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Inventor(s)	Ahn; Jonathan Young et al.

Forming End Effector and Methods of Use

Abstract

A forming end effector and methods of use are presented. Methods of forming a composite material onto a mandrel are presented. A forming end effector carrying the composite material is positioned over the mandrel. The forming end effector is connected to the mandrel. The composite material is swept onto the mandrel using sweepers of the forming end effector.

Inventors: **Ahn; Jonathan Young (Seattle, WA), Brown; Christopher Robert (Seattle, WA), Mealey; Karina Elizabeth (San Luis Obispo, CA), Fritzke; Ricardo Andreas (Sammamish, WA), Strait; Alexander K. (Seattle, WA), Noronha; Colin (Burien, WA), Willden; Kurtis Shuldberg (Kent, WA)**

Applicant: **The Boeing Company** (Arlington, VA)

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Background/Summary

BACKGROUND INFORMATION
1. Field

[0001] The present disclosure relates generally to shaping composite material and more specifically to a forming end effector configured to shape composite material onto a mandrel.

2. Background

[0002] Currently, gantry formers can be used to form a composite material onto a mandrel. However, gantry formers have a limited work envelope. Gantry formers cannot accommodate more than a few degrees of tool tilting.

[0003] Robots are capable of orienting to unique angles for tasks. However, robots are not as rigid as gantries.

[0004] Therefore, it would be desirable to have a method and apparatus that takes into account at least some of the issues discussed above, as well as other possible issues. It would be desirable to provide an alternative method of forming composite material onto a mandrel.

SUMMARY

[0005] An embodiment of the present disclosure provides a method of forming a composite material onto a mandrel. A forming end effector carrying the composite material is positioned over the mandrel. The forming end effector is connected to the mandrel. The composite material is swept onto the mandrel using sweepers of the forming end effector.

[0006] Another embodiment of the present disclosure provides a forming end effector for forming a composite material. The forming end effector comprises a frame, a number of legs movably connected to the frame, and forming heads with sweepers movably connected to the frame by a number of actuators movably connected to the frame. The number of legs has engagement pins configured to connect the forming end effector to a mandrel.

[0007] Yet another embodiment of the present disclosure provides a forming end effector for forming a composite material. The forming end effector comprises a frame; a number of actuators movably connected to the frame; and forming heads with sweepers movably connected to the frame by the number of actuators. The number of actuators is connected to the forming heads by pairs of hinges such that the forming heads are configured to rotate to form the composite material.

[0008] A further embodiment of the present disclosure provides a method. A composite material is formed onto a mandrel using sweepers of a forming end effector. Loads from the forming end effector are reacted into the mandrel during forming of the composite material.

[0009] The features and functions can be achieved independently in various embodiments of the present disclosure or may be combined in yet other embodiments in which further details can be seen with reference to the following description and drawings.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] The novel features believed characteristic of the illustrative embodiments are set forth in the appended claims. The illustrative embodiments, however, as well as a preferred mode of use, further objectives, and features thereof will best be understood by reference to the following detailed description of an illustrative embodiment of the present disclosure when read in conjunction with the accompanying drawings, wherein:

[0011] FIG. **1** is an illustration of an aircraft in accordance with an illustrative embodiment;

[0012] FIG. **2** is an illustration of a block diagram of a manufacturing environment in accordance with an illustrative embodiment;

[0013] FIG. **3** is an illustration of an isometric view of a forming end effector in an engaged orientation in accordance with an illustrative embodiment;

[0014] FIG. **4** is an illustration of an isometric view of a forming end effector in an unengaged orientation in accordance with an illustrative embodiment;

[0015] FIG. **5** is an illustration of a front view of a forming end effector in an unengaged

orientation in accordance with an illustrative embodiment;
[0016] FIG. **6** is an illustration of an isometric view of a forming end effector in an engaged orientation in accordance with an illustrative embodiment;
[0017] FIG. **7** is an illustration of an isometric view of an engagement pin on a leg of a forming end effector in accordance with an illustrative embodiment;
[0018] FIG. **8** is an illustration of an isometric view of a composite holding system of a forming end effector in accordance with an illustrative embodiment;
[0019] FIG. **9** is an illustration of a front view of a forming end effector in an engaged orientation and connected to a mandrel in accordance with an illustrative embodiment;
[0020] FIG. **10** is an illustration of a front view of a forming end effector in an engaged orientation and connected to a mandrel in accordance with an illustrative embodiment;
[0021] FIG. **11** is an illustration of a front view of a forming end effector in an engaged orientation and connected to a mandrel in accordance with an illustrative embodiment;
[0022] FIG. **12** is an illustration of a front view of a forming end effector in an engaged orientation and connected to a mandrel in accordance with an illustrative embodiment;
[0023] FIG. **13** is an illustration of a front view of a forming end effector in an engaged orientation and connected to a mandrel in accordance with an illustrative embodiment;
[0024] FIG. **14** is an illustration of a front view of a forming end effector in an engaged orientation and connected to a mandrel in accordance with an illustrative embodiment;
[0025] FIG. **15** is an illustration of an isometric view of forming end effectors positioned relative to a mandrel in accordance with an illustrative embodiment;
[0026] FIG. **16** is an illustration of an isometric view of a center actuator with center pressers of a forming end effector in accordance with an illustrative embodiment;
[0027] FIG. **17** is an illustration of an isometric view of a center actuator with center pressers of a forming end effector in accordance with an illustrative embodiment;
[0028] FIG. **18** is an illustration of an isometric view of a composite holding system of a forming end effector in accordance with an illustrative embodiment;
[0029] FIG. **19** is an illustration of a top view of a composite holding system of a forming end effector in accordance with an illustrative embodiment;
[0030] FIG. **20** is a flowchart of a method of forming a composite material onto a mandrel in accordance with an illustrative embodiment;
[0031] FIG. **21** is a flowchart of a method of forming a composite material onto a mandrel in accordance with an illustrative embodiment;
[0032] FIG. **22** is an illustration of an aircraft manufacturing and service method in a form of a block diagram in accordance with an illustrative embodiment; and
[0033] FIG. **23** is an illustration of an aircraft in a form of a block diagram in which an illustrative embodiment may be implemented.

DETAILED DESCRIPTION

[0034] Turning now to FIG. **1**, an illustration of an aircraft is depicted in accordance with an illustrative embodiment. Aircraft **100** has wing **102** and wing **104** attached to body **106**. Aircraft **100** includes engine **108** attached to wing **102** and engine **110** attached to wing **104**.
[0035] Body **106** has tail section **112**. Horizontal stabilizer **114**, horizontal stabilizer **116**, and vertical stabilizer **118** are attached to tail section **112** of body **106**.
[0036] Aircraft **100** is an example of an aircraft that can have a composite structure formed using a forming end effector of the illustrative examples. A composite structure in wing **102**, wing **104**, body **106**, or tail section **112** can be made using the forming end effector of the illustrative examples.
[0037] Turning now to FIG. **2**, an illustration of a block diagram of a manufacturing environment is depicted in accordance with an illustrative embodiment. Forming end effector **200** is used within manufacturing environment **202** for forming composite material **204**.

[0038] Forming end effector **200** comprises frame **206**, number of legs **208**, and forming heads **210** with sweepers **212**. Number of legs **208** is movably connected to frame **206**. Number of legs **208** has engagement pins **214** and engagement pins **216**. Number of legs **208** comprises legs **215** and legs **217**. Legs **215** and legs **217** are on opposite sides of frame **206**. Legs **215** and legs **217** are on opposite sides of center actuator **256**.
[0039] Engagement pins **214** and engagement pins **216** are configured to connect forming end effector **200** to mandrel **218**. Legs **215** connect to mandrel **218** on an opposite side of mandrel **218** than legs **217**. Legs **215** are configured to connect to first side **228** of base **230** of mandrel **218** while legs **217** connect to second side **229** of base **230** of mandrel **218**.
[0040] Mandrel **218** takes the form of tool **266** upon which composite material **204** will be applied and formed. Composite material **204** is formed onto forming surface **264** by sweeping composite material **204** using sweepers **212** of forming end effector **200**. Mandrel **218** further comprises base **230** onto which forming end effector **200** connects.
[0041] Forming end effector **200** can be moved between engaged orientation **286** and unengaged orientation **288** to connect or disconnect forming end effector **200** to mandrel **218**. Engaged orientation **286** is an orientation for forming end effector **200** to be connected to mandrel **218**. When in engaged orientation **286**, forming end effector **200** can be used for forming composite material **204** to mandrel **218**. Unengaged orientation **288** is an orientation for forming end effector **200** to be moved onto or away from mandrel **218**. When in unengaged orientation **288**, legs **215** and legs **217** of forming end effector **200** can be used for forming composite material **204** to mandrel **218**.
[0042] Forming heads **210** with sweepers **212** are movably connected to frame **206** by a number of actuators movably connected to frame **206**. Forming heads **210** with sweepers **212** are movably connected to frame **206** by number of actuators **220**, number of actuators **222**, number of actuators **224**, and number of actuators **226**.
[0043] As depicted, forming heads **210** comprise forming head **211** and forming head **213**. Forming head **211** is attached to number of actuators **220** and number of actuators **222**.
[0044] Forming heads **210** are connected to the number of actuators by pairs of hinges configured to rotate the sweepers relative to mandrel **218** beneath frame **206**. In this illustrative example, for forming head **211**, the pairs of hinges comprise hinge **232** and hinge **233**. Forming head **211** is connected to number of actuators **220** by hinge **232**. Forming head **211** is connected to number of actuators **222** by hinge **233**. Hinge **232** has first axis **234** distance **235** from forming head **211**. Hinge **233** has second axis **236** distance **237** from forming head **211**. Distance **235** is different from distance **237** such that actuating one of number of actuators **220** or number of actuators **222** rotates sweeper **238**.
[0045] The horizontal positions, angles, and extensions of actuators control the movement of a respective forming head and its respective sweeper. For example, horizontal position **248**, angle **249** and an extension of number of actuators **220** as well as horizontal position **250**, angle **251**, and an extension of number of actuators **222** can control the rotational sweeping **291** and translational sweeping **293** of sweeper **238**. The use of rotational sweeping **291** and translational sweeping **293** for sweepers, such as inflatable bladders, allows the ability to control the compaction force and pulling tension independently. Number of translation systems **295** can be used to modify at least one of horizontal position **248** or angle **249** of number of actuators **220** or horizontal position **250** or angle **251** of number of actuators **222**. Number of translation systems **295** can comprise at least one of bearings, railings, or carts.
[0046] In this illustrative example, for forming head **213**, the pairs of hinges comprise hinge **240** and hinge **241**. Forming head **213** is connected to number of actuators **224** by hinge **240**. Forming head **213** is connected to number of actuators **226** by hinge **241**. Hinge **240** has first axis **242** distance **243** from forming head **213**. Hinge **241** has second axis **244** distance **245** from forming head **213**. Distance **243** is different from distance **245** such that actuating one of number of

actuators **224** or number of actuators **226** rotates sweeper **246**.
[0047] The horizontal positions, angles, and extensions of actuators control the movement of a respective forming head and its respective sweeper. For example, horizontal position **252**, angle **253**, and an extension of number of actuators **224** as well as horizontal position **254**, angle **255**, and an extension of number of actuators **226** can control the rotational sweeping and translational sweeping of sweeper **246**. Number of translation systems **297** can be used to modify at least one of horizontal position **252** or angle **253** of number of actuators **224** or horizontal position **254** or angle **255** of number of actuators **226**. Number of translation systems **297** can comprise at least one of bearings, railings, or carts.
[0048] In some illustrative examples, sweepers **212** take the form of inflatable bladders. In this illustrative example, sweeper **238** takes the form of inflatable bladder **239**. In this illustrative example, sweeper **246** takes the form of inflatable bladder **247**.
[0049] Using number of actuators **220** and number of actuators **222**, sweeper **238** is used to sweep composite material **204** onto forming surface **264**. Number of actuators **220** and number of actuators **222** are used to perform both rotational sweeping **291** and translational sweeping **293** of composite material **204** onto forming surface **264**. Number of actuators **220** and number of actuators **222** are used to rotate sweeper **238** around a corner of forming surface **264** to reduce undesirable pulling of composite material **204**. Using rotational sweeping **291**, sweeper **238** continues to compress composite material **204** while sweeper **238** is moving around a corner of forming surface **264**. During translational sweeping **293**, sweeper **238** moves along forming surface **264** to pull composite material **204** along forming surface **264**.
[0050] Using number of actuators **224** and number of actuators **226**, sweeper **246** is used to sweep composite material **204** onto forming surface **264**. Number of actuators **224** and number of actuators **226** are used to perform both rotational sweeping **291** and translational sweeping **293** of composite material **204** onto forming surface **264**. Number of actuators **224** and number of actuators **226** are used to rotate sweeper **246** around a corner of forming surface **264** to reduce undesirable pulling of composite material **204**. Using rotational sweeping **291**, sweeper **246** continues to compress composite material **204** while sweeper **246** is moving around a corner of forming surface **264**. During translational sweeping **293**, sweeper **246** moves along forming surface **264** to pull composite material **204** along forming surface **264**.
[0051] In some illustrative examples, forming heads **210** further comprise vacuum pads configured to hold composite material **204** prior to forming. As depicted, forming head **211** further comprises composite holding system **275** configured to hold composite material **204** prior to forming. Composite holding system **275** comprises vacuum pads **277** and guard **278**. Guard **278** is a mechanical component to safeguard composite material **204** while transporting composite material **204**.
[0052] As depicted, forming head **213** further comprises composite holding system **276** configured to hold composite material **204** prior to forming. Composite holding system **276** comprises vacuum pads **279** and guard **280**. Guard **280** is a mechanical component to safeguard composite material **204** while transporting composite material **204**.
[0053] Forming end effector **200** further comprises center actuator **256** connected to frame **206** between forming heads **210**. Center pressers **258** are movably connected to center actuator **256**. In some illustrative examples, center pressers **258** comprise inflatable bladders **260** movably connected to center actuator **256**. In this illustrative example, center pressers **258** are connected to center actuator **256** by rotating pedals **262**. In some illustrative examples, center actuator **256** takes the form of air cylinder **257**.
[0054] Center actuator **256** is used to compress composite material **204** against forming surface **264** of mandrel **218** during forming of composite material **204**. In some illustrative examples, when center pressers **258** take the form of inflatable bladders **260**, inflatable bladders **260** can be inactive when forming end effector **200** is not forming composite material **204**. In some illustrative

examples, inflatable bladders **260** are uninflated for space conservation when forming end effector **200** is not actively forming composite material **204**. To utilize inflatable bladders **260** for compacting composite material **204**, inflatable bladders **260** are inflated and rotating pedals **262** are rotated outwardly to compress composite material **204** on forming surface **264**.

[0055] Forming end effector **200** can be transported to mandrel **218** by robotic arm **290**. Forming end effector **200** can form and shape composite material **204** onto forming surface **264** without being connected to robotic arm **290**. Robotic arm **290** can be used to transport and place a plurality of forming end effectors to apply composite materials to mandrel **218**. By forming end effector **200** performing forming operations without being attached to robotic arm **290**, fewer robotic arms can be used in manufacturing environment **202**. Further, by having several independently operated forming end effectors including forming end effector **200**, composite material **204** can be applied to mandrel **218** in a more efficient manner.

[0056] Forming end effector **200** can be connected to forming end effector **200** through utility port **292**. Utility port **292** is connected to frame **206**. Utility port **292** is configured to interface with robotic arm **290** for transportation of forming end effector **200** and is configured to interface with utilities **294** for forming operations independently of robotic arm **290**. Utilities **294** can be provided to forming end effector **200** through utility port **292** through a manufacturing floor of manufacturing environment **202**.

[0057] In some illustrative examples, engagement pins are further configured to receive at least one utility through the engagement pins and transport the utility to other components of the forming end effector. In some illustrative examples, engagement pins **214** are configured to receive at least one utility of utilities **294** through engagement pins **214**. In some illustrative examples, engagement pins **214** are configured to receive a utility from mandrel **218**.

[0058] In some illustrative examples, engagement pins **214** comprise vacuum channels **282**. Vacuum channels **282** can be used to provide a resource such as a vacuum or pneumatic pressure to forming end effector **200**. In some illustrative examples, vacuum channels **282** are present in engagement pins **214** to receive at least one utility from mandrel **218**. In some illustrative examples, air pressure is supplied to forming end effector **200** from mandrel **218** through engagement pins **214**.

[0059] In some illustrative examples, engagement pins **216** comprise vacuum channels **284**. Vacuum channels **284** can be used to provide a resource such as a vacuum or pneumatic pressure to forming end effector **200**. In some illustrative examples, vacuum channels **284** are present in engagement pins **216** to receive at least one utility from mandrel **218**. In some illustrative examples, air pressure is supplied to forming end effector **200** from mandrel **218** through engagement pins **216**.

[0060] In some illustrative examples, loads from forming end effector **200** react loads into mandrel **218** during the sweeping. In some illustrative examples, reacting loads from forming end effector **200** comprises reacting loads from forming end effector **200** through legs **215** and legs **217** of forming end effector **200** connected to mandrel **218**. In some illustrative examples, reacting loads from forming end effector **200** comprises reacting loads from forming end effector **200** through engagement pins **214** and engagement pins **216** of legs **215** and legs **217**. In some illustrative examples, connection to mandrel **218** through engagement pins **214** and engagement pins **216** will react loads from forming end effector **200** to mandrel **218** during forming of composite material **204**. Reacting the loads from forming composite material **204** into mandrel **218** allows for use of forming end effector **200** rather than a larger gantry system.

[0061] In some illustrative examples, forming end effector **200** comprises frame **206**, number of actuators **220**, **222**, **224**, and **226** movably connected to frame **206**, and forming heads **210** with sweepers **212** movably connected to frame **206** by number of actuators **220**, **222**, **224**, and **226**. Number of actuators **220**, **222**, **224**, and **226** connected to forming heads **210** by pairs of hinges such that forming heads **210** are configured to rotate to form composite material **204**. Forming end

effector **200** further comprises a number of legs **208** movably connected to frame **206**. The number of legs **208** have engagement pins, engagement pins **214** and engagement pins **216**, configured to connect forming end effector **200** to mandrel **218** and react loads from forming end effector **200** into mandrel **218** during forming of composite material **204**.

[0062] In some illustrative examples, each of forming heads **210** comprises a set of compliant joints to provide forming of composite material **204** on mandrel **218** with bend **270**. Bend **270** is perpendicular to length **268** of mandrel **218**. Bend **270** can be a vertical bend or a horizontal bend in mandrel **218**. In some illustrative examples, the set of compliant joints can be used to accommodate bend **270** in either a horizontal or vertical direction of mandrel **218**.

[0063] The illustration of manufacturing environment **202** in FIG. **2** is not meant to imply physical or architectural limitations to the manner in which an illustrative embodiment may be implemented. Other components in addition to or in place of the ones illustrated may be used. Some components may be unnecessary. Also, the blocks are presented to illustrate some functional components. One or more of these blocks may be combined, divided, or combined and divided into different blocks when implemented in an illustrative embodiment.

[0064] For example, in some illustrative examples, sweepers **212** can take the form of a different type of sweeper than inflatable bladders **260**. In some illustrative examples, sweepers **212** can take the form of foam sweepers, squeegees, or other acceptable forms of sweepers.

[0065] Turning now to FIG. **3**, an illustration of an isometric view of a forming end effector in an engaged orientation is depicted in accordance with an illustrative embodiment. Forming end effector **300** is a physical implementation of forming end effector **200** of FIG. **2**.

[0066] Forming end effector **300** comprises frame **302**, number of legs **304** movably connected to frame **302**, and forming heads **306** with sweepers **308** movably connected to frame **302** by number of actuators **310** movably connected to frame **302**. As can be seen in view **301**, number of legs **304** can be moved by actuators **312**. As depicted, actuators **312** are hydraulic actuators. Number of legs **304** has engagement pins **305** configured to connect forming end effector **300** to a mandrel. In some illustrative examples, engagement pins **305** react loads from the forming end effector **300** into the mandrel during forming of the composite material. In some illustrative examples, engagement pins **305** provide a number of utilities from the mandrel to forming end effector **300**. In some illustrative examples, engagement pins **305** are hollow and act as a conduit for providing hydraulic pressure from the mandrel to forming end effector **300**. In some illustrative examples, engagement pins **305** are further configured to receive at least one utility through engagement pins **305** and transport the utility to other components of forming end effector **300**.

[0067] Number of legs **304** are movably connected to frame **302** to allow for application and removal of forming end effector **300** to a mandrel. The forming end effector **300** can be applied to a mandrel, form a composite material, and then be removed from the mandrel. The forming end effector **300** can be used serially across a mandrel. The forming end effector **300** can be used on a plurality of different mandrels.

[0068] In view **301** of forming end effector **300**, forming end effector **300** is in engaged orientation **318**. Engaged orientation **318** is an orientation for forming end effector **300** to be connected to a mandrel. When in engaged orientation **318**, forming end effector **300** can be used for forming a composite material to the mandrel.

[0069] To form a composite material to a mandrel, number of actuators **310** move along number of translation systems **314**. In some illustrative examples, number of translation systems **314** comprise a number of cart and rail systems. In these illustrative examples, number of actuators **310** are connected to a number of cart and rail systems to move number of actuators **310** in a horizontal direction relative to frame **302**. When an actuator of number of actuators **310** moves in a horizontal direction, the actuator moves towards one pair of legs in number of legs **304** and away from another pair of legs in number of legs.

[0070] In some illustrative examples, forming end effector **300** can transport the composite

material (not depicted) to be formed. As depicted, forming end effector **300** comprises composite holding system **316**. Composite holding system **316** allows forming end effector **300** to carry a composite material as the forming end effector **300** is moved to a mandrel and connected to the mandrel.

[0071] As depicted, sweepers **308** take the form of inflatable bladders **309**. In other illustrative examples, sweepers **308** can take the form of squeegees or other forms of sweepers capable of reaching all indentations and surface features.

[0072] Forming heads **306** are connected to number of actuators **310** by pairs of hinges configured to rotate sweepers **308** relative to a mandrel beneath frame **302**. The hinges and number of actuators **310** are configured to enable translational sweeping of sweepers **308**. The hinges and number of actuators **310** are configured to enable independent rotational sweeping of sweepers **308**. The rotational sweeping allows for sweepers **308** to rotate around a corner of a forming surface of a mandrel.

[0073] Turning now to FIG. **4**, an illustration of an isometric view of a forming end effector in an unengaged orientation is depicted in accordance with an illustrative embodiment. View **400** is a view of forming end effector **300** in unengaged orientation **401**. Forming end effector **300** can be transported to a mandrel or away from a mandrel in unengaged orientation **401**.

[0074] In view **400**, composite holding systems of forming end effector **300** are visible. Forming end effector **300** comprises composite holding system **403** and composite holding system **405**.

[0075] Forming heads **306** further comprises vacuum pads **402** configured to hold the composite material prior to forming. In this illustrative example, composite holding system **403** comprises vacuum pads **402** configured to hold composite material prior to forming. Composite holding system **403** further comprises guard **404**. Guard **404** is a mechanical component to safeguard composite material while transporting composite material.

[0076] Forming heads **306** further comprise vacuum pads **406** configured to hold the composite material prior to forming. In this illustrative example, composite holding system **405** comprises vacuum pads **406** configured to hold composite material prior to forming. Composite holding system **405** further comprises guard **408**. Guard **408** is a mechanical component to safeguard composite material while transporting composite material.

[0077] Turning now to FIG. **5**, an illustration of a front view of a forming end effector in an unengaged orientation is depicted in accordance with an illustrative embodiment. View **500** is a front view of forming end effector **300**. In view **500** forming end effector **300** is in unengaged orientation **401**.

[0078] Forming end effector **300** comprises center actuator **504** connected to frame **302** between forming heads **306**. Center pressers **506** are movably connected to center actuator **504**.

[0079] The center pressers **506** comprise inflatable bladders movably connected to center actuator **504**.

[0080] Utility port **502** is connected to frame **302**. Utility port **502** is configured to interface with a robotic arm for transportation of forming end effector **300**. Utility port **502** is also configured to interface with utilities for forming operations independently of a robotic arm. Utility port **502** allows for powering and operating forming end effector **300** without the robot staying connected.

[0081] Turning now to FIG. **6**, an illustration of an isometric view of a forming end effector in an engaged orientation is depicted in accordance with an illustrative embodiment. In view **600** of forming end effector **300**, utility port **502** is visible. As depicted, utility port **502** takes the form of a robotic tool changer.

[0082] Turning now to FIG. **7**, an illustration of an isometric view of an engagement pin on a leg of a forming end effector is depicted in accordance with an illustrative embodiment. In view **700**, engagement pin **704** is connected to leg **702** of forming end effector **701**. Engagement pin **704** is a physical implementation of an engagement pin of engagement pins **214** of FIG. **2**. Engagement pin **704** can be one of engagement pins **305** of FIGS. **3**-**6**. Engagement pin **704** comprises vacuum

channel **706**. Vacuum channel **706** can be used to provide a resource such as a vacuum or pneumatic pressure to forming end effector **701**.
[0083] Engagement pin **704** can be used to connect forming end effector **701** to a mandrel. Connection to a mandrel through engagement pin **704** will react loads from forming end effector **701** to the mandrel during forming of a composite material.
[0084] Turning now to FIG. **8**, an illustration of an isometric view of a composite holding system of a forming end effector is depicted in accordance with an illustrative embodiment. View **800** is an isometric view of composite holding system **806** of forming end effector **802**. Composite holding system **806** is a physical implementation of composite holding system **275** of FIG. **2**. Composite holding system **806** can be the same as composite holding system **316** of FIGS. **3**-**6**.
[0085] Composite holding system **806** is connected to forming head **804** of forming end effector **802**. Composite holding system **806** is configured to hold composite material **812** to be formed by forming end effector **802**. Composite holding system **806** allows forming end effector **802** to hold and carry composite material **812** to the mandrel upon which composite material **812** will be formed.
[0086] Composite holding system **806** comprises vacuum pads **810** configured to hold composite material **812** prior to forming. Composite holding system **806** further comprises guard **808**. Guard **808** is a mechanical component to safeguard composite material **812** while transporting composite material **812**.
[0087] Turning now to FIG. **9**, an illustration of a front view of a forming end effector in an engaged orientation and connected to a mandrel is depicted in accordance with an illustrative embodiment. In view **900** forming end effector **902** is connected to mandrel **904**. Forming end effector **902** is a physical implementation of forming end effector **200** of FIG. **2**. Forming end effector **902** can be the same as forming end effector **300** of FIGS. **3**-**6**. In some illustrative examples, forming end effector **902** is connected to mandrel **904** by engagement pin **704** of FIG. **7**. In some illustrative examples, forming end effector **902** is the same as forming end effector **802** of FIG. **8**.
[0088] In view **900**, forming end effector **902** is at the beginning of the forming process. Forming end effector **902** comprises frame **901**, number of legs **908** movably connected to frame **901**, and forming heads **914** with sweepers **916**. Number of legs **908** have engagement pins (not depicted) configured to connect forming end effector **902** to mandrel **904** and react loads from forming end effector **902** into mandrel **904** during forming of a composite material.
[0089] In view **900**, forming end effector **902** is in engaged orientation **906**. In engaged orientation **906**, number of legs **908** of forming end effector **902** connect forming end effector **902** to mandrel **904**. Mandrel **904** is a tool upon which forming end effector **902** will form composite material **917**. Mandrel **904** comprises base **910** and forming surface **912**. Base **910** is a portion of mandrel **904** configured to interface with forming end effector **902**. In some illustrative examples, base **910** also interacts with a manufacturing floor. Forming surface **912** is a surface upon which composite material **917** will be formed. Forming surface **912** is the surface upon which sweepers **916** of forming end effector **902** will form composite material **917**.
[0090] In view **900**, sweepers **916** are in contact with composite material **917** to apply pressure to composite material **917** on forming surface **912**. Center pressers **920** are not activated in view **900**. In view **900**, center pressers **920** are not yet inflated. Forming heads **914** with sweepers **916** movably connected to frame **901** by number of actuators **903**. Number of actuators **903** is connected to forming heads **914** by pairs of hinges such that forming heads **914** are configured to rotate to form composite material **917**.
[0091] Center actuator **918** is connected to frame **901** between forming heads **914**. Center pressers **920** movably connected to center actuator **918**. Center pressers **920** comprise inflatable bladders movably connected to center actuator **918**.
[0092] Turning now to FIG. **10**, an illustration of a front view of a forming end effector in an

engaged orientation and connected to a mandrel is depicted in accordance with an illustrative embodiment. Between view **900** and view **1000**, forming heads **914** have moved relative to mandrel **904**. In view **1000**, the lateral inflatable bladders, sweepers **916**, begin to sweep form outward. In view **1000**, inflatable bladders **1020** of center pressers **920** push against the inside of inflatable bladders of sweepers **916** as center actuator **918** extends downward and rotating pedals **1018** rotate open.

[0093] In view **1000**, actuators **903** comprise number of actuators **1002** and number of actuators **1008**. In view **1000**, forming heads **914** comprise forming head **1004** connected to number of actuators **1002** and forming head **1010** connected to number of actuators **1008**. Actuators **1002** are connected to translation system **1006** and actuators **1008** are connected to translation system **1012**. Between view **900** and view **1000**, actuators **1002** and forming head **1004** have moved in direction **1014** away from center actuator **918**. Between view **900** and view **1000**, actuators **1008** and forming head **1010** have moved in direction **1016** away from center actuator **918**. Between view **900** and view **1000**, actuators **1002** and actuators **1008** have moved in opposite directions so that actuators **1002** and actuators **1008** move away from each other.

[0094] The horizontal positions, angles, and extensions of actuators **1002** control the movement of forming head **1004** and its respective sweeper. The horizontal positions, angles, and extensions of actuators **1002** are controlled to perform both rotational sweeping and translational sweeping. Between view **900** and view **1000**, actuators **1002** moved in direction **1014** to create translational sweeping of composite material **917** by the sweeper of forming head **1004** in direction **1014**.

[0095] The horizontal positions, angles, and extensions of actuators **1008** control the movement of forming head **1010** and its respective sweeper. The horizontal positions, angles, and extensions of actuators **1008** are controlled to perform both rotational sweeping and translational sweeping. Between view **900** and view **1000**, actuators **1008** moved in direction **1016** to create translational sweeping of composite material **917** by the sweeper of forming head **1010** in direction **1016**.

[0096] In view **1000**, center pressers **920** is movably connected to center actuator **918** have been activated for compaction of composite material **917**. In view **1000**, center pressers **920** take the form of inflatable bladders **1020**. Inflatable bladders **1020** are connected to rotating pedals **1018**. Between view **900** and view **1000**, rotating pedals have rotated outwardly to allow for inflation of inflatable bladders **1020**.

[0097] Turning now to FIG. **11**, an illustration of a front view of a forming end effector in an engaged orientation and connected to a mandrel is depicted in accordance with an illustrative embodiment. In this illustrative example, sweepers **916** comprise inflatable bladders, inflatable bladder **1118** and inflatable bladder **1120**. In view **1100**, inflatable bladder **1118** and inflatable bladder **1120** begin to rotate about corner **1202** and corner **1204** of mandrel **904**. In some illustrative examples, corner **1202** and corner **1204** can be referred to as radiuses. Between view **1000** and view **1100**, the horizontal positions, angles, and extensions of actuators **1002** have changed to begin rotating inflatable bladder **1118** around corner **1202**. Between view **1000** and view **1100**, the horizontal positions, angles, and extensions of actuators **1008** have changed to begin rotating inflatable bladder **1120** around corner **1204**.

[0098] In view **1100**, inflatable bladder **1118** and inflatable bladder **1120** sweep, but begin to rotate around each corner of mandrel **904**. Rotating forming head **1004** and forming head **1010** prevents undesirable amounts of pulling on composite material **917**.

[0099] Actuators **1002** comprises actuator **1102** and actuator **1104**. Actuator **1102** is connected to forming head **1004** by hinge **1110**. Actuator **1104** is connected to forming head **1004** by hinge **1112**. Hinge **1110** is a first distance away from forming head **1004** and hinge **1112** is a second distance away from forming head **1004**. As can be seen in view **1100**, a difference between the first distance and the second distance enables rotation of inflatable bladder **1118** for forming composite material **917** around edges such as corner **1202**. As can be seen in view **1100**, hinge **1110** is a greater distance from forming head **1004** than hinge **1112**. By at least one of extending actuator **1102** and

retracting actuator **1104**, inflatable bladder **1118** is rotated in direction **1122**.
[0100] Actuators **1008** comprises actuator **1106** and actuator **1108**. Actuator **1106** is connected to forming head **1010** by hinge **1114**. Actuator **1108** is connected to forming head **1010** by hinge **1116**. Hinge **1114** is a first distance away from forming head **1010** and hinge **1116** is a second distance away from forming head **1010**. As can be seen in view **1100**, a difference between the first distance and the second distance enables rotation of inflatable bladder **1120** for forming composite material **917** around edges such as corner **1204**. As can be seen in view **1100**, hinge **1116** is a greater distance from forming head **1010** than hinge **1114**. By at least one of extending actuator **1108** and retracting actuator **1106**, inflatable bladder **1120** is rotated in direction **1124**.
[0101] Turning now to FIG. **12**, an illustration of a front view of a forming end effector in an engaged orientation and connected to a mandrel is depicted in accordance with an illustrative embodiment. In view **1200**, inflatable bladder **1118** has rotated around corner **1202** in direction **1122** and is compacting composite material **917** against forming surface **912** of mandrel **904**. In view **1200**, rotation of inflatable bladder **1118** is complete and inflatable bladder **1118** begins translational sweeping in direction **1206** along forming surface **912**.
[0102] In view **1200**, inflatable bladder **1120** has rotated around corner **1204** in direction **1124** and is compacting composite material **917** against forming surface **912** of mandrel **904**. In view **1200**, rotation of inflatable bladder **1120** is complete and inflatable bladder **1120** begins translational sweeping in direction **1208** along forming surface **912**.
[0103] Turning now to FIG. **13**, an illustration of a front view of a forming end effector in an engaged orientation and connected to a mandrel is depicted in accordance with an illustrative embodiment. In view **1300**, inflatable bladder **1118** is being rotated in direction **1122**. In view **1300**, inflatable bladder **1120** is being rotated in direction **1124**. Rotation of inflatable bladder **1118** in direction **1122** can be referred to as reverse rotation in this example.
[0104] In view **1300**, inflatable bladder **1118** and inflatable bladder **1120** rotate in reverse to further sweep and pull composite material **917** as it nears the end of forming. In view **1300**, actuator **1102** moves horizontally in direction **1014** to perform rotational sweeping and translational sweeping. Actuator **1104** is extended to perform rotational sweeping and translational sweeping. The cooperative interaction of actuator **1102** and actuator **1104** purposefully creates rotational motion.
[0105] Turning now to FIG. **14**, an illustration of a front view of a forming end effector in an engaged orientation and connected to a mandrel is depicted in accordance with an illustrative embodiment. In view **1400**, inflatable bladder **1118** is being rotated in direction **1122**. In view **1400**, inflatable bladder **1120** is being rotated in direction **1124**. Rotation of inflatable bladder **1120** in direction **1124** can be referred to as reverse rotation in this example.
[0106] Between view **1300** and view **1400**, actuator **1106** has been extended to rotate inflatable bladder **1120** in direction **1124**. Between view **1300** and view **1400**, actuator **1106** has been extended to rotate inflatable bladder **1120** in direction **1124**.
[0107] In view **1400**, reverse rotation and pulling is depicted. In view **1400**, rotational sweeping and translational sweeping is depicted. In view **1400**, the translational sweeping comprises movement of inflatable bladder **1118** down forming surface **912** away from corner **1202**. In view **1400**, the translational sweeping comprises movement of inflatable bladder **1120** down forming surface **912** away from corner **1204**. Rotational sweeping and translational sweeping while compacting the last bit of composite material **917** will prevent the layers from peeling back and wrinkling.
[0108] Turning now to FIG. **15**, an illustration of an isometric view of forming end effectors positioned relative to a mandrel is depicted in accordance with an illustrative embodiment. Forming end effector **1504** and forming end effector **1506** are physical implementations of forming end effector **200** of FIG. **2**. Mandrel **1502** is a physical implementation of mandrel **218** of FIG. **2**. Forming end effector **1504** can be the same as forming end effector **300** of FIGS. **3**-**6**. Forming end effector **1506** can be the same as forming end effector **300** of FIGS. **3**-**6**. Forming end effector **1504**

can be the same as forming end effector **902** of FIGS. **9-14**. Forming end effector **1506** can be the same as forming end effector **902** of FIGS. **9-14**.

[0109] In view **1500**, forming end effector **1504** is connected to base **1510** of mandrel **1502** and is forming a composite material onto forming surface **1512** of mandrel **1502**. In this illustrative example, engagement pins **1516** of forming end effector **1504** engage with holes **1514** in base **1510** of mandrel **1502**. Engagement pins **1516** lock forming end effector **1504** to mandrel **1502**.

[0110] After forming the composite material on mandrel **1502**, forming end effector **1504** can be disconnected and moved away from mandrel **1502**. In some illustrative examples, to move forming end effector **1504** away from mandrel **1502**, robotic arm **1508** connects to forming end effector **1504** to disengage forming end effector **1504** from mandrel **1502** and move forming end effector **1504** away from mandrel **1502**. In this illustrative example, robotic arm **1508** connects to forming end effector **1504** using utility port **1518**.

[0111] In view **1500**, forming end effector **1506** is being positioned relative to mandrel **1502** and connected to mandrel **1502**. In view **1500**, robotic arm **1508** is connected to forming end effector **1506** and is positioning forming end effector **1506** relative to mandrel **1502**. Robotic arm **1508** is connected to utility port **1522** of forming end effector **1506**. In this illustrative example, engagement pins **1520** of forming end effector **1506** will be used to engage with holes **1514** in base **1510** of mandrel **1502**. Engagement pins **1520** will lock forming end effector **1506** to mandrel **1502**.

[0112] As depicted, neither forming end effector **1504** or forming end effector **1506** is positioned over a bend in mandrel **1502**. However, in some illustrative examples, at least one of forming end effector **1504** or forming end effector **1506** can be used on a bend of mandrel **1502** due to a set of compliant joints in the forming heads.

[0113] Turning now to FIG. **16**, an illustration of an isometric view of a center actuator with center pressers of a forming end effector is depicted in accordance with an illustrative embodiment. In view **1600**, forming end effector **1602** comprises center actuator **1606** connected to frame **1604**. Forming end effector **1602** can be a physical implementation of forming end effector **200**. Forming end effector **1602** can be the same as forming end effector **300** of FIGS. **3-6**. Forming end effector **1602** can include leg **702** of FIG. **7**. Forming end effector **1602** can be the same as forming end effector **802** of FIG. **8**. Forming end effector **1602** can be the same as forming end effector **902** of FIGS. **9-14**. Forming end effector **1602** can be the same as either of forming end effector **1504** or forming end effector **1506**.

[0114] Center actuator **1606** of forming end effector **1602** is connected to frame **1604**. Center actuator **1606** connected to frame **1604** is positioned between forming heads. Center actuator comprises extendable shafts **1607** connected to platform **1608**. Center pressers **1610** are movably connected to center actuator **1606**.

[0115] Center pressers **1610** comprise inflatable bladders **1612** movably connected to center actuator **1606**. Center pressers **1610** comprise inflatable bladders **1612** connected to rotating pedals **1614**. As depicted, inflatable bladders **1612** are not filled. Inflatable bladders **1612** are collapsed to conserve space. Rotating pedals **1614** can rotate away from each other to provide additional space to inflate inflatable bladders **1612**.

[0116] Turning now to FIG. **17**, an illustration of an isometric view of a center actuator with center pressers of a forming end effector is depicted in accordance with an illustrative embodiment. In view **1700**, center pressers **1610** are in extended position **1702**. In extended position **1702**, center pressers **1610** can be used to hold a center portion of a composite material against a forming surface of a mandrel.

[0117] Between view **1600** and view **1700**, pedals **1614** have rotated outwardly away from a center of platform **1608**. Platform **1608** acts as a hard stop for pedals **1614**.

[0118] Turning now to FIG. **18**, an illustration of an isometric view of a forming head and a respective composite holding system of a forming end effector is depicted in accordance with an

illustrative embodiment. Forming head **1802** comprises portion **1804** and portion **1806** connected by set of compliant joints **1808**. Set of compliant joints **1808** enables forming of a composite material on a mandrel with a bend.

[0119] Portion **1804** of forming head **1802** is a separate plate from portion **1806**. Having two separate plates, portion **1804** and portion **1806** allows for flexing of forming head **1802**. Set of compliant joints **1808** comprises rod ends with floating pins to allow for flexing. Set of compliant joints **1808** comprise compliant rod end and rail joints that allow for conforming to the kinks or bends in a mandrel.

[0120] Composite holding system **1810** is visible in view **1800**. Composite holding system **1810** comprises vacuum pads **1812** and guard **1814**. Vacuum pads **1812** comprise vacuum pad **1816**, vacuum pad **1818**, vacuum pad **1820**, and vacuum pad **1822**. As portion **1804** moves relative to portion **1806**, vacuum pad **1816** and vacuum pad **1818** move relative to vacuum pad **1820** and vacuum pad **1822**.

[0121] As depicted, set of compliant joints **1808** allows an angle between portion **1804** and portion **1806** in direction **1824**. Direction **1824** may be referred to as a vertical direction.

[0122] Turning now to FIG. **19**, an illustration of a top view of a forming head and a respective composite holding system of a forming end effector is depicted in accordance with an illustrative embodiment. View **1900** is a view from direction **1824** of FIG. **18**.

[0123] In view **1900**, the floating pins of set of compliant joints **1808** are visible. Set of compliant joints **1808** comprise floating pin **1902** and floating pin **1904**. The floating pins, floating pin **1902** and floating pin **1904**, will extend through a respective rod end of a connection rod to join forming head **1802** to the forming end effector. Floating pin **1902** and floating pin **1904** are connected to outer rod ends that are part of forming head **1802**.

[0124] In view **1900**, movement of portion **1804** and portion **1806** can be moved in direction **1910**. Movement in direction **1910** causes an edge of portion **1804** to be a varying distance from an edge of portion **1806**. Movement in direction **1910** can be referred to as movement in a horizontal direction.

[0125] In this illustrative example, set of compliant joints **1808** forms part of first set of hinges **1906** and second set of hinges **1908**. First set of hinges **1906** can include hinge **232** of FIG. **2**. Second set of hinges **1908** can include hinge **233** of FIG. **2**. Extending selected actuators to impart rotational sweeping comprises extending actuators connected to one of first set of hinges **1906** or second set of hinges **1908** more than the other of first set of hinges **1906** or second set of hinges **1908**.

[0126] Turning now to FIG. **20**, a flowchart of a method of forming a composite material onto a mandrel is depicted in accordance with an illustrative embodiment. Method **2000** can be used to form a composite component of aircraft **100** of FIG. **1**. Method **2000** can be performed using forming end effector **200** of FIG. **2**. Method **2000** can be performed using forming end effector **300** of FIGS. **3-6**. Method **2000** can be performed using forming end effector **701** of FIG. **7**. Method **2000** can be performed using forming end effector **802** of FIG. **8**. Method **2000** can be performed using forming end effector **902** of FIGS. **9-14**. Method **2000** can be performed using mandrel **1502** and at least one of forming end effector **1504** or forming end effector **1506** of FIG. **15**. Method **2000** can be performed using a forming end effector having center pressers **1610** of FIGS. **16-17**. Method **2000** can be performed using a forming end effector having composite holding system **1810** of FIGS. **18-19**.

[0127] Method **2000** positions a forming end effector carrying the composite material over the mandrel (operation **2002**). Method **2000** connects the forming end effector to the mandrel (operation **2004**). Method **2000** sweeps the composite material onto the mandrel using sweepers of the forming end effector (operation **2006**). Afterwards, method **2000** terminates.

[0128] In some illustrative examples, positioning the forming end effector over the mandrel comprises moving the forming end effector using a robotic arm (operation **2008**). In some

illustrative examples, the robotic arm is only used to transport and connect the forming end effector to the mandrel. In some illustrative examples, the robotic arm is used to move multiple forming end effectors to be connected to the mandrel.

[0129] In some illustrative examples, method **2000** disconnects the robotic arm from a utility port of the forming end effector after positioning the forming end effector (operation **2010**). In some illustrative examples, method **2000** connects the forming end effector to utilities using the utility port prior to sweeping the composite material onto the mandrel (operation **2012**). In some illustrative examples, the utilities are provided by the mandrel. In some illustrative examples, the utilities are provided by outlets on the manufacturing floor.

[0130] In some illustrative examples, connecting the forming end effector to the mandrel comprises locking the forming end effector to the mandrel using engagement pins (operation **2014**). In some illustrative examples, the engagement pins are connected to legs of the forming end effector.

[0131] In some illustrative examples, method **2000** supplies at least one utility from the mandrel to the forming end effector through the engagement pins (operation **2016**). In some illustrative examples, vacuum channels are present in the engagement pins to receive the at least one utility from the mandrel. In some illustrative examples, air pressure is supplied to the forming end effector from the mandrel through the engagement pins.

[0132] In some illustrative examples, sweeping the composite material onto the mandrel comprises urging the composite material against the mandrel using inflatable bladders of the sweepers (operation **2018**). In some illustrative examples, urging the composite material comprises moving the inflatable bladders relative to the mandrel. In some illustrative examples, urging the composite material comprises moving the inflatable bladders along a forming surface of the mandrel.

[0133] In some illustrative examples, sweeping the composite material onto the mandrel comprises rotating the inflatable bladders prior to urging the composite material onto corners of the mandrel (operation **2020**). In some illustrative examples, sweeping the composite material comprises rotational sweeping and translational sweeping. In some illustrative examples, the rotational sweeping and the translational sweeping can be performed independently. The rotational sweeping is an active rotation of the inflatable bladders. In some illustrative examples, the rotational sweeping is performed using a number of actuators.

[0134] In some illustrative examples, method **2000** reacts loads from the forming end effector into the mandrel during the sweeping (operation **2022**). In some illustrative examples, reacting loads from the forming end effector comprises reacting loads from the forming end effector through legs of the forming end effector connected to the mandrel. In some illustrative examples, reacting loads from the forming end effector comprises reacting loads from the forming end effector through the engagement pins of the legs.

[0135] Turning now to FIG. **21**, a flowchart of a method of forming a composite material onto a mandrel is depicted in accordance with an illustrative embodiment. Method **2100** can be used to form a composite component of aircraft **100** of FIG. **1**. Method **2100** can be performed using forming end effector **200** of FIG. **2**. Method **2100** can be performed using forming end effector **300** of FIGS. **3-6**. Method **2100** can be performed using forming end effector **701** of FIG. **7**. Method **2100** can be performed using forming end effector **802** of FIG. **8**. Method **2100** can be performed using forming end effector **902** of FIGS. **9-14**. Method **2100** can be performed using mandrel **1502** and at least one of forming end effector **1504** or forming end effector **1506** of FIG. **15**. Method **2100** can be performed using a forming end effector having center pressers **1610** of FIGS. **16-17**. Method **2100** can be performed using a forming end effector having composite holding system **1810** of FIGS. **18-19**.

[0136] Method **2100** forms a composite material onto a mandrel using sweepers of a forming end effector (operation **2102**). Method **2100** reacts loads from the forming end effector into the mandrel during forming of the composite material (operation **2104**). Afterwards, method **2100** terminates.

[0137] In some illustrative examples, method **2100** connects the forming end effector to the

mandrel prior to forming the composite material onto the mandrel (operation **2106**). In some illustrative examples, connecting the forming end effector to the mandrel comprises locking the forming end effector to the mandrel using engagement pins (operation **2108**). In some illustrative examples, the engagement pins are connected to legs of the forming end effector.

[0138] In some illustrative examples, connecting the forming end effector to the mandrel comprises locking the forming end effector to the mandrel using legs of the forming end effector (operation **2110**). In some illustrative examples, engagement pins on the legs of the forming end effector lock the forming end effector to the mandrel. In some illustrative examples, engagement pins on the legs of the forming end effector lock the legs to holes on the base of the mandrel.

[0139] In some illustrative examples, reacting loads from the forming end effector comprises reacting loads from the forming end effector through legs of the forming end effector connected to the mandrel (operation **2112**). In some illustrative examples, reacting loads from the forming end effector comprises reacting loads from the forming end effector through the engagement pins of the legs.

[0140] As used herein, the phrase “at least one of,” when used with a list of items, means different combinations of one or more of the listed items may be used and only one of each item in the list may be needed. For example, “at least one of item A, item B, or item C” may include, without limitation, item A, item A and item B, or item B. This example also may include item A, item B, and item C, or item B and item C. Of course, any combinations of these items may be present. In other examples, “at least one of” may be, for example, without limitation, two of item A; one of item B; and ten of item C; four of item B and seven of item C; or other suitable combinations. The item may be a particular object, thing, or a category. In other words, at least one of means any combination items and number of items may be used from the list but not all of the items in the list are required.

[0141] As used herein, “a number of,” when used with reference to items means one or more items.

[0142] The flowcharts and block diagrams in the different depicted embodiments illustrate the architecture, functionality, and operation of some possible implementations of apparatuses and methods in an illustrative embodiment. In this regard, each block in the flowcharts or block diagrams may represent at least one of a module, a segment, a function, or a portion of an operation or step.

[0143] In some alternative implementations of an illustrative embodiment, the function or functions noted in the blocks may occur out of the order noted in the figures. For example, in some cases, two blocks shown in succession may be executed substantially concurrently, or the blocks may sometimes be performed in the reverse order, depending upon the functionality involved. Also, other blocks may be added in addition to the illustrated blocks in a flowchart or block diagram. Some blocks may be optional. For example, operation **2008** through operation **2022** may be optional. As another example, operation **2106** through operation **2112** may be optional.

[0144] Illustrative embodiments of the present disclosure may be described in the context of aircraft manufacturing and service method **2200** as shown in FIG. **22** and aircraft **2300** as shown in FIG. **23**. Turning first to FIG. **22**, an illustration of an aircraft manufacturing and service method in a form of a block diagram is depicted in accordance with an illustrative embodiment. During pre-production, aircraft manufacturing and service method **2200** may include specification and design **2202** of aircraft **2300** in FIG. **23** and material procurement **2204**.

[0145] During production, component and subassembly manufacturing **2206** and system integration **2208** of aircraft **2300** takes place. Thereafter, aircraft **2300** may go through certification and delivery **2210** in order to be placed in service **2212**. While in service **2212** by a customer, aircraft **2300** is scheduled for routine maintenance and service **2214**, which may include modification, reconfiguration, refurbishment, or other maintenance and service.

[0146] Each of the processes of aircraft manufacturing and service method **2200** may be performed or carried out by a system integrator, a third party, and/or an operator. In these examples, the

operator may be 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 vendors, subcontractors, and suppliers; and an operator may be an airline, a leasing company, a military entity, a service organization, and so on.

[0147] With reference now to FIG. **23**, an illustration of an aircraft in a form of a block diagram is depicted in which an illustrative embodiment may be implemented. In this example, aircraft **2300** is produced by aircraft manufacturing and service method **2200** of FIG. **22** and may include airframe **2302** with plurality of systems **2304** and interior **2306**. Examples of systems **2304** include one or more of propulsion system **2308**, electrical system **2310**, hydraulic system **2312**, and environmental system **2314**. Any number of other systems may be included.

[0148] Apparatuses and methods embodied herein may be employed during at least one of the stages of aircraft manufacturing and service method **2200**. One or more illustrative embodiments may be manufactured or used during at least one of component and subassembly manufacturing **2206**, system integration **2208**, in service **2212**, or maintenance and service **2214** of FIG. **22**.

[0149] The illustrative examples enable composite forming at multiple orientations using a robot system. The illustrative examples provide a forming end-effector that is designed with several articulating joints to allow for more complex forming sweeps, capable of compacting while preventing radius thinning. The forming end effector comprises a flat pre-cured composite picking system to transport and begin forming on a complex mandrel tool. The forming end effector of the illustrative examples is capable of forming composite material on a mandrel that would not be cost effective for designing a traditional gantry system. The forming end-effector is attached to the mandrel (tool) using several indexing pins that hold the forming end effector in place and allow for the robot to withdraw while the end-effector continues to form.

[0150] The forming end effector comprises utility couplers that continue to supply energy and air pressure. The use of forming end effectors that receive utilities independently of a robotic arm allows for multiple forming end-effectors to be placed onto a mandrel (tool) at desired locations.

[0151] In some illustrative examples, the forming end effector uses pins to attach the forming end-effector to the mandrel (tool) directly, which removes the stresses from deflecting the robot.

[0152] The sweepers for compacting/forming the composite are configured to actively rotate. The sweepers, which can take the form of inflatable bladders, are not fixed at a static angle. Rotating the sweepers can prevent radius thinning which can be created by applying compaction force with only translational sweeping around a corner of a mandrel. Rotating the sweepers allows the sweepers to apply enough compaction force without pulling the fibers of the composite material too much in tension around the bending corner. In some illustrative examples, the sweepers take the form of inflatable bladders.

[0153] In the illustrative examples, robotic arms attach the forming end-effector to a mandrel (tool), to create a rigid cage for forming. The use of a rolling sweeper is used in addition to compaction. The sweeper can take the form of an inflatable bladder. The ability to drop off the forming end-effector to operate without the robot allows the robotic asset to perform other tasks such as metrology on a previously formed portion of the tool. The forming end effectors can use a center compacting feature with fins (rotating pedals) that open to extend the compaction area at the top of the tool to hold the flat charge in place. In some illustrative examples, the use of linked plates in the forming heads for compaction allow for forming kinks and reaching within tool pits.

[0154] The use of legs and pins to connect the forming end effector and the mandrel allow for forming forces up from 3-10 kips, depending on the length of the forming part segment. The illustrative examples utilize rotating sweepers, such as inflatable bladders, for being able to control the compaction force and pulling tension independently. The forming end effector comprises a center compaction foot that expands.

[0155] The illustrative examples can allow for more complex composite forming as a larger or

single piece. In some illustrative examples, the robotic arm can be a commercially off the shelf robots. A commercially available robot may be easily maintained and/or replaced in production. Maintaining or replacing a robotic arm may be less time consuming or less expensive than a large custom gantry going offline and affecting production rate.

[0156] The description of the different illustrative embodiments has been presented for purposes of illustration and description and is not intended to be exhaustive or limited to the embodiments in the form disclosed. Many modifications and variations will be apparent to those of ordinary skill in the art. Further, different illustrative embodiments may provide different features as compared to other illustrative embodiments. The embodiment or embodiments selected are chosen and described in order to best explain the principles of the embodiments, the practical application, and to enable others of ordinary skill in the art to understand the disclosure for various embodiments with various modifications as are suited to the particular use contemplated.

Claims

1. A method of forming a composite material onto a mandrel: positioning a forming end effector carrying the composite material over the mandrel; connecting the forming end effector to the mandrel; and sweeping the composite material onto the mandrel using sweepers of the forming end effector.

2. The method of claim 1, wherein positioning the forming end effector over the mandrel comprises moving the forming end effector using a robotic arm.

3. The method of claim 2 further comprising: disconnecting the robotic arm from a utility port of the forming end effector after positioning the forming end effector; and connecting the forming end effector to utilities using the utility port prior to sweeping the composite material onto the mandrel.

4. The method of claim 1, wherein connecting the forming end effector to the mandrel comprises locking the forming end effector to the mandrel using engagement pins.

5. The method of claim 4 further comprising: supplying at least one utility from the mandrel to the forming end effector through the engagement pins.

6. The method of claim 1, wherein sweeping the composite material onto the mandrel comprises urging the composite material against the mandrel using inflatable bladders of the sweepers.

7. The method of claim 6, wherein sweeping the composite material onto the mandrel comprises rotating the inflatable bladders prior to urging the composite material onto corners of the mandrel.

8. The method of claim 1 further comprising: reacting loads from the forming end effector into the mandrel during the sweeping.

9. A forming end effector for forming a composite material comprising: a frame; a number of legs movably connected to the frame, the number of legs having engagement pins; and forming heads with sweepers movably connected to the frame by a number of actuators movably connected to the frame.

10. The forming end effector of claim 9, wherein the engagement pins are configured to connect the forming end effector to a mandrel.

11. The forming end effector of claim 9, wherein the legs are configured to react loads from the forming end effector into the mandrel during forming of the composite material.

12. The forming end effector of claim 9, wherein the forming heads further comprise vacuum pads configured to hold the composite material prior to forming.

13. The forming end effector of claim 9, wherein the sweepers take the form of inflatable bladders.

14. The forming end effector of claim 9, wherein the forming heads are connected to the number of actuators by pairs of hinges configured to rotate the sweepers relative to a mandrel beneath the frame.

15. The forming end effector of claim 9 further comprising: a center actuator connected to the frame between the forming heads; and center pressers movably connected to the center actuator.

16. The forming end effector of claim 15, wherein the center pressers comprise inflatable bladders movably connected to the center actuator.
17. The forming end effector of claim 9 further comprising: a utility port connected to the frame, the utility port configured to interface with a robotic arm for transportation of the forming end effector and configured to interface with utilities for forming operations independently of a robotic arm.
18. The forming end effector of claim 9, wherein the engagement pins are further configured to receive at least one utility through the engagement pins and transport the utility to other components of the forming end effector.
19. A forming end effector for forming a composite material comprising: a frame; a number of actuators movably connected to the frame; and forming heads with sweepers movably connected to the frame by the number of actuators, the number of actuators connected to the forming heads by pairs of hinges.
20. The forming end effector of claim 19, wherein the number of actuators is connected to the forming heads by the pairs of hinges such that the forming heads are configured to rotate to form the composite material.
21. The forming end effector of claim 19, wherein the sweepers comprise inflatable bladders and wherein the pairs of hinges comprise a first hinge a first distance away from the forming head and a second hinge a second distance away from the forming head, wherein a difference between the first distance and the second distance enables rotation of the sweepers for forming the composite material around edges.
22. The forming end effector of claim 19, wherein each of the forming heads comprises a composite holding system for carrying the composite material to be formed.
23. The forming end effector of claim 19 further comprising: a number of legs movably connected to the frame, the number of legs having engagement pins configured to connect the forming end effector to a mandrel and react loads from the forming end effector into the mandrel during forming of the composite material.
24. The forming end effector of claim 19, wherein each of the forming heads comprises a set of compliant joints to provide forming of the composite material on a mandrel with a bend.
25. A method comprising: forming a composite material onto a mandrel using sweepers of a forming end effector; and reacting loads from the forming end effector into the mandrel during forming of the composite material.
26.-**29**. (canceled)