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(54) **VACUUM BAG-LESS COMPOSITE REPAIR SYSTEMS AND METHODS**

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(71) Applicant: **The Boeing Company**, Chicago, IL (US)

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(72) Inventor: **John F. Spalding**, Tukwila, WA (US)

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(73) Assignee: **The Boeing Company**, Chicago, IL (US)

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(74) *Attorney, Agent, or Firm* — Kwan & Olynick LLP

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B29C 73/04 (2006.01)
B29L 31/30 (2006.01)

(57) **ABSTRACT**

(52) **U.S. Cl.**
CPC *B29C 73/04* (2013.01); *B29L 2031/3076* (2013.01)

Described are methods and systems for repair of composite components without the use of vacuum bagging. The systems described herein include a composite repair structure with a repair laminate and a film sealant. The film sealant covers the repair laminate to prevent intrusion of air and other volatiles during bonding of the composite repair structure to the composite being repaired. As the film sealant prevents intrusion of air and other volatiles, the composite repair structure can be bonded to the structure to be repaired without the use of a vacuum bag. Thus, vehicle components can be repaired without disassembly from the vehicle.

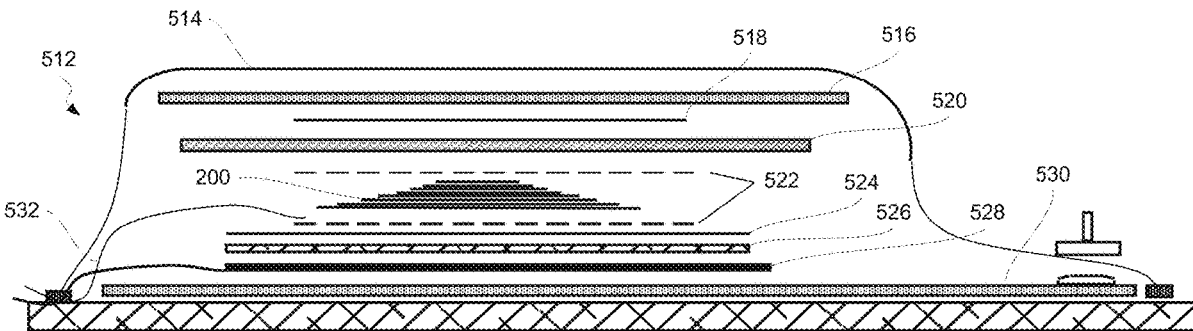
(58) **Field of Classification Search**
CPC .. *B29C 73/10*; *B29C 73/04*; *B29L 2031/3076*
See application file for complete search history.

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20 Claims, 7 Drawing Sheets



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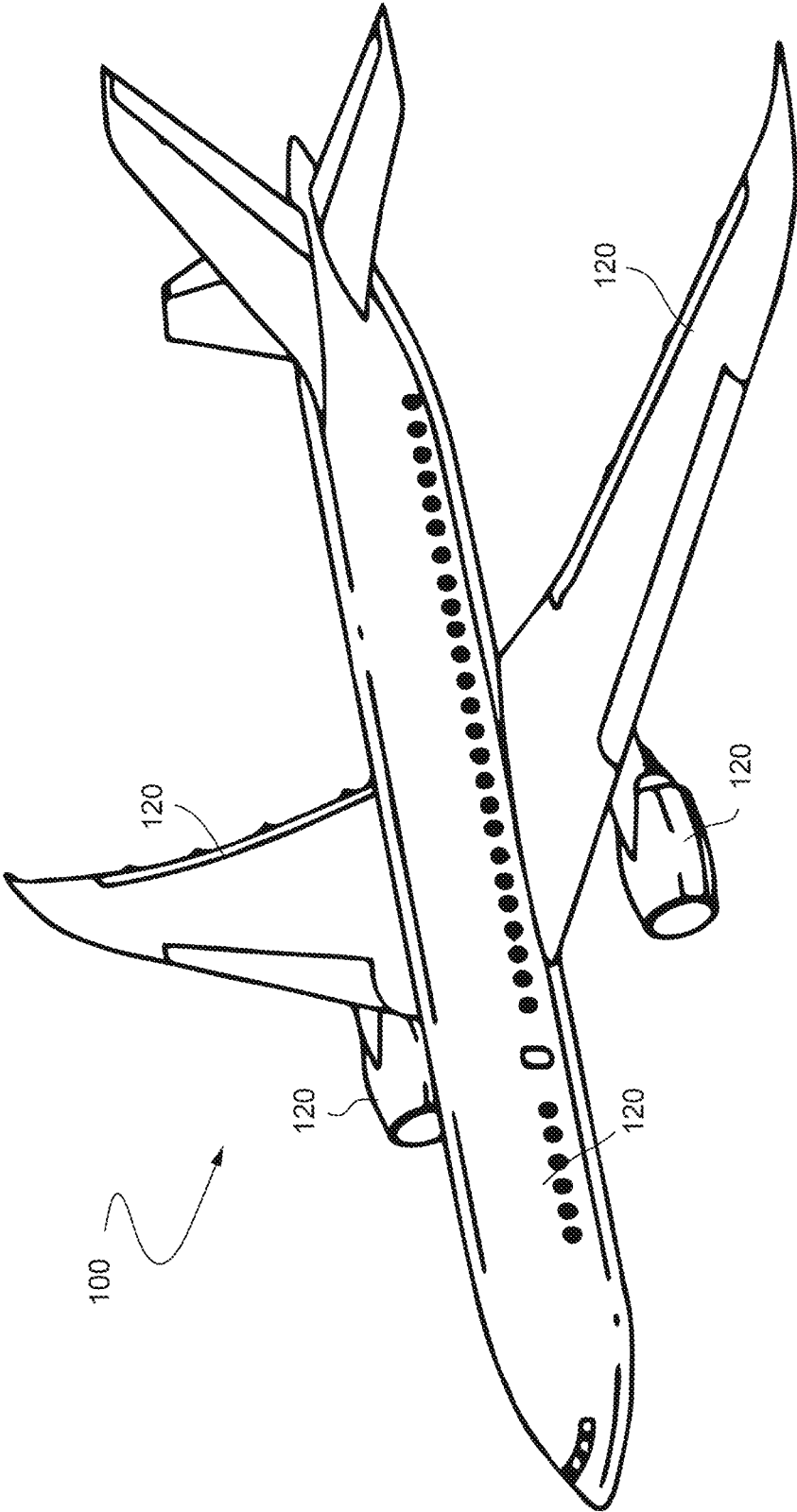


FIG. 1

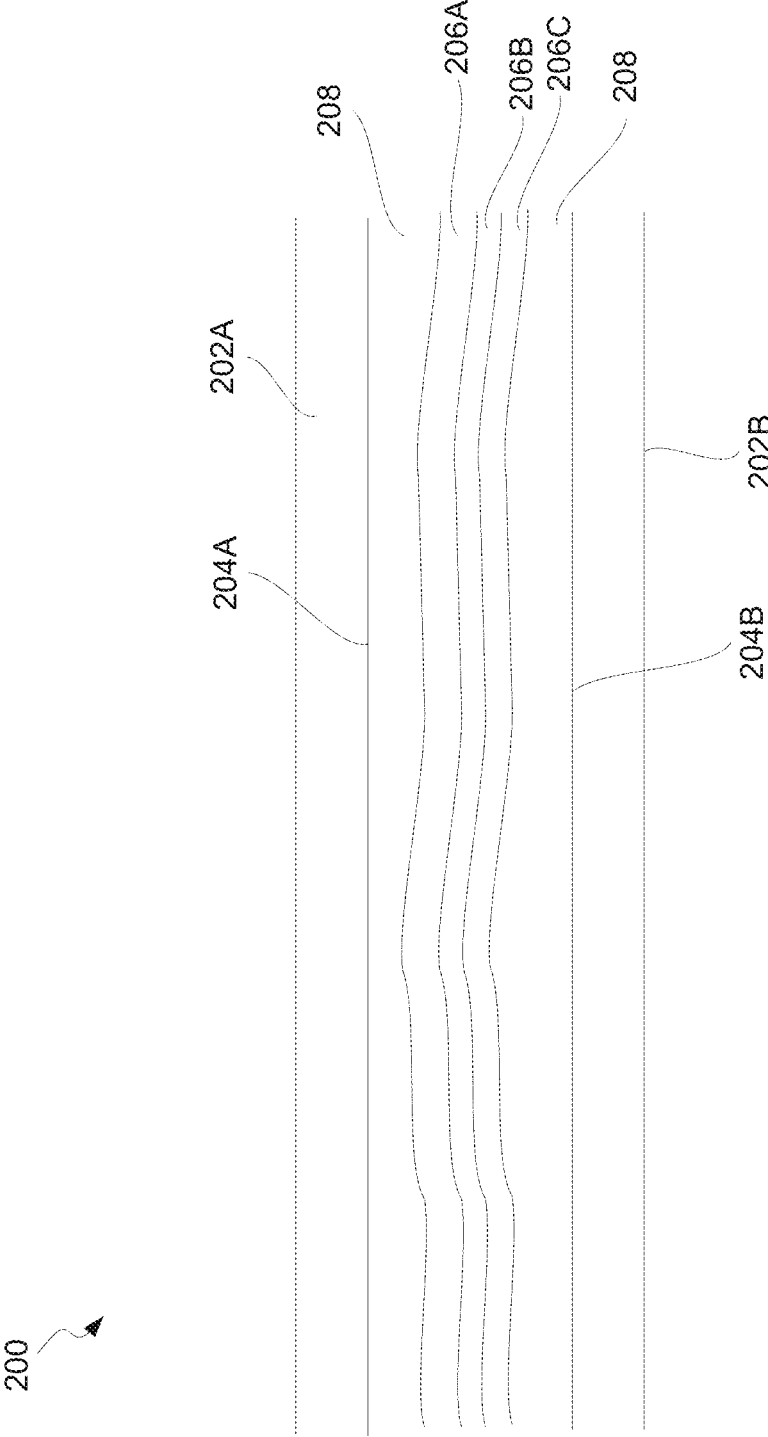


FIG. 2

300A

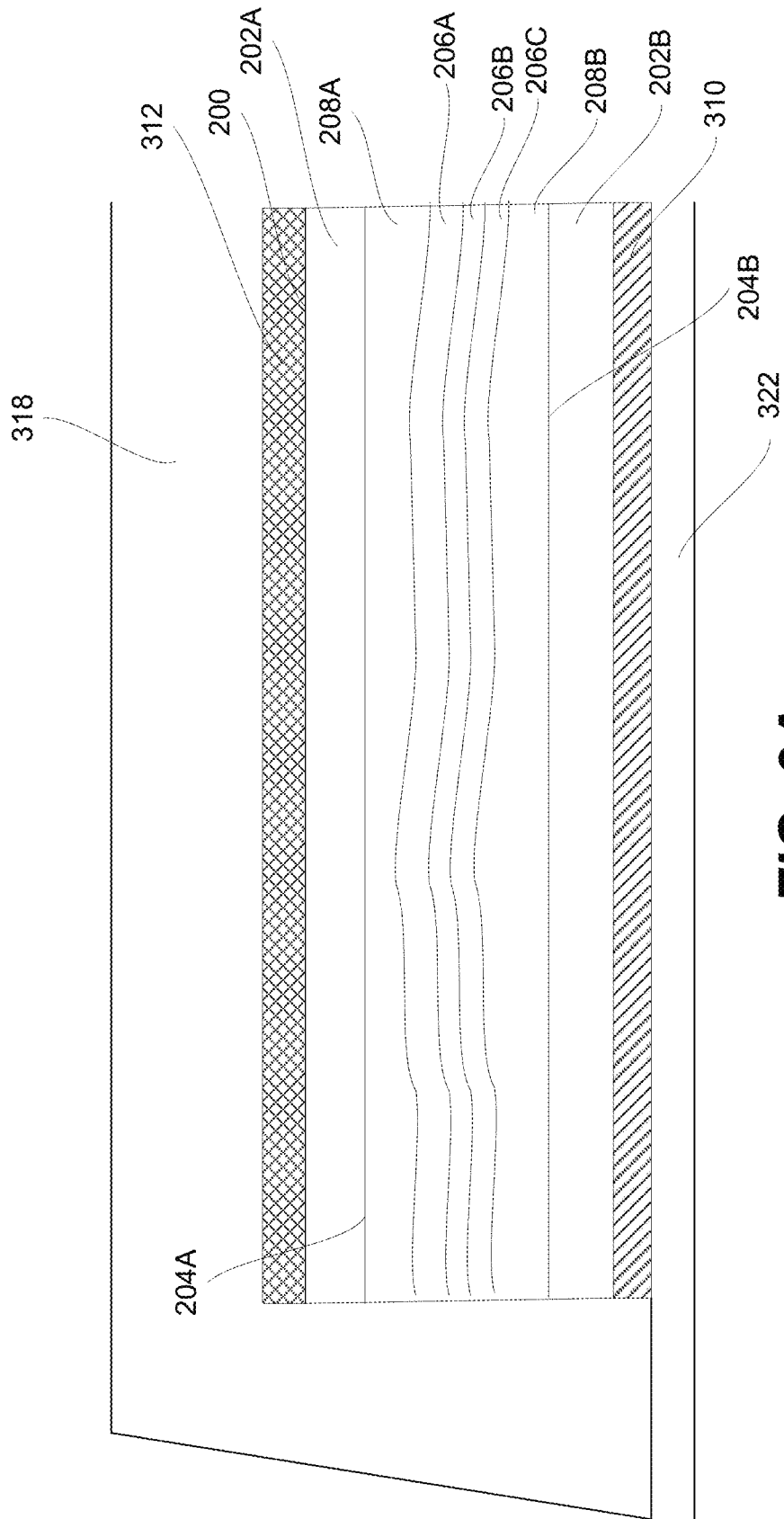


FIG. 3A

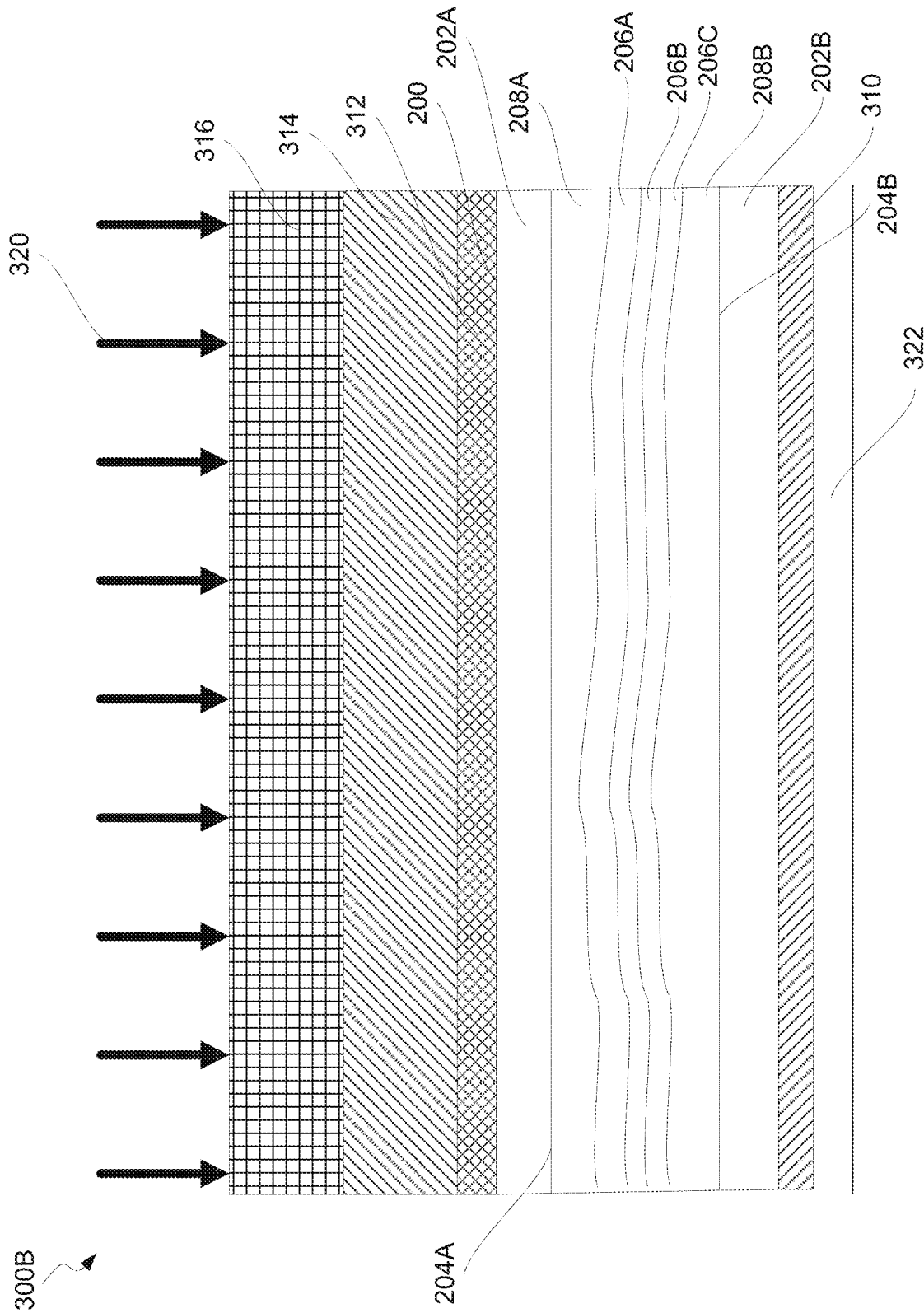


FIG. 3B

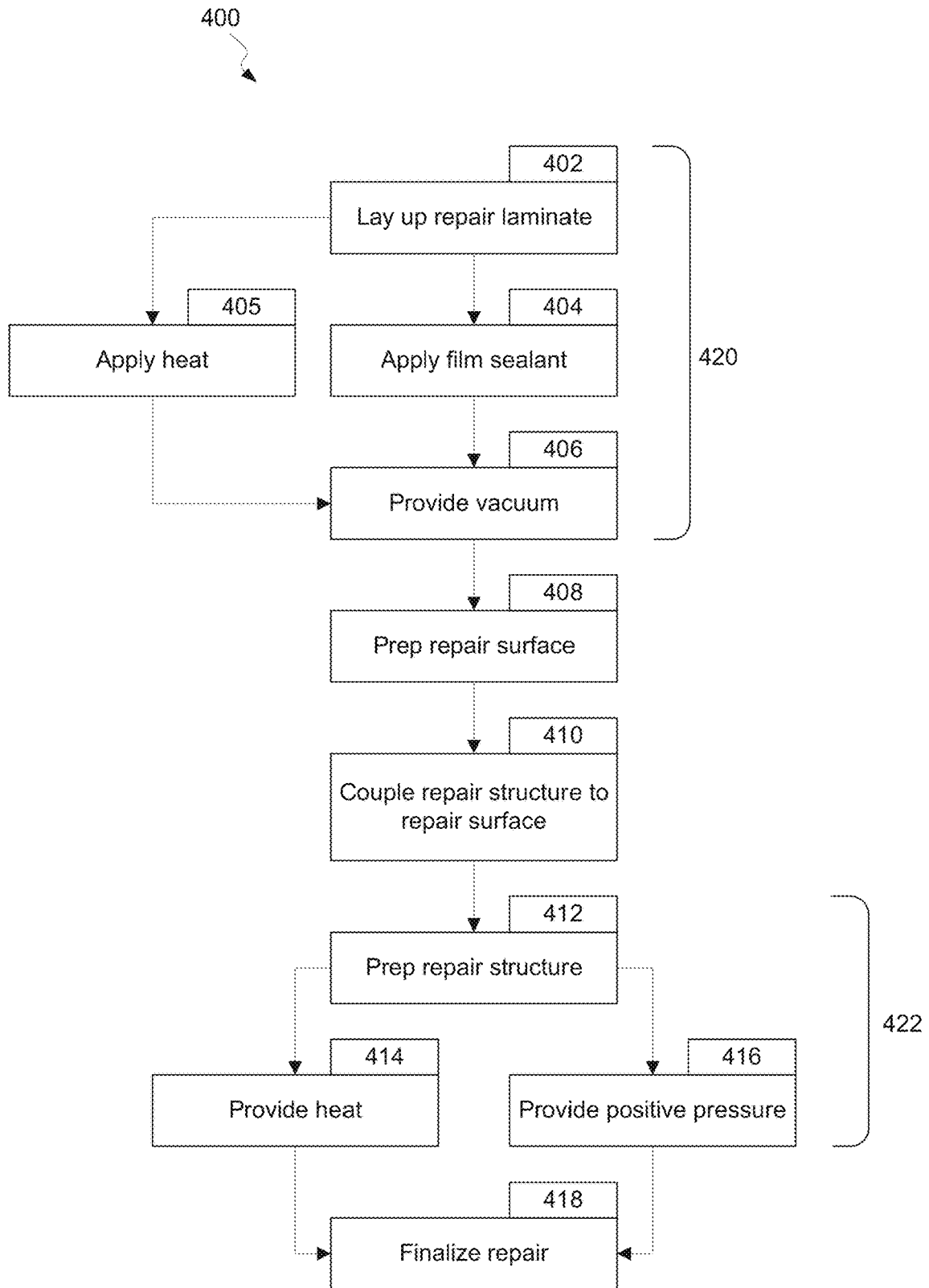


FIG. 4

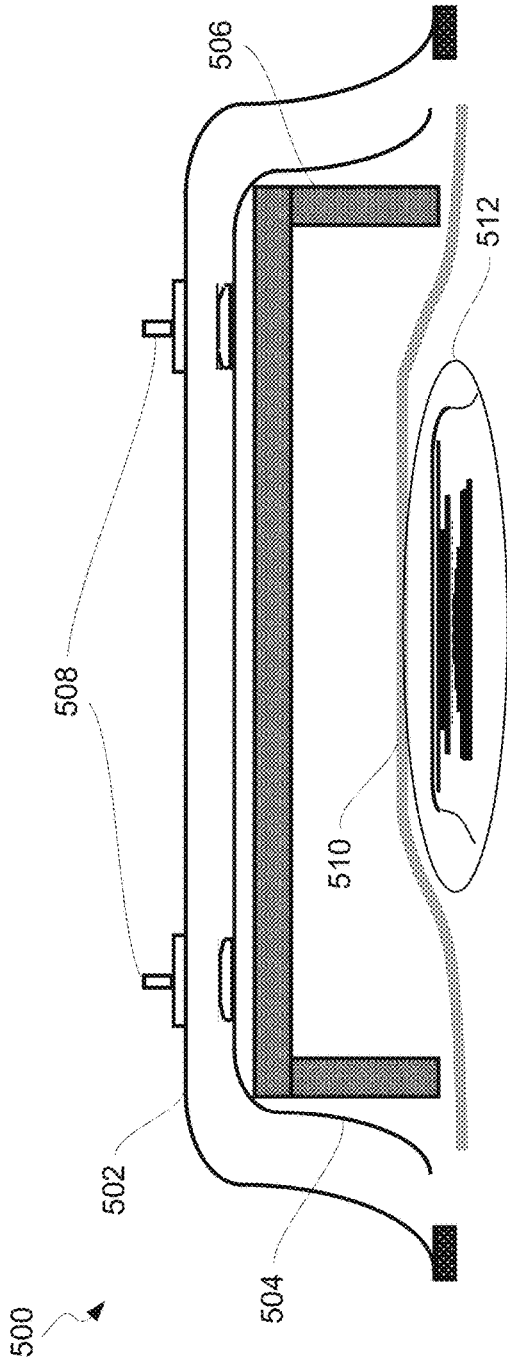


FIG. 5A

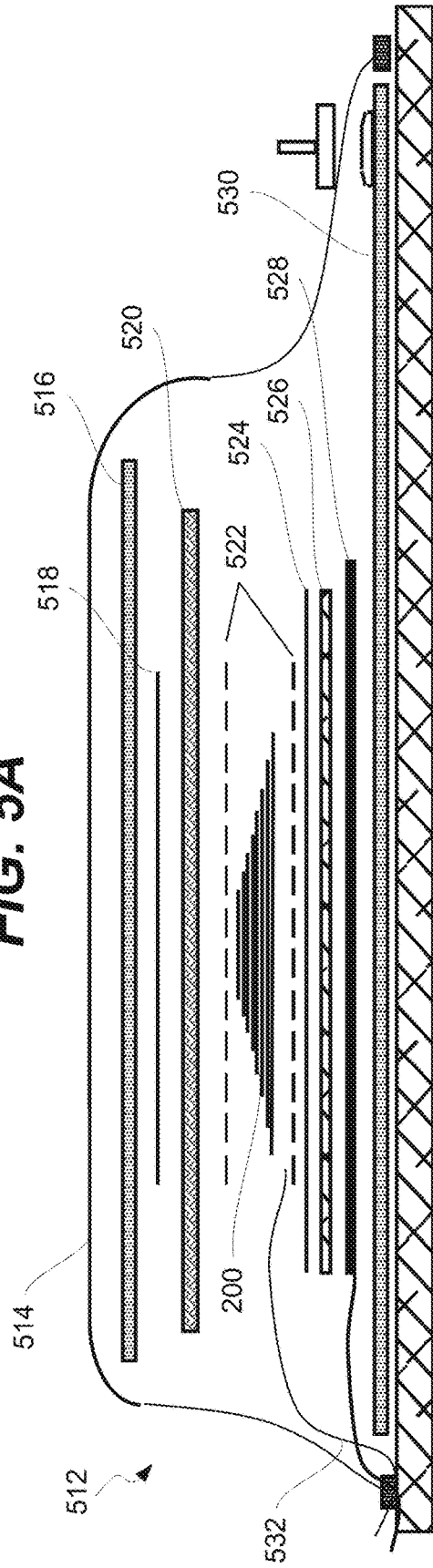


FIG. 5B

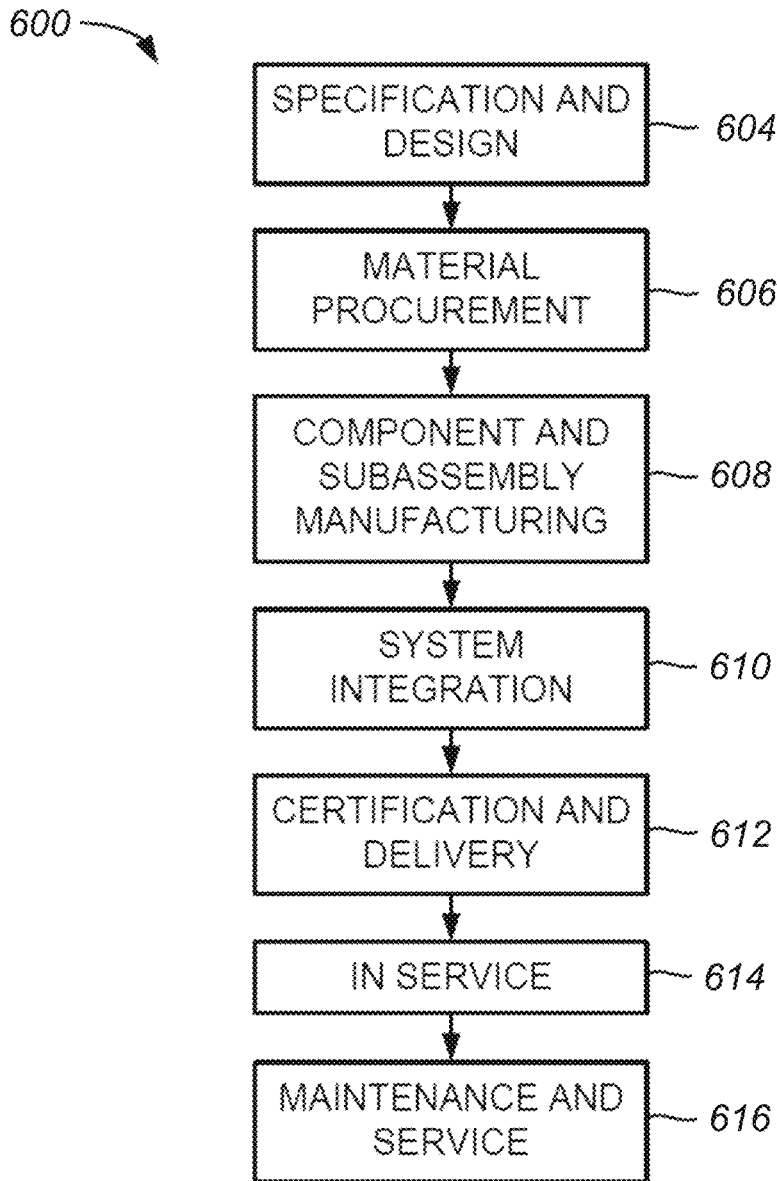


FIG. 6A

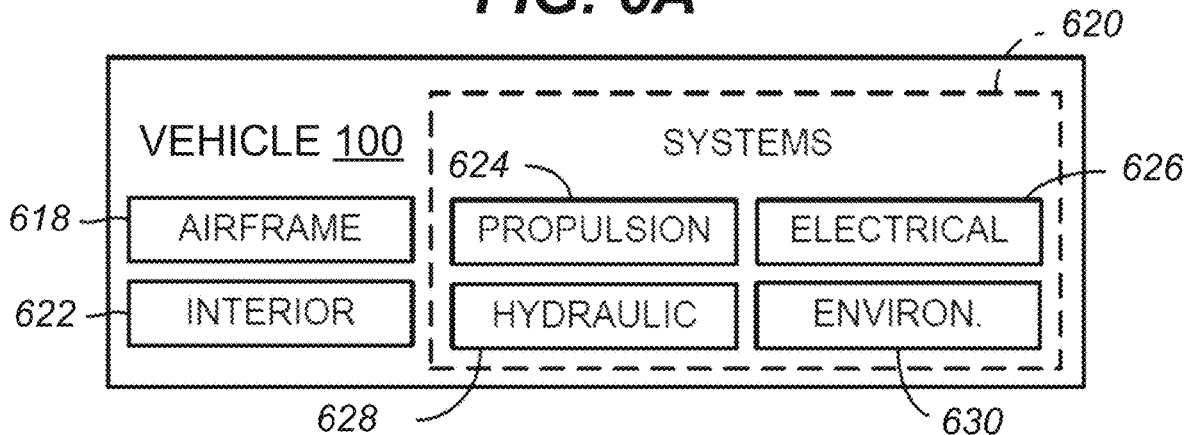


FIG. 6B

VACUUM BAG-LESS COMPOSITE REPAIR SYSTEMS AND METHODS

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a divisional of U.S. patent application Ser. No. 16/669,247, now U.S. Pat. No. 11,534,993, which is incorporated herein by reference in its entirety for all purposes.

BACKGROUND

Current composite repair processes require vacuum bags for repair of composite laminates. However, use of vacuum bags adds complication to the repair process. For example, in certain processes, the vacuum bag must pass a vacuum leak check and maintain a minimum vacuum to ensure that the vacuum bag provides adequate sealing. These vacuum requirements are problematic as they cannot be met in many repair instances. For example, it is often difficult or impossible for vacuum bags used to repair composite propulsion structures, such as acoustic inlets and thrust reverser inner walls, with sound attenuating features, such as perforated composite face sheets and slotted honey comb cores, to pass these requirements. Such perforations or slotted features are difficult or impossible to seal and create a large number of possible leak paths.

To overcome this problem, repair of these propulsion structures require the structures to be removed from the aircraft and disassembled so that they can be completely enclosed in a giant vacuum bag. The number of labor hours required to disassemble and then reassemble the part adds days to the repair process, complicates the repair process, and requires specialized equipment and facilities, increasing the cost of repair and the downtime of aircraft.

SUMMARY

Described are methods and systems for repair of composite components without the use of vacuum bagging. Systems described herein allow for repair of a structure, such as a vehicle structure, with a composite repair patch known as a composite repair structure. The composite repair structure can be bonded to a vehicle structure through the application of heat and positive pressure. To prevent air and volatiles from intruding during bonding of the composite repair structure to the vehicle structure, the composite repair structure includes a film sealant disposed over a repair laminate. As the film sealant prevents intrusion of air and other volatiles, the composite repair structure can be cured and bonded to the structure to be repaired without the use of a vacuum bag.

Illustrative, non-exclusive examples of inventive features according to present disclosure are described in following enumerated paragraphs:

A1. Method **400** comprising:

forming (step **420**) composite repair structure **200**, wherein composite repair structure **200** comprises repair laminate **206**, and wherein forming (step **420**) composite repair structure **200** comprises applying (step **404**) film sealant **202** to first surface **204A** of repair laminate **206**;

coupling (step **410**) composite repair structure **200** to vehicle structure **120**; and

curing and/or bonding (step **422**) composite repair structure **200** to vehicle structure **120** by providing (step

416) positive pressure **320** to composite repair structure **200** coupled to vehicle structure **120**, wherein film sealant **202** prevents air intrusion into repair laminate **206** during curing and/or bonding of composite repair structure **200** to vehicle structure **120**.

A2. Method **400** of paragraph A1, wherein curing and/or bonding (step **422**) composite repair structure **200** to vehicle structure **120** further comprises providing (step **414**) heat to composite repair structure **200** coupled to vehicle structure **120**.

A3. Method **400** of any one of paragraphs A1-A2, wherein film sealant **202** is further applied (step **404**) to second surface **204B** opposite first surface **204A** of repair laminate **206**.

A4. Method **400** of any one of paragraphs A1-A3, wherein positive pressure **320** is provided (step **416**) without vacuum.

A5. Method **400** of any one of paragraphs A1-A4, wherein forming **420** composite repair structure **200** further comprises:

applying (step **405**) heat to composite repair structure **200** to degas composite repair structure **200**;

disposing composite repair structure **200** within chamber **500**, wherein chamber **500** is configured to minimize compaction on composite repair structure **200** when a vacuum is present within chamber **500**; and providing (step **406**) vacuum within chamber **500**.

A6. Method **400** of any one of paragraphs A1-A5, wherein repair laminate **206** comprises resin **208**, and wherein film sealant **202** has a higher minimum viscosity temperature than resin **208**.

A7. Method **400** of any one of paragraphs A1-A6, wherein forming (step **420**) composite repair structure **200** further comprises laying (step **402**) up a plurality of repair laminate **206**.

A8. Method **400** of any one of paragraphs A1-A7, wherein curing and/or bonding (step **422**) composite repair structure **200** further comprises prepping (step **412**) composite repair structure **200** after coupling (step **410**) composite repair structure **200** to vehicle structure **120**, wherein prepping (step **412**) composite repair structure **200** comprises:

applying release film **312** to a portion of composite repair structure **200**; and

applying compliance layer **314** to the portion of composite repair structure **200**.

A9. Method **400** of any one of paragraphs A1-A8, wherein coupling the composite repair structure **200** to vehicle structure **120** comprises:

applying film adhesive **310** to portion **322** of vehicle structure **120**;

coupling composite repair structure **200** to film adhesive **310**;

disposing compaction bag **318** over composite repair structure **200** after composite repair structure **200** has been coupled to film adhesive **310** to seat composite repair structure **200**; and

removing compaction bag **318**.

Alternatively, venting compaction bag **318** to atmosphere to remove vacuum from repair laminate **206** and applying positive pressure and heat through or over compaction bag **318**.

A10. Method **400** of any one of paragraphs A1-A9, wherein composite repair structure **200** is coupled to vehicle structure **120** when vehicle structure **120** is coupled to vehicle **100**.

A11. A composite repair structure **200**, composite repair structure **200** comprising:

a repair laminate **206**; and
 a film sealant **202** disposed on a first surface **204A** of the repair laminate **206**, wherein the composite repair structure **200** is configured to be cured and/or bonded to a vehicle structure **120** through positive pressure **320** applied to the composite repair structure **200** when the composite repair structure **200** is coupled to the vehicle structure **120**, and wherein the film sealant **202** prevents air intrusion into the repair laminate **206** during curing and/or bonding of the composite repair structure **200** to the vehicle structure **120**.

A12. Composite repair structure **200** of paragraph A11, wherein the film sealant **202** is further disposed on a second surface **204B** opposite the first surface **204A** of the repair laminate **206**.

A13. Composite repair structure **200** of any one of paragraphs A11-A12, wherein the repair laminate **206** comprises a resin **208**, and wherein the film sealant **202** has a higher minimum viscosity temperature than the resin **208**.

A14. A method **420** of forming composite repair structure **200** of any one of paragraphs A11-A13, the method comprising:

laying up **402** repair laminate **206**;
 applying **405** heat to repair laminate **206** to degas repair laminate **206**; and
 applying **404** film sealant **202** to first surface **204A**.

A15. Method **420** of paragraph A14, wherein applying **405** heat to repair laminate **206** to degas repair laminate **206** comprises:

reducing a viscosity of resin **208** of repair laminate **206**;
 and
 covering fibers of repair laminate **206** with the resin **208**.

A16. An apparatus comprising:

a vehicle structure **120**; and
 a composite repair structure **200** bonded to a portion of the vehicle structure **120**, the composite repair structure **200** comprising:
 a repair laminate **206**; and
 a film sealant **202** disposed on a first surface **204A** of the repair laminate **206**, wherein the film sealant **202** is configured to prevent air intrusion into the repair laminate **206** during curing and/or bonding of the composite repair structure **200** to the vehicle structure **120**.

A17. The apparatus of paragraph A16, wherein the film sealant **202** is further disposed on a second surface **204B** opposite the first surface **204A** of the repair laminate **206**.

A18. The apparatus of any one of paragraphs A16-A17, wherein the repair laminate **206** comprises a resin **208**, and wherein the film sealant **202** has a higher minimum viscosity temperature than the resin **208**.

A19. The apparatus of any one of paragraphs A16-A18, the apparatus further comprising:

a release film **312** disposed on the portion of the vehicle structure **120**;
 a compliance layer **314** disposed on the portion of the vehicle structure **120**; and
 a weight, pneumatic bladder, or actuator coupled to the composite repair structure **200** to apply positive pressure **320** on the composite repair structure **200**.

A20. The apparatus of any one of paragraphs A16-A19, wherein the vehicle structure **120** is a propulsor, a fuselage, or a wing.

These and other examples are described further below with reference to figures.

BRIEF DESCRIPTION OF THE DRAWINGS

The disclosure may best be understood by reference to the following description taken in conjunction with the accompanying drawings, which illustrate various examples.

FIG. 1 illustrates a vehicle with composite structures, in accordance with some examples.

FIG. 2 illustrates a cross-sectional representation of a composite repair structure, in accordance with some examples.

FIG. 3A illustrates a cross-sectional representation of a step in a technique of composite repair utilizing the composite repair structure of FIG. 2, in accordance with some examples.

FIG. 3B illustrates a cross-sectional representation of another step in the technique of composite repair utilizing the composite repair structure of FIG. 3A, in accordance with some examples.

FIG. 4 is a process flowchart corresponding to a method of composite repair, in accordance with some examples.

FIG. 5A illustrates a cross-sectional representation of a double vacuum debulk chamber, in accordance with some examples.

FIG. 5B illustrates a cross-sectional representation of a lower bag of the double vacuum debulk chamber of FIG. 5A, in accordance with some examples.

FIG. 6A illustrates a flow chart of an example of an aircraft production and service methodology, in accordance with some examples.

FIG. 6B illustrates a block diagram of an example of a vehicle, in accordance with some examples.

DETAILED DESCRIPTION

In the following description, numerous specific details are set forth in order to provide a thorough understanding of the presented concepts. The presented concepts may be practiced without some, or all, of these specific details. In other instances, well known process operations have not been described in detail to avoid unnecessarily obscuring the described concepts. While some concepts will be described with the specific examples, it will be understood that these examples are not intended to be limiting.

Introduction

Currently, technique to repair certain composite vehicle components, such as nacelles or propulsor inlets with noise attenuation features, is to remove the components from the vehicle and strip down the components before repairing with a vacuum bag. Even minor repairs require removal of these very large and expensive parts from the vehicles and placement of these parts within vacuum bags. Furthermore, disassembly (fastener removals, separating surface sealed components, removal of rivets, and other such disassembly steps) and subsequent handling of such large unwieldy structures greatly increase the risk of incidental damage to the part. Thus, such techniques require a large number of hours and great care to perform and add complication and expense to the repair process.

An example of a vehicle with such structures is shown in FIG. 1. FIG. 1 illustrates a vehicle with composite structures, in accordance with some examples. FIG. 1 illustrates a vehicle **100** that can be a fixed wing aircraft. In other examples, the systems and techniques described herein can be used to repair composites and structures of other types of vehicles such as other types of aircraft (e.g., helicopters, spacecraft, rockets, and other aircraft), automobiles, ships, submarines, and other such vehicles.

Vehicle **100** includes a plurality of vehicle structures **120**. In various examples, vehicle structures **120** can be different portions of vehicle **100**. For example, for the aircraft shown in FIG. **1**, vehicle structures **120** can be a fuselage, a wing (e.g., a fixed portion of the wing or a flap or other movable portion), an aircraft propulsor (e.g., a nacelle or inlet of the aircraft propulsor), an empennage, or another structure of the aircraft. Various examples of vehicle structures **120** can be made of composites such as one or more of fiberglass, carbon fiber, Kevlar®, and other such composites. Examples of Structures for No Vacuum Bag Composite Repair

FIG. **2** illustrates a cross-sectional representation of a composite repair structure, in accordance with some examples. FIG. **2** illustrates a composite repair structure **200** for use in repairing (e.g., patching) composite structures such as vehicle structures **120** described herein. In some examples, composite repair structure **200** is used to repair composite vehicle structures by, for example, coupling or bonding to the composite vehicle structure. For example, bonding of composite repair structure **200** to such vehicle structures is accomplished through application of positive pressure and heat and without the use of vacuum bagging. Composite repair structure **200** includes film sealant **202A** and **202B** and repair laminate **206A-C**.

Repair laminate **206A-C** includes composite plies such as one or more of carbon fiber plies, fiberglass plies, Kevlar® plies, and other such composite plies. In certain examples, layers of repair laminate is laid on top of each other to form the core repair structure. Though the example shown in FIG. **2** illustrates a composite repair structure **200** that includes three layers of repair laminate **206A-C**, other examples can include any number of layers of repair laminate.

Repair laminate **206A-C** is bonded together with resin **208** or another type of polymer. Resin **208** penetrates through the fibers of repair laminate **206A-C** to solidify repair laminate **206A-C**. In certain examples, repair laminate **206A-C** is, for example, pre-impregnated (pre-preg) composites with resin **208** pre-impregnated within repair laminate **206A-C**. The pre-preg is heated during production to liquefy resin **208**, allowing resin **208** to penetrate the fibers of repair laminate **206A-C** and displace any air within the fibers. As any air remaining within repair laminate **206A-C** can weaken composite repair structure **200**, repair laminate **206A-C** is fully penetrated with resin **208** to fully displace any air during the production process. Fully displacing the air maximizes the strength of composite repair structure **200**.

Repair structures are typically heated to bond the repair structures to vehicle structures. As repair structures are heated, resin will return to a liquid state. In conventional repair processes, containing the vehicle structure and repair structure within a vacuum bag prevents subsequent air intrusion while the resin is in the liquid state. However, without vacuum bagging, air and other volatiles will intrude into the resin and thus the repair laminate during conventional repair processes, causing porosity and weakening the structure.

Film sealant **202A** and **202B** is disposed on surfaces of repair laminate **206A-C**. Thus, for example, film sealant **202A** is disposed on a first surface of repair laminate **206A-C** and film sealant **202B** is disposed on a second surface of repair laminate **206A-C** opposite the first surface. In various examples, film sealant is disposed on a variety of portions of repair laminate **206A-C** or on all outer surfaces of repair laminate **206A-C**. Film sealant (including film sealant **202A** and **202B**) prevents air intrusion to the repair laminate during bonding of composite repair structure **200** to

vehicle structure **120**. As the film sealant prevents air intrusion to the repair laminate, composite repair structure **200** can accordingly be bonded to a vehicle structure without the use of vacuum or vacuum bag.

In certain examples, to prevent intrusion of air and other volatiles, film sealant **202A** and **202B** has a higher minimum viscosity temperature than that of resin **208**. Thus, film sealant **202A** and **202B** function as effective air barriers when the resin is most vulnerable to air intrusion (e.g., when the resin is at its lowest viscosity, such as when composite repair structure **200** is heated to bond composite repair structure **200** to vehicle structure **120**). During the repair process, as the temperature increases due to heating, resin **208** then subsequently gels (e.g., the viscosity of resin **208** increases) to the point where air no longer or only minimally penetrates resin **208** and/or repair laminate **206A-C**. At this increased temperature, viscosity of film sealant **202A** and **202B** can then be at its minimum level. Film sealant **202A** and **202B** can thus comingle with resin **208** and any adhesives on the vehicle structure, creating a strong and durable bond.

As such, film sealant **202A** and **202B**, as well as any other film sealant disposed on the surface of composite repair structure **200**, allow for composite repair structure **200** to be bonded to vehicle structure **120** without the use of a vacuum bag while still preventing air and volatiles intrusion into resin **208**.

Various steps of vacuum bag-less repair techniques are now illustrated herein. FIG. **3A** illustrates a cross-sectional representation of a step in a technique of composite repair utilizing the composite repair structure of FIG. **2**, in accordance with some examples. FIG. **3A** illustrates an assembly **300A** detailing a step when composite repair structure **200** is coupled to vehicle structure **120**. Assembly **300A** illustrates a step where composite repair structure **200** is positioned on vehicle structure **120** (e.g., to prepare for bonding during a patch repair).

Thus, composite repair structure **200** is placed over portion **322** of vehicle structure **120**. In certain examples, portion **322** is a portion of vehicle structure **120** that requires repair. Film adhesive **310** is placed on portion **322**. Film adhesive **310** is placed between portion **322** and composite repair structure **200**. Film adhesive **310** encourages the bonding of composite repair structure **200** to portion **322**.

Compaction bag **318** can optionally be placed over and/or contain composite repair structure **200** to provide a vacuum to properly seat composite repair structure **200** over portion **322**. In certain examples, compaction bag **318** does not meet the typical vacuum requirements of a vacuum bag application. Instead, compaction bag **318** can be a temporary compaction bag for seating composite repair structure **200**. In certain examples, a release film **312** is disposed between composite repair structure **200** and compaction bag **318** to promote release of compaction bag **318** from composite repair structure **200** once composite repair structure **200** is seated. After use, compaction bag **318** can be discarded. Alternatively, in some examples, compaction bag **318** is vented to atmosphere to remove vacuum from repair laminate **206** and positive pressure and/or heat is applied through or over compaction bag **318**.

FIG. **3B** illustrates a cross-sectional representation of another step in the technique of composite repair utilizing the composite repair structure of FIG. **3A**, in accordance with some examples. FIG. **3B** illustrates an assembly **300B** detailing a step when composite repair structure **200** is bonded to vehicle structure **120**.

In certain examples, after composite repair structure 200 is coupled to vehicle structure 120, release film 312 is disposed over composite repair structure 200. A compliance layer 314 is then applied over release film 312. In certain such examples, compliance layer is a thin (e.g., 0.5 inch or thinner), low durometer, thermally conductive material that will conform to the shape of the repair (e.g., of composite repair structure 200) to provide better load transfer to composite repair structure 200.

Heating blanket 316 is disposed over compliance layer 314. Heating blanket 316 is configured to provide heat to composite repair structure 200 and/or portion 322 to allow composite repair structure 200 to bond to portion 322. Additionally, in certain examples, a layer of silicone rubber foam (e.g., between 0.25 to 2 inches thick) is placed over heating blanket 316 to thermally isolate the repair from items that provide positive pressure 320 to the repair.

Heating blanket 316 provides heat to increase the temperature of composite repair structure 200 and/or vehicle structure 120. Certain examples of heating blanket 316 are configured to heat composite repair structure 200 to a variety of different temperatures. Thus, for such examples, heating blanket 316 increases the temperature of composite repair structure 200 through a period of time by continuously providing heat to composite repair structure 200. As such, composite repair structure 200 is heated through a period of time. For example, composite repair structure 200 is first heated to a first temperature whereby resin 208 is more viscous or liquid to aid in bonding with vehicle structure 120. As the temperature increases, resin 208 begins to harden while film sealant 202A and 202B becomes more viscous or liquid. The decreasing viscosity of film sealant 202A and 202B allows film sealant 202A and 202B to come together with resin 208 and any adhesives of vehicle structure 120, creating a strong and durable bond.

In certain examples, positive pressure 320 is further provided to create a strong and durable bond. Positive pressure as described herein denotes any sort of pressure applied. For example, positive pressure includes pressure provided by weight (e.g., shot or sand bags), a machine (e.g., an actuator, a clamp, press, or other machine), a pneumatic bladder or through other techniques to provide pressure. In some examples, positive pressure 320 is any amount of pressure, including pressure of between 1 to 10 pounds per square inch (psi) applied to composite repair structure 200. Positive pressure 320 further bonds composite repair structure 200 to vehicle structure 120 by allowing resin 208, film sealant 202A and/or 202B, and/or any adhesives of vehicle structure 120 to come together and/or mix to form a strong bond. Examples of Method for No Vacuum Bag Composite Repair

FIG. 4 is a process flowchart corresponding to a method of composite repair, in accordance with some examples. Various operations of method 400 of FIG. 4 are executed using systems and apparatus described herein. Steps 402 to 406 describe forming 420 of composite repair structure 200, while steps 408 to 418 describe the repair of a vehicle structure with the composite repair structure.

In step 402, repair laminate 206 is laid up. In certain examples, repair laminate 206 includes a plurality of composite plies (e.g., carbon fiber composite plies). The plies laid up in step 402 form repair laminate 206. In step 404, film sealant 202 is applied to the outer surfaces of repair laminate 206. Film sealant 202 prevents air and volatile intrusion into resin 208 and/or repair laminate 206 during vacuum bag-less bonding to vehicle structure 120.

In step 406, composite repair structure 200 is disposed within a vacuum chamber and vacuum is provided to

composite repair structure 200. Such vacuum is applied, for example, in a double vacuum debulk chamber (as described in FIGS. 5A and 5B). Double vacuum debulk allows for removal of volatiles from repair laminate 206 without the use of an autoclave. Double vacuum debulk allows for application of heat and vacuum to composite repair structure 200 without subjecting composite repair structure 200 to vacuum compaction (e.g., from atmospheric pressure acting on a vacuum bag).

Heat is applied during one or more of steps 402, 404, and 406 in step 405. Heating of film sealant 202, repair laminate 206, resin 208, and/or another portion of composite repair structure 200 to various temperatures decreases resin and/or sealant viscosity and/or partially cures the resin and/or sealant to partially cure composite repair structure 200. In certain examples, heat is applied during both steps 402 and 404 to, for example, allow venting or degassing of entrapped air and gases from repair laminate 206 as well as, potentially, curing of repair laminate 206 in step 402 and curing of film sealant 202 in step 404, respectively. In other examples, heat is applied during step 406 to first decrease viscosity to allow venting of air from repair laminate 206 before then partially curing both repair laminate 206 and film sealant 202 simultaneously.

As such, after step 402, 404, 405, and/or 406, composite repair structure 200 is formed to be in a pliant intermediate state. Such an intermediate state allows for composite repair structure 200 to be coupled to and conform to a surface of a vehicle structure. Once coupled to the vehicle structure, heat and positive pressure is then applied to fully cure composite repair structure 200 into a solid state, as described herein.

Thus, after composite repair structure 200 has been formed, composite repair structure 200 is used to repair a vehicle structure in steps 408 to 418. In step 408, the surface of a portion of vehicle structure 120 to be repaired is prepped. Prepping includes, for example, applying film adhesive 310 over the surface of vehicle structure 120, cleaning and sanding of the surface of vehicle structure 120 (e.g., to promote better adhesion), and/or other such preparation activities.

After vehicle structure 120 has been prepped in step 408, composite repair structure 200 is coupled to vehicle structure 120 in step 410, according to techniques described herein. Thus, for example, composite repair structure 200 is positioned over a portion of vehicle structure 120 to be repaired. In certain examples, compaction bag 318 is also disposed over composite repair structure 200 to seat composite repair structure 200 over the proper portion of vehicle structure 120.

Composite repair structure 200 is thus properly positioned over vehicle structure 120. Afterwards, composite repair structure 200 is then cured and/or bonded 422 to vehicle structure 120 or a portion thereof in steps 412 to 416. Curing and/or bonding 422 includes, for example, prepping of composite repair structure 200 in step 412. Prepping of composite repair structure 200 includes, for example, applying release film 312 and/or disposing compliance layer 314 over composite repair structure 200.

Heat and positive pressure is then applied in steps 414 and 416, respectively, to cure and/or bond 422 composite repair structure 200 to vehicle structure 120. In certain examples, composite repair structure 200 and vehicle structure 120 is co-bonded. That is, composite repair structure 200 (e.g., repair laminate 206) is cured while simultaneously bonded to vehicle structure 120 (which is a second cured laminate).

In step **416**, positive pressure is applied through the techniques described herein (e.g., mechanically, through weight, through force exerted on the surface of composite repair structure **200**, or other another technique). In step **414**, heat is applied to composite repair structure **200** and/or vehicle structure **120** through, for example, heat emitted by heating blanket **316**, emitted by heating lamps, emitted by heat guns, or from another source. Composite repair structure **200** is thus be bonded to vehicle structure **120**. The repair is then be finalized in step **418** by, for example, surfacing (e.g., smoothing) and finishing (e.g., painting) of the repair.

Manufacturing Chamber for the Composite Repair Structure

As described herein, composite repair structure **200** is at least partially formed in a double vacuum debulk chamber. FIG. **5A** illustrates a cross-sectional representation of a double vacuum debulk chamber, in accordance with some examples. Double vacuum debulk allows for removal of volatiles from repair laminate **206**, after repair laminate **206** has been laid up, without the use of an autoclave by applying heat and vacuum while forming composite repair structure **200** without subjecting composite repair structure **200** to vacuum compaction.

Double vacuum debulk chamber **500** shown in FIG. **5A** includes an upper bagging film **502**, a breather cloth **504**, a hardback **506**, vacuum probes **508**, a breather **510**, and a lower bag **512**. Composite repair structure **200** is disposed within lower bag **512** during forming thereof. Upper bagging film **502** is a vacuum bag and is configured to contain a vacuum. Vacuum probes **508** allow for adjustment of vacuum within upper bagging film **502**.

Hardback **506** is disposed over lower bag **512** and, in certain examples, is a rigid or semi-rigid structure. In certain examples, hardback **506** prevents upper bagging film **502** from imparting force on lower bag **512** when there is a vacuum within upper bagging film **502**. As vacuum is generated within upper bagging film **502**, hardback **506** prevents compaction force from the vacuum within upper bagging film **502** from being imparted onto composite repair structure **200** (contained within lower bag **512**). Thus, hardback **506** allows composite repair structure **200** to be formed within a vacuum, but without being subjected to compaction forces from the vacuum.

FIG. **5B** illustrates a cross-sectional representation of a lower bag of the double vacuum debulk chamber of FIG. **5A**, in accordance with some examples. FIG. **5B** further illustrates lower bag **512**. Lower bag **512** shown in FIG. **5B** includes a lower bagging film **514**, a breather **516**, nonporous release film **518** and **524**, a bleeder **520**, porous or perforated release film or fabric **522**, a thermally conductive sheet **526**, heating element **528**, a breather **530**, and electrical circuitry **532**. In the example shown, composite repair structure **200** is disposed within the layers of porous or perforated release film or fabric **522**.

Electrical circuitry **532** provides electrical power to heating element **528**. Heating element **528** is, for example, a heating blanket. Heating element **528** generates heat from the provided electrical power. The heat is then used to reduce the resin viscosity of the composite repair structure **200**. In some examples, preventing air compaction while repair laminate **206** is formed (e.g., when vacuum is generated and heat is provided by heating element **528**) allows for the extraction of gases and other volatiles from the fibers of repair laminate **206**. The reduced viscosity of resin **208** allows for resin **208** to flow into the volume previously

occupied by the gases and volatiles. In certain examples, resin **208** can then occupy most or all of the space around the fibers of repair laminate **206**.

In certain examples, after extraction of the gases and volatiles, hardback **506** is vented to atmosphere. Atmospheric pressure is then able to impart a compaction force on lower bag **512** and, thus, composite repair structure **200** to form composite repair structure **200** to the final shape. By applying compaction forces only after the gases and volatiles are extracted, the techniques described herein allow for venting of trapping of gases and volatiles and, thus, avoid trapping of such gases and volatiles within composite repair structure **200**. Such a technique produces a stronger composite repair structure **200**. Afterwards, composite repair structure **200** is removed from double vacuum debulk chamber **500** and ready to bond to a vehicle structure.

VEHICLE EXAMPLES

While the systems, apparatus, and methods disclosed above have been described with reference to airplanes and the aerospace industry, it will be appreciated that the examples disclosed herein is applicable to other contexts as well, such as automotive, railroad, and other mechanical and vehicular contexts. Accordingly, examples of the disclosure is described in the context of an airplane manufacturing and service method **600** as shown in FIG. **6A** and vehicle **100** as shown in FIG. **6B** in applicable to such other contexts.

FIG. **6A** illustrates a flow chart of an example of a vehicle production and service methodology, in accordance with some examples. In some examples, during pre-production, method **600** includes the specification and design **604** of vehicle **100** (e.g., an aircraft as shown in FIG. **1**) and material procurement **606**. During production, component and subassembly manufacturing **608** and system integration **610** of vehicle **100** takes place. Thereafter, vehicle **100** goes through certification and delivery **612** in order to be placed in service **614**. While in service by a customer, the vehicle **100** is scheduled for routine maintenance and service **616** (e.g., modification, reconfiguration, refurbishment, and so on).

In certain examples, each of the processes of method **600** is 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 includes any number of airplane manufacturers and major-system subcontractors; a third party includes any number of vendors, subcontractors, and suppliers; and an operator can be an airline, leasing company, military entity, service organization, and so on.

FIG. **6B** illustrates a block diagram of an example of a vehicle, in accordance with some examples. As shown in FIG. **6B**, the vehicle **100** (e.g., an aircraft) produced by method **600** includes airframe **618** with plurality of systems **620**, and interior **622**. Examples of systems **620** include one or more of propulsion system **624**, electrical system **626**, hydraulic system **628**, and environmental system **630**. In various examples, other systems are also included within vehicle **100**. Although an aerospace example is shown, the principles of the embodiments disclosed herein is applicable to other industries, such as the automotive industry.

CONCLUSION

Although foregoing concepts have been described in some detail for purposes of clarity of understanding, it will be apparent that certain changes and modifications may be practiced within scope of appended claims. It should be

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noted that there are many alternative ways of implementing processes, systems, and apparatuses. Accordingly, present examples are to be considered as illustrative and not restrictive.

The invention claimed is:

1. A composite repair structure comprising:
a repair laminate comprising a resin with a resin minimum viscosity temperature; and
a film sealant with a sealant minimum viscosity temperature, disposed on a first surface of the repair laminate, wherein the composite repair structure is configured to be cured and/or bonded to a vehicle structure through positive pressure applied to the composite repair structure when the composite repair structure is coupled to the vehicle structure, wherein the sealant minimum viscosity temperature is higher than the resin minimum viscosity temperature, wherein the sealant minimum viscosity temperature is a temperature where the resin at least partially gels, and wherein the film sealant prevents air intrusion into the repair laminate during curing and/or bonding of the composite repair structure to the vehicle structure when at the resin minimum viscosity temperature.
2. The composite repair structure of claim 1, wherein the film sealant is further disposed on a second surface opposite the first surface of the repair laminate.
3. The composite repair structure of claim 1, wherein at the sealant minimum viscosity temperature, the film sealant comingles with the resin.
4. The composite repair structure of claim 1, wherein with the application of heat, the repair laminate degases.
5. The composite repair structure of claim 4, wherein with application of heat, a viscosity of the resin of the repair laminate is reduced and fibers of the repair laminate are covered with the resin.
6. A method of forming the composite repair structure of claim 1, the method comprising:
laying up the repair laminate;
applying heat to the repair laminate to degas the repair laminate; and
applying the film sealant to the first surface.
7. The method of claim 6, wherein the applying the heat to the repair laminate to degas the repair laminate comprises:
reducing a viscosity of the resin of the repair laminate; and
covering fibers of the repair laminate with the resin.
8. An apparatus comprising:
a vehicle structure; and
the composite repair structure of claim 1.
9. The apparatus of claim 8, wherein the film sealant is further disposed on a second surface opposite the first surface of the repair laminate.

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10. The apparatus of claim 8, wherein at the sealant minimum viscosity temperature, the film sealant comingles with the resin.

11. The apparatus of claim 8, further comprising:
a release film disposed on the portion of the vehicle structure;
a compliance layer disposed on the portion of the vehicle structure; and
a weight coupled to the composite repair structure to apply positive pressure on the composite repair structure.

12. The apparatus of claim 11, wherein the vehicle structure is a propulsor, a fuselage, or a wing.

13. The apparatus of claim 8, wherein with the application of heat, the repair laminate degases.

14. The apparatus of claim 13, wherein with application of heat, a viscosity of the resin of the repair laminate is reduced and fibers of the repair laminate are covered with the resin.

15. A method of forming the composite repair structure of claim 8, the method comprising:

- laying up the repair laminate;
- applying heat to the repair laminate to degas the repair laminate; and
- applying the film sealant to the first surface.

16. The method of claim 15, wherein the applying the heat to the repair laminate to degas the repair laminate comprises:
reducing a viscosity of the resin of the repair laminate; and
covering fibers of the repair laminate with the resin.

17. The method of claim 15, further comprising:
coupling the composite repair structure to a vehicle structure; and

bonding the composite repair structure to the vehicle structure by providing a positive pressure to the composite repair structure coupled to the vehicle structure, wherein the film sealant prevents air intrusion to the repair laminate during the bonding of the composite repair structure to the vehicle structure.

18. The method of claim 17, wherein the bonding the composite repair structure to the vehicle structure further comprises providing heat to the repair structure coupled to the vehicle structure.

19. The method of claim 17, wherein the film sealant is applied to a first surface and a second surface opposite the first surface of the repair laminate.

20. The method of claim 17, wherein the positive pressure is applied without vacuum.

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