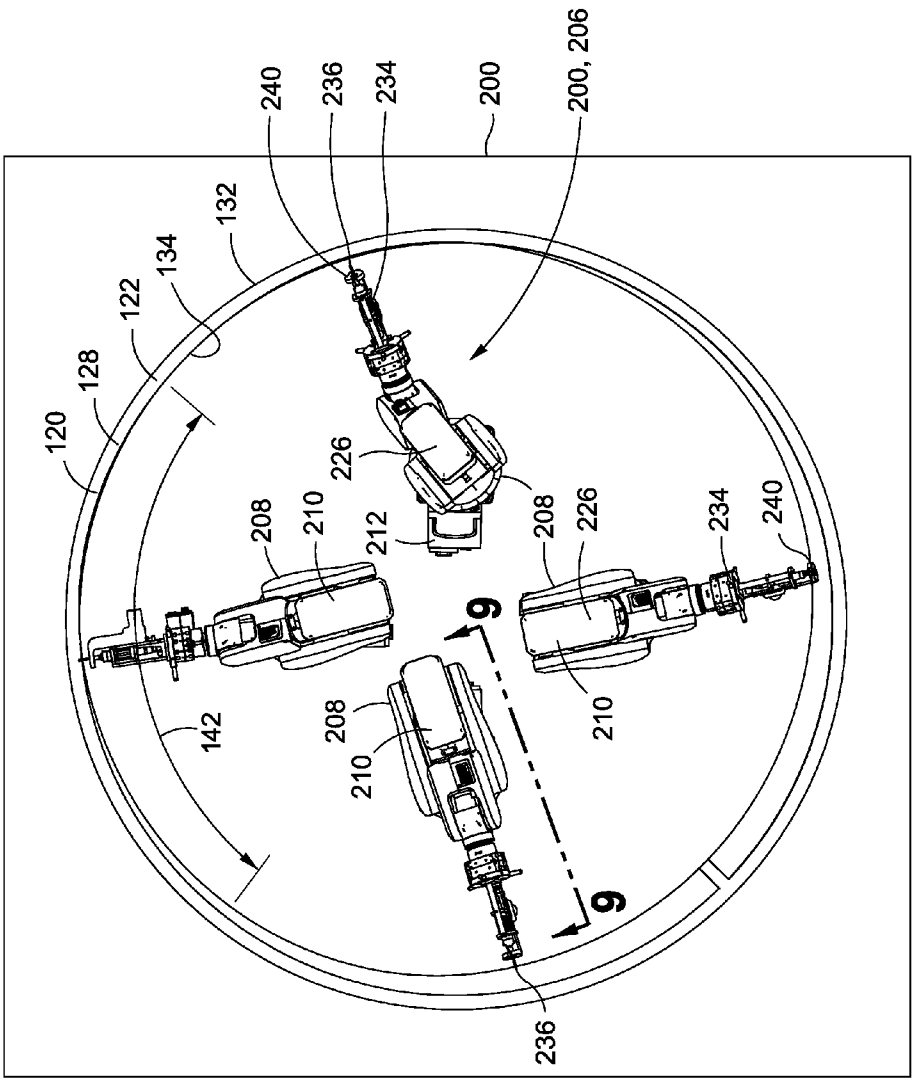
200, 206
200
234
236
240
132
134
122
128
120
226
208
212
210
208
226
234
240
9
9
142
208
210
210
236

FIG. 8

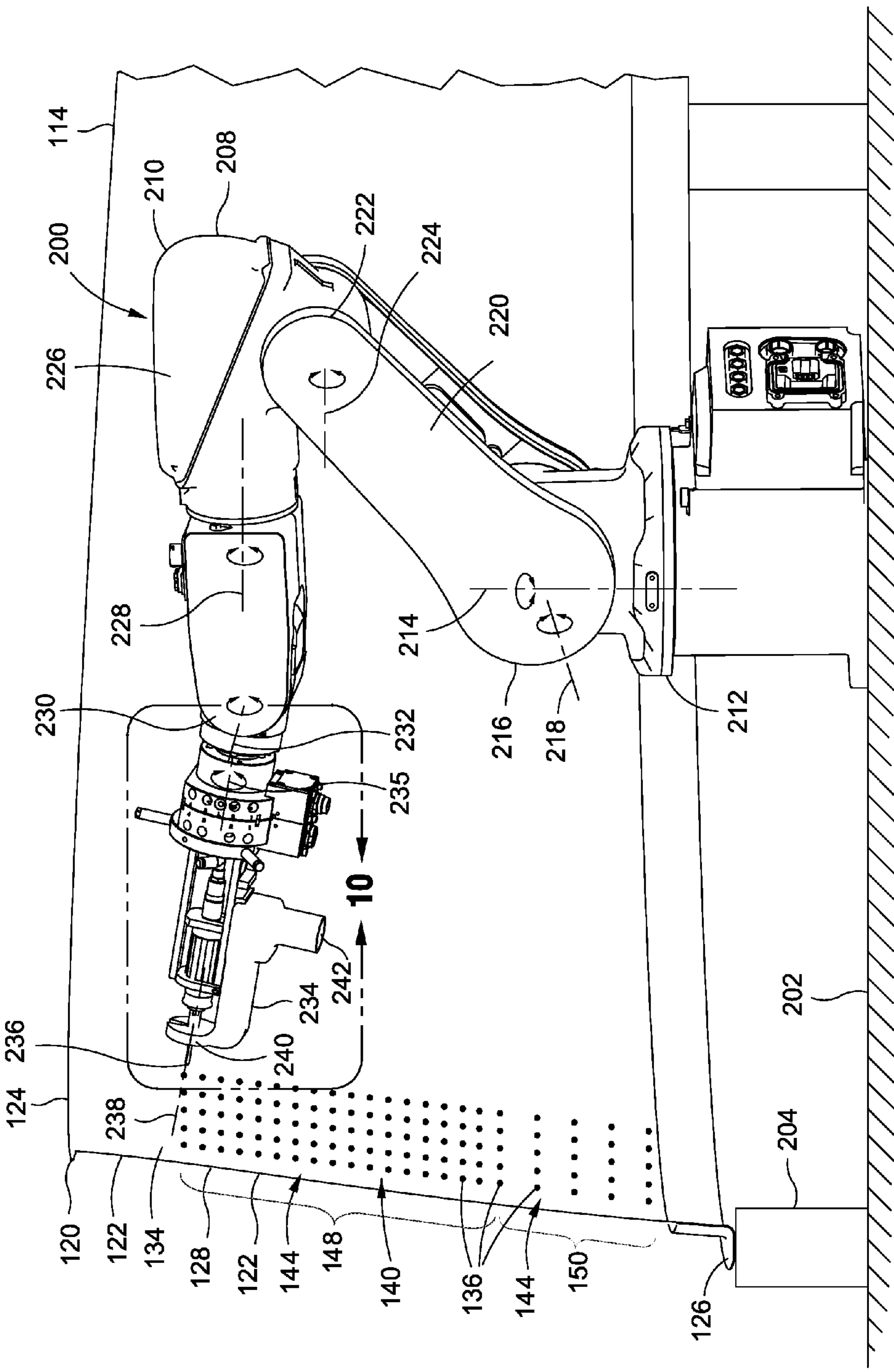
114
208
210
200
222
224
220
226
228
214
230
232
235
216
218
212
10
242
234
240
236
238
124
202
204
120
122
134
128
122
144
148
140
136
144
150
126

FIG. 9

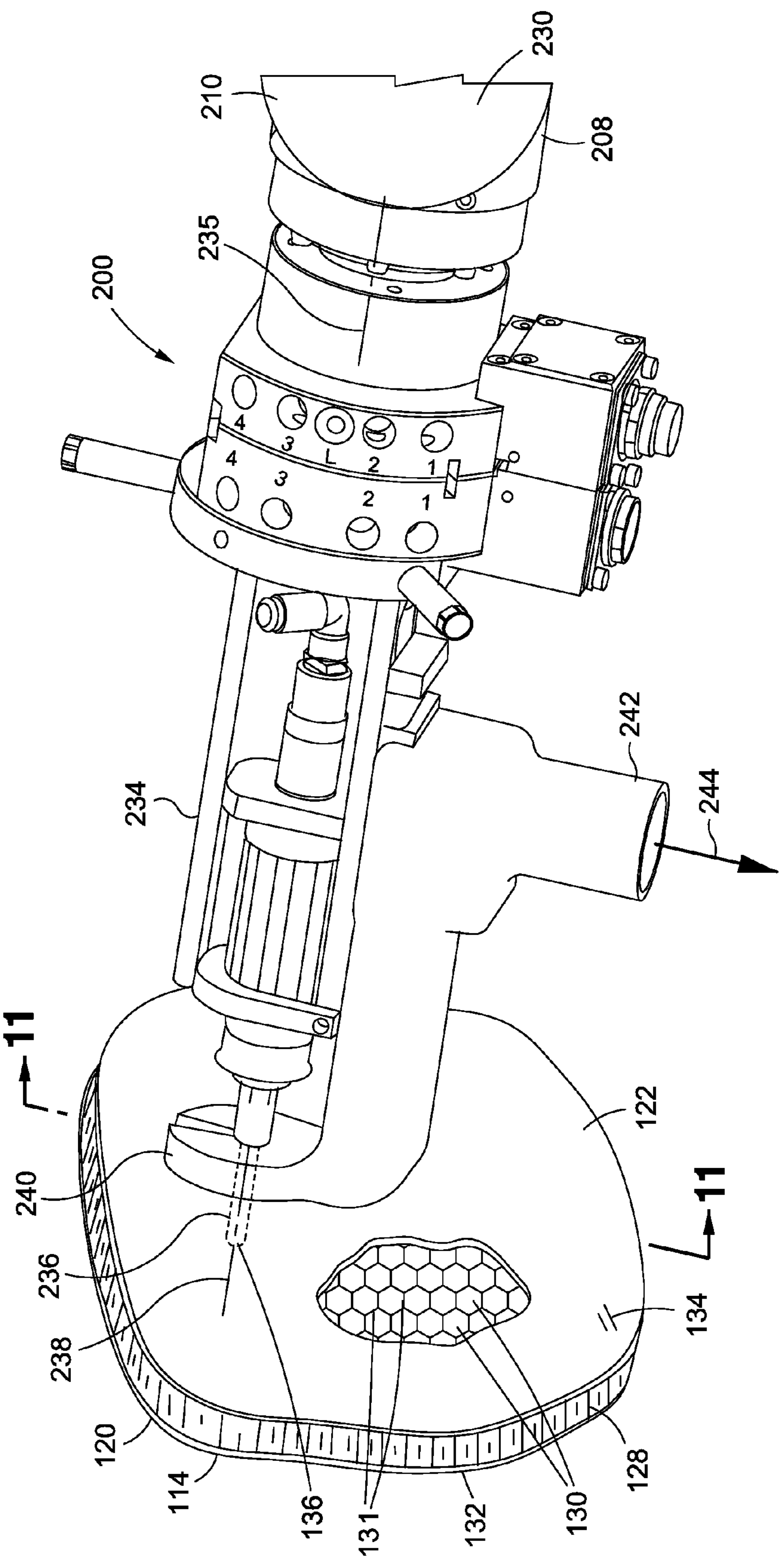
230
210
208
235
200
4
3
L
2
1
242
244
234
11
122
11
240
236
134
238
120
128
114
136
131
132
130

FIG. 10

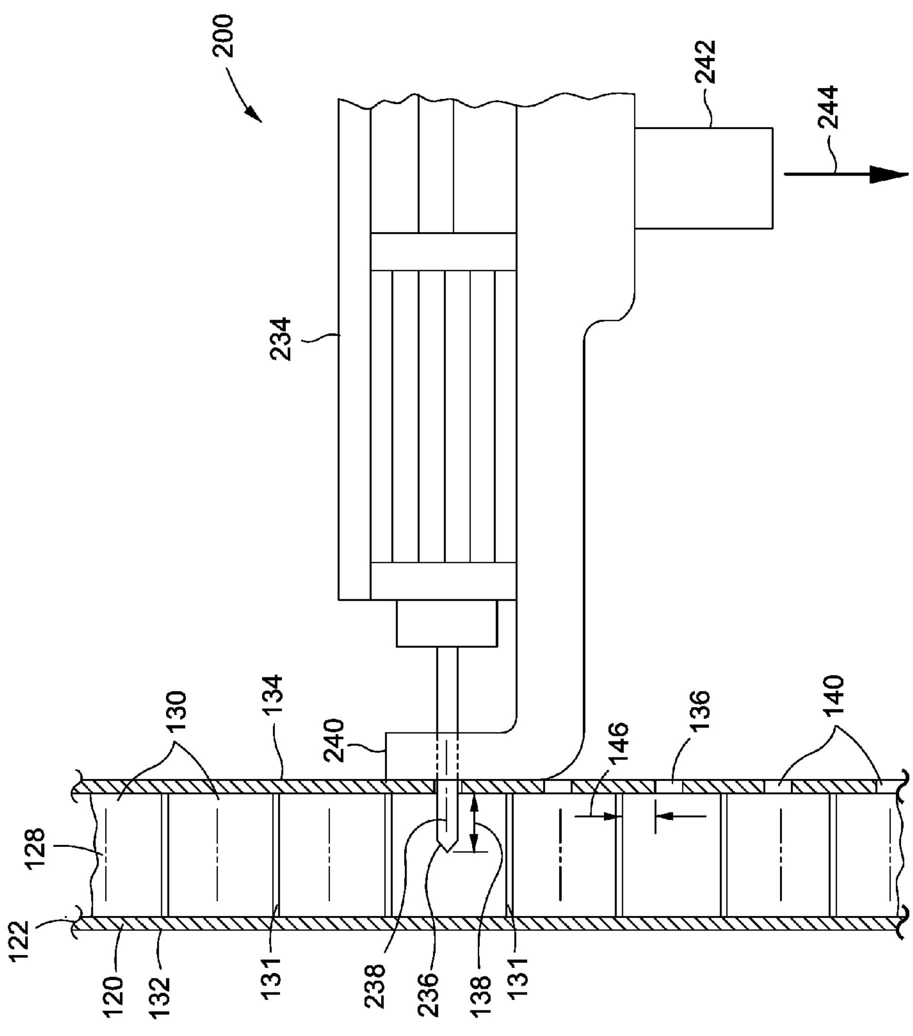
200
242
244
234
130
134
240
136
140
146
128
122
120
132
131
238
236
138
131

FIG. 11

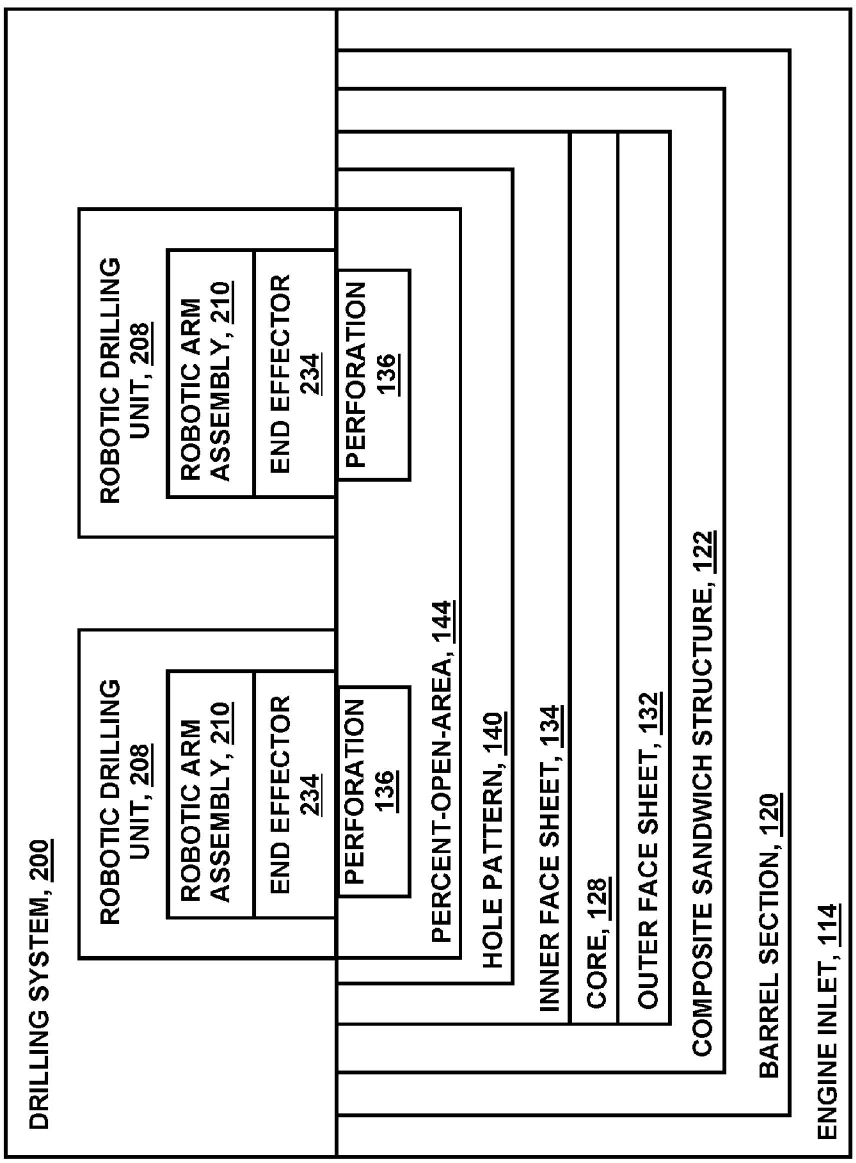
DRILLING SYSTEM, 200
ROBOTIC DRILLING UNIT, 208
ROBOTIC ARM ASSEMBLY, 210
END EFFECTOR 234
PERFORATION 136
ROBOTIC DRILLING UNIT, 208
ROBOTIC ARM ASSEMBLY, 210
END EFFECTOR 234
PERFORATION 136
PERCENT-OPEN-AREA, 144
HOLE PATTERN, 140
INNER FACE SHEET, 134
CORE, 128
OUTER FACE SHEET, 132
COMPOSITE SANDWICH STRUCTURE, 122
BARREL SECTION, 120
ENGINE INLET, 114

FIG. 12

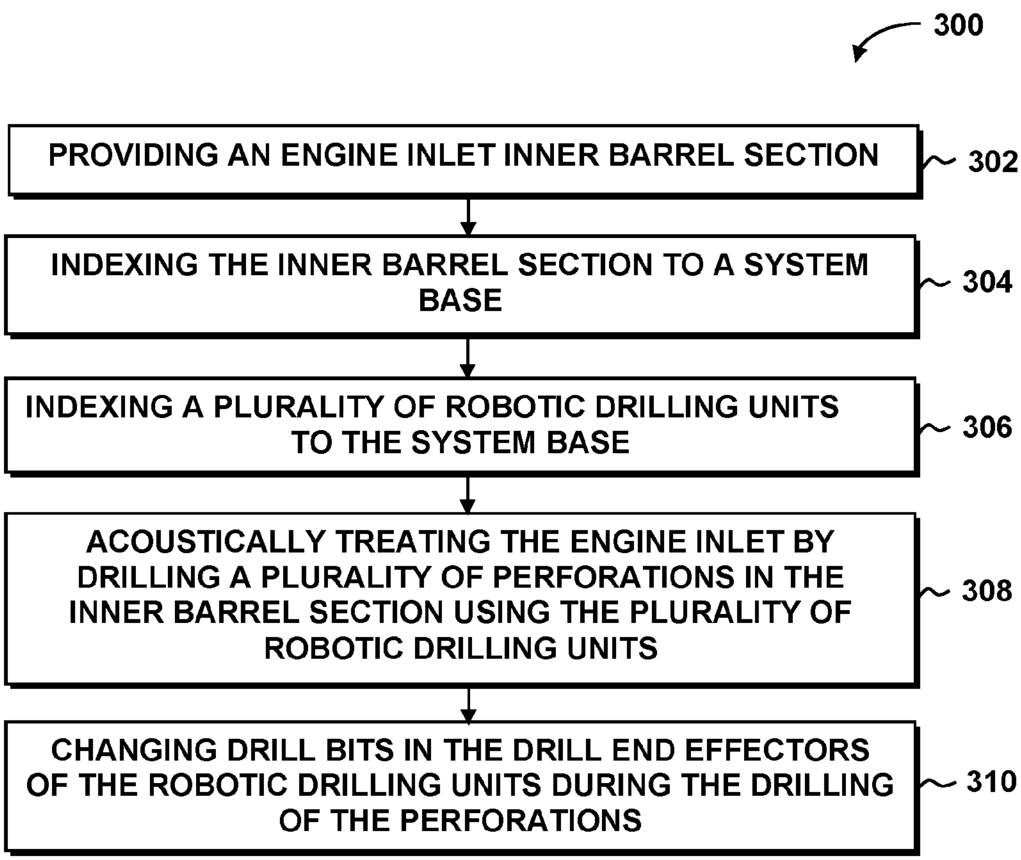
300
PROVIDING AN ENGINE INLET INNER BARREL SECTION
302
INDEXING THE INNER BARREL SECTION TO A SYSTEM BASE
304
INDEXING A PLURALITY OF ROBOTIC DRILLING UNITS TO THE SYSTEM BASE
306
ACOUSTICALLY TREATING THE ENGINE INLET BY DRILLING A PLURALITY OF PERFORATIONS IN THE INNER BARREL SECTION USING THE PLURALITY OF ROBOTIC DRILLING UNITS
308
CHANGING DRILL BITS IN THE DRILL END EFFECTORS OF THE ROBOTIC DRILLING UNITS DURING THE DRILLING OF THE PERFORATIONS
310

FIG. 13

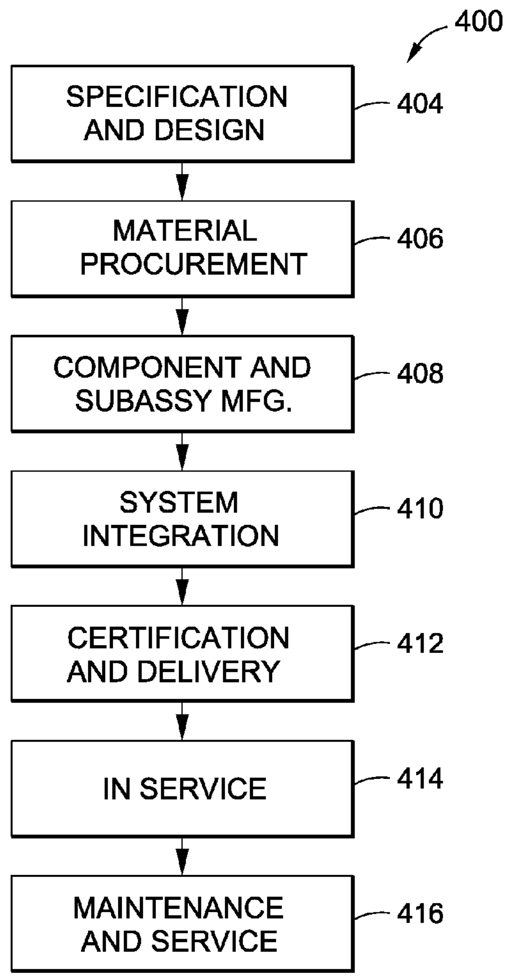
400
SPECIFICATION AND DESIGN
404
MATERIAL PROCUREMENT
406
COMPONENT AND SUBASSY MFG.
408
SYSTEM INTEGRATION
410
CERTIFICATION AND DELIVERY
412
IN SERVICE
414
MAINTENANCE AND SERVICE
416

FIG. 14

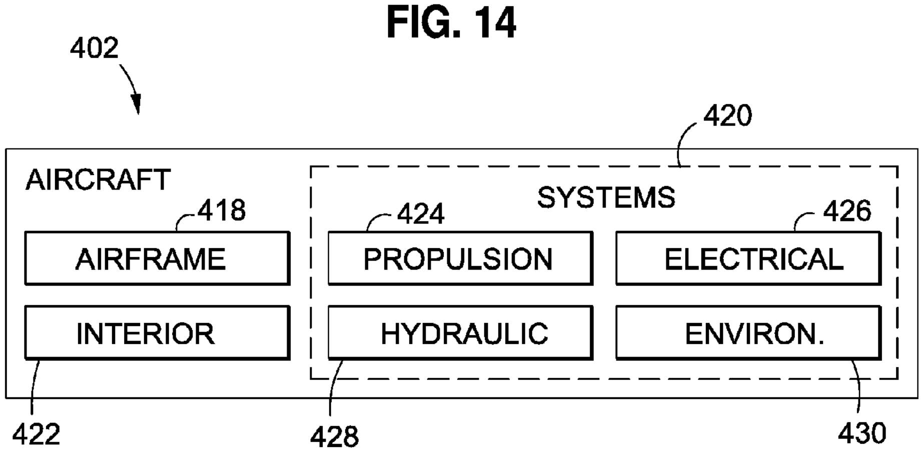
402
420
AIRCRAFT
418
AIRFRAME
INTERIOR
SYSTEMS
424
PROPULSION
426
ELECTRICAL
HYDRAULIC
ENVIRON.
422
428
430

FIG. 15

SYSTEM FOR FORMING PERFORATIONS IN A BARREL SECTION

CROSS-REFERENCE TO RELATED APPLICATIONS

The present application is a divisional application of and claims priority to pending U.S. application Ser. No. 14/012,243 filed on Aug. 28, 2013, and entitled SYSTEM AND METHOD FOR FORMING PERFORATIONS IN A BARREL SECTION, the entire contents of which is expressly incorporated by reference herein.

FIELD

The present disclosure relates generally to production of acoustic treatment of structures and, more particularly, to the forming of acoustic perforations in an engine inlet barrel section.

BACKGROUND

Commercial airliners are required to meet certain noise standards such as during takeoff and landing. A large portion of the noise produced by a commercial airliner during takeoff and landing is generated by gas turbine engines commonly used on airliners. Known methods for reducing the noise level of a gas turbine engine include acoustically treating the engine inlet of the engine nacelle. In this regard, the inner barrel section of a gas turbine engine inlet may be provided with a plurality of relatively small perforations formed in the walls of the inner barrel section. The perforations absorb some of the noise that is generated by fan blades rotating at high speed at the engine inlet, and thereby reduce the overall noise output of the gas turbine engine.

Conventional methods for forming perforations in acoustic structures such as the barrel section include forming the inner wall of the barrel section as a separate component, followed by forming the perforations in the inner wall. The inner wall may then be assembled with other components that make up the barrel section, which is then assembled with the nacelle of the gas turbine engine. Unfortunately, such conventional methods for forming acoustic structures include operations that may result in the blockage of some of the perforations after the perforations have been formed.

Conventional methods for forming acoustic structures may also result in missing perforations. Such blocked perforations or missing perforations may reduce the percent-open-area (POA) of the inner wall (e.g., the total area of the perforations as a percentage of the surface area of the inner wall) which is a characteristic of acoustic structures for measuring their overall effectiveness in absorbing or attenuating noise. Furthermore, conventional methods of forming perforations in acoustic structures are time-consuming processes that add to the production schedule and cost.

As can be seen, there exists a need in the art for a system and method for forming perforations in an acoustic structure which minimizes or eliminates the occurrence of blocked or missing perforations, and which may be performed in a timely and cost-effective manner.

SUMMARY

The above-noted needs associated with forming perforations in an acoustic structure such as an engine inlet are specifically addressed and alleviated by the present disclosure which provides a drilling system that may include a

plurality of robotic drilling units. Each one of the robotic drilling units may include a drill end effector positioned inside a barrel section of an engine inlet. The barrel section may be configured as a composite sandwich structure having an inner face sheet. The robotic drilling units may be operable in synchronized movement with one another to drill a plurality of perforations into the inner face sheet using the drill end effectors in a manner providing a predetermined percent-open-area of the inner face sheet.

Also disclosed is a method of fabricating an engine inlet. The method may include providing an engine inlet inner barrel section configured as a composite sandwich structure having an inner face sheet, a core, and an outer face sheet. The method may further include robotically drilling a plurality of perforations in the inner face sheet after final cure of the composite sandwich structure. The method may additionally include forming the plurality of perforations in a quantity providing a predetermined percent-open-area of the inner face sheet.

In a further embodiment, disclosed is a method of fabricating an engine inlet including the step of providing an engine inlet inner barrel section configured as a one-piece composite sandwich structure having an inner face sheet, an outer face sheet, and a honeycomb core. The composite sandwich structure may be formed in a single stage cure wherein the inner face sheet, the core, and the outer face sheet may be co-cured and/or co-bonded in a single operation. The method may include drilling, using a plurality of robotic drilling units, a plurality of perforations in the inner face sheet after final cure of the composite sandwich structure. The method may further include operating the plurality of robotic drilling units in synchronized movement with one another to simultaneously drill the plurality of perforations. The method may also include forming the plurality of perforations in a quantity providing a predetermined percent-open-area of the inner face sheet.

The features, functions and advantages that have been discussed can be achieved independently in various embodiments of the present disclosure or may be combined in yet other embodiments, further details of which can be seen with reference to the following description and drawings below.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other features of the present disclosure will become more apparent upon reference to the drawings wherein like numbers refer to like parts throughout and wherein:

FIG. **1** is a perspective illustration of an aircraft;

FIG. **2** is a perspective illustration of a nacelle of a gas turbine engine of the aircraft of FIG. **1**;

FIG. **3** is a perspective illustration of an inner barrel section of an engine inlet of the gas turbine engine of FIG. **2**;

FIG. **4** is a cross-sectional illustration of a leading edge of the engine inlet of the gas turbine engine of FIG. **2**;

FIG. **5** is a perspective illustration of an embodiment of a drilling system for forming perforations in a barrel section;

FIG. **6** is a perspective illustration of the drilling system with the barrel section shown in phantom lines to illustrate a plurality of robotic drilling units of the drilling system;

FIG. **7** is a side view of the drilling system;

FIG. **8** is the top view of the drilling system;

FIG. **9** is a side view of one of the robotic drilling units forming a hole pattern along an inner face sheet of the inner barrel section;

FIG. **10** is a perspective illustration of a drill end effector forming a perforation in an inner face sheet of a composite sandwich structure of the inner barrel section;

FIG. **11** is a cross sectional illustration taken along line **11** of FIG. **10** and illustrating a drill bit of the drill end effector drilling a perforation in the inner face sheet of the composite sandwich structure;

FIG. **12** is a block diagram of an embodiment of the drilling system;

FIG. **13** is an illustration of a flow chart including one or more operations that may be implemented in a method of fabricating an engine inlet;

FIG. **14** is a flow diagram of an aircraft manufacturing and service methodology; and

FIG. **15** is a block diagram of an aircraft.

DETAILED DESCRIPTION

Referring now to the drawings wherein the showings are for purposes of illustrating various embodiments of the present disclosure, shown in FIG. **1** is a perspective illustration of an aircraft **100**. The aircraft **100** may include a fuselage **102** extending from a nose to an empennage **104**. The empennage **104** may include one or more tail surfaces for directional control of the aircraft **100**. The aircraft **100** may include a pair of wings **106** extending outwardly from the fuselage **102**.

In FIG. **1**, the aircraft **100** may include one or more propulsion units which, in an embodiment, may be supported by the wings **106**. Each one of the propulsion units may be configured as a gas turbine engine **108** having a core engine (not shown) surrounded by a nacelle **110**. The nacelle **110** may include an engine inlet **114** and a fan cowl **118** surrounding one or more fans (not shown) mounted on a forward end (not shown) of the core engine. The nacelle **110** may have an exhaust nozzle **112** (e.g., a primary exhaust nozzle and a fan nozzle) at an aft end (not shown) of the gas turbine engine **108**.

FIG. **2** illustrates an embodiment of a gas turbine engine **108** having an engine inlet **114**. The engine inlet **114** may include a leading edge **116** and an inner barrel section **120** located aft of the leading edge **116** of the engine inlet **114**. The inner barrel section **120** may provide a boundary surface or wall for directing airflow (not shown) entering the engine inlet **114** and passing through the gas turbine engine **108**. The inner barrel section **120** may be located in relatively close proximity to one or more fans (not shown). In this regard, the inner barrel section **120** may also be configured to serve as an acoustic structure having a plurality of perforations **136** (FIG. **9**) in an inner face sheet **134** (FIG. **10**) of the inner barrel section **120** for absorbing noise generated by the rotating fans and/or noise generated by the airflow entering the engine inlet **114** and passing through the gas turbine engine **108**.

As described below, the total area of the perforations **136** in the inner face sheet **134** may be expressed as percent-open-area **144** (FIG. **9**) which represents the total area of the perforations **136** as a percentage of the surface area of the inner face sheet **134**. The percent-open-area **144** may be a characteristic for measuring the overall effectiveness or acoustic-attenuating capability of the inner barrel section **120**. During the design and/or development of the aircraft **100**, a specific, a predetermined percent-open-area **144** (FIG. **9**) may be selected for the inner barrel section **120** to meet acoustic performance requirements of the engine inlet **114**.

FIG. **3** is a perspective illustration of an embodiment of an inner barrel section **120** of an engine inlet **114**. In the embodiment shown, the barrel section **120** may have a diameter (not shown) of up to 5-8 feet or larger, and a length (not shown) extending from an aft edge **126** to a forward edge **124** of up to 2-3 feet or longer. However, the barrel section **120** may be provided in any size, shape, and configuration, without limitation. The inner barrel section **120** may be formed as a composite sandwich structure **122** having an inner face sheet **134** and an outer face sheet **132** separated by a core **128**. The inner face sheet **134** and/or the outer face sheet **132** may be formed of composite material including fiber-reinforced polymeric matrix material such as graphite-epoxy, fiberglass-epoxy, or other composite material. Alternatively, the inner face sheet **134** and/or the outer face sheet **132** may be formed of metallic material such as titanium, steel, or other metallic materials or combinations of materials. The core **128** may comprise honeycomb core having a plurality of cells **130** oriented generally transverse to the inner face sheet **134** and outer face sheet **132**. The core **128** may be formed of metallic material and/or non-metallic material and may include aluminum, titanium, aramid, fiberglass, or other core materials.

In FIG. **3**, in an embodiment, the engine inlet **114** may comprise a one-piece engine inlet **114** inner barrel section **120**. The inner barrel section **120** may be fabricated from raw materials (not shown) and assembled and cured in one or more stages. For example, the inner face sheet **134** and the outer face sheet **132** may be separately formed by laying up dry fiber fabric (not shown) or resin-impregnated ply material (i.e., pre-preg) on separate layup mandrels (not shown) and separately cured, followed by bonding the inner face sheet **134** and the outer face sheet **132** to the core **128**. Alternatively, the inner barrel section **120** may be fabricated in a single-stage cure process wherein the inner face sheet **134** may be laid up on a layup mandrel (not shown), after which the core **128** may be laid up over the inner face sheet **134**, followed by laying up the outer face sheet **132** over the core **128**. The layup assembly (not shown) may be cured in a single stage, after which the drilling system **200** (FIG. **5**) disclosed herein may be implemented for forming perforations **136** (FIG. **9**) in the inner face sheet **134**.

In an embodiment described in greater detail below, the drilling system **200** (FIG. **5**) disclosed herein may be implemented for forming a plurality of perforations **136** (FIG. **9**) in the inner face sheet **134** (FIG. **9**) of the assembled barrel section **120**. For example, the drilling system **200** (FIG. **5**) disclosed herein may include a plurality of robotic drilling units **208** (FIG. **8**) positioned inside the barrel section **120** for robotically drilling a plurality of the perforations **136** in the inner face sheet **134** after final cure of the composite sandwich structure **122** engine inlet inner barrel section **120**. The perforations **136** (FIG. **9**) may be formed in a size and quantity to provide a predetermined percent-open-area **144** for the inner barrel section **120** to allow the inner barrel section **120** to meet acoustic performance requirements of the engine inlet **114**.

In FIG. **3**, the inner barrel section **120** may comprise a unitary structure having closed shape with a generally cylindrical configuration. However, in an embodiment, the inner barrel section **120** may be formed as multiple segments (not shown) assembled together to form a closed shape. The inner barrel section **120** may be provided in a contoured cross-sectional shape (not shown) to promote airflow (not shown) through the gas turbine engine **108**. In this regard, when viewed along a circumferential direction, the inner barrel section **120** may have a cross section that may be complexly curved and may be formed complementary to the shape of the engine inlet **114** leading edge **116** at a forward edge **124** of the inner barrel section **120**, and complementary to the shape of the interior nacelle surfaces (not shown) aft of the inner barrel section **120**. However, the inner barrel section **120** may be provided in any shape including a simple cylindrical shape and/or a conical shape.

FIG. **4** is a cross-sectional illustration of the leading edge **116** of the engine inlet **114** showing the composite sandwich construction including the circumferential inner face sheet **134**, the circumferential outer face sheet **132**, and the core **128** separating the inner face sheet **134** and outer face sheet **132** of the barrel section **120**. The forward edge **124** of the inner barrel section **120** may be coupled to or may interface with the engine inlet **114** leading edge **116**. The aft edge **126** of the inner barrel section **120** may be coupled to or may interface with the nacelle interior (not shown). In the embodiment shown, the inner face sheet **134**, the core **128**, and the outer face sheet **132** have a complexly-curved cross sectional shape to promote efficient airflow through the nacelle **110**.

FIG. **5** is an illustration of an embodiment of a drilling system **200** as may be implemented for forming perforations **136** (FIG. **9**) in a barrel section **120** such as the inner barrel section **120** of an engine inlet **114** of a gas turbine engine **108** (FIG. **3**). However, the drilling system **200** disclosed herein may be implemented for forming perforations **136** (FIG. **9**) in any type of barrel structure for any application, without limitation. For example, the drilling system **200** may be implemented for forming perforations **136** (FIG. **9**) in a barrel section of any one of a variety of different types of commercial, civilian, and military aircraft **100** (FIG. **1**). Furthermore, the drilling system **200** may be implemented for forming perforations **136** (FIG. **9**) in the barrel section **120** of a gas turbine engine **108** (FIG. **1**) of rotorcraft, hovercraft, or in any other vehicular or non-vehicular application wherein a predetermined quantity of acoustic perforations **136** (FIG. **9**) are required in a barrel section **120** for acoustic attenuating purposes.

In FIG. **5**, the drilling system **200** is shown mounted within an interior of a barrel section **120**. The drilling system **200** may include robotic drilling units **208** that advantageously allow for forming perforations **136** (FIG. **9**) in a barrel section **120** to provide the predetermined percent-open-area **144** (FIG. **9**) of the inner face sheet **134** of the barrel section **120**. As indicated above, the predetermined percent-open-area **144** may be determined during the design and/or development of the aircraft **100** (FIG. **1**) to meet acoustic performance requirements of the engine inlet **114**. The drilling system **200** disclosed herein advantageously allows for consistently forming perforations **136** in the inner face sheets **134** of composite sandwich structure **122** barrel sections **120** to provide a predetermined percent-open-area **144** (FIG. **9**) in the inner face sheet **134**. In this regard, the drilling system **200** advantageously overcomes the drawbacks associated with conventional methods for forming perforations (not shown) in conventional inner barrel sections (not shown) such as the above-mentioned drawbacks associated with blocked perforations (not shown) due to subsequent processing of a conventional inner barrel section (not shown) in a conventional multi-stage forming process (not shown), and/or due to missing perforations (not shown) during conventional perforating (not shown) of the inner skin (not shown) of a conventional inner barrel section. Such blocked perforations or missing perforations may reduce the predetermined percent-open-area **144** of the inner skin of the conventional inner barrel section which may reduce the acoustic performance of the engine inlet **114**.

In FIG. **5**, a plurality of robotic drilling units **208** (e.g., two robotic drilling units **208**, three robotic drilling units **208**, etc.) may be supported on a system base **202**. Each one of the robotic drilling units **208** may include a drill end effector **234**. In an embodiment, the system base **202** may comprise a relatively rigid structure and may include a tooling fixture, a shop floor, or a table configured to support the plurality of robotic drilling units **208**. In addition, the system base **202** may be configured to support the barrel section **120**. However, the drilling system **200** may be provided in an alternative embodiment wherein the plurality of robotic drilling units **208** are supported by a structure that is located separate from the barrel section **120**. For example, the plurality of robotic drilling units **208** may be suspended over the inner barrel section **120** such as by an overhead fixture (not shown) in a manner such that the drill end effectors **234** may be positioned within the interior of the barrel section **120**, and/or the plurality of robotic drilling units **208** may be mounted inside or outside of the barrel section **120**.

FIG. **6** is a perspective illustration of the plurality of robotic drilling units **208** positioned on the system base **202** and mounted within relatively close proximity to one another such that the barrel section **120** circumscribes the plurality of robotic drilling units **208** when the barrel section **120** is mounted to the system base **202**. Although four (4) robotic drilling units **208** are shown, any number may be provided. In an embodiment, the robotic drilling units **208** may be mounted in an array. For example, each one of the robotic drilling units **208** may include a drilling unit base **212** (FIG. **7**). The drilling unit bases **212** (FIG. **7**) may be mounted to the system base **202** in a circular array **206** (FIG. **8**) such that when the barrel section **120** is mounted to the system base **202**, each one of the drilling unit bases **212** (FIG. **7**) is positioned at substantially the same distance from the inner face sheet **134** of the barrel section **120**.

FIG. **7** is a side view of an embodiment of the drilling system **200**. The barrel section **120**, shown in phantom lines, may be supported on one fixture **204** or multiple fixtures **204**. The fixtures **204** may comprise spacers sized and configured to position the barrel section **120** at a vertical location that is complementary to the movement capability of the drill end effectors **234** of the robotic drilling units **208**. In this regard, the fixtures **204** may be configured such that the drill end effectors **234** may form perforations **136** (FIG. **9**) in the inner face sheet **134** of the barrel section **120** at any vertical location between the forward edge **124** of the barrel section **120** and the aft edge **126** of the barrel section **120**. The fixtures **204** may be comprised of a rigid material and may be configured as simple blocks (not shown) formed of metallic or polymeric material and which may be fixedly coupled to the system base **202**. The fixtures **204** may extend vertically along any portion of the height of the barrel section and horizontally along any portion of the circumference of the barrel section **120**.

FIG. **8** is a top view of the drilling system **200** illustrating an arrangement of the robotic drilling units **208**. Each one of the robotic drilling units **208** may include a robotic arm assembly **210** having a drill end effector **234** mounted on an end of the robotic arm assembly **210**. The robotic drilling units **208** may be mounted such that drilling unit bases **212** are positioned adjacent to a center of the array of the robotic drilling units **208**. In an embodiment, the drilling system **200** may comprise a single robotic drilling unit **208** or a plurality of robotic drilling units **208**. For example, the drilling system **200** may include two (2) or more robotic drilling units **208** having drilling unit bases **212** which may be arranged at a predetermined spacing relative to one another, such as a substantially equiangular spacing relative to one another.

Referring still to FIG. **8**, the plurality of robotic drilling units **208** may be configured (e.g., programmed) to drill perforations **136** (FIG. **9**) within substantially equivalent arc segments **142** of the barrel section **120**. For example, for the embodiment shown, the plurality of robotic drilling units **208** may comprise four (4) robotic drilling units **208**. The drilling unit bases **212** may be arranged such that the drilling unit bases **212** are positioned at an angular spacing of approximately ninety degrees relative to one another. In an embodiment, each one of the robotic drilling units **208** may be configured to drill perforations **136** (FIG. **9**) within an approximate ninety-degree arc segment **142** of the barrel section **120**. However, the robotic drilling units **208** may be positioned at any location relative to one another and may be configured to form perforations **136** (FIG. **9**) at any circumstantial location or any vertical location of the barrel section **120**.

In FIG. **8**, the drill end effector **234** of each one of the robotic drilling units **208** may be oriented generally radially outwardly away from the drilling unit base **212**. The drilling unit bases **212** may be positioned to provide space for movement of the robotic arm assemblies **210** during operation of the drilling system **200**. In this regard, the robotic drilling units **208** are simultaneously operable in synchronized movement with one another in a manner allowing the drill end effectors **234** to simultaneously drill a plurality of perforations **136** (FIG. **9**) in the barrel section **120**. The robotic drilling units **208** may be programmed to avoid collisions with one another and with the barrel section **120** during the synchronized movement with one another.

FIG. **9** is a side view of one of the robotic drilling units **208** showing the barrel section **120** supported on fixtures **204** and illustrating a drill bit **236** of one of the drill end effectors **234** forming perforations **136** in a predetermined hole pattern **140** along the inner face sheet **134** of the inner barrel section **120**. In this regard, in an embodiment, each one of the robotic drilling units **208** may be indexed to the system base **202**. The barrel section **120** may also be indexed to the system base **202** such as with fixtures **204** to provide a means for the drill end effector **234** to form perforations **136** within a relatively small positional tolerance relative to a circumferential direction (not shown) of the barrel section **120** and relative to an axial direction (not shown) of the barrel section **120**. However, the barrel section **120** and the robotic drilling units **208** may be indexed relative to one another by other means, and are not necessarily limited to being indexed to the system base **202**.

In FIG. **9**, the robotic drilling units **208** may be operated in a manner to drill the perforations **136** in the inner face sheet **134** such that a percent-open-area **144** in one section **148** of the inner face sheet **134** is different than the percent-open-area **144** in another section **150** of the inner face sheet **134**. In this regard, the robotic drilling units **208** may be programmed to drill perforations **136** to provide a greater percent-open-area **144** in a first section **148** of the inner face sheet **134** relative to drilling perforations **136** to provide a lower percent-open-area **144** in a second section **150** of the inner face sheet **134**. For example, the second section **150** with a smaller percent-open-area **144** may be located adjacent to a forward edge **124** and/or an aft edge **126** of the barrel section **120**, and the first section **148** with a larger percent-open-area **144** may be located in an interior region (not shown) of the inner barrel section **120** between the forward edge **124** and the aft edge **126**. However, the robotic drilling **208** units may drill the perforations **136** such that the percent-open-area **144** in the inner face sheet **134** is different at different circumferential sections (not shown) of the barrel section **120**, or the percent-open-area **144** of the inner barrel section **120** may vary in a different manner than the above-noted embodiments.

In FIG. **9**, one or more of the robotic drilling units **208** may have a six-axis robotic arm assembly **210** which may allow for accurately positioning the drill end effector **234** at any desired location and orientation along the inner face sheet **134**. As the drill end effector **234** is positioned and oriented at a desired location of a perforation **136**, the drill end effector **234** may be moved axially to drive the rotating drill bit **236** into the inner face sheet **134** to form a perforation **136**. Alternatively, the drill end effector **234** may be positioned at a desired location of a perforation **136** on the inner face sheet **134**, and the drill end effector **234** may axially drive the rotating drill bit **236** along a direction of the drill bit axis **238** to drill the perforation **136** in the inner face sheet **134**. In an embodiment, the six-axis robotic arm assembly **210** may include a first arm **220** which may be attached to the drilling unit base **212** at a shoulder joint **216**. The first arm **220** may be attached to a second arm **226** at an elbow joint **222**. The second arm **226** may be attached to the drill end effector **234** at a wrist joint **230**.

In FIG. **9**, the drilling unit base **212** may be configured to rotate about a vertical base axis **214** relative to the system base **202**. The first arm **220** may be configured to rotate about a shoulder axis **218** of the shoulder joint **216** coupling the first arm **220** to the drilling unit base **212**. The second arm **226** may be configured to rotate about an elbow axis **224** of the elbow joint **222** coupling the second arm **226** to the first arm **220**. A portion of the second arm **226** may also be configured to swivel about a second arm axis **228** extending along a direction from the elbow joint **222** to the wrist joint **230**. The drill end effector **234** may be configured to rotate about a wrist axis **232** of the wrist joint **230**. In addition, the drill end effector **234** may be configured to rotate about an end effector axis **235** which may be generally parallel to the drill bit axis **238**. In an optional embodiment, the end effector may be configured to linearly translate the drill bit **236** along a drill bit axis **238** such as when drilling a perforation **136** in the inner face sheet **134**.

In FIG. **9**, the robotic arm assembly **210** is shown in a six-axis embodiment. However, the robotic arm assembly **210** may be provided in alternative arrangements. For example, the robotic arm assembly **210** may be provided in a 3-axis embodiment (not shown), a 4-axis embodiment (not shown), or a 5-axis embodiment (not shown). In addition, the robotic arm assembly **210** may be provided in an embodiment having more than six (6) axes. Furthermore, the robotic arm assembly **210** may be configured as a motion control system (not shown), a rigid frame (not shown) having linear axes along which the end effector is movable, or any other type of motion control device for controlling a drill end effector **234** for drilling perforations **136**. In addition, each robotic arm assembly **210** may include more than one drill end effector **234**. Furthermore, each drill end effector **234** may have more than one drill bit **236** for simultaneously forming perforations **136**.

FIG. **10** shows a drill end effector **234** forming a perforation **136** in the inner face sheet **134** of a composite sandwich structure **122** of the inner barrel section **120**. Advantageously, the drilling system **200** provides a means for accurate and rapid placement of the drill end effector **234** for drilling perforations **136** in a predetermined hole pattern **140** (FIG. **9**). For example, in an embodiment, each one of the drill end effectors **234** of a robotic drilling unit **208** may be configured to form up to three (3) or more perforations **136** per second, per drill end effector **234**. In an embodiment, the drill end effector **234** may be provided with a drill bit **236** configured to form acoustic perforations **136** having a hole diameter of approximately 0.010 to 0.10 inch, although larger or smaller perforations **136** are possible based on the drill bit **236** diameter.

In FIG. **10**, for forming perforations **136** in a composite inner face sheet **134**, the drill end effector **234** may be configured to drive the drill bit **236** at a feed rate of approximately 20-60 inches per minute, and at rotational speeds of between approximately 20,000 to 40,000 rpm, although larger or smaller feed rates and larger or smaller rotational speeds may be selected based on the material being drilled and the composition of the drill bit **236**. The drill bit **236** feed rate and the drill bit **236** rotational speed may be controlled to minimize drill bit **236** wear, and such that the perforations **136** may meet tight tolerances for roundness and other hole parameters. Significantly, each robotic drilling unit **208** is configured to quickly and accurately form hole patterns **140** (FIG. **9**) at a relatively small center-to-center positional tolerance (i.e., perforation-to-perforation) such as a center-to-center positional tolerance of approximately 0.010 inch or less. However, the center-to-center positional tolerance may be greater than 0.010 inch, such as up to approximately 0.050 inch or greater.

In FIG. **10**, one or more of the drill end effectors **234** may include a vacuum attachment **240** for removing debris (not shown) such as dust and chips that may be generated during the drilling of the perforations **136**. The vacuum attachment **240** may have a hollow (not shown) or open portion (not shown) that may be positioned around the drill bit **236** and may be placed adjacent to or in contact with the inner face sheet **134** when the drill bit **236** contacts the inner face sheet **134** and drills a perforation **136**. The vacuum attachment **240** may include a vacuum port **242** for connection to a vacuum source (not shown) using a vacuum hose (not shown) for drawing a vacuum **244** on the vacuum attachment **240** for drawing debris (not shown) from the area surrounding the perforation **136**.

In FIG. **10**, in a further embodiment, the drilling system **200** may be provided with an automated bit changer (not shown) for changing the drill bits **236** using robotic control. In this manner, worn drill bits **236** may be replaced after drilling a predetermined quantity of perforations **136**. For example, an automated bit changer (not shown) may replace each drill bit **236** after drilling anywhere from approximately 1,000 to 30,000 perforations **136**, although the drill bits **236** may be replaced after drilling a smaller or larger quantity of perforations **136** than the above-noted range. Depending upon the size (e.g., diameter and height) of the inner barrel section **120** and the total quantity of robotic drilling units **208** that are used, each drill end effector **234** may undergo 1 to 20 or more drill bit changes per barrel section **120**.

Referring briefly to FIG. **9**, in an embodiment, the drill end effectors **234** may be controlled to drill perforations **136** in a hole pattern **140** of vertical rows (not shown) along a height of the barrel section **120**. In this regard, each drill end effector **234** may drill a vertical row of perforations **136**, and the drill end effector **234** may be rotated about the vertical base axis **214** to allow the drill end effector **234** to drill another vertical row of perforations **136** adjacent to the previously-drilled vertical row of perforations **136**. The drill end effectors **234** may also be controlled to drill perforations **136** in horizontal rows (not shown), or in any other direction or combination of directions. As indicated above, the robotic arm assemblies **210** may be operated in a synchronized manner such that the drill end effectors **234** are maintained at a generally equiangular spacing from one another during the simultaneous drilling of perforations **136** in the inner face sheet **134** of the barrel section **120**. For example, for a drilling system **200** having four (4) robotic drilling units **208**, the drill end effectors **234** may be maintained at an angular separation of approximately ninety (90) degrees from each other during the simultaneous drilling of perforations **136** in the inner face sheet **134**.

FIG. **11** is a cross sectional view of a drill bit **236** of the drill end effector **234** forming a perforation **136** in the inner face sheet **134** of a composite sandwich structure **122**. In an embodiment, the drill end effector **234** may include a drill stop (not shown) to control a depth **138** at which the drill bit **236** extends into the composite sandwich structure **122**, and minimize the depth **138** of the drill bit **236** into the core **128** material. Furthermore, a drill stop (not shown) may stabilize the drill end effector **234** when drilling the perforation **136** to prevent lateral movement of the drill bit **236** relative to the perforation **136**, and which may advantageously avoid a non-conformance regarding the positional tolerance, roundness tolerance, or other tolerance parameters of the perforation **136**. In an embodiment, each drill end effector **234** may include a non-contact method of gauging the depth **138** at which each perforation **136** is drilled such as by using a laser device (not shown), an ultrasonic device (not shown), and other non-contact device. The depth **138** of drilling may also be controlled by a controller (not shown) controlling the drill end effector **234**.

FIG. **12** is a block diagram of an embodiment of a drilling system **200**. The drilling system **200** may include a plurality of robotic drilling units **208**. Each one of the robotic drilling units **208** may include a robotic arm assembly **210** as described above. A drill end effector **234** may be coupled to the end of each one of the robotic arm assemblies **210** of each robotic drilling unit **208**. The robotic drilling units **208** may be simultaneously operable in synchronized movement with one another such that the drill end effectors **234** may simultaneously drill a plurality of perforations **136** in the barrel section **120**.

In FIG. **12**, the barrel section **120** may comprise an inner barrel section **120** of an engine inlet **114** such as of a gas turbine engine **108** (FIG. **3**), as indicated above. In an embodiment, the barrel section **120** may be formed as a composite sandwich structure **122**. The composite sandwich structure **122** may have an outer face sheet **132**, a core **128**, and an inner face sheet **134** which may be assembled or bonded together to form a one-piece engine inlet inner barrel section **120**. The drilling system **200** may rapidly and accurately form a plurality of perforations **136** in a predetermined hole pattern of perforations **136** (FIG. **9**) in the inner face sheet **134** to provide a predetermined percent-open-area **144** for the inner barrel section **120** to meet acoustic performance requirements.

FIG. **13** is an illustration of a flow chart including one or more operations that may be included in a method **300** of fabricating an engine inlet **114** (FIG. **3**). Step **302** of the method may include providing a barrel section **120** (FIG. **3**) such as an inner barrel section **120** (FIG. **3**) of an engine inlet **114** (FIG. **3**). As indicated above, the inner barrel section **120** (FIG. **3**) may be provided as a one-piece composite sandwich structure **122** (FIG. **3**). In such a composite sandwich structure **122** (FIG. **3**), the inner face sheet **134**

(FIG. 3) may be formed of composite material and the outer face sheet **132** (FIG. **3**) may be formed of composite material (e.g., fiber-reinforced polymeric matrix material). However, the inner face sheet **134** (FIG. **3**) and/or the outer face sheet **132** (FIG. **3**) may be formed of metallic material, or a combination of metallic material and non-metallic material.

As indicated above, the core **128** (FIG. **3**) may comprise honeycomb core formed of metallic material and/or non-metallic material and may include aluminum, titanium, aramid, fiberglass, or other core materials. The engine inlet **114** (FIG. **3**) inner barrel section **120** (FIG. **3**) may be fabricated as a one-piece composite sandwich structure **122** (FIG. **3**) formed in a single-stage cure. As described above, the barrel section **120** (FIG. **3**) may be provided in a single-stage cure wherein the inner face sheet **134** (FIG. **3**), the core **128** (FIG. **3**), and the outer face sheet **132** (FIG. **3**) may be laid up on a layup mandrel, after which heat and/or pressure may be applied to the layup (not shown) for a predetermined time for curing in a single stage.

Step **304** of the method **300** of FIG. **13** may include mounting and indexing the inner barrel section **120** (FIG. **7**) to a system base **202** (FIG. **7**). In this regard, the inner barrel section **120** (FIG. **7**) may be supported on a plurality of fixtures **204** (FIG. **7**) which may be mounted to the system base **202** (FIG. **7**). The fixtures **204** (FIG. **7**) may fixedly position the inner barrel section **120** (FIG. **7**) on the system base **202** (FIG. **7**) which may comprise a table (not shown), an assembly (not shown), or other relatively rigid structure configured to support the inner barrel section **120** (FIG. **7**) and prevent movement thereof during the drilling of the perforations **136** (FIG. **9**) in the inner barrel section **120** (FIG. **7**).

As indicated above, the fixtures **204** may be positioned at spaced intervals around a perimeter (not shown) of the inner barrel section **120** such as along the aft edge **126** (FIG. **9**) or forward edge **124** (FIG. **9**) of the inner barrel section **120**. The fixtures **204** may include mechanical indexing features (not shown) to index the inner barrel section **120** to the fixtures **204**. A laser system (not shown) may be implemented to aid in positioning the inner barrel section **120** relative to the fixtures **204**. The inner barrel section **120** may be mechanically coupled to the fixtures **204** to rigidly clamp the inner barrel section **120** in position.

Step **306** of the method **300** of FIG. **13** may include indexing the plurality of robotic drilling units to the system base **202** (FIG. **7**) as shown in FIG. **7**. In an embodiment, each one of the plurality of robotic drilling units **208** (FIG. **7**) may have a drilling unit base **212** (FIG. **7**) that may be directly mounted to the system base **202** and indexed to the system base **202** and/or to the fixtures **204** (FIG. **7**) supporting the inner barrel section **120** (FIG. **7**). For example, the drilling unit bases **212** of the robotic drilling units **208** may be mounted to the system base **202** and may be located inside the inner barrel section **120** as shown in FIG. **7**. Alternatively, the drilling unit bases **212** may be located outside of the inner barrel section **120** and the drill end effectors **234** (FIG. **7**) of the robotic arm assemblies **210** (FIG. **7**) may extend inside the inner barrel section **120** to drill the perforations **136** (FIG. **9**). In a further embodiment, the robotic drilling units **208** may be supported by a structure (not shown) that is located separate from the system base **202** and separate from the barrel section **120**. For example, the drilling unit bases **212** of the robotic drilling units **208** may be mounted to an overhead fixture (not shown) that may be indexed to the system base **202** and/or to the fixtures **204** supporting the inner barrel section **120**. The drill end effectors **234** may extend inside the barrel section **120** to drill the perforations **136**.

Step **308** of the method **300** of FIG. **13** may include acoustically treating the engine inlet **114** (FIG. **9**) by robotically drilling a plurality of perforations **136** (FIG. **9**) into the inner face sheet **134** (FIG. **9**) of the composite sandwich structure **122** (FIG. **9**) engine inlet **114** inner barrel section **120** (FIG. **9**) such as after final cure of the composite sandwich structure **122**. For example, the method **300** may include robotically drilling the plurality of perforations **136** in the inner barrel section **120** using a plurality of the robotic drilling units **208** (FIG. **9**). The method **300** may include simultaneously drilling the plurality of perforations **136** in the inner face sheet **134** using the drill end effectors **234** (FIG. **9**) to provide a predetermined percent-open-area **144** of the inner face sheet **134**. In an embodiment, each one of the robotic drilling units **208** may include a robotic arm assembly **210** (FIG. **9**) configured as a three-axis, four-axis, five-axis, or six-axis arm assembly respectively having three axes, four axe, five axes, and six axes. The robotic arm assemblies **210** may be programmed to move the drill end effectors **234** in a synchronized manner relative to one another to drill the perforations **136** at a relatively rapid rate. For example, each one of the drill end effectors **234** may be configured to form 2-3 or more perforations **136** per second.

The method **300** (FIG. **13**) may include drilling the perforations **136** (FIG. **9**) in a predetermined hole pattern **140** (FIG. **9**) in the engine inlet **114** (FIG. **9**) inner barrel section **120** (FIG. **9**) which may have a honeycomb core **128** (FIG. **11**). The robotic drilling units **208** (FIG. **9**) may be configured to control the drill end effectors **234** (FIG. **9**) to drill the perforations **136** normal (e.g., perpendicular) to the inner face sheet **134** (FIG. **10**). In addition, the robotic drilling units **208** may be configured to drill the perforations **136** at a spaced distance to the cell walls **131** (FIG. **11**) of the honeycomb core **128**. In this regard, the robotic drilling units **208** may be configured to drill one or more perforations **136** in each of the cells **130** at a distance from the cell walls **131** to avoid drilling into the cell walls **131**. The robotic drilling units **208** may drill the perforations **136** in a hole pattern **140** that may be configured complementary to the geometry and size of the cells **130** of honeycomb core **128**. For example, the hole pattern **140** (FIG. **9**) may be such that one perforation **136** (FIG. **11**) is drilled into each cell **130** (FIG. **11**) such as at an approximate center (not shown) of each cell **130**. However, the hole pattern **140** may be such that two or more perforations **136** may be drilled into each cell **130** of the honeycomb core **128** (FIG. **11**).

The robotic drilling units **208** (FIG. **9**) may be configured to index or position the hole pattern **140** (FIG. **9**) relative to the cell **130** (FIG. **11**) centers (not shown) or relative to the cell walls **131** (FIG. **11**) of a honeycomb core **128**. For example, for a honeycomb core **128** having a generally uniform arrangement of cells **130** of equal size and shape, the robotic drilling units **208** may be configured to establish a location of one of the cell walls **131** in order to index a hole pattern **140** relative to the locations of the cell **130** of the honeycomb core **128**. After establishing the location of one or more cell walls **131**, the robotic drilling units **208** may be configured to drill the hole pattern **140** of perforations **136** in the inner face sheet **134** of the honeycomb core **128** such that each perforation **136** is drilled at a predetermined location in each cell **130** such as at a center (not shown) of each cell **130**, or at a predetermined location or spaced distance **146** relative to the cell walls **131** of each cell **130**. The hole pattern **140** may also be such that multiple perforations **136** may be drilled into each cell **130** and may be located at predetermined distances or spaced distances **146** from the cell walls **131** of each cell **130**.

Advantageously, the robotic drilling units **208** (FIG. **9**) may be configured to form perforations **136** (FIG. **9**) within a relatively high positional tolerance (e.g., 0.010 inch on centers) in the hole-to-hole spacing. In addition, as indicated above, each one of the drill end effectors **234** (FIG. **10**) may include a vacuum attachment **240** (FIG. **10**) configured to be positioned adjacent to or against the inner face sheet **134** during the drilling of the perforations **136**. The vacuum attachment **240** may include a vacuum port **242** (FIG. **11**) that may be coupled to a vacuum source (not shown) via a vacuum hose (not shown) to provide a vacuum **244** (FIG. **10**) for suctioning dust, chips, and other debris away from a location where a perforation **136** is being drilled.

Step **310** of the method **300** of FIG. **13** may include periodically changing the drill bits **236** (FIG. **10**) of the drill end effectors **234** (FIG. **10**) during the process of drilling perforations **136** (FIG. **10**) in the inner barrel section **120** (FIG. **10**). In an embodiment, the method may include robotically changing the drill bits **236** using an automated bit changer (not shown). Drill bits **236** may be replaced after drilling a predetermined quantity of perforations **136**. For example, each drill bit **236** may be replaced after drilling several thousand or more perforations **136**. The frequency at which the drill bits **236** may be replaced may be affected by the thickness of the inner face sheet **134** (FIG. **11**), the material composition of the inner face sheet **134**, the rotational speed of the drill bit **236**, the feed rate of the drill bit **236**, the material composition of the drill bit **236**, and other factors. In an embodiment not shown, the method may include detecting when a drill bit **236** is becoming dull, at which point the method may include replacing the dull drill bit **236** with a new or sharpened drill bit (not shown).

Advantageously, the drilling system **200** (FIG. **12**) and method disclosed herein provides for operating a plurality of robotic drilling units **208** (FIG. **12**) in a synchronized manner to accurately and rapidly form perforations **136** (FIG. **12**) in the inner face sheet **134** (FIG. **12**) of an inner barrel section **120** (FIG. **12**) with a high degree of repeatability. In addition, the drilling system **200** provides a means for forming perforations **136** with a significant reduction in defects and rework commonly associated with conventional methods. In this regard, the drilling system **200** and method disclosed herein may avoid the above-mentioned defects of missing perforations (not shown) and/or blocked perforations (not shown) during subsequent processing in a multistage barrel section fabrication process (not shown), and the associated reduction in percent-open-area **144** (FIG. **9**) in the inner face sheet **134** of the inner barrel section **120**.

As indicated above, the percent-open-area **144** (FIG. **9**) of the inner face sheet **134** is the total area of the perforations **136** (FIG. **9**) as a percentage of the surface area (not shown) of the inner face sheet **134** (FIG. **9**) and is a characteristic for measuring the overall effectiveness or acoustic-attenuating capability of the inner barrel section **120** (FIG. **9**). In FIG. **9**, the robotic drilling units **208** (FIG. **9**) may be operated in a manner to drill perforations **136** to provide a percent-open-area **144** (FIG. **9**) in one section **148** (FIG. **9**) of the inner face sheet **134** that is different than the percent-open-area **144** in another section **150** (FIG. **9**) of the face sheet **134**. For example, in FIG. **9**, a first section **148** of perforations **136** drilled in the inner face sheet **134** may have a larger percent-open-area **144** relative to a second section **150** of perforations **136** which may be located adjacent to a forward edge **124** and/or an aft edge **126** of the barrel section **120**. However, as indicated above, differing sections (not shown) of percent-open-area **144** may be arranged in any manner along the inner face sheet **134** of the inner barrel section **120** (FIG. **9**), and are not limited to the arrangement shown in FIG. **9** or described above.

Referring to FIGS. **14**-**15**, embodiments of the disclosure may be described in the context of an aircraft manufacturing and service method **400** as shown in FIG. **14** and an aircraft **402** as shown in FIG. **15**. During pre-production, exemplary method **400** may include specification and design **404** of the aircraft **402** and material procurement **406**. During production, component and subassembly manufacturing **408** and system integration **410** of the aircraft **402** takes place. Thereafter, the aircraft **402** may go through certification and delivery **412** in order to be placed in service **414**. While in service by a customer, the aircraft **402** is scheduled for routine maintenance and service **416** (which may also include modification, reconfiguration, refurbishment, and so on).

Each of the processes of method **400** may be performed or carried out by a system integrator, a third party, and/or an operator (e.g., a customer). For the purposes of this description, a system integrator may include without limitation any number of aircraft manufacturers and major-system subcontractors; a third party may include without limitation any number of venders, subcontractors, and suppliers; and an operator may be an airline, leasing company, military entity, service organization, and so on.

As shown in FIG. **15**, the aircraft **402** produced by exemplary method **400** may include an airframe **418** with a plurality of systems **420** and an interior **422**. Examples of high-level systems **420** include one or more of a propulsion system **424**, an electrical system **426**, a hydraulic system **428**, and an environmental system **430**. Any number of other systems may be included. Although an aerospace example is shown, the principles of the invention may be applied to other industries, such as the automotive industry.

Apparatus and methods embodied herein may be employed during any one or more of the stages of the production and service method **400**. For example, components or subassemblies corresponding to production process **408** may be fabricated or manufactured in a manner similar to components or subassemblies produced while the aircraft **402** is in service. Also, one or more apparatus embodiments, method embodiments, or a combination thereof may be utilized during the production stages **408** and **410**, for example, by substantially expediting assembly of or reducing the cost of an aircraft **402**. Similarly, one or more of apparatus embodiments, method embodiments, or a combination thereof may be utilized while the aircraft **402** is in service, for example and without limitation, to maintenance and service **416**.

Many modifications and other embodiments of the disclosure will come to mind to one skilled in the art to which this disclosure pertains having the benefit of the teachings presented in the foregoing descriptions and the associated drawings. The embodiments described herein are meant to be illustrative and are not intended to be limiting or exhaustive. Although specific terms are employed herein, they are used in a generic and descriptive sense only and not for purposes of limitation.

What is claimed is:

1. A drilling system, comprising:

a plurality of robotic drilling units;

each one of the robotic drilling units having a drill end effector positioned inside a barrel section configured as a composite sandwich structure having an inner face sheet; and

the robotic drilling units being operable in synchronized movement with one another to drill a plurality of perforations into the inner face sheet using the drill end effectors;

wherein the robotic drilling units are configured to index a hole pattern of perforations to one or more cell walls of a honeycomb core of the composite sandwich structure and the robotic drilling units are configured to form the hole pattern in the inner face sheet such that the perforations are located at a spaced distance from the cell walls of the honeycomb core.

2. The drilling system of claim **1**, wherein:

the drill end effectors are positioned inside a one-piece engine inlet inner barrel section cured in a single stage.

3. The drilling system of claim **1**, wherein:

the robotic drilling units are operated in a manner to drill the perforations such that a percent-open-area in one section of the inner face sheet is different than the percent-open-area in another section of the inner face sheet.

4. The drilling system of claim **1**, wherein:

the plurality of robotic drilling units comprise at least three robotic drilling units.

5. The drilling system of claim **1**, wherein:

the robotic drilling units are arranged at a substantially equiangular spacing relative to one another.

6. The drilling system of claim **1**, wherein:

at least one of the robotic drilling units has a robotic arm assembly being movable about at least five axes.

7. The drilling system of claim **1**, wherein:

the robotic drilling units each have a drilling unit base positioned inside the barrel section.

8. The drilling system of claim **7**, wherein:

the robotic drilling units each have a first arm and a second arm;

the first arm being attached to the drilling unit base at a shoulder joint;

the second arm being attached to the first arm at an elbow joint; and

a drill end effector being attached to the first arm at a wrist joint.

9. The drilling system of claim **7**, wherein:

the drilling unit base is configured to rotate about a base axis.

10. The drilling system of claim **1**, wherein:

the barrel section and the robotic drilling units are indexed to at least one fixture supporting the barrel section.

11. The drilling system of claim **1**, wherein:

the plurality of robotic drilling units are configured to drill perforations within substantially equivalent arc segments of the barrel section.

12. The drilling system of claim **1**, wherein:

each one of the drill end effectors includes a drill stop configured to control a depth at which a drill bit extends into the barrel section.

13. The drilling system of claim **1**, wherein:

the drill end effectors are configured to drill the perforations at an orientation normal to the inner face sheet.

14. The drilling system of claim **1**, wherein:

at least one of the drill end effectors includes a vacuum attachment for removing debris generated during drilling of the perforations.

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