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(54) AIRFOIL STRUCTURE, PRESSURE VESSEL AND METHOD OF PRODUCING THE SAME

(57) The present invention relates to an airfoil structure, a pressure vessel for an airfoil structure, a method of manufacturing a pressure vessel for an airfoil structure and a method of manufacturing an airfoil structure. The airfoil structure (10) comprising:
- an outer airfoil shape (12) configured to contact an airflow; and
- at least one pressure vessel (20) disposed inside the outer airfoil shape (12) so that the at least one pressure vessel (20) is configured to carry at least a part of a load applied to the outer airfoil shape (12);
wherein the at least one pressure vessel (20) comprises a plurality of vessel segments (30),
wherein the plurality of vessel segments (30) are connected substantially in an axial direction (A) of the at least one pressure vessel (20), and
wherein the plurality of connected vessel segments (30) substantially are wrapped with at least one pressure vessel layer (40) of fibre reinforced plastic so as to form one substantially continuous pressure vessel (20).

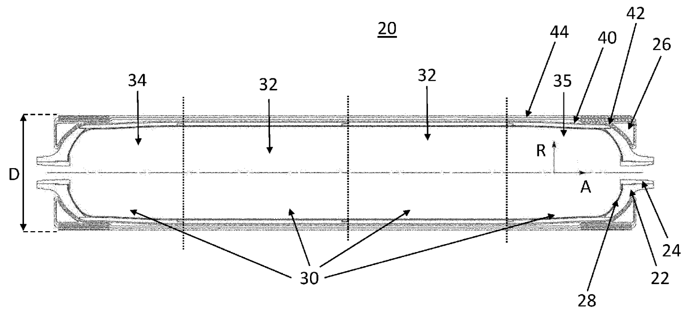

FIG. 2

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Description

[0001] Airfoil structure, pressure vessel for an airfoil structure, method of manufacturing a pressure vessel for an airfoil structure and method of manufacturing an airfoil structure.

[0002] The present invention relates to an airfoil structure, a pressure vessel for an airfoil structure, a method of manufacturing a pressure vessel for an airfoil structure and a method of manufacturing an airfoil structure.

[0003] In commercial air traffic kerosene is generally used as a fuel for powering airplane propulsion systems such as a turbojet engine, a turboprop engine or the like. Alternative fuel and propulsion systems which may rely on gases such as hydrogen or rely on batteries are subject to current studies but are however not yet used in commercial air traffic. The fuel and propulsion system provide certain requirements and restrictions to the airplane conception overall with particular regards to the arrangement of the engines at the airplane, as well as with regards to the arrangement of the fuel storage at or in the airplane. However, as an environmentally friendly approach, it is intended to provide for propulsion systems which rely less on fossil fuels. Therefore however, switching fuel systems away from kerosene in order to reduce the consumption of fossil energy sources faces various complex difficulties as an airplane is generally affected overall.

[0004] In view of the above, an object of the present invention is to provide an improved airfoil structure, in particular to provide an airfoil structure with improved fuel system, and to provide an improved method for manufacturing an airfoil structure.

[0005] The problem is solved by the subject-matter of the independent claims. Particular embodiments are defined by the dependent claims.

[0006] According to an aspect, an airfoil structure is provided, the airfoil structure comprising:

- an outer airfoil shape configured to contact an airflow; and
- at least one pressure vessel disposed inside the outer airfoil shape so that the at least one pressure vessel is configured to carry at least a part of a load applied to the outer airfoil shape;

  wherein the at least one pressure vessel comprises a plurality of vessel segments,
  wherein the plurality of vessel segments are connected substantially in an axial direction of the at least one pressure vessel, and
  wherein the plurality of connected vessel segments substantially are wrapped with at least one pressure vessel layer of fibre reinforced plastic so as to form one substantially continuous pressure vessel.

[0007] In other words, an airfoil structure is provided which in particular comprises at least one pressure vessel which is configured to carry at least a part of a load applied to the outer airfoil shape. Said load applied to the outer airfoil shape may in particular include a weight of the airfoil structure, as well as a load during flight of an airplane having said airfoil structure, for example aerodynamic loads.

[0008] Owing to the at least one pressure vessel which is configured to carry at least a part of a load applied to the outer airfoil shape, the airfoil structure provides for an improved integration of a fuel system into an airfoil structure, wherein a pressure vessel which may in particular be configured to store a pressurized fuel, such as a fluid or gas, integrally facilitates and improves the load carriage of the airfoil structure.

[0009] In particular embodiments, the at least one pressure vessel is configured to structurally reinforce the outer airfoil shape.

[0010] Owing to the at least one pressure vessel which is configured to carry at least a part of a load applied to the outer airfoil shape and/or to structurally reinforce the outer airfoil shape, the weight of the outer airfoil shape and/or of the airfoil structure as a whole may advantageously be reduced. For example, the airfoil structure may particularly include a reduced number of reinforcing ribs compared to conventional airfoil structures.

[0011] In further particular embodiments of the airfoil structure, the airfoil structure does not include a rib, and/or a stringer, and/or a frame inside. That is, owing the airfoil structure which comprises at least one pressure vessel configured to carry at least a part of a load applied to the outer airfoil shape, the airfoil structure may be manufactured without a rib, and/or a stringer, and/or a frame inside it, as the at least one pressure vessel provides the airfoil structure with the necessary structural properties for take-off, flight and landing of an airplane. Accordingly, the at least one pressure vessel may particularly be configured to provide the aifoil structure with the necessary stiffness and/or stability for take-off, flight and landing of an airplane, while enhancing the ability to manufacture the airfoil structure.

[0012] That is, the in exemplary embodiment, the airfoil structure does not include a rib, and/or a stringer, and/or a frame inside which is disposed between a lower airfoil segment and an upper airfoil segment of the outer airfoil shape.

[0013] Thus, owing to the at least one pressure vessel, an improved fuel storage for an airplane is provided which on the one hand allows for storage of fuel, and on the other hand allows for improving or even simplifying an airfoil structure, wherein the airfoil structure is not in need of other reinforcing elements, generally known as a rib, a stringer, and/or a frame disposed inside and between an upper airfoil segment and a lower airfoil segment of the airfoil structure.

[0014] In particular embodiments of the airfoil structure, the at least one pressure vessel may be configured to carry at least about 30 % of a load applied to the airfoil structure, particularly at least about 50 % of a load applied to the airfoil structure, further particularly at least about 60 % of a load applied to the airfoil structure, and still further particularly at least about 70 % of a load applied to the airfoil structure. Nevertheless, the at least one pressure vessel may be configured to carry a load applied to the airfoil structure according to the material properties provided by the at least one pressure vessel, particularly by the at least one pressure vessel layer of fibre reinforced plastic. Specifically, in particular embodiments, the at least one pressure vessel may be configured with a predetermined stiffness in order to carry a desired predetermined load applied to the outer airfoil structure.

[0015] Furthermore, owing to the at least one pressure vessel comprising a plurality of vessel segments, an advantageous pressure vessel is provided, which may modularly be adjusted so as to geometrically correspond to a predetermined outer airfoil shape. Specifically, the plurality of vessel segments particularly facilitate a lengthwise adjustment, and the wrapping of the pressure vessel comprising the plurality of vessel segments particularly facilitates a cross-sectional adjustment. Thus, the at least one pressure vessel which includes the plurality of vessel segments is suitable to be integrated into a variety of specific outer airfoil shapes, and accordingly enhances the integration of a fuel storage into an airfoil structure.

[0016] Owing to the wrapping of the at least one pressure vessel, that is, owing to the wrapping of the vessel segments of the plurality of vessel segments, the at least one pressure vessel provides for sufficient stiffness particularly in a direction in which the vessel segments are connected, which may be a substantially axial direction of the at least one pressure vessel, which may in turn substantially correspond to a wingspan direction of the airfoil structure. The wingspan direction may substantially direct from a wing root disposed at an airplane fuselage to a wing tip which may correspond to a distal tip of the airfoil structure.

[0017] In particular embodiments, the plurality of vessel segments includes a first end segment, a second end segment and a number of mid segments (as particular intermediate segments). The number of mid segments may be any number starting from 1, that is, the number of mid segments may for example include 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14 mid segment(s) and so forth. In particular embodiments, the plurality of vessel segments are connected so that the number of mid segments is sandwiched between the first end segment and the second end segment.

[0018] Each vessel segment of the plurality of vessel segments may respectively have a substantially hollow shape. Specifically, a mid segment of the number of mid segments may have a hollow shape, wherein an open first end of a mid segment is configured to face the first end segment or an open second end of another mid segment which is disposed closer toward the first end segment. In turn, a mid segment of the number of mid segments having the hollow shape may have an open second end which is configured to face the second end segment or an open first end of another mid segment which is disposed closer toward the second end segment.

[0019] Furthermore owing to the substantially continuous pressure vessel, the at least one pressure vessel may advantageously provide for a continuous load transfer into, as well as through the at least one pressure vessel element, and further in between an upper airfoil segment and a lower airfoil segment of the outer airfoil shape. Still further, the substantially continuous pressure vessel advantageously allows for a continuous integration or attachment to the outer airfoil shape, thus providing for a continuous support or reinforcement to the airfoil structure.

[0020] In exemplary embodiments, a vessel segment of the plurality of vessel segments may independent from other vessel segments have a substantially cylindrical shape and may in particular have a substantially circular cross section. However, the vessel segments are not limited to this. That is, a vessel segment of the plurality of vessel segments may have a substantially circular cross section, a substantially elliptical cross section, a substantially polygonal cross section, and/or any contoured cross section.

[0021] In exemplary embodiments, a mid segment of the plurality of vessel segments may have a substantially constant cross section. That is, a mid segment of plurality of vessel segments may have the substantially same cross section along an axial direction of said mid segment, wherein the axial direction of the said mid segment may substantially correspond to the axial direction of the at least one pressure vessel. However, in alternative embodiments, the axial direction of a mid segment may be inclined with respect to the axial direction of the at least one pressure vessel. Specifically, the axial direction of a mid segment may be inclined with respect to the axial direction of the at least one pressure vessel in a range of about 0° to about 10°, particularly in a range of about 0° to about 5°, further particularly in a range of about 0° to about 2°, and most particularly be parallel to the axial direction of the at least one pressure vessel. However, in some embodiments, a certain degree of inclination of the axial direction of a mid segment with respect to the axial direction of the at least one pressure vessel may be different from the above given ranges may be intended to conform with a predetermined outer airfoil shape which is curved in a wingspan direction, for example to conform to a winglet.

[0022] The axis of a mid segment is generally considered as a line between a mid point of the cross section of the said mid segment at its open first end and a mid point of the cross section of the said mid segment at its open second end. In case the mid segment has a substantially cylindrical shape, i.e. a substantially circular cross section, the axis of the mid segment may substantially correspond to a cylindrical axis.

[0023] The first and second end segments of the plurality of vessel segments may respectively have a substantially hollow shape. Specifically, the first end segment may have a hollow shape, wherein an open second end of the first end segment is configured to face a first open end of a mid segment. Accordingly, the first end segment having the hollow shape may in particular have an open first end which is configured to be connected with a first dome. Similarly, the second end segment may have a hollow shape, wherein an open first end of the second end segment is configured to face a second open end of a mid segment. Further, the second end segment having the hollow shape may in particular have an open second end which is configured to be connected with a second dome.

[0024] In exemplary embodiments, the first and second end segments of the plurality of vessel segments may have a substantially constant cross section or a substantially varying cross section, in particular a transitioning cross section which transitions from a first cross section to a second cross section. That is, the first and second end segments of the plurality of vessel segments may have a different cross section along an axial direction of said respective first and second end segment. The axial direction of the said first and second end segment may substantially correspond to the axial direction of the at least one pressure vessel. However, in alternative embodiments, the axial direction of an end segment of the first and second end segments may be inclined with respect to the axial direction of the at least one pressure vessel. Specifically, the axial direction of an end segment may be inclined with respect to the axial direction of the at least one pressure vessel in a range of about 0° to about 20°, particularly in a range of about 0° to about 10°, further particularly in a range of about 0° to about 5°, most particularly in a range of about 0° to about 2°. However, in some embodiments, a certain degree of inclination of the axial direction of an end segment with respect to the axial direction of the at least one pressure vessel may be different from the above given ranges may be intended to conform with a predetermined outer airfoil shape which is curved in a wingspan direction, for example to conform to a winglet.

[0025] In some embodiments, the substantially varying cross section or the substantially transitioning cross section may respectively vary or transition from an open end configured to face a mid segment of the plurality of vessel segments to an open end configured to be connected with a dome. In particular embodiments, the first and/or second end segment substantially maintains its wall thickness when transitioning or varying with the cross section between the first and second open end of the respective end segment.

[0026] Nevertheless, in alternative embodiments, the first end segment and/or the second end segment of the plurality of vessel segments may have a substantially closed end at an axial end. Therefore, the first end segment and/or the second end segment may have a substantially semi circular closing shape. In other words, the first end segment and/or the second end may have a substantially semi spherical closed shape at one end, and particularly an open end at the axial opposite end of the respective end segment. In some embodiments, one of the first and the second end segment may have a closed end, and the other of the first and second end segment may be connected to a dome.

[0027] In exemplary embodiments, the dome is configured to selectively connect an inside of the at least one pressure vessel with an airplane engine, a fuel cell, and/or with a refueling gas tank in fluid communicating manner. In exemplary embodiments, a dome may include a valve, particularly a selectively controllable valve.

[0028] The at least one pressure vessel as mentioned herein generally relates to a vessel which is configured to store or contain pressurized fuel, such as a pressurized fluid or gas, for example hydrogen, methane, or another fluid or gas composition suitable for powering an aircraft engine or a fuel cell. In exemplary embodiments, the at least one pressure vessel may be connected to a fuel cell, so as to particularly be in selective fluid communication with said fuel cell, for example, however without being limited to it, via a valve included in the dome.

[0029] The airfoil structure as mentioned herein may relate to a pair of airplane wings, or at least to one wing of a pair of airplane wings, wherein a wing or pair of wings are generally considered as providing for the necessary lift during take-off, flight and landing of an airplane.

[0030] Therefore, in exemplary embodiments, the at least one pressure vessel may be configured to extend at least partially within both wings of a pair of wings of an airplane. In other words, the at least one pressure vessel may be configured to continuously extend at least partially within both wings of a pair of wings of an airplane and through a portion of the fuselage between the pair of wings. Alternatively, the at least one pressure vessel may be configured to extend at least partially only within one wing of a pair of wings of an airplane.

[0031] The at least one pressure vessel which is configured to carry at least a part of a load applied to the outer airfoil shape may be configured to be deformable and/or movable in accordance with deformation and/or movement of the airfoil structure, in particular with the deformation and/or movement of the outer airfoil shape, during take-off, flight and landing, and further in exceptional high load situations of the airfoil structure. With respect to deformations and movements of the at least one pressure vessel, said deformations and movements particularly relate to resilient deformations and/or movements, further particularly to elastic deformations and/or movements. Nevertheless, it is intended that also certain plastic deformations to the airfoil structure, and in particular to the at least one pressure vessel are allowed, as long as a predetermined leakage of a fluid or gas contained in the at least one pressure vessel can be prevented.

[0032] Herein, in case a direction, is given with the indication substantially or about, the respective direction may be understood to be in a range of 0° to 10°, particularly in a range of 0° to 5° deviating from the respective direction.

[0033] Herein, in case a measure or an amount is given with the indication substantially or about, the respective measure or amount may be understood to be in a range of 0% to 10%, particularly in a range of 0% to 5% deviating from the respective measure or amount.

[0034] An axis of the at least one pressure vessel may generally be considered as a line between a first midpoint at a first end of the at least one pressure vessel and a second midpoint at a second end of the at least one pressure vessel. In exemplary embodiments of the airfoil structure, the axis of the at least one pressure vessel may be a symmetrical axis of the at least one pressure vessel, particularly substantially a symmetrical axis of each of the vessel segments of the at least one pressure vessel, similar to an axis of a cylinder.

[0035] An axial direction of the at least one pressure vessel may generally be considered as pointing from a first midpoint at a first end of the at least one pressure vessel to a second midpoint at a second end of the at least one pressure vessel, particularly along the axis of the at least one pressure vessel.

[0036] A radial direction of the at least one pressure vessel may generally be considered as pointing from the axis of the at least one pressure vessel to the circumferential surface of at least a portion of the at least one pressure vessel. Particularly, the radial direction may be substantially perpendicular to the axis of the at least one pressure vessel.

[0037] A radial direction of a vessel segment of the plurality of vessel segments may generally be considered as pointing from an axis of said vessel segment to the circumferential surface of at least a portion of said vessel segment. Particularly, the radial direction may be substantially perpendicular to the axis of said vessel segment, and further particularly, the radial direction of a vessel segment may substantially correspond to a radial direction of the at least one pressure vessel.

[0038] With regards to angle measures of fibres of a layer of fibre reinforced plastic as described herein, it is noted that in a plane view, the maximum angle deviation between a given direction and a direction at which a certain fibre of a layer of fibre reinforced plastic extends is considered to be 90°. Thus, in case an angle deviation is for example indicated with +80°, the given direction and the direction of the fibre are considered as enclosing an angle of about 80°. In turn, in case an angle deviation is for example indicated with -80°, the given direction and the direction of the fibre are also considered as enclosing an angle of about 80°, which is however measured on the other side compared to the measurement applied with regards to the aforementioned indication of +80°. Consequently, as both indications +80° and -80° deviate from about 90° by about 10°, fibres which extend at an angle of +80° and fibres which extend at an angle of -80° are considered as exemplarily enclosing an angle of about 20°

[0039] The present invention is not limited to the pair of wings of an airplane but may for example also be applied to an elevator unit of an airplane or other structural elements of an airplane. Still further, the present invention may for example also be applied to multiple pairs of wings or only to one wing of one or more pairs of wings.

[0040] Even though the airfoil structure according to the present invention is not in need of a a rib, a stringer, and/or a frame disposed inside and between an upper airfoil segment and a lower airfoil segment of an airfoil structure for carrying a load or loads generally applied to the airfoil structure, the airfoil structure may be configured to include at least one or a combination of a rib, a stringer, and/or a frame disposed inside and between an upper airfoil segment and a lower airfoil segment of the airfoil structure.

[0041] In particular embodiments, a vessel segment of the plurality of vessel segments such as a mid segment and/or an end segment of the plurality of vessel segments may have an open first end and/or an open second end which is configured to be connected to another vessel segment of the plurality of vessel segments. Said open first end and/or open second end may in particular have a stepped shape. Specifically, a vessel segment of the plurality of vessel segments may have an open first end and/or an open second end having a stepped shape, wherein a radial inner portion of the respective vessel segment does have an axial extension, particularly along an axis of the vessel segment which is different from an axial extension of the respective vessel segment at a radial outer portion.

[0042] In other words, a vessel segment of the plurality of vessel segments may have a stepped shape at an interface configured to be connected to or mate with another vessel segment of the plurality of vessel segments, wherein an axial extension at a radial inner portion of the vessel segment is different from an axial extension at a radial outer portion of said vessel segment. In turn, said another vessel segment may particularly have an interface corresponding to the interface of the vessel segment which it is configured to be connected to or mated with, such that in preferable embodiments, the vessel segments configure a form fit between one another, particularly a stepwise form fit.

[0043] Conventionally, in order to provide a smooth transition of stresses between axially joined elements, in particular when connecting elements which at least partially include fibre reinforced plastics, one element of the elements to be joined generally includes a chamfered edge suitable to be adhered to a corresponding chamfered edge of the other element to be joined. However, it was found that a stepped shape at a connection interface of a vessel segment as provided herein provides for an advantageous and particularly defined connection between adjacent vessel segments of the plurality of vessel segments which also facilitates the handling of the vessel segments when connecting them.

[0044] In addition or alternatively, adjacent vessel segments of the plurality of vessel segments which are configured to be connected or mated may configure a frictional fit and/or may be adhesively connected to one another.

[0045] In particular embodiments, the plurality of connected vessel segments which are substantially wrapped with at least one pressure vessel layer of fibre reinforced plastic so as to form one substantially continuous pressure vessel may be wrapped by winding, however without being limited thereto. That is, in particular embodiments, the plurality of connected vessel segments may be substantially winded with at least one pressure vessel layer of fibre reinforced plastic so as to form one substantially continuous pressure vessel. Nevertheless, in addition or alternatively, one or more pressure vessel layers of fibre reinforced plastic may be applied to the plurality of connected vessel segments by braiding, tape laying, fibre patch placement and/or another suitable method in order to apply and in particular cover the plurality of vessel segments with at least one pressure vessel layer of fibre reinforced plastic so as to form one substantially continuous or integral pressure vessel.

[0046] Particularly, the at least one pressure vessel layer of fibre reinforced plastic is applied to the plurality of vessel segments, wherein the fibres of said at least one pressure vessel layer continuously extend from at least a first end of the at least one pressure vessel to a at least a second end of the at least one pressure vessel layer. A pressure vessel layer having continuously extending fibres at least between the first end and the second end of the pressure vessel enhances the axial stiffness and strength of the at least one pressure vessel even though being modularly formed of a plurality of vessel segments. Winding particularly allows for a cost efficient application of continuously extending fibres to the plurality of vessel segments. Nevertheless, in particular braiding, tape laying and/or fibre patch placement particularly allow for a specific application of a pressure vessel layer to the plurality of vessel segments, wherein cross sections of the plurality of vessel segments which do not have a constant diameter or shape may readily be reinforced and/or covered.

[0047] In particular embodiments of the airfoil structure, the plurality of vessel segments may be connected with a pre-stress,

the pre-stress particularly being a compression stress.

[0048] Owing to the connection of the plurality of vessel segments with a pre-stress, the pre-stress applied to the vessel segments may compensate stresses which the plurality of vessel segments are subject to when the at least one pressure vessel is fueled and/or during take-off, flight or landing, i.e. stresses applied when the airfoil structure particularly provides for the necessary lift.

[0049] In particular embodiments, a pre-stress may be applied to the plurality of vessel segments when or particularly prior to the plurality of vessel segments being wrapped. In still further particular embodiments, a compression stress may be applied to the plurality of vessel segments as a pre-stress, i.e. a pre-compression stress, in particular when or prior to the plurality of vessel segments being wrapped. Specifically, a compression stress may be applied to the plurality of vessel segments in a substantially axial direction of the at least one pressure vessel, i.e. particularly in a substantially axial direction of the vessel segments of the plurality of vessel segments.

[0050] Owing to the compression stress applied to the vessel segments of the plurality of vessel segments, the sustainability for tensile stresses of the vessel segments of the plurality of vessel segments is increased in particular when the at least one pressure vessel is fueled with a pressurized fluid or gas, as well as when the airfoil structure is bent.

[0051] In particular embodiments, one or more vessel segments of the plurality of vessel segments include at least one vessel segment layer of fibre reinforced plastic. Owing to a pre-stress, in particular owing to a compression stress applied to the vessel segments, in particular vessel segments which include at least one vessel segment layer of fibre reinforced plastic have the plastic of the fibre reinforced plastic layer in a pre-compressed state.

[0052] Then, when the at least one pressure vessel is fueled or filled with a pressurized fluid or gas, a tensile stress acts onto the vessel segments, wherein owing to the pre-compression stress of the plastic of the vessel segment layer, crack formation in the plastic of said vessel segment layer can be reduced or prevented, which in turn ensures an increased operating life of the vessel segments, and thus an increased operating life of the at least one pressure vessel. Furthermore, prevented or reduced crack formation in the plastic of a vessel segment may improve the tightness for containing or storing a certain fluid or gas.

[0053] In particular embodiments of the airfoil structure, the vessel segments of the plurality of vessel segments may include at least one vessel segment layer of fibre reinforced plastic, wherein a direction of the fibres of the pressure vessel layer may deviate from a direction of the fibres of the vessel segment layer by an angle in a range of about 30° to about 90°,

particularly by an angle in a range of about 45° to about 90°,

further particularly by an angle in a range of about 60° to about 90°.

[0054] Owing to the vessel segments of the plurality of vessel segments including at least one vessel segment layer of fibre reinforced plastic, wherein a direction of the fibres of the pressure vessel layer deviates from a direction of the fibres of the vessel segment layer by an angle of at least about 30° up to about 90°, the at least one pressure vessel is provided with advantageous crack stopping properties, wherein progression of a crack in a substantially radial direction of the at least one pressure vessel is decelerated or even prevented.

[0055] Starting from an exemplary deviation angle in a range of about 30° to about 90°, transitioning across a deviation angle in a range of about 45° to about 90° toward a deviation angle in a range of about 60° to about 90°, crack stopping properties of the at least one pressure vessel may further be improved. Furthermore, an advantageous pressure vessel layup comprising at least one vessel segment layer of fibre reinforced plastic and at least one pressure vessel layer of fibre reinforced plastic may be provided, which enhance the capability of the at least one pressure vessel to carry and sustain loads applied to the airfoil structure, as well as to carry and sustain loads applied by a fueled pressurized fluid or gas.

[0056] In particular embodiments, the at least one vessel segment layer may include fibres which substantially extend with an angle in a range of about +80° to about -80° with respect to an axis of the vessel segment, particularly with an angle of about +80° and/or an angle of about -80° with respect to an axis of the vessel segment, wherein the axis of the vessel segment may correspond to the axis of the at least one pressure vessel. In other words, the at least one vessel segment layer may include fibres which substantially extend with an angle in a range of about +10° to about -10° with respect to a circumference of the vessel segment, particularly with an angle of about +10° and/or an angle of about -10° with respect to a circumference of the vessel segment, wherein the circumference of the vessel segment may be substantially perpendicular to the axis of the vessel segment, wherein the axis of the vessel segment may in turn correspond to the axis of the at least one pressure vessel.

[0057] Owing to the vessel segment layer having fibres extending as described above, a segmentation to the plurality of vessel segments is enhanced, wherein continuous fibres which extend roughly in a circumferential direction are provided to the vessel segments, which therefore are provided with improved mechanical properties in particular for carrying loads which are applied to the vessel segments in a substantially radial direction of said vessel segments, which may for example derive from a pressurized fluid or gas.

[0058] In particular embodiments, the at least one pressure vessel layer may include fibres which substantially extend with an angle in a range of about +10° to about -10° with respect to an axis of the pressure vessel, particularly with an angle of about +10° and/or about 0° and/or about -10° with respect to the axis of the pressure vessel. In other words, the at least one pressure vessel layer may include fibres which substantially extend with an angle in a range of about +80° to about -80° with respect to a circumference of the pressure vessel, particularly with an angle of about +80° and/or an angle of about -80° and/or with an angle of about 90°, i.e. substantially perpendicular, with respect to a circumference of the pressure vessel.

[0059] Owing to the pressure vessel layer having fibres extending as described above, a layer suitable for wrapping the plurality of vessel segments is provided, wherein continuous fibres which extend roughly in an axial direction are provided to the pressure vessel, which therefore is provided with improved mechanical properties in particular for carrying loads which are applied to the pressure vessel in a substantially axial direction of said pressure vessel, which may for example derive from a pressurized fluid or gas, as well as from loads applied to the airfoil structure during take-off, light and landing.

[0060] Furthermore, the pressure vessel layer having fibres extending roughly in the axial direction of the pressure vessel facilitates the fixation of a pre-stressed state, particularly a pre-compressed state of the plurality of vessel segments.

[0061] Still further, the combination of a vessel segment layer having fibres extending roughly in the circumferential direction plus a pressure vessel layer having fibres extending roughly in the axial direction advantageously provide the at least one pressure vessel with improved crack stopping properties.

[0062] In particular embodiments of the airfoil structure, the at least one pressure vessel layer may include a plurality of pressure vessel layers, wherein a first pressure vessel layer of the plurality of pressure vessel layers extends over the connected vessel segments in the axial direction of the at least one pressure vessel and is folded back so as to be at least partially sandwiched by further pressure vessel layers of the plurality of pressure vessel layers.

[0063] Owing to the at least one pressure vessel layer which is folded back so as to be at least partially sandwiched by further pressure vessel layers of the plurality of pressure vessel layers, in particular an end portion of the at least one pressure vessel may be reinforced with additional layers of fibre reinforced plastic without impairing a continuous outer shape of the at least one pressure vessel. That is, owing to the at least one pressure vessel layer which is folded back so as to be at least partially sandwiched by further pressure vessel layers of the plurality of pressure vessel layers, the at least one pressure vessel may be locally reinforced with additional layers of fibre reinforced plastic, wherein a substantially continuous form of the at least one pressure vessel is not impaired.

[0064] In particular embodiments, the at least one pressure vessel layer which is folded back may enclose a ring member disposed at a first end and/or at a second end of the at least one pressure vessel.

[0065] Furthermore, in particular embodiments, a dome may be connected to a first end segment and/or to a second end segment of the plurality of vessel segments. Thus, in particular embodiments, a first dome may be connected to the first end segment of the plurality of vessel segments and/or a second dome may be connected to the second end segment of the plurality of vessel segments. The first dome and/or the second dome may in particular form a closing means and/or a valve, particularly for axially closing or selectively closing and opening the at least one pressure vessel. In some embodiments, the first dome and/or the second dome may configure a valve suitable to enable a fluid communication upon a predetermined activation or actuation.

[0066] In particular embodiments, a dome connected to a first end segment and/or to a second end segment of the plurality of vessel segments may at least partially be substantially radially surrounded by the at least one pressure vessel layer which is folded back, and in particular by the at least one pressure vessel layer which is folded back and the ring member, wherein the ring member is particularly enclosed by the at least one pressure vessel layer which is folded back.

[0067] Owing to the configuration wherein a dome particularly is connected to an end segment of the plurality of vessel segments, and wherein the dome is at least partially surrounded by the at least one pressure vessel layer which is folded back, furthermore particularly surrounded by the at least one pressure vessel layer which is folded back and the ring member, an improved and reinforced axial fixation of the dome to an end segment of the plurality of vessel segments may be provided, which therefore enhances an axial stiffness and strength of the at least one pressure vessel, as well as its tightness when fueled with a pressurized fluid or gas.

[0068] In particular embodiments of the airfoil structure, the plurality of vessel segments may include a first end segment and a second end segment, wherein the first end segment and/or the second end segment has a conical shape, wherein the conical shape has a reduced cross section toward an axial end of the pressure vessel, i.e. toward an axial end of the at least one pressure vessel which includes the plurality of vessel segments.

[0069] Particularly owing to the conical shape with reduced cross section toward the axial end of the at least one pressure vessel, a local reinforcement by additional layers of fibre reinforced plastic may be applied at an axial end portion of the at least one pressure vessel without affecting a particularly constant outer shape or outer diameter of the at least one pressure vessel.

[0070] Furthermore, owing to the conical shape particularly with reduced cross section toward the axial end of the at least one pressure vessel, a layer of fibre reinforced plastic may self-align more toward the axial direction of the at least one pressure vessel when being wrapped toward an axial end of the conical shape of the first and/or second end segment of the plurality of vessel segments. This in turn enhances the axial stiffness and strength of the at least one pressure vessel and may improve the axial fixation of a dome connected to an end segment of the plurality of vessel segments.

[0071] In particular embodiments of the airfoil structure, the outer airfoil shape may include an upper airfoil segment and a lower airfoil segment, wherein the at least one pressure vessel directly connects the upper airfoil segment with the lower airfoil segment.

[0072] That is, in particular embodiments, the at least one pressure vessel may be configured to directly connect an upper airfoil segment of the outer airfoil shape with a lower airfoil segment of the outer airfoil shape. In other words, the at least one pressure vessel may be configured to directly contact the upper airfoil segment of the outer airfoil shape and at the same time be configured to directly contact the lower airfoil segment of the outer airfoil shape.

[0073] Particularly owing to the at least one pressure vessel which directly connects the upper airfoil segment with the lower airfoil segment of the outer airfoil shape, the upper and lower airfoil segments may structurally be directly supported or reinforced by the at least one pressure vessel.

[0074] Furthermore, owing to the at least one pressure vessel particularly which directly or indirectly connects the upper airfoil segment with the lower airfoil segment of the outer airfoil shape, a load applied to the upper and/or to lower airfoil segments may structurally be directly guided into the at least one pressure vessel and furthermore be guided to the respective other airfoil segment which carries a comparatively minor load.

[0075] Accordingly, the at least one pressure vessel which directly connects the upper airfoil segment with the lower airfoil segment of the outer airfoil shape structurally improves the airfoil structure which is not in need of a rib, a stringer, and/or a frame disposed inside and between the upper airfoil segment and the lower airfoil segment of the airfoil structure for carrying a load or loads generally applied to the airfoil structure. That is, in particular embodiments, the airfoil structure does not include a rib and/or a stringer and/or a frame disposed between the upper airfoil segment and the lower airfoil segment further to the at least one pressure vessel.

[0076] In particular embodiments, the at least one pressure vessel, the upper airfoil segment and the lower airfoil segment are connected by curing the at least one pressure vessel, the upper airfoil segment and the lower airfoil segment in one predetermined curing step, wherein the at least one pressure vessel, the upper airfoil segment and the lower airfoil segment contact one another.

[0077] In other words, the at least one pressure vessel, the upper airfoil segment and the lower airfoil segment may particularly be co-cured. The at least one pressure vessel, the upper airfoil segment and the lower airfoil segment are particularly co-cured in a single predetermined curing step, wherein the at least one pressure vessel, the upper airfoil segment and the lower airfoil segment contact one another.

[0078] Nevertheless, in alternative embodiments, the at least one pressure vessel, the upper airfoil segment and the lower airfoil segment may by connected via an adhesive, via mechanical means such as rivets, screws, via a form fit, and/or via a press fit, for example.

[0079] In particular embodiments of the airfoil structure, the at least one pressure vessel may be configured to tightly contain hydrogen at a pressure of at least about 200 bar.

[0080] Particularly owing to the at least one pressure vessel which tightly contains hydrogen, a fuel cell may advantageously be supplied with hydrogen in an airplane. Furthermore, as the at least one pressure vessel may be configured to tightly contain hydrogen at a pressure of at least about 200 bar, particularly in range of about 100 bar to about 800 bar, a fuel cell in an airplane may securely be supplied with hydrogen for various flight scenarios.

[0081] In particular embodiments of the aircraft structure, the at least one pressure vessel may be provided with a liner inside at least a portion of the connected plurality of vessel segments.

[0082] In exemplary embodiments, the liner may be configured to form a liner bag and/or include a plurality of layers.

[0083] The liner or liner bag provided inside at least a portion of the connected plurality of vessel segments advantageously allows for enhancing the tightness of an inside of the at least one pressure vessel, in particular for enhancing the tightness when a pressurized fluid or gas such as hydrogen is contained inside the at least one pressure vessel, particularly inside the liner or inside the liner bag.

[0084] In particular embodiments, the liner or liner bag comprises and/or consists at least partially of a polymer material particularly suitable for tightly storing a pressurized fluid or gas such as hydrogen or methane. In some embodiments, the liner or liner bag includes a number of layers of same or different materials. Exemplary materials which the liner or liner bag comprises and/or consists of may be TPU, i.e. thermoplastic urethane, PE, i.e. polyethylene, aluminum, PET, i.e. polyethylene terephthalate, PP, i.e. polypropylene, PA, i.e. polyamide, EVOH, i.e. ethylene-vinyl alcohol copolymer, and/or nylon. In particular embodiments, the liner or liner bag comprises or consists of a laminate including PE, aluminum and PET, or a laminate including PET, aluminum and PP, or a PA film which includes a barrier layer of EVOH, or a laminate film which includes or consists of nylon and aluminum.

[0085] According to another aspect, a method of manufacturing a pressure vessel for an airfoil structure is provided, the method comprising the steps of:

- providing a plurality of vessel segments;
- connecting the plurality of vessel segments substantially in an axial direction;
- wrapping at least one pressure vessel layer of fibre reinforced plastic around the plurality of connected vessel segments so as to form one substantially continuous pressure vessel.

[0086] The aforementioned exemplary, preferable, particular and alternative aspects and embodiments of the airfoil structure, along with their advantageous effects, also respectively apply to the method of manufacturing a pressure vessel for an airfoil structure and vice versa.

[0087] Particularly owing to the above mentioned steps in the method of manufacturing a pressure vessel for an airfoil structure, an advantageously modular pressure vessel may be provided for an airfoil structure which allows a geometrical adjustment so as to be suitable to be disposed inside various different airfoil structures, and which at the same time provides for an improved structural reinforcement of an airfoil structure, such that the airfoil structure does not require a rib and/or a stringer and/or a frame disposed inside an outer airfoil shape.

[0088] In particular embodiments, the method of manufacturing a pressure vessel may further comprise a step of:

- compressively biasing the plurality of connected vessel segments,
  wherein the step of compressively biasing the plurality of connected vessel segments is particularly applied before the step of wrapping at least one pressure vessel layer of fibre reinforced plastic around the plurality of connected vessel segments.

[0089] The step of compressively biasing the plurality of connected vessel segments allows to advantageously apply a pre-compression to the vessel segments, which in turn facilitates the prevention of crack formation in the vessel segments of the plurality of vessel segments when the at least one pressure vessel is fueled with a pressurized fluid or gas.

[0090] Furthermore, when the pre-compression is applied to the vessel segments before the step of wrapping at least one pressure vessel layer of fibre reinforced plastic around the plurality of vessel segments, a compressive stress may advantageously be secured to the plurality of vessel segments by the wrapped at least one pressure vessel layer of fibre reinforced plastic.

[0091] In particular embodiments of the method of manufacturing a pressure vessel, the step of wrapping at least one pressure vessel layer of fibre reinforced plastic around the plurality of connected vessel segments may include wrapping a plurality of pressure vessel layers of fibre reinforce plastic around the plurality of connected vessel segments,
wherein a first pressure vessel layer of the plurality of pressure vessel layers is wrapped so as to extend over the connected vessel segments in the axial direction, the method further comprising the steps of:

- folding the first pressure vessel layer backwards substantially opposite the axial direction, and
- sandwiching the first pressure vessel layer by further pressure vessel layers.

[0092] The folding of the first pressure vessel layer backwards substantially opposite the axial direction and sandwiching said first pressure vessel layer by further pressure vessel layers particularly allows for advantageously reinforcing a portion at an axial end of the pressure vessel, i.e. in particular allows for advantageously locally reinforcing a portion of the pressure vessel without impairing a particularly continuous outer shape of the at least one pressure vessel.

[0093] In particular embodiments, however without being limited to it, the first pressure vessel layer to be folded may be sandwiched between further pressure vessel layers which are different from the first pressure vessel layer to be folded. Such sandwiching in particular enhances the strength of the at least one pressure vessel, specifically for axially fixing a dome to an end segment of the plurality of vessel segments, for example via a ring member which is at least partially enclosed by the first pressure vessel layer to be folded.

[0094] In particular embodiments of the method of manufacturing a pressure vessel, the method further may comprise a step of:

- providing a liner inside at least a portion of the connected plurality of vessel segments.

[0095] The liner provided inside at least a portion of the connected plurality of vessel segments advantageously allows for enhancing the tightness of an inside of the at least one pressure vessel, in particular for enhancing the tightness when a pressurized fluid or gas is contained inside the at least one pressure vessel, particularly inside the liner.

[0096] In some embodiments, the liner may be or may comprise a liner bag

[0097] According to another aspect, a method of manufacturing an airfoil structure is provided, the method comprising:

- providing a lower airfoil segment of an outer airfoil shape;
- arranging at least one pressure vessel manufactured according to the aforementioned exemplary, preferable and alternative aspects and embodiments of the method of manufacturing a pressure vessel for an airfoil structure at the lower airfoil segment;
- arranging an upper airfoil segment of the outer airfoil shape at the lower airfoil segment and at the at least one pressure vessel; and
- curing the lower airfoil segment, the at least one pressure vessel and the upper airfoil segment.

[0098] The aforementioned exemplary, preferable, particular and alternative aspects and embodiments of the airfoil structure and the method of manufacturing a pressure vessel for an airfoil structure, along with their advantageous effects, also respectively apply to the method of manufacturing an airfoil structure and vice versa.

[0099] The method of manufacturing an airfoil structure, wherein at least one pressure vessel is arranged at the lower airfoil segment and the upper airfoil segment is arranged at the lower airfoil segment and at said at least one pressure vessel segment, provides for an advantageous method for structurally integrating at least one pressure vessel into an airfoil structure.

[0100] In particular embodiments, the at least one pressure vessel and the upper airfoil segment may respectively be arranged so that at least one pressure vessel contacts the lower airfoil segment and the upper airfoil segment, particularly directly contacts the lower airfoil segment and the upper airfoil segment.

[0101] For example, in case a plurality of pressure vessels is arranged in the step of arranging at least one pressure vessel at the lower airfoil segment, it is preferable that at least one of the plurality of pressure vessels contacts the lower airfoil segment as well as the upper airfoil segment. In exemplary embodiments, a predetermined number of pressure vessels of a plurality of pressure vessels may be configured to contact the lower airfoil segment as well as the upper airfoil segment. Nevertheless, another predetermined number of pressure vessels of a plurality of pressure vessels may be configured to contact only one of the lower airfoil segment and the upper airfoil segment.

[0102] In still further particular embodiments, in case a plurality of pressure vessels is arranged at the lower airfoil segment, the pressure vessels may be configured to not contact one another, in particular to not directly contact one another.

[0103] A pressure vessel contacting the lower airfoil segment and/or the upper airfoil segment advantageously enhances the strength of the airfoil structure. Furthermore, in case the pressure vessels are arranged so as to not contact or not directly contact one another, the elastic behavior of the airfoil structure overall is improved, because the pressure vessels do not press one another when being fueled with a pressurized fluid or gas, and because the pressure vessels may follow structural displacements of the outer airfoil shape without interfering one another, thus securing an improved structural reinforcement to the airfoil stricture.

[0104] In particular embodiments, the at least one pressure vessel is arranged so as to contact at least one of the lower airfoil segment and the upper airfoil segment prior to the step or curing, such that the lower airfoil segment, the upper airfoil segment and the at least one pressure vessel are particularly co-cured, i.e. cured in one step so as to be connected to one another.

[0105] Curing of the lower airfoil segment, the upper airfoil segment and the at least one pressure vessel in one step advantageously enhances the structural connection between the lower airfoil segment, the upper airfoil segment and the at least one pressure vessel, wherein the resin or plastic of at least one pressure vessel layer of fibre reinforced plastic particularly cures and bonds to at least one of the lower airfoil segment and the upper airfoil segment.

[0106] In still further particular embodiments, at least one pressure vessel layer of fibre reinforced plastic applied or wrapped to the at least one pressure vessel may not be cured, or may at least not be fully cured, when the at least one pressure vessel is arranged at the lower airfoil segment. This advantageously enhances the structural bonding of the at least one pressure vessel layer to the outer airfoil shape.

[0107] However, in alternative embodiments, at least one pressure vessel layer of fibre reinforced plastic applied or wrapped to the at least one pressure vessel may be at least partially cured. This advantageously provides for an improved handling, when arranging the at least one pressure vessel at the lower airfoil segment. Furthermore, this advantageously allows for securing a predetermined pre-stress, which may particularly be a compression stress to one or more vessel segments of the plurality of vessel segments.

[0108] Even though the arranging steps have been described on the basis of an initially provided lower airfoil segment, it is understood that also the upper airfoil segment may be provided at first, wherein afterwards the at least one pressure vessel is arranged at the upper airfoil segment, whereafter the lower airfoil segment is arranged at the upper airfoil segment, and whereafter the upper airfoil segment, the lower airfoil segment and the at least one pressure vessel may be cured.

[0109] In particular embodiments of the method of manufacturing an airfoil structure, in the step of curing, the lower airfoil segment, the at least one pressure vessel and the upper airfoil segment are structurally bonded to one another.

[0110] Particularly owing to the structural bonding of the lower airfoil segment, the at least one pressure vessel and the upper airfoil segment, an advantageously reinforced and stable airfoil structure is provided which is not in need of other reinforcing elements, generally known as a rib, a stringer, and/or a frame disposed inside and between an upper airfoil segment and a lower airfoil segment of an airfoil structure.

[0111] According to another aspect, a pressure vessel for an airfoil structure is provided, the pressure vessel comprising:

- a plurality of vessel segments,

  wherein the plurality of vessel segments are connected substantially in an axial direction of the pressure vessel, and
  wherein the plurality of connected vessel segments are wrapped with at least one pressure vessel layer of fibre reinforced plastic so as to form one substantially continuous pressure vessel.

[0112] The aforementioned exemplary, preferable, particular and alternative aspects and embodiments of the airfoil structure, the method of manufacturing a pressure vessel for an airfoil structure and the method of manufacturing an airfoil structure, along with their advantageous effects, also respectively apply to the pressure vessel for an airfoil structure and vice versa.

[0113] Particularly owing to the at least one pressure vessel comprising a plurality of vessel segments, an advantageous pressure vessel is provided, which may modularly be adjusted so as to geometrically correspond to a predetermined outer airfoil shape. Specifically, the plurality of vessel segments particularly facilitate a lengthwise adjustment, and the wrapped plurality of vessel segments particularly facilitates a cross-sectional adjustment. Thus, the pressure vessel which includes the plurality of vessel segments is suitable to be integrated into a variety of specific outer airfoil shapes, and advantageously enhances the integration of a fuel storage, in particular for storing a pressurized liquid or gas in an airfoil structure.

[0114] In particular embodiments of the pressure vessel for an airfoil structure, the plurality of vessel segments may include a first end segment and a second end segment, wherein the first end segment and/or the second end segment has a conical shape, wherein the conical shape has a reduced cross section toward an axial end of the pressure vessel.

[0115] Particularly owing to the conical shape with reduced cross section toward the axial end of the pressure vessel, a local reinforcement by additional layers of fibre reinforced plastic may be applied at an axial end portion of the pressure vessel without affecting a particularly constant outer shape or outer diameter of the at least one pressure vessel.

[0116] Furthermore, owing to the conical shape with reduced cross section toward the axial end of the pressure vessel, a layer of fibre reinforced plastic starts self-aligning more toward the axial direction of the pressure vessel when being wrapped toward an axial end of the conical shape of the first and/or second end segment of the plurality of vessel segments. This in turn enhances the axial stiffness and strength of the pressure vessel, may improve the axial fixation of a dome connected to an end segment of the plurality of vessel segments, and furthermore may facilitate the securing of a certain pre-stress to one or more vessel segments, particularly a pre-stress in a substantially axial direction of the pressure vessel.

[0117] In particular embodiments of the pressure vessel for an airfoil structure, the plurality of vessel segments may be connected with a pre-stress,
the pre-stress particularly being a compression stress.

[0118] Particularly owing to the connection of the plurality of vessel segments with a pre-stress, the pre-stress applied to the vessel segments may compensate for stresses which the plurality of vessel segments are subject to when the pressure vessel is fueled with a pressurized fluid or gas and/or during take-off, flight or landing, i.e. applied when the airfoil structure particularly provides for the necessary lift of an airplane.

[0119] In particular embodiments, a pre-stress may be applied to the plurality of vessel segments, when or particularly prior to the plurality of vessel segments being wrapped. In still further particular embodiments, a compression stress may be applied to the plurality of vessel segments when or particularly prior to the plurality of vessel segments being wrapped. Specifically, a compression stress may be applied to the plurality of vessel segments in a substantially axial direction of the pressure vessel, i.e. particularly in a substantially axial direction of the vessel segments of the plurality of vessel segments.

[0120] Particularly owing to the compression stress applied to the vessel segments of the plurality of vessel segments, the sustainability for tensile stresses of the vessel segments of the plurality of vessel segments is increased in particular when the pressure vessel is fueled with a pressurized fluid or gas, as well as when the airfoil structure is bent or deformed due to the weight of the airfoil structure and/or due to aerodynamic loads.

[0121] In particular embodiments, one or more vessel segments of the plurality of vessel segments include at least one vessel segment layer of fibre reinforced plastic. Particularly owing to a pre-stress, in particular owing to a compression stress applied to the vessel segments, in particular vessel segments which include at least one vessel segment layer of fibre reinforced plastic have the plastic of the fibre reinforced plastic layer in a pre-compressed state. Then, when the pressure vessel is fueled with a pressurized fluid or gas, a tensile stress acts onto the vessel segments, wherein owing to the pre-compression stress of the plastic of the vessel segment layer, crack formation in the plastic of said vessel segment layer can be prevented or at least decelerated, which in turn ensures an increased operating life of the vessel segments, and thus an increased operating life of the pressure vessel. Furthermore, prevented, decelerated or reduced crack formation in the plastic of a vessel segment may improve the tightness for containing or storing a certain pressurized fluid or gas.

[0122] These and other objects, features and advantages of the present invention will become more apparent upon reading of the following detailed description of particular embodiments and accompanying drawings. It should be understood that even though embodiments are separately described, single features thereof may be combined to additional embodiments.

Figure 1 shows a perspective sectional view of an exemplary airfoil structure;

Figure 2 shows a sectional view of an exemplary pressure vessel;

Figure 3 shows a side view of an exemplary vessel segment;

Figure 4 shows an exemplary state in an exemplary method of manufacturing a pressure vessel in a sectional view;

Figure 5 shows a further exemplary state in an exemplary method of manufacturing a pressure vessel in a sectional view;

Figure 6 shows a further exemplary state in an exemplary method of manufacturing a pressure vessel in a sectional view;

Figure 7 shows a further exemplary state in an exemplary method of manufacturing a pressure vessel in a sectional view;

Figure 8 shows a further exemplary state in an exemplary method of manufacturing a pressure vessel in a sectional view;

Figure 9 shows a flowchart of an exemplary method for manufacturing a vessel segment;

Figure 10 shows a flowchart of an exemplary method for manufacturing a pressure vessel; and

Figure 11 shows a flowchart of an exemplary method for manufacturing an airfoil structure.

[0123] Figure 1 shows a perspective sectional view on an exemplary embodiment of an airfoil structure 10. As indicated in Fig. 1, the airfoil structure 10 may form part of a wing of an airplane, wherein the outer airfoil shape 12 is configured to contact in use an airflow, in particular an outside airflow, which in combination with a shape of the outer airfoil shape 12 is generally considered as creating a lift force for an aircraft, for example when the aircraft takes off, flies or lands.

[0124] As shown in Fig. 1, the outer airfoil shape 12 may be comprised or substantially formed of an upper airfoil segment 16 and a lower airfoil segment 14. This partition is not to be considered as limiting. Specifically, the upper airfoil segment 16 (as a particular first airfoil segment) is not limited to a segment of the outer airfoil shape 12 which is disposed strictly above the lower airfoil segment 14 (as a particular second airfoil segment) and vice versa. Instead, a portion of the upper airfoil segment 16 may be disposed in front, behind, and/or below a portion of the lower airfoil segment 14. In turn, a portion of the lower airfoil segment 14 may be disposed in front, behind, and/or above a portion of the upper airfoil segment 16. Further, the outer airfoil shape 12 may have more than two segments, also when regarding a cross-section of the outer airfoil shape 12.

[0125] In exemplary embodiments, the upper airfoil segment 16 and/or the lower airfoil segment 14 may include at least one airfoil layer of fibre reinforced plastic, particularly a sandwich structure of fibre reinforced plastic, in particular a fibre reinforced honeycomb sandwich. Without being limited thereto, an exemplary fibre reinforced honeycomb sandwich for the upper airfoil segment 16 and/or the lower airfoil segment 14 may include at least two layers of fibre reinforced plastic which are spaced apart by at least one layer of honeycomb core at least partly disposed in between said at least two layers of fibre reinforced plastic.

[0126] As shown in Fig. 1, the airfoil structure 10 includes at least one pressure vessel 20 arranged substantially between an upper airfoil segment 16 and a lower airfoil segment 14. As specifically shown in Fig. 1, but without being limited to it, four pressure vessels 20 may be arranged substantially between the upper airfoil segment 16 and the lower airfoil segment 14.

[0127] The pressure vessels 20 may respectively substantially extend along an axial direction A of the respective pressure vessel 20. Said axial direction A of a pressure vessel may be substantially parallel to a wingspan direction W of the airfoil structure 10. However, in alternative embodiments, the axial direction A of a pressure vessel 20 which is arranged between the upper airfoil segment 16 and the lower airfoil segment 14 may be inclined with respect to the wingspan direction W of the airfoil structure 10. The wingspan direction W is considered as substantially indicating an extension of a wing of an airplane.

[0128] One of the pressure vessels 20 shown in Fig. 1 is indicated with a radial direction R pointing from an axis A of the respective pressure vessel 20 toward a sidewall of the pressure vessel 20. The radial direction R of the pressure vessel 20 may be substantially perpendicular to the axis A or to the axial direction A of the pressure vessel 20. As thus shown in Fig. 1, the pressure vessels 20 may have a substantially cylindrical shape, i.e. have a substantially cylindrical cross section. Even though not shown, one or more pressure vessels 20 of a plurality of pressure vessels 20 may at least partially have a shape different from a cylindrical shape, i.e. different from a substantially cylindrical cross section, such as an elliptical, polygonal, and/or other contoured cross section.

[0129] As exemplarily illustrated in Fig. 1, the pressure vessels 20 disposed between the lower airfoil segment 14 and the upper airfoil segment 16 are structurally affixed to the lower airfoil segment 14 and/or the upper airfoil segment 16, particularly configured to directly or indirectly contact (or be connected to) the lower airfoil segment 14 and the upper airfoil segment 16, which provides for an enhanced structural support to the outer airfoil shape 12. Furthermore, the pressure vessels 20 disposed between the lower airfoil segment 14 and the upper airfoil segment 16 are particularly configured to be arranged distant from one another, as exemplarily shown by the gap 54, which allows the pressure vessels 20 to follow a displacement, deformation and/or movement of the outer airfoil shape 12 without interference of adjacent pressure vessels 20. The gap 54 may particularly be a gap between adjacent or adjacently arranged pressure vessels 20. Furthermore, said gap 54 may in particular be a gap in a direction substantially perpendicular to the wingspan direction W.

[0130] Even though a pressure vessel 20 may be configured to directly contact the lower airfoil segment 14 and/or the upper airfoil segment 16, one or more prismatic caps 50 may be applied between a portion of the pressure vessel 20 and a portion of the respective lower and/or upper airfoil segment 14, 16.

[0131] Specifically, since the pressure vessel 20 disposed between the lower airfoil segment 14 and the upper airfoil segment 16 generally has a curvature or shape which is at least partially different from the curvature or shape of the lower airfoil segment 14 and the upper airfoil segment 16, a spandrel 52 may be formed between a portion of the pressure vessel 20 and an adjacent portion of the respective lower or upper airfoil segment 14, 16, in particular between portions of the pressure vessel 20 and the respective lower or upper airfoil segment 14, 16 which are adjacent to a contacting portion between the pressure vessel 20 and the respective lower or upper airfoil segment 14, 16.

[0132] Particularly, the at least one prismatic cap 50 may be disposed at at least at one of the spandrels 52 formed between a portion of the pressure vessel 20 and an adjacent portion of the respective lower or upper airfoil segment 14, 16, wherein the one or more prismatic caps 50 may for example extend in a substantially axial direction A of the pressure vessel 20.

[0133] The one or more prismatic caps 50 advantageously improve guidance of a load applied to the respective lower or upper airfoil segment 14, 16 to the pressure vessel 20 disposed in between said lower and upper airfoil segment 14, 16. The one or more prismatic caps 50 may particularly be applied to or disposed at a pressure vessel 20 prior to arrangement of the pressure vessel 20 at one of the lower or upper airfoil segments 14, 16. Furthermore, the one or more prismatic caps 50 may particularly be configured to reinforce the pressure vessel 20 at which they are applied to or disposed. Specifically, the one or more prismatic caps 50 may be configured to carry at least a portion of the load of the pressure vessel 20, when the pressure vessel 20 is in a high pressurized state, and/or a bending load of the airfoil structure 10 during flight.

[0134] Further particularly, the one or more prismatic caps 50 may include at least one layer of fibre reinforced plastic. Still further particularly, the one or more prismatic caps 50 may be co-cured with the upper airfoil segment 16, the lower airfoil segment 14 and the at least one pressure vessel 20 so as to be bonded with the respectively adjacent ones of the upper airfoil segment 16, the lower airfoil segment 14 and the at least one pressure vessel 20 in one curing step.

[0135] Fig. 2 shows a sectional view on an exemplary pressure vessel 20 according to an embodiment of the present invention in a side view. As exemplarily illustrated in Fig. 2, a pressure vessel 20 may comprise a plurality of vessel segments 30 which are connected to one another, particularly substantially in an axial direction A of the pressure vessel 20. While Fig. 2 illustrates a pressure vessel 20 with four vessel segments 30, it is to be noted that a pressure vessel 20 may modularly include any number of two or more vessel segments 30.

[0136] As shown by the sectional view in Fig. 2, the vessel segments 30 may have a substantially hollow shape. Each vessel segment 30 may in particular have a first open end at an axial end thereof and a second open end at an opposite axial end thereof, wherein the vessel segment 30 particularly extends between the first axial end and the opposite second axial end in a substantially hollow manner, similar to a cylinder.

[0137] As shown on the left side of Fig. 2, a first end segment 34 of the plurality of vessel segments 30 is provided, which has a first open end which is particularly connected to a first dome 22. The first dome 22 may in particular be configured to form a closure of the pressure vessel 20 and/or a valve of the pressure vessel 20.

[0138] At a second open end of the first end segment 34, which is disposed at the axial opposite of the first open end of the first end segment 34, the first end segment 34 is connected to a mid segment 32 of the plurality of vessel segments 30. Specifically, the second open end of the first end segment 34 may be connected to a first open end of the mid segment 32.

[0139] As indicated in Fig. 2 and further particularly shown in Figs. 4 to 8, an open end of a vessel segment 30, 32, 34, 35 may at least partly have a stepped shape which may particularly be configured to mate with a corresponding open end of an adjacent vessel segment 30, 32, 34, 35, specifically to substantially mate with a corresponding open end of an axially adjacent vessel segment 30, 32, 34, 35. Thus, even though dotted lines are shown in Fig. 2 which roughly indicate a separation between adjacent vessel segments 30, 32, 34, 35, adjacently connected vessel segments 30, 32, 34, 35 rather stepwise transition from one vessel segment 30, 32, 34, 35 to an axially adjacent vessel segment 30, 32, 34, 35.

[0140] Accordingly, each of the vessel segments 30, 32, 34, 35 may have one or two stepped open ends in an axial direction, wherein a radially inner portion of the respective vessel segment 30, 32, 34, 35 particularly has an axial or lengthwise extension which is different from an axial or lengthwise extension of a radially outer portion of the respective vessel segment 30, 32, 34, 35, the radially outer portion being radially adjacent to the radial inner portion. In other words, a vessel segment 30, 32, 34, 35 may have a stepped open end, wherein at a respective first and/or second axial end of the vessel segment 30, 32, 34, 35 one of a radially inner portion and a radially outer portion protrudes further in an axial direction A than the other one of the radially inner portion and the radially outer portion of the respective vessel segment 30, 32, 34, 35.

[0141] In particular embodiments, the one or more stepped open ends may be formed to the respective vessel segment 30, 32, 34, 35 by cutting. Alternatively, the one or more stepped open ends may be formed integrally to the respective vessel segment 30, 32, 34, 35 and/or by milling or etching or other suitable means.

[0142] In this manner, the plurality of vessel segments 30 may be substantially axially connected to one another along the axial direction A, particularly with at least a form fit owing to the stepped open ends of the respective vessel segments 30.

[0143] As shown in Fig. 2, the second end segment 35 of the plurality of vessel segments 30 may have a second open end which is configured to be connected to a second dome 22.

[0144] As furthermore indicated in Fig. 2, the respective first and second dome 22, 22 is at least partially radially surrounded by a first and second ring member 26, 26 respectively, wherein the ring members 26, 26 are in turn particularly at least partially enclosed by at least a first pressure vessel layer 40 of fibre reinforced plastic, to improve the axial fixation of the dome 22, 22 to the respectively connected vessel segments 30, 32, 34, 35.

[0145] As furthermore shown in Fig. 2, the pressure vessel 20 may include at least a first pressure vessel layer 40 of fibre reinforced plastics and particularly further pressure vessel layers 44 of fibre reinforced plastic. In particular at least a portion of the first and second end segments 34, 35 and the mid segments 32 of the plurality of pressure vessel segments 30 may be wrapped with at least a first pressure vessel layer 40 of fibre reinforced plastics and particularly with further pressure vessel layers 44 of fibre reinforced plastic in order to provide the pressure vessel 20 with a predetermined strength and/or stiffness, in particular with a certain axial strength and/or stiffness.

[0146] As shown in Fig. 2, at least part of the end segments 34, 35 of the plurality of vessel segments 30 may have a substantially conical shape, wherein a diameter D or a cross section toward a respective axial end of the end segment 34, 35 is gradually or stepwise reduced. As illustrated in Fig. 2 however, said reduced cross section or diameter D of the respective end segments 34, 35 particularly allows for applying, wrapping and/or folding of additional layers of fibre reinforced plastic at an axial end of the pressure vessel 20 without affecting (particularly increasing) the cross section or diameter of the pressure vessel 20 at its said respective axial end.

[0147] Fig. 3 shows a side view on an exemplary vessel segment 30, in particular on a mid or intermediate segment 32 of the plurality of vessel segments 30. Nevertheless, Fig. 3 may also at least partially relate to an end segment 34, 35.

[0148] As exemplarily indicated in Fig. 3, a vessel segment 30, 32 may particularly include at least one vessel segment layer 36 of fibre reinforced plastic, wherein the fibres included in said at least one vessel segment layer 36 of fibre reinforced plastic are exemplarily drawn as oblique lines extending along an outer circumferential surface of the vessel segment 30, 32.

[0149] As shown in Fig. 3, the fibres of the at least one vessel segment layer 36 may roughly or substantially extend perpendicularly with respect to the axial direction A of the pressure vessel 20, which may substantially correspond to an axial direction A of the vessel segment 30,

32. In other words, the vessel segment 30, 32 may include at least one vessel segment layer 36 of fibre reinforced plastic, wherein the fibres of said at least one vessel segment layer 36 roughly extend in substantially circumferential direction of said vessel segment 30, 32.

[0150] In particular embodiments, the fibres of the at least one vessel segment layer 36 may substantially extend with an angle in a range of about +80° to about -80° with respect to the axis A of the pressure vessel 20, particularly with an angle of about +80° and/or an angle of about -80° with respect to the axis A of the pressure vessel 20, wherein the axis of the pressure vessel 20 may correspond to an axis of the vessel segment 30, 32. In other words, the fibres of the at least one vessel segment layer may substantially extend with an angle in a range of about +10° to about -10° with respect to a circumference of the vessel segment 30, 32 or a radial direction R of the pressure vessel 20, particularly with an angle of about +10° and/or an angle of about -10° with respect to a circumference of the vessel segment 30, 32 or the radial direction R of the pressure vessel 20, wherein the circumference of the vessel segment 30, 32 may be substantially perpendicular to an axis A of the vessel segment 30, 32, and wherein the axis A of the vessel segment 30, 32 may in turn correspond to the axis A of the pressure vessel 20.

[0151] Nevertheless, in alternative embodiments, the fibres of the at least one vessel segment layer 36 may extend in any suitable direction for manufacturing a vessel segment which may be different from the above emphasized angle range of about +80° to about -80° with respect to the axis A of the pressure vessel 20.

[0152] An end segment 34, 35, may also have fibres of at least one vessel segment layer 36 which substantially extend in the same manner as described above. However, depending on the method for applying the at least one vessel segment layer 36, and in the particular case the end segment 34, 35 does have a conical shape with reduced cross section, for example by using a conical core onto which the at least one vessel segment layer 36 is applied, the fibres of the at least one vessel segment layer 36 may tend to increasingly self-align toward the axial direction A when applied further toward an axial end of the end segment 34, 35, for example when applying the fibres by winding or braiding.

[0153] As furthermore indicated in Fig. 3, a vessel segment 30 may have a stepped open end at one or both axial ends 38, 39 of said vessel segment 30.

[0154] As exemplarily shown but not to be considered as limiting, at a first end 38 of the vessel segment 30, a radially inner portion may protrude further forward in the axial direction A than a radially outer portion at said first end 38 of the vessel segment 30. In other words, at a first end 38 of the vessel segment 30, the vessel segment 30 may have a radially inner portion which has an inner diameter Di and which substantially axially protrudes further forward than a radially outer portion which has an outer diameter Do.

[0155] Similarly, at a second end 39 of the vessel segment 30, the vessel segment 30 may have a radially inner portion which has an inner diameter Di and which substantially axially protrudes further forward than a radially outer portion which has an outer diameter Do.

[0156] In particular embodiments, the stepped open end at one or both axial ends 38, 39 particularly is substantially perpendicularly stepped. That is, particularly at least one of the radially inner portion and/or the radially outer portion has a surface which is substantially parallel to a radial direction R of the vessel segment 30, wherein the radial direction R of the vessel segment 30 may substantially correspond to a radial direction R of the pressure vessel 20. Nevertheless, in some embodiments, at least one of the radially inner portion and the radially outer portion may have a surface which is substantially oblique or inclined with respect to the radial direction R of the vessel segment 30.

[0157] It is understood that a vessel segment 30 which is configured to be connected to or mated with an adjacent vessel segment 30 particularly has a substantially corresponding stepped open end, in accordance with the stepped open end it is to be connected to or mated with.

[0158] Fig. 4 shows an exemplary state in an exemplary method of manufacturing a pressure vessel in a sectional view, in particular in a side view.

[0159] Fig. 4 shows a state in which a mid segment 32 (as a particular intermediate segment) of a plurality of vessel segments 30 and an end segment 34, 35 of a plurality of vessel segments 30 are connected to one another, in particular substantially axially connected to one another.

[0160] As shown in Fig. 4, a stepped open end of the mid segment 32 engages a stepped open end of the end segment 34, 35. In exemplary embodiments, the mid segment 32 and the end segment 34, 35 may be adhesively joined, joined via frictionally fit and/or merely axially stacked.

[0161] Alternatively, the mid segment 32 and the end segment 34, 35 may be joined via form fit and/or joined merely by pressing adjacent vessel segments to one another by wrapping the vessel segments 30, 32, 34, 35 with at least one pressure vessel layer 40 of fibre reinforced plastic.

[0162] Owing to the segmented structure of the pressure vessel 20 which includes a plurality of vessel segments 30, an advantageous modular structure is provided.

[0163] Without being limited thereto, the modular structure of the plurality of vessel segments 30 particularly allows for distinct configuring each vessel segment 32, 34, 35 of the plurality of vessel segments 30, for example the mid segments 32 and/or the end segments 34, 35, with different mechanical or structural properties than other mid segments 32 and/or other end segments 34, 35.

[0164] Thus, in some embodiments, a mid segment 32 and/or an end segment 34, 35 may have a different stiffness, strength and/or shape than another, particularly an adjacent, mid segment 32 and/or another end segment 34, 35. This allows for providing customized vessel segments 30 which enhance the structural behavior of the airfoil structure 10 at one or more predetermined locations, for example when connecting a link element to a predetermined portion of the plurality of vessel segments 30. Nevertheless, in particular embodiments a mid segment 32 may have the substantially same stiffness, strength and/or shape than another mid segment 32, and an end segment 34, 35 may have the substantially same stiffness, strength and/or shape than the other end segment 34, 35.

[0165] Fig. 5 shows a further exemplary state in an exemplary method of manufacturing a pressure vessel 20 in a sectional view in a side view.

[0166] In comparison to Fig. 4, Fig. 5 shows a state in which further to the vessel segments 30, 32, 34, 35 which are adjacently connected, particularly substantially axially connected, a dome 22 is connected to at least one end segment 34, 35 of the plurality of connected vessel segments 30. Furthermore, a liner 28 is disposed inside or internally of at least a portion of the plurality of connected vessel segments 30.

[0167] In particular embodiments, the dome 22 may be adhesively connected to at least one end segment 34, 35 of the plurality of vessel segments 30. Additionally or alternatively, the dome 22 may be connected to at least one of end segments 34, 35 via other suitable connection means including a press fit, a form fit, one or more screws, one or more rivets, a snapping engagement or any other suitable means.

[0168] As shown in Fig. 5, the liner 28 may be mounted to the dome 22, particularly mounted to the dome 22 via at least one boss part 24 which may be fitted, snapped, screwed or otherwise connected to the dome 22. Specifically, the liner 28 may be tightly fit to the dome 22 via the boss part 24, in particular press fit to the dome 22 and/or sandwiched between a substantially radial protrusion of the boss part 24 and an axial inner end of the dome 22.

[0169] As shown in Fig. 5, the boss part 24 may particularly have a flange 25 disposed at an axial end of the boss part 24, specifically at an axial end which is configured to face an axial inner end of the dome 22. The axial inner end of the dome 22 may correspond to an axial side of the dome 22 which is configured to face the vessel segments 30. The flange 25 may particularly be configured to tightly seal the liner 28 to the dome 22. In some embodiments, the flange 25 may be configured to tightly press the liner to the dome 22. Furthermore, the liner 28 may be configured to be tightly sandwiched between the flange 25 of the boss part 24 and the axial inner end of the dome 22.

[0170] Particularly, the liner 28 may be adhesively connected or bonded to at least a portion of the flange 25 and/or adhesively connected or bonded to the axial inner end of the dome 22. Nevertheless, in alternative embodiments, the liner 28 may be fixed by other means suitable for tightly connecting or fixing the liner 28 to the boss part 24, particularly to the flange 25 of the boss part 24, and/or to the dome 22.

[0171] In exemplary embodiments, the liner 28 may be continuously disposed inside the plurality of vessel segments 30 and the domes 22, wherein the domes 22 are disposed at the first and second end segments 34, 35.

[0172] Fig. 6 shows a further exemplary state in a particular method of manufacturing a pressure vessel 20 in a sectional view in a side view.

[0173] In comparison to Fig. 5, Fig. 6 shows a state in which at least a first pressure vessel layer 40 of fibre reinforced plastic is applied to the plurality of connected vessel segments 30. As illustrated in Fig. 6, the first pressure vessel layer 40 may be applied so as to at least partially extend over the connected plurality of vessel segments 30 and the respective domes 22 connected to the plurality of vessel segments 30.

[0174] Even though the first pressure vessel layer 40 is indicated as folded back in Fig. 6, in particular folded in a direction substantially opposite the axial direction A, it is noted that before folding the first pressure vessel layer 40, said first pressure vessel layer 40 is configured to at least partially extend over the vessel segments 30 and the domes 22 in the substantially axial direction A, i.e. beyond the vessel segments 30 and the domes 22 in the substantially axial direction A.

[0175] In particular embodiments, the first pressure vessel layer 40 includes fibres which extend substantially in the axial direction A. Nevertheless, the first pressure vessel layer 40 may include fibres which extend in a direction different from the substantially axial direction A, particularly in a range of an angle of about +40° to about -40°, further particularly in a range of an angle of about +30° to about -30°, still further particularly in a range of an angle of about +20° to about -20°, and still more particularly in a range of an angle of about +10° to about -10° with respect to the axial direction A.

[0176] The first pressure vessel layer 40 particularly including fibres which roughly extend in the axial direction A advantageously provides for an axial strength and stiffness for the pressure vessel 20, and may furthermore facilitate securing a predetermined pre-stress applied to the one or more of the plurality of vessel segments 30.

[0177] Fig. 7 shows a further exemplary state in a particular method of manufacturing a pressure vessel 20 in a sectional view in a side view.

[0178] In comparison to Fig. 6, Fig. 7 shows a state in which at least a second pressure vessel layer 42 of fibre reinforced plastic is applied to at least a portion of the first pressure vessel layer 40. Similar to the first pressure vessel layer 40, the second pressure vessel layer 42 particularly extends over at least a portion of the dome 22, in particular beyond the dome 22 in the substantially axial direction A.

[0179] As illustrated in Fig. 7, at least one ring member 26 may be disposed to at least partially radially surround dome 22 at a respective axial end. The ring member 26 is particularly disposed at a folding portion of the first and/or second pressure vessel layer 40, 42. In other words, the ring member 26 may be at least partially enclosed by the first and/or second pressure vessel layer 40, 42 by folding the respective first and/or second pressure vessel layer 40, 42 axially backwards, i.e. in a direction substantially opposite the axial direction A or the direction of extending beyond the respective dome 22. In other words, the first and/or second pressure vessel layer 40, 42 are configured to at least partially axially extend beyond the dome 22, and to be folded back in a direction substantially axially toward the end segment 34, 35, to which said dome 22 is connected to. In the folding portion formed by the first and/or second pressure vessel layer 40, 42, particularly the at least one ring member 26 is disposed which at least partially radially surrounds the respective dome 22.

[0180] Fig. 8 shows a further exemplary state in a particular method of manufacturing a pressure vessel 20 in a sectional view in a side view.

[0181] In comparison to Fig. 7, Fig. 8 shows a state in which the first and/or the second pressure vessel layer 40, 42 is at least partially sandwiched by further pressure vessel layers 44, particularly radially sandwiched by further pressure vessel layers 44. That is, further to an at least one first pressure vessel layer 40, further pressure vessel layers 44 may be applied, particularly wrapped to the plurality of vessel segments 30, and further particularly at least partially wrapped radially around the first pressure vessel layer 40.

[0182] As illustrated in Fig. 8, the ring member 26 may be at least partially enclosed by at least the first pressure vessel layer 40, and optionally by further pressure vessel layers, such as a second pressure vessel layer 42. The ring member 26 is particularly disposed so as to axially face the dome 22, and further particularly to axially face the dome 22 while at least partially radially surrounding the dome 22.

[0183] Owing to one or more pressure vessel layers 40, 42 which are particularly folded and configured to at least partially enclose the ring member 26, the ring member 26 may be axially secured to the dome 22, and thus enhance the axial the strength of the pressure vessel 20 overall.

[0184] In particular the first pressure vessel layer 40 and/or the second pressure vessel layer 42 may include fibres which substantially extend roughly in the axial direction A, particularly in a range of an angle of about +20° to about -20°, further particularly in a range of an angle of about +10° to about -10° with respect to the axial direction A. This advantageously enhances the axial strength of the pressure vessel 20, in particular at an axial end of the pressure vessel 20, wherein the dome 24 is fixed to an end segment 34, 35.

[0185] As shown in Fig. 8, at least the folded back portions of the first pressure vessel layer 40 and/or the second pressure vessel layer 42 may be at least partially sandwiched or arranged between further pressure vessel layers 44.

[0186] In exemplary embodiments, the further pressure vessel layers 44 which are configured to sandwich at least a portion of the first and/or the second pressure vessel layer 40, 42 may have fibres which extend at an angle which deviates from an angle of the fibres of the first and/or the second pressure vessel layer 40, 42, particularly in a range of an angle of about +5° to about -5°, further particularly in a range of an angle of about +10° to about -10°, still further particularly in a range of an angle of about +20° to about - 20°.

[0187] Further pressure vessel layers 44 which include fibres extending as described above, advantageously may enhance the axial strength of the pressure vessel 20 and/or provide at least a certain predetermined resistance against crack formation or crack growth in radial direction R.

[0188] Fig. 9 shows an exemplary flowchart of a method for manufacturing a vessel segment 30, the method comprising the steps of:

- S11: applying at least one vessel segment layer 36 of fibre reinforced plastic on a core;
- S12: at least partially curing the applied at least one vessel segment layer 36 of fibre reinforced plastic;
- S13: removing the at least one at least partially cured vessel segment layer 36 from the core so as to substantially form a vessel segment 30; and
- S14: forming a connectable shape to at least one axial end 38, 39 of the vessel segment 30.

[0189] Owing to the above exemplary method, an individual vessel segment 30 can be manufactured, wherein the connectable shape formed to at least one axial end 38, 39 of the vessel segment 30 is particularly configured to be connectable with a corresponding at least one axial end 38, 39 of another vessel segment 30, to which the vessel segment 30 is configured to be connected to, particularly to which the vessel segment 30 is configured to be substantially axially connected to.

[0190] In particular embodiments, the vessel segment layer 36 of fibre reinforced plastic includes fibres which roughly extend in the radial direction R of the vessel segment 30, particularly in a range of an angle of about +80° to about -80° with respect to the axial direction A of the vessel segment 30. This advantageously allows the vessel segment 30 to be mechanically cut at an axial end, without cutting through a majority of fibres of the vessel segment layer 36 which substantially extend in circumferential direction.

[0191] The fibres of the vessel segment layer 36 substantially extending in the circumferential direction therefore advantageously enhance the stress-resistance of the pressure vessel 20 in circumferential direction, while particularly allowing an advantageous segmented modular structure of the pressure vessel 20.

[0192] Furthermore, the particularly extension of the fibres of the vessel segment layer 36 advantageously facilitates the application of a pre-stress, in particular a compression stress in the axial direction A, in particular to the plastic of the vessel segment layer 36 of fibre reinforced plastic, because the fibres of the vessel segment layer 36 which extend in a substantially circumferential direction, i.e. substantially in the radial direction R, do not provide for a possibly hindering stiffness in the axial direction A.

[0193] In the above described manner according to steps S11 to S14, and in accordance with a predetermined application method and/or a predetermined core shape, a plurality of individual but connectable vessel segments 30 may be manufactured, suitable for being included in a pressure vessel 20 for an airfoil structure 10.

[0194] Fig. 10 shows an exemplary flowchart for manufacturing a pressure vessel 20, the method comprising (particularly in this order) the steps of:

S21: connecting a plurality of vessel segments 30;

S22: disposing a liner 28 in a portion of the plurality of connected vessel segments 30;

S23: connecting a first dome 22 with a first end segment 34 of the plurality of vessel segments 30 and a second dome 22 with a second end segment 35 of the plurality of vessel segments 30;

S24: applying a compression stress to at least one vessel segment 30 of the plurality of vessel segments 30;

S25: wrapping at least a first pressure vessel layer 40 of fibre reinforced plastic to the plurality of connected vessel segments 30;

S26: fixing a first ring member 26 to the first dome 22 and a second ring 26 member to the second dome 22; and

S27: at least partially curing the at least one pressure vessel layer 40.

[0195] Further to the above mentioned exemplary steps S21 to S27 of manufacturing a pressure vessel 20, the method of manufacturing a pressure vessel 20 may optionally further include a step S28 of applying at least one prismatic cap 50 to the at least one pressure vessel. Said step S28 may particularly be performed in between steps S26 and S27 or after step S27.

[0196] Furthermore, step S27 may be optional, so that an exemplary method of manufacturing a pressure vessel 20 may be performed without at least partially curing the at least one pressure vessel layer 40.

[0197] Furthermore, also step S26 may in particular be optional, so that an exemplary method of manufacturing a pressure vessel 20 may be performed without fixing a first ring member 26 and second ring member 26 to respective domes 22.

[0198] In particular embodiments however, step S27 includes partially curing the at least one pressure vessel layer 40, and/or may include partially curing a radially outer pressure vessel layer of fibre reinforced plastic. In other words, the pressure vessel 20 particularly includes at least one radially outer pressure vessel layer of fibre reinforced plastic which is partially cured, i.e. not fully cured, to advantageously allow a co-curing of the at least one pressure vessel 20 with a lower airfoil segment 14 and/or an upper airfoil segment 16, for structurally bonding, in particular integrally bonding, the pressure vessel 20 to at least one of the lower airfoil segment 14 and the upper airfoil segment 16.

[0199] Fig. 11 shows an exemplary flowchart for manufacturing an airfoil structure 10, the method comprising (particularly in this order) the steps of:

S31: providing a lower airfoil segment 14 or an upper airfoil segment 16;

S32: arranging at least one pressure vessel 20 at the provided lower or upper airfoil segment 14, 16;

S33: arranging the other of the provided lower airfoil segment 14 or upper airfoil segment 16 at the at least one pressure vessel 20 and at the provided lower airfoil segment 14 or upper airfoil segment 16; and

S34: curing the lower airfoil segment 14, the upper airfoil segment 16 and the at least one pressure vessel 20.

[0200] In particular embodiments, at least one of the at least one pressure vessel 20 and the lower and upper airfoil segments 14, 16 may include a facing layer of at most partially cured or partially cured fibre reinforced plastic, in order to facilitate a co-curing of the at least one pressure vessel 20 with the lower airfoil segment 14 and/or the upper airfoil segment 16, for structurally bonding, in particular integrally bonding the pressure vessel 20 to at least one of the lower airfoil segment 14 and the upper airfoil segment 16. In other words, at least one of the at least one pressure vessel 20 and the lower and upper airfoil segments 14, 16 may include an outermost layer of fibre reinforced plastic which is at most partially cured or includes partially cured fibre reinforced plastic, in order to facilitate a co-curing of the at least one pressure vessel 20 with the lower airfoil segment 14 and/or the upper airfoil segment 16, for structurally bonding, in particular integrally bonding the pressure vessel 20 to at least one of the lower airfoil segment 14 and the upper airfoil segment 16.

[0201] The facing layer or the outermost layer of at most partially cured or partially cured fibre reinforced plastic of the at least one pressure vessel 20 may be a radially outer pressure vessel layer or the at least one first pressure vessel layer 40.

[0202] A partially or at most partially cured layer of fibre reinforced plastic as mentioned herein may be or may be considered as a wet layer, i.e. a layer of fibre reinforced plastic wherein at least a portion of the plastic material may still be cured or hardened.

[0203] The layers of fibre reinforced plastic as mentioned herein, without being limited thereto, may independently in particular include or substantially consist of carbon fibres, glass fibres, aramid fibres, basaltic fibres or other fibres. Furthermore, the layers of fibre reinforced plastic as mentioned herein, without being limited thereto, may independently in particular include or substantially consist of a thermoset and/or a thermoplastic resin, in particular an epoxy resin, a polyester resin, a vinyl ester resin, and/or other thermoplastic resins.

[0204] In exemplary embodiments, the fibre volume content, i.e. the volume ratio of fibres to fibres plus resin may be in a range of about 35% to about 70%, particularly in a range of about 45% to about 68% to provide for sufficient stiffness and strength of the pressure vessel 20.

List of Reference Numerals

[0205]

10	airfoil structure
12	outer airfoil shape
14	lower airfoil segment
16	upper airfoil segment
20	pressure vessel
22	dome
24	boss part
25	flange
26	ring member
28	liner
30	vessel segment
32	mid segment (intermediate segment)
34	first end segment
35	second end segment
36	vessel segment layer (of fibre reinforced plastic)
38	first end
39	second end
40	first pressure vessel layer (of fibre reinforced plastic)
42	second pressure vessel layer (of fibre reinforced plastic)
44	further pressure vessel layer(s)
50	prismatic cap
52	spandrel
54	gap
A	axis, axial direction
D	diameter
Di	inner diameter
Do	outer diameter
R	radial direction
S11-S14	steps for manufacturing a vessel segment
S21-S27	steps for manufacturing a pressure vessel
S31-S34	steps for manufacturing an airfoil structure
W	wingspan direction

Claims

1. An airfoil structure (10) comprising:

   - an outer airfoil shape (12) configured to contact an airflow; and
   - at least one pressure vessel (20) disposed inside the outer airfoil shape (12) so that the at least one pressure vessel (20) is configured to carry at least a part of a load applied to the outer airfoil shape (12);

     wherein the at least one pressure vessel (20) comprises a plurality of vessel segments (30),
     wherein the plurality of vessel segments (30) are connected substantially in an axial direction (A) of the at least one pressure vessel (20), and
     wherein the plurality of connected vessel segments (30) substantially are wrapped with at least one pressure vessel layer (40) of fibre reinforced plastic so as to form one substantially continuous pressure vessel (20).

2. The airfoil structure (10) of claim 1, wherein the plurality of vessel segments (30) are connected with a pre-stress,
   the pre-stress particularly being a compression stress.

3. The airfoil structure (10) of claim 1 or 2, wherein the vessel segments (30) of the plurality of vessel segments (30) include at least one vessel segment layer (36) of fibre reinforced plastic, and wherein a direction of the fibres of the pressure vessel layer (40) deviates from a direction of the fibres of the vessel segment layer (36) by an angle in a range of about 30° to about 90°,

   particularly by an angle in a range of about 45° to about 90°,
   further particularly by an angle in a range of about 60° to about 90°.

4. The airfoil structure (10) of any one of the preceding claims, wherein the at least one pressure vessel layer (40) includes a plurality of pressure vessel layers (40; 42; 44), wherein a first pressure vessel layer (40) of the plurality of pressure vessel layers (40; 42; 44) extends over the connected vessel segments (30) in the axial direction (A) of the at least one pressure vessel (20) and is folded back so as to be at least partially sandwiched by further pressure vessel layers (44) of the plurality of pressure vessel layers (40; 42; 44).

5. The airfoil structure (10) of any one of the preceding claims, wherein the outer airfoil shape (12) includes an upper airfoil segment (16) and a lower airfoil segment (14), wherein the at least one pressure vessel (20) directly connects the upper airfoil segment (16) with the lower airfoil segment (14).

6. The airfoil structure (10) of any one of the preceding claims, wherein the at least one pressure vessel (20) is configured to tightly contain hydrogen at a pressure of at least about 200 bar.

7. A method of manufacturing a pressure vessel (20) for an airfoil structure (10), the method comprising the steps of:

- providing a plurality of vessel segments (30);
- connecting the plurality of vessel segments (30) substantially in an axial direction (A);
- wrapping at least one pressure vessel layer (40) of fibre reinforced plastic around the plurality of connected vessel segments (30) so as to form one substantially continuous pressure vessel (20).

8. The method of manufacturing a pressure vessel (20) of claim 7, the method further comprising a step of:

- compressively biasing the plurality of connected vessel segments (30),
wherein the step of compressively biasing the plurality of connected vessel segments (30) is particularly applied before the step of wrapping at least one pressure vessel layer (40) of fibre reinforced plastic around the plurality of connected vessel segments (30).

9. The method of manufacturing a pressure vessel (20) of claim 7 or 8, wherein the step of wrapping at least one pressure vessel layer (40) of fibre reinforced plastic around the plurality of connected vessel segments (30) includes wrapping a plurality of pressure vessel layers (40; 42; 44) of fibre reinforce plastic around the plurality of connected vessel segments (30),
wherein a first pressure vessel layer (40) of the plurality of pressure vessel layers (40; 42; 44) is wrapped so as to extend over the connected vessel segments (30) in the axial direction (A), the method further comprising the steps of:

- folding the first pressure vessel layer (40) backwards substantially opposite the axial direction (A), and
- sandwiching the first pressure vessel layer (40) by further pressure vessel layers (44).

10. The method of manufacturing a pressure vessel (20) of any one of the claims 7 to 9, the method further comprising a step of:

- providing a liner (28) inside at least a portion of the connected plurality of vessel segments (30),

11. A method of manufacturing an airfoil structure (10), the method comprising:

- providing a lower airfoil segment (14) of an outer airfoil shape (12);
- arranging at least one pressure vessel (20) manufactured according to the method of any one of the claims 7 to 10 at the lower airfoil segment (14);
- arranging an upper airfoil segment (16) of the outer airfoil shape (12) at the lower airfoil segment (14) and at the at least one pressure vessel (20); and
- curing the lower airfoil segment (14), the at least one pressure vessel (20) and the upper airfoil segment (16).

12. The method of manufacturing an airfoil structure (10) of claim 11, wherein in the step of curing, the lower airfoil segment (14), the at least one pressure vessel (20) and the upper airfoil segment (16) are structurally bonded to one another.

13. A pressure vessel (20) for an airfoil structure (10), the pressure vessel comprising:

- a plurality of vessel segments (30),

wherein the plurality of vessel segments (30) are connected substantially in an axial direction (A) of the pressure vessel (20), and wherein the plurality of connected vessel segments (30) are wrapped with at least one pressure vessel layer (40) of fibre reinforced plastic so as to form one substantially continuous pressure vessel (20).

14. The pressure vessel (20) for an airfoil structure (10) of claim 13, wherein the plurality of vessel segments (30) includes a first end segment (34) and a second end segment (36), wherein the first end segment (34) and/or the second end segment (35) has a conical shape, wherein the conical shape has a reduced cross section toward an axial end of the pressure vessel (20).

15. The pressure vessel (20) for an airfoil structure (10) of claim 13 or 14, wherein the plurality of vessel segments (30) are connected with a pre-stress,
the pre-stress particularly being a compression stress.

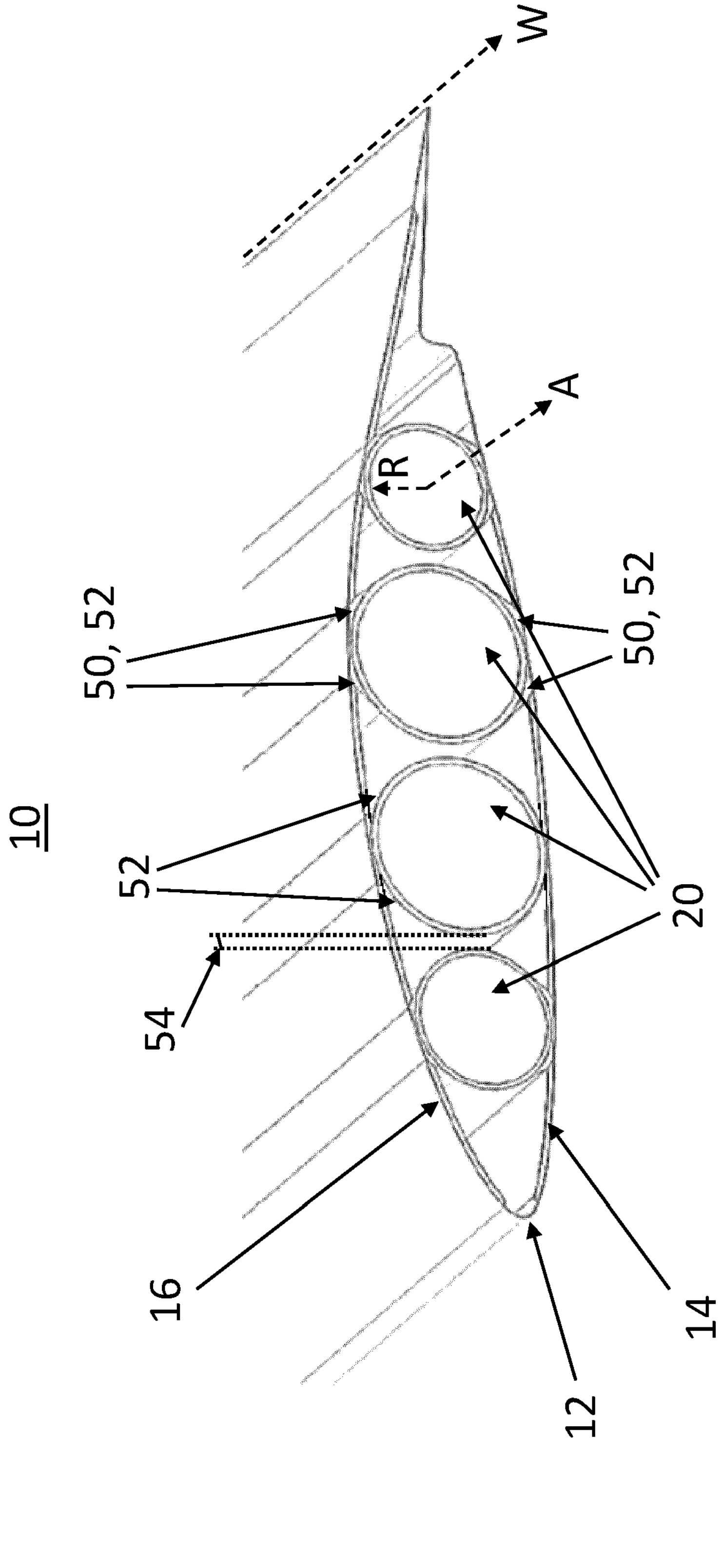

FIG. 1

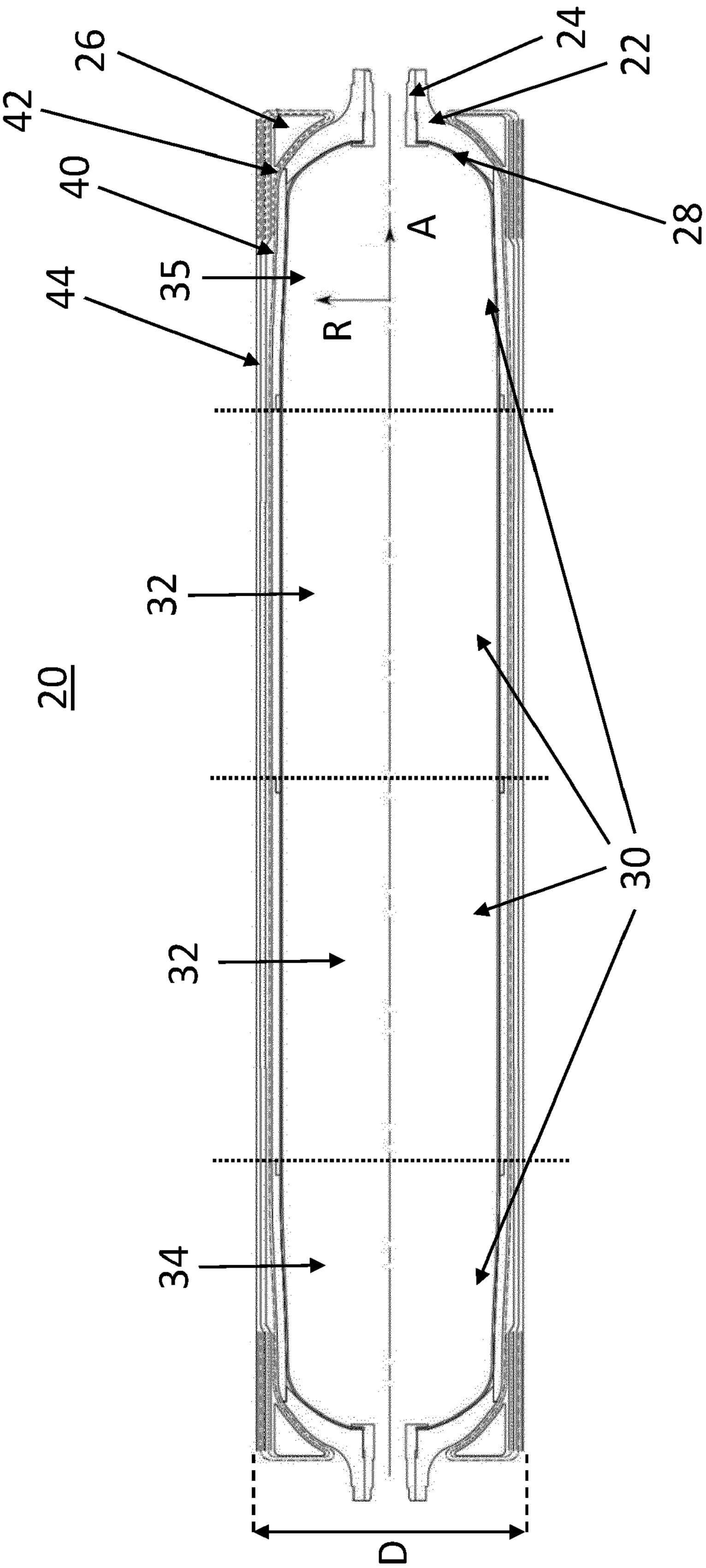

FIG. 2

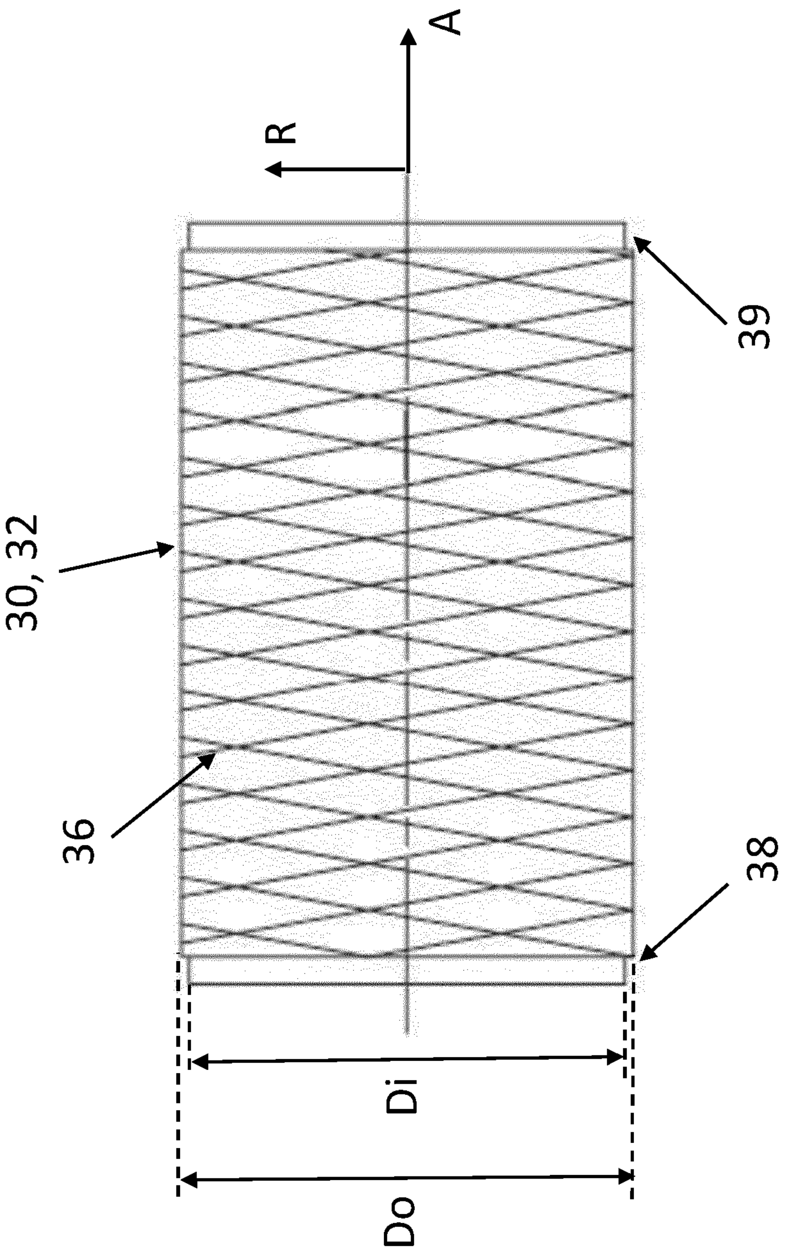

FIG. 3

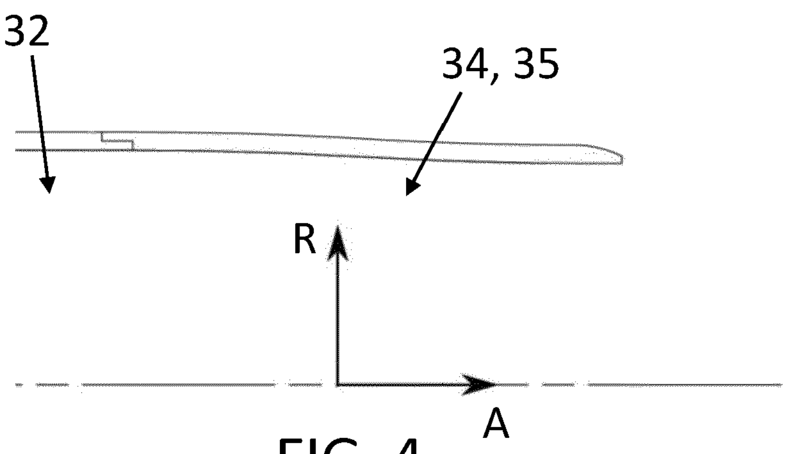

FIG. 4

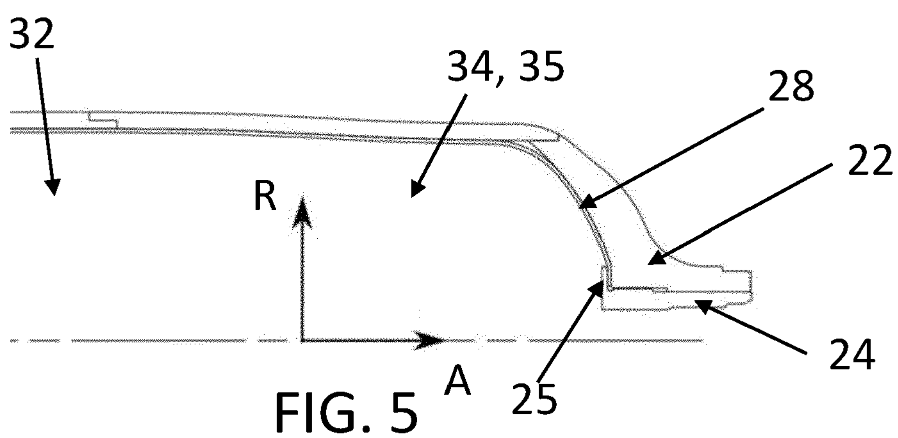

FIG. 5

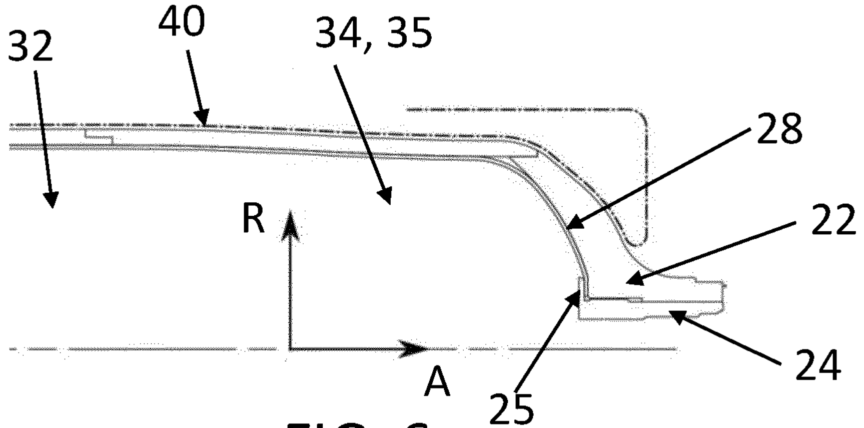

FIG. 6

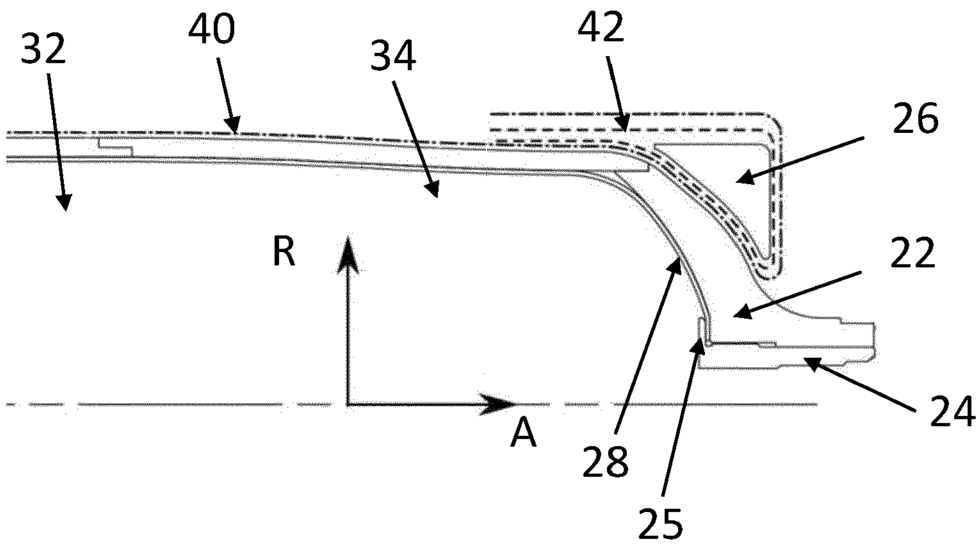

FIG. 7

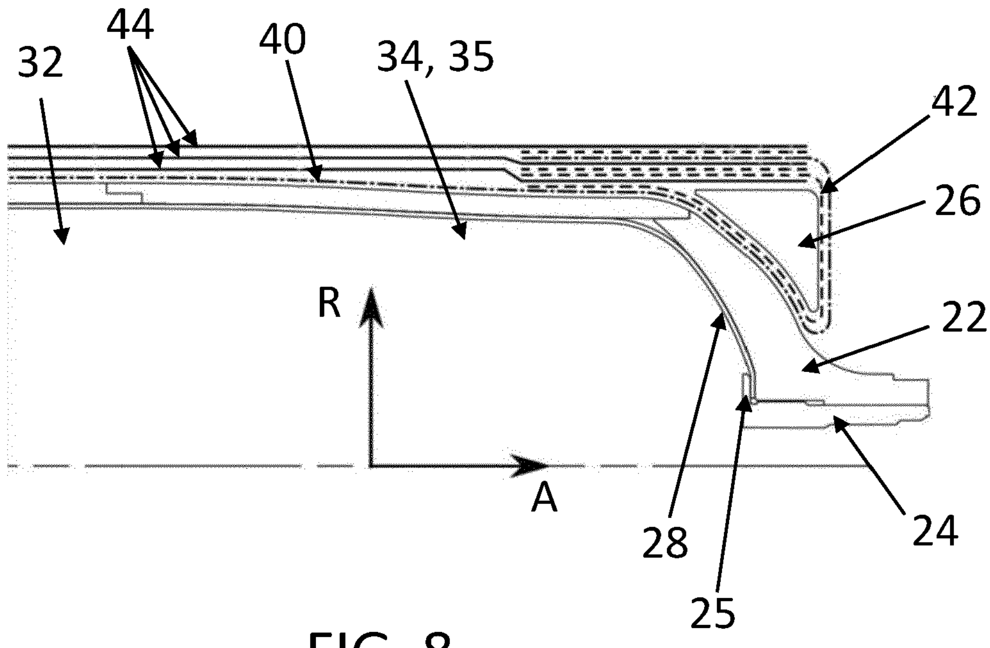

FIG. 8

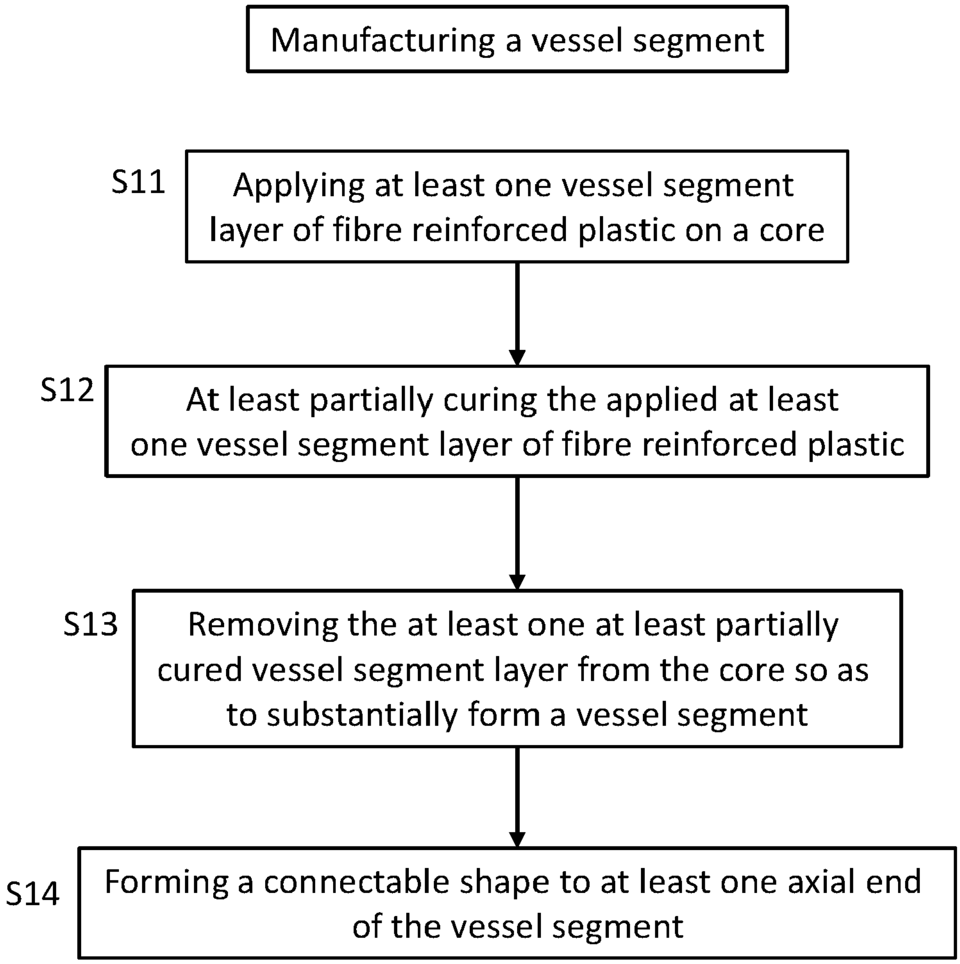
Manufacturing a vessel segment
S11
Applying at least one vessel segment layer of fibre reinforced plastic on a core
S12
At least partially curing the applied at least one vessel segment layer of fibre reinforced plastic
S13
Removing the at least one at least partially cured vessel segment layer from the core so as to substantially form a vessel segment
S14
Forming a connectable shape to at least one axial end of the vessel segment

FIG. 9

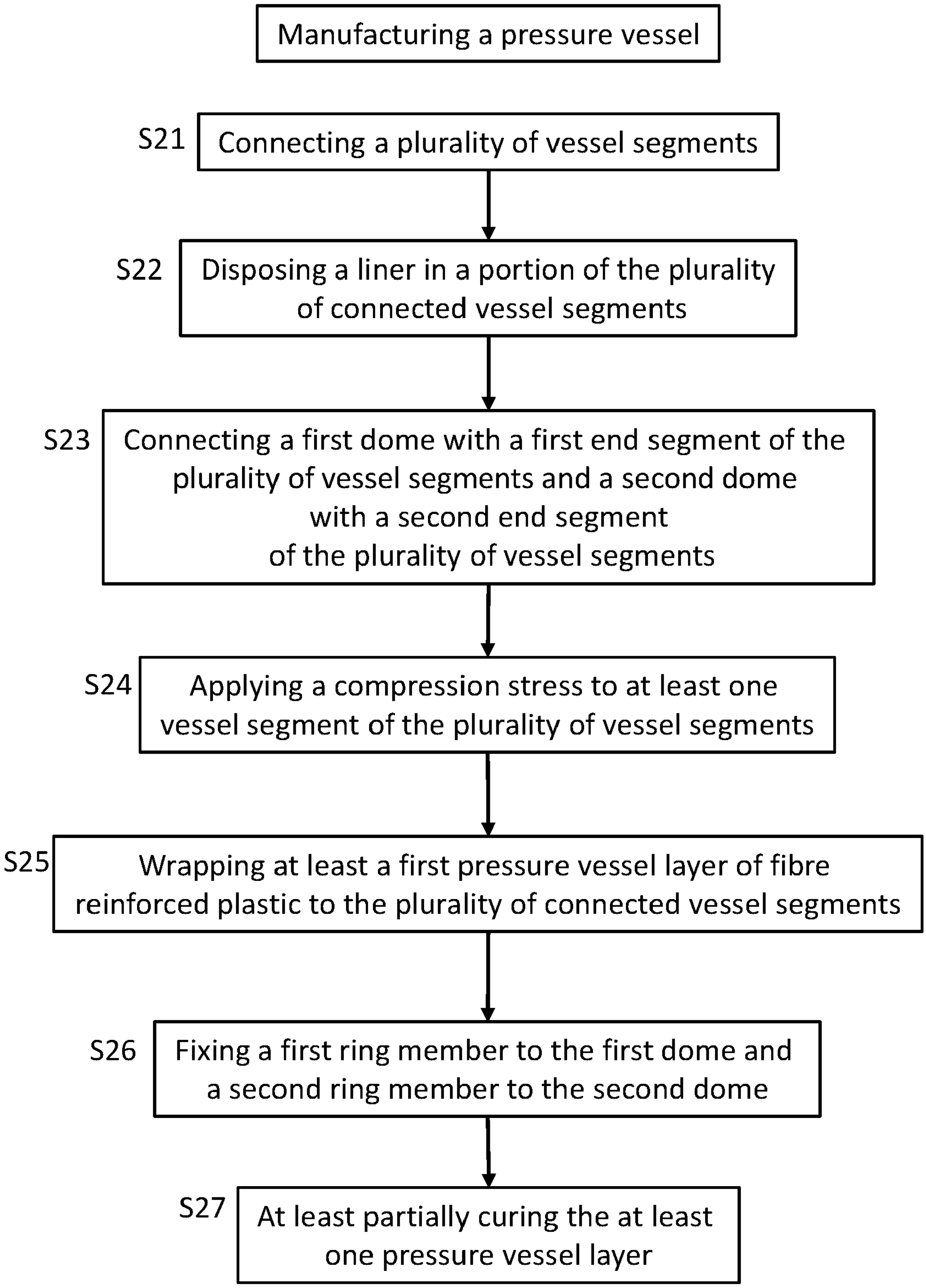
Manufacturing a pressure vessel
S21
Connecting a plurality of vessel segments
S22
Disposing a liner in a portion of the plurality of connected vessel segments
S23
Connecting a first dome with a first end segment of the plurality of vessel segments and a second dome with a second end segment of the plurality of vessel segments
S24
Applying a compression stress to at least one vessel segment of the plurality of vessel segments
S25
Wrapping at least a first pressure vessel layer of fibre reinforced plastic to the plurality of connected vessel segments
S26
Fixing a first ring member to the first dome and a second ring member to the second dome
S27
At least partially curing the at least one pressure vessel layer

FIG. 10

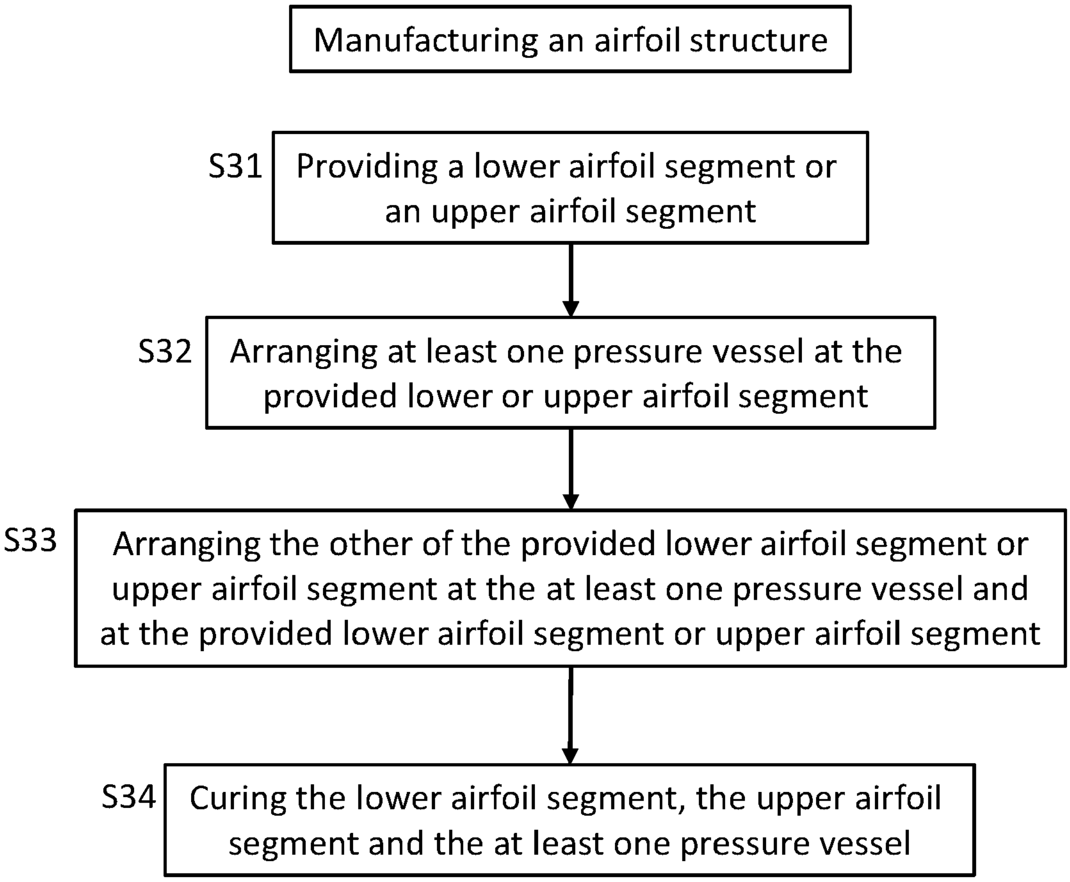
Manufacturing an airfoil structure
S31
Providing a lower airfoil segment or an upper airfoil segment
S32
Arranging at least one pressure vessel at the provided lower or upper airfoil segment
S33
Arranging the other of the provided lower airfoil segment or upper airfoil segment at the at least one pressure vessel and at the provided lower airfoil segment or upper airfoil segment
S34
Curing the lower airfoil segment, the upper airfoil segment and the at least one pressure vessel

FIG. 11

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EUROPEAN SEARCH REPORT

Application Number
EP 21 21 0641

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The present search report has been drawn up for all claims

2

Place of search	Date of completion of the search	Examiner
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