

A METHOD AND A PRODUCTION LINE FOR THE MANUFACTURE OF A TORSION-BOX
TYPE SKIN COMPOSITE STRUCTURE

TECHNICAL FIELD

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The present invention regards a method for manufacture of a torsion-box type skin composite structure according to claim 1 and regards a torsion-box type skin composite structure according to the preamble of claim 8. The invention also regards a data medium storing program comprising a program code, which program when run on a computer executes the method according to the invention. The invention also regards a production line per se adapted to make use of the data medium storing program for executing the method.

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The invention relates to the aircraft industry and to aircraft service engineering. However, the invention is not limited thereto.

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BACKGROUND ART

Current aerodynamic technologies for aircraft wings, vertical/horizontal stabilizers, fins, nacelles etc., use composite or sheet metal skins and make use of different solutions for releasable connecting the aircraft skin to a main sub-structure.

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Today composite aircraft structures are often made by hand. The production is personal intensive and personnel often add additional composite material to the structure for securing strength to the composite structure. However, such addition for securing strength implies increased weight of the aircraft. There is a desire to minimize weight of the composite structure at the same time as the structure can be built in a production line with such design that the strength properties are satisfactory achieved and with an aerodynamic smooth outer skin surface. At the same time there is a desire to decrease the amount of personnel and/or eliminate hand-work labour efforts, which otherwise involves high costs in production line. Thus, there is a desire to achieve a cost-effective production of aircraft, which are of low weight, have a smooth outer surface, and exhibit high strength.

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The aircraft skin may be coupled or bond to the sub-structure, or part of the sub-structure, by means of rib feet coupled to ribs etc. In some cases bolts are used, which extend through bore holes of the wing skin and further to brackets, which are secured to the sub-structure for holding the skin to the sub-structure. Such bolt arrangement through the wing skin means that

bolt heads disturb the laminar flow over the aircraft skin, whereby drag is produced increasing the aircraft fuel consumption.

5 There are large shear and peel loads on said rib feet. In some rare cases micro cracks may appear in said rib feet caused by heavy loads on the skin structure. Such damages are critical in view of flight safety and may also involve complex repair process.

10 US 1212/0094077 discloses a aircraft component having a skin stiffened with stringers. The skin and stringers are co-cured together and thereby joined to each other. Ribs intersect the stringers and the latter passing so called "mouseholes" of the ribs. Local flarings of the stringers are used to join the skin to the ribs.

15 For rigid co-bonding the skin to the ribs, rivets or bolts may be used according to prior art techniques. The outer surface (aerodynamic surface) of the skin (wing skin, fuselage skin, stabilizer skin, fin skin, nacelle skin etc.) of prior art will thus exhibit rivet or bolt heads being exposed to the airflow. The heads will disturb the natural flow of air flowing over the outer surface when the component is used.

20 There is thus a need to provide a coupling between an aircraft skin to a sub-structure, i.e. provide a torsion-box type skin composite structure, which technical solution still involves strength, and promotes laminar flow over aircraft skin.

25 There is a desire to decrease the amount or eliminate personal intensive work efforts, which otherwise involves high costs in production line, still achieving a structure which is of high strength and is of low weight. Prior art production lines comprises today superfluous personal hand work, which implies human ambitions to add more composite material to the structure at the same time as this involves high costs in production.

30 There is also a need to shorten the time required for manufacture of the torsion-box type skin composite structure.

35 An object of the present invention is to provide a semi-automatic automatic production of a torsion-box type aircraft skin structure, which skin structure is ready to mount on a sub-structure or part thereof.

An object is to provide a torsion-box type aircraft structure that is cost-effective to use and produce, and which torsion-box type aircraft structure having a low service cost for inspection

of the structure.

An object is to provide an aircraft, which has low fuel consumption, and therefore can be regarded as green technology.

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An object of the present invention is to provide a method for producing a torsion-box type skin composite structure and a torsion-box type aircraft structure, wherein the method being cost-effective in production and provides a high strength structure.

10 An object is to provide a method for producing a torsion-box type composite skin structure and a computer program for performing such method.

An object is to provide software (data medium storing program) that, when it is executed on a computer together with a production line data system or included in it, enables an automatic or
15 semi-automatic execution of the various stages of the aforementioned method.

SUMMARY OF THE INVENTION

This has been achieved by the method defined by the features of claim 1.

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In such way is achieved a torsion-box type skin composite structure, which can be manufactured in one curing cycle and thereafter just finished and trimmed for mounting to a main sub-structure (such as ribs of a wing or other airfoil). By the method step of positioning and co-curing the stiffener lay-up and the fastener lay-up together with the skin-lay up there
25 will be provided a torsion-box type skin composite structure, which is mountable to a main sub-structure (such as ribs of an aircraft wing) via the fastening elements (such as a rib feet). In such way, at the same time, is achieved a smooth outer surface of the torsion-box type skin composite structure, which outer surface serves as an aerodynamic surface when the structure (such as a wing) moves through the air.

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By means of the integrated fastening elements (i.e. the elements connecting together the skin component and the stiffener element) a rigid joint between the fastener element and the stiffener element is achieved. The integrated fastening elements will thus promote that the main sub-structure is rigidly joined to the skin component at the same time as no bolt heads
35 are exposed on the skin outer surface, and wherein the structure is possible to be made in one curing cycle cost-effective and by means of the achieved uncomplicated method, the production line can be automatized.

By means of connecting the main sub-structure (e.g. ribs) to the integrated fastening elements (e.g. rib feet), which elements are co-cured with the skin component and the stiffener element (e.g. stringer), eventual load stresses - acting on each fastener element and on the joint between the latter and the skin component - will be balanced and equalized due to the inventive
5 integral structure and co-curing of the fastener element with the stiffener element and the skin component.

Suitably, a flange of the stiffener element and a skin substrate holding a plurality of said flanges constitute the skin component, wherein all parts comprise composite material. The
10 integral fastener element is suitably defined as an integral attachment of the fastener element to both the stiffener element (e.g. stringer) and the skin component (skin). The integral attachment to the skin component is preferably made via the flanges of the stiffener element, which flanges in turn are attached (co-cured) to a skin substrate component. The thickness of said flanges and that of the skin substrate component preferably defines the skin component
15 overall thickness.

Thereby the thickness can be made relatively thin, since also the said flanges are used for building the skin component.

20 In such way is also an efficient aircraft manufacture achieved in view of cost-effective production of wings, stabilizers, control surfaces etc. An ATL (automatic tape laying) apparatus may be used for providing the skin lay-ups onto the forming tool and onto the box tools.

The box tools are preferably adapted to be used in a so called hot drape forming HDF
25 procedure, wherein a membrane is used to form the lay-up over the box tool. Also the hot drape procedure can be performed semi-automatic or automatic.

Preferably, the torsion box-type skin composite structure comprises a plurality of said fastener
30 elements.

As e.g. an aircraft wing exhibits a large amount of fastener elements (e.g. rib feet) the method is suitable for automatization.

Suitably, the lay-ups used for the fastener element (rib feet), stiffener element (stringers), are
35 formed into L-shaped profile. The box tools are used for forming two mirror L-profiles, which in turn form a U-profile (L profiles abutting each other on a small gap there between to be filled with resin).

Preferably, the U-profile formed by the box tool will contact an adjacent U-profile (with parallel flanges) formed over an adjacent box tool, wherein the flanges of respective adjacent U-profile bonded together will constitute a fastening web of the fastener element (and correspondingly a stiffener web of the stiffening element, to which stiffening web the integrated fastener element is co-cured for rigid joint). The rigid joint between the integrated fastener element and the stiffener web and the skin component will make the fastener element extremely well suited for attachment to the main sub-structure, as said rigid joint takes up both shear forces and peel forces acting on the joint interface between the skin and fastener element.

5 Suitably, said stiffener webs are integrated parts of the skin component and being co-cured with the skin component.

The fastener lay-up is thus co-cured with skin lay-up and stiffener lay-up. As the thereby integrated fastener element will have a rigid joint to both the skin component and the stiffener element, peel and shear stresses acting at the joints will be extremely balanced, especially by means of the integral joint between the integrated fastener element and the stiffener element.

15 Suitably, the main sub-structure is adapted to be bolted to the integrated fastener elements of the torsion-box type skin composite structure.

20 Thus, integrated fastener elements will act as a chain of integrated fastener elements taking up torque forces between the latter and the skin component by means of the integral joints to the stiffener elements.

25 Preferably, the step of positioning the stiffener and the fastener lay-up is performed after forming said stiffener and fastener lay-ups over a box tool.

Thereby is achieved that a fastener and stiffener lay-up will be provided, which lay-ups constitute an integrated lay-up.

30 Preferably the box tool makes part of a box tool module comprising connectable to each other separate box tool units, each of which being used for forming separate/or pair wise/or of four pieces made/ fastener lay-up or lay-ups.

35 Suitably, the step of positioning the stiffener and the fastener lay-up is performed such that a first portion of the fastener lay-up joins the stiffener lay-up.

In such way peel and shear loads are balanced and absorbed by the joint between fastener element and stiffener element.

5 Preferably, the forming of a fastener lay-up is performed over the box tool prior the forming of the stiffener lay-up over said box tool and said fastener lay-up.

Suitably, the forming of the stiffener lay-up is performed over a serie of box tools over which are formed fastener lay-ups.

10 Preferably, the box tools are configured to fit in module system and being arranged with fixing members for mounting the box tools to each other.

Suitably, the box tools is made of aluminum or other hard tool material.

15 Preferably, the forming of the fastener lay-ups and the stiffener lay-up is performed by a robot apparatus.

Suitably, the positioning of the stiffener and the fastener lay-up is made by a robot apparatus.

20 Preferably, the step of positioning the stiffener and the fastener lay-up is performed such that a second portion of the fastener lay-up joins the skin lay-up.

In such way is achieved that the produced intergral fastener element also is rigidly joined and bonded to the skin component, which in turn alternatively consists of a skin composite
25 substrate and flanges of stiffener elements.

Suitably, the step of positioning the stiffener and fastener lay-up to the skin lay-up is made after the application of an adhesive to a joining area between said lay-ups.

30 In such way is achieved that a filling between the lay-ups is achieved will which increase the strength of the structure.

Thereby is also achieved that a filling is provided between the stiffener lay-up and the skin lay-up. I.e. the adhesive may be applied beween both stiffener lay-up flanges and skin lay-up and
35 between fastener lay-up flanges and stiffener lay-up flanges.

Suitably, the adhesive is applied between stiffener lay-up and fastener lay-up and also between stiffener lay-up and skin lay-up.

Preferably, such application is performed by an automatic procedure.

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Suitably, the adhesive comprises fiber-like reinforcement elements.

In such way is achieved strength properties being extraordinary high.

10 Preferably, the step of co-curing the integrated lay-up is made in an autoclave.

In such way is achieved that a torsion-box type skin composite structure can be made in one curing cycle which is cost-effective.

15 Suitably, the foming tool comprises a male forming tool and a female forming tool.

Preferably, the skin lay-up is applied onto the male tool forming surface. The male tool being thereafter turned up-side down and positioned into the female tool in such way that the skin lay-up will come into proper contact with a female tool forming surface of the female tool.

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Suitably, the female tool comprises nano-sized fiber-like elements (such as CNTs) for strenghtening the forming surface (thus being hard and smooth) and thereby promoting an outer surface of the skin component (after co-curing of the integral lay-up) that is smooth.

25 Preferably, the fiber-like reinforcement elements are oriented i z-direction, i.e. transverse to the plane of the lay-ups in between the plies and within the plies per se.

Suitably, the fiber-like reinforcement elements comprises carbon nano tubes (CNTs).

30 The lay-up material may be of any suitable resin pre-impregnated fibre material.

Preferably, the material used can be pre-impregnated woven fabric.

Alternatively, the material used can be dry woven fabric, in a second step injected or
35 impregnated with resin.

Suitably, the material used can be dry woven fabric interleaved with resin film. The lay-ups may be based on pre-preg tapes such as unidirectional pre-impregnated fiber plies, wherein the fibers being of woven carbon fiber pre-preg fabrics, Kevlar, spectra pre-preg tapes and fabrics etc.

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Preferably, prior the step of co-curing, the intergral lay-up is subject to a bagging procedure for eliminating eventual air pockets within the lay-up.

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Suitably, the method comprises the further step of mounting the fastener element to the main sub-structure. Preferably, this further step also includes mounting of fastening members (such as a set of bolts) having extensions parallel with each other and parallel with the plane of the skin component.

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The further step may also comprise the application of an adhesive or sealing between the fastener elements and elements of the main sub-structure.

In such way is achieved that the fastener element is rigidly coupled to the main sub-structure.

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In such way bolts fasten the main sub-structure to the integrated fastener elements. When the bolts are removed, the skin composite structure can be removed from the main sub-structure (ribs).

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The apparatus for providing a forming tool can be an automatic machining apparatus CNC adapted to machine the forming tool. The apparatus for providing a skin lay-up onto the forming tool may be an ATL apparatus operated semi-automatic or automatic. The apparatus for positioning a stiffener lay-up and a fastener lay-up to the skin lay-up forming an integrated lay-up can be a robot cooperating with an automatic forming tool for forming fastener elements one by one and stiffener elements one by one and thereafter automatically or semi-automatically arranging the lay-ups on a box tool modular set up. The apparatus for co-curing the integral lay-up may be an autoclave into which the integral lay-up automatically or semi-automatically being inserted. Thereafter the integral structure (laminated) being demoulded, wherein the box tools are removed from co-cured laminate. This can be performed by a robot arm connected to a gripping device.

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Preferably, the introduction of a module box forming tool, on which a second lay-up has been pre-formed, is provided into and in proper position relative the female skin forming tool in such way that the second lay-up contacts the skin lay-up.

Suitably, an automatic sealing is achieved around the female skin forming tool and introduced module box forming tool by positioning the skin lay-up and the second lay-up within a vacuum bag for evacuation.

- 5 Preferably, after the co-curing process, an automatic demoulding step is performed, where after machining, application of primer and wrapping steps are performed.

The objects herein described is also solved by the torsion-box type skin composite structure defined in the introduction, wherein the torsion-box type skin composite structure being
10 characterized by the features being claimed in the characterizing part of claim 8.

This promotes that peel stresses acting at one edge area (seen in longitudinal direction of the fastener element, e.g. rib foot flange, wherein the opposite edge area of the fastener element is subjected to compression) can be balanced by means of the stiffener element.

15 Thereby is provided that eventual load caused by skin component pressure/tension forces relative the main sub-structure (such as ribs of an aircraft wing) will be balanced and absorbed by the fastener element (e.g. rib foot) rigidly bonded to and co-cured with the stiffener element (e.g. stringers).

20 Also is achieved that a smooth aerodynamic surface is achieved as no rivets extend through the skin for bonding the fastener element to the structure.

No additional working procedure steps have to be done with regard to bolting additional
25 clamps, brackets etc. for strengthening the fastener element to the skin component.

Suitably, the stiffener element exhibits a second portion (e.g. a flange), which is firmly integrated with the skin component.

30 In such way is achieved that the bond between stiffener element and fastener element is even more secured and which integral design also strengthens the fastener element bond with the skin component (the skin component laminate preferably comprises flanges of the T-profile stiffener element).

35 Thereby is achieved an increase in strenght and thus at the same time a decrease in stress concentration between skin and rib feet (by the inventive chord wise shear connection).

The fastener element will thus have high strength bond to the skin component due to the integral bond to the stiffener element, wherein the shear and peel forces acting on the contact area between skin component and the fastener element will be balanced.

- 5 Preferably, the fastening element exhibits a third portion, which comprises at least one bore hole.

In such way the fastening element is suitable to use as a rib foot.

- 10 Suitably, the fastening element is configured as a three-wall laminate co-cured with the stiffener element and the skin component.

This is also solved by an aircraft wing comprising a torsion-box type skin composite structure according according the above-mentioned inventive solution, wherein the torsion-box skin
15 composite structure is releasable mounted to a main sub-structure via the integral fastener elements.

In such way is achieved an aircraft wing, which comprises a smooth outer surface at the same time as the bonding of the wing skin to the ribs of the wing is strengthened. The releasable
20 mounting can be achieved by bolts. The aircraft wing is of low weight, exhibits a smooth aerodynamic surface, can be made efficient in production.

This is also solved by a production line for the manufacture of a torsion-box type skin composite structure mountable to a main sub-structure, the torsion-box type skin composite
25 structure comprises a skin component, a stiffener element, a fastener element for bonding the torsion-box type skin composite structure to the main sub-structure, wherein the production line comprises an apparatus for providing a forming tool; an apparatus for providing a skin lay-up onto the forming tool; an apparatus for positioning a stiffener lay-up and a fastener lay-up to the skin lay-up for forming an integral lay-up and an apparatus for co-curing the integral lay-up.

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In such way is achieved a production line which is suitable for automatization, which production line provides a torsion-box type skin composite structure cost-effectively, in such way that the outer surface of the skin being smooth still achieving a rigid joint of the fastener element to the skin component (the skin component is preferably co-cured of integral outer
35 skin substrate and inner skin layer provided by the stringer flanges). Such production line will permit a high production rate of the manufacture of the torsion-box type skin composite structure. There is no need to separately mount brackets and bolts through the skin

component for securing the fastener element to the skin component. Such production line promotes the use of robots and automatization apparatuses for efficiency in production.

This has been solved also by means of a data medium storing program for causing (in a
5 production line according to the inventive solution) an automatic or semi-automatic
manufacture of a torsion-box type skin composite structure, wherein said program comprises a
program code stored on a medium, which is readable on a computer, for causing a control unit
to perform the method steps of: providing a forming tool; providing a skin lay-up onto the
forming tool; positioning a stiffener lay-up and a fastener lay-up to the skin lay-up for forming
10 an integral lay-up and co-curing the integral lay-up.

This has also been solved by a data medium storing program product comprising a program
code stored on a medium, which is readable on a computer, for performing the method steps
according to any of claims 1 to 7, when a data medium storing program according to claim 14
15 is run on a computer device.

In such way is an effective production of the inventive article achieved, which is cost-effective
and time saving.

20 Thereby is also provided a program product that can be used for a plurality of production lines
for production of the inventive structure.

The foregoing and other objects and advantages of the present invention will be apparent and
may be combined with features claiming the invention for all embodiments to those skilled in
25 the art, in view of the following detailed description, taken in conjunction with the appended
claims and the accompanying drawings. The inventive solutions achieved by the invention can
thus be taken into account for all claim categories herein disclosed.

BRIEF DESCRIPTION OF THE DRAWINGS

30 The present invention will now be described by way of examples with references to the
accompanying schematic drawings, of which:

Fig. 1 illustrates an aircraft comprising an aircraft wing provided with a torsion-box type skin
35 composite structure according to one aspect of the present invention;

Fig. 2 illustrates a torsion-box type skin composite structure according to one aspect of the
present invention;

Figs. 3a to 3e illustrate different configurations of fastener lay-ups according to different aspects of the present invention;

Fig. 4 illustrates a pre-preg lay-up used as a blank formed to a similar profile as shown in Fig. 3c;

5 Fig. 5a illustrates a forming tool according to one aspect of the present invention;

Figs. 5b-5c illustrate a section of a modular system of box tools according to one aspect of the present invention;

Fig. 5d illustrates the section in Fig. 5c further coupled to additional sections of the modular system of box tools for forming an integral lay-up;

10 Figs. 6a to 6e illustrate method steps and manufacture tools of a production line according to one aspect of the present invention;

Figs. 7a to 7b illustrate the part of the principle of the present invention, where Fig. 7a shows prior art principle;

Fig. 8 illustrates one aspect of the present invention;

15 Figs. 9a to 9c illustrate fiber mats cut into shape suitable for the fastener elements shown in Fig. 8;

Figs. 10a to 10b illustrate flowcharts disclosing methods according to different aspects of the present invention; and

Fig. 11 illustrates a computer device according to one aspect of the invention.

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DETAILED DESCRIPTION

Hereinafter, embodiments of the present invention will be described with reference to the accompanying drawings, wherein for the sake of clarity and understanding of the invention
25 some details of no importance are deleted from the drawings.

Fig. 1 illustrates an aircraft 1 comprising a torsion-box type skin composite structure 3 according to the invention. In this case the structure 3 is part of an airfoil (aircraft wing 5) of the aircraft 1.

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Fig. 2 illustrates a torsion-box type skin composite structure 3 of a wing 5, which is mountable to a main sub-structure 6, such as wing ribs 7. The torsion-box type skin composite structure 3 comprises a skin component 9 which is co-cured with stiffener elements 11 (here stringers) and integral fastener elements 13 (here rib feet flanges integrated by co-curing with adjacent
35 stringer web), thereby forming an integral wing skin. The flanges 11F of the stiffener elements 11 and flanges 13F of the fastener elements 13 constitute the skin component 9 and can be a part of the total thickness of the wing 5 skin. The stiffener elements 11 extend spanwise and

the fastener elements 13 may extend chordwise or correspondingly with the extension of the wing ribs 7. The wing ribs 7 of the main sub-structure 6 are bolted to the webs of the fastener elements 13 for holding the torsion-box type skin composite structure 3 (i.e. a stiffened skin component) to the main sub-structure 6 (see also Fig. 1).

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Figs. 3a to 3e illustrate different configurations of fastener lay-ups 14 of an integral lay-up 17 according to different aspects of the present invention. Bore holes 15 are drilled after co-using of the lay-ups. Fig. 3a illustrates one example of a fastener lay-up 14. With reference to a flange portion comprising bore holes 15 for bolting the structure 3 to a main sub-structure 6, the lay-up 14 exhibits a first portion 21 extending essentially orthogonally from the bore holes flange portion F1 parallel with an imaginary line (normal) perpendicular to the plane of the bore holes flange portion F1. This first portion 21 of the lay-up 14 is adapted to co-cure with a stiffener lay-up 12 of the integral lay-up 17 later on constituting the structure 3. A second portion 23 of the fastener lay-up 14 also extends orthogonally from the bore holes flange portion F1, but herewith the extension direction is opposite the direction of extension regarding the first portion 21 and the plane is rotated about 90 degrees relatively the plane of the first portion 21. The second portion 23 of the lay-up 14 is adapted to co-cure with a skin lay-up 10 of the finished structure 3. Fig. 3b illustrates one example of a fastener lay-up 14. With reference from a flange portion F1, the lay-up 14 exhibits a first portion 21 extending essentially orthogonally from the bore holes flange portion F1 parallel with an imaginary line (normal) perpendicular to the plane of the flange portion F1. This first portion 21 is adapted to co-cure with an upper flange of a I-profile stiffener lay-up 12. A second portion 23 extends from the bore holes flange portion F1 parallel with the first portion 21 for attachment to a lower flange of the I-profile stiffener lay-up 12. Fig. 3c illustrates one example of a fastener lay-up 14. With reference from a flange portion F1 arranged for drilling of bore holes for bolting the structure 3 to a main sub-structure 6, the lay-up 14 exhibits a first portion 21 extending essentially orthogonally from the bore holes flange portion F1 parallel with an imaginary line (normal) perpendicular to the plane of the flange portion F1. This first portion 21 is adapted to co-cure with a web of a stiffener lay-up 12. A second portion 23 extends in the same direction as the plane of first portion 21, but the plane of the second portion 23 is rotated with an angle of about 90 degrees relatively the plane of the first portion 21. I.e. the bore holes flange portion F1 (fastening portion), the first portion 21, the second portion 23 exhibit three walls of an imaginary box. The angle between the bore holes flange portion F1 plane and the first portion 21 plane corresponds with the angle between the main sub-structure 6 extension (e.g. wing rib) and stiffener element 11 extension (e.g. stringer). Fig. 3d illustrates one example of a fastener lay-up 14. This fastener lay-up 14 is adapted to extend between two adjacent stiffener elements 11. For achieving resilience of the fastener element, the lay-up is formed with a

waist. Fig. 3e illustrates one example of a fastener lay-up 14 arrangement of a set of lay-ups of the type shown in Fig. 3c. Each stiffener lay-up 12, for each fastener position, being attached to four separate fastener lay-ups 14. A first set 24' of two fastener lay-ups 14 is mirrored and positioned face to face. A corresponding second set 24" of two fastener lay-ups 14 is mirrored to the first set 24' and arranged to an adjacent stiffener lay-up 12. A gap 25 between the first 24' and second 24" set is provided for reaching resilience in the structure. The respective set 24', 24" attached on both sides of a stiffener lay-up 12 will contact each other via the lay-up 12 and their respective first flanges 21. In such way is a rigid structure achieved.

Fig. 4 illustrates a pre-preg lay-up used for a blank formed to a similar profile as shown in Fig. 3c. The pre-preg lay-up is cut into L-shaped flat blank 27. The blank 27 is conformed along the lines marked with dotted lines 29. A flange portion F1 designed for attachment to a second structure or rib foot (not shown) comprises said lines 29, which will constitute the edge areas of the flange portion F1. Each first 21 (surface to be attached to stringer lay-up) and second 23 portion (surface to be attached to skin lay-up) is formed (conformed or folded) with an angle about 90 degrees to the plane of the flange portion F1. Of course, such angle can be 70-80 degrees (or other) depending upon application.

Fig. 5a illustrates a forming tool 31 according to one aspect of the present invention. Figs. 5b-5c illustrate a section of a modular system of box tools 33 according to one aspect of the present invention. Fig. 5d illustrates the section in Fig. 5c further coupled to additional sections of the modular system of box tools 33 for forming an integral lay-up 17. Figs. 5a to 5d thus illustrate a box tool 33 of a modular system (just shown in part) of box tools according to one aspect of the present invention. The box tool 33 shown in Fig. 5a comprises a forming surface 35 onto which a fastener lay-up 14 having the cut configuration shown in Fig. 4 is applied. The fastener lay-up comprises a plurality of pre-preg plies, each having a fiber orientation tailor made for each application. The box tool 33 is manufactured semi-automatically or automatically by means of an automatic miller machine coupled to a central control unit (not shown). The central control unit is in turn coupled to a designer (not shown) personal computer PC (not shown) adapted for the design of the torsion-box type skin composite structure 3. In Fig. 5b is shown a fastener lay-up 14 laid in the shape of such box-like imaginary box fastener lay-up having three walls as described in Fig 3c. Almost each corner of the box tools 33 are used for application of three wall box-like fastener lay-ups 14. The blanks 27 are preferably conformed by means of hot drape forming. Thereafter, the box tools 33 are assembled and rigidly secured to each other constituting a part of a modular box tool 34. In Fig. 5c is shown the application of stiffener lay-ups 12. Each stiffener lay-up 12 being formed by two L profile lay-ups extending over the previous applied fastener lay-ups 14. Essentially all cavities are

filled with so called noodles cut from pre-preg tapes. In Fig. 5d is illustrated the securing and mounting (bolting not shown) of the box tools 33 into a rigid module box tool 34, wherein the L profile lay-ups will abut each other with web portions WP forming a stiffening rib of the stiffening element 11 when co-cured. The flanges 40 of the L profiles (i.e. co-cured flanges of the stiffener lay-ups 12) will, due to their fully extension in the composite skin's plane, form an intergal part of the skin component 9. The definition of stiffener flanges 40 may in this application therefore be also part of the skin component 9. The skin lay-up 10 will suitably after co-curing together with the stiffener flanges 40 lay-up 12 constitute a part of the skin component 9. Fig. 5d thus illustrates box tools 33 arranged in series, which in turn are secured to a parallelly provided skin component 9 arranged set of box tools 33 in series. The respective set of box tools 33 is secured to each other and the flanges 40 of the L-profiles will abut each other forming a web having a T-shaped lay-up. Each T-shaped lay-up will form a stiffener lay-up 12 having a web portion WP constituting (after co-curing) a stiffening web, which will also serves as an attachment (co-curing area) section for connection to the fastener lay-up 14. Noodles (not shown) cut from pre-preg tape have been arranged in cavities formed by the radius of the lay-ups, 10, 12, 14, which noodles will serve as reinforcement fillers of the structure 3.

Fig. 6a to 6e illustrate method steps and manufacture tools of a production line 45 according to one aspect of the present invention. Fig. 6a illustrates an ATL (automatic tape laying) apparatus 47, which is semi-automatic or automatic operated for the application of a skin lay-up 10 onto a forming surface 49 of a male forming tool 51. The skin lay-up 10 comprises resin pre-impregnated fiber plies (not shown) not yet being fully cured. The plies are laid in different directions for achieving a proper strength of the finished laminate. A control processor unit 200 is provided to operate the ATL apparatus 47. Fig. 6b illustrates the application of the male tool 51 comprising the skin lay-up 10 (after being turned up-side down) in position over a female forming tool 53. A set of prolonged actuators 55 (such as hydrauls) are operated by a first control unit 200' to move the skin lay-up 10 into position onto a forming surface 57 of the female forming tool 53. Fig. 6c illustrates how the hydrauls 55 are operated to position an integrated stiffener lay-up 12 and fastener lay-up 14 onto the skin lay-up 10 inner side, thereby forming an integral lay-up 17 comprising stiffener 12 and fastener lay-ups 14 and skin lay-up 10. The first control unit 200' operates also this procedure. Prior the positioning of each stiffener lay-up 12 over the fastener lay-ups 14, the latter are applied with an adhesive for filling eventual gaps between the lay-ups. In Fig. 6d is illustrated an integral lay-up 17 ready for an automatic insertion into an autoclave 60 tool for co-curing. The integral lay-up 17 is assembled together with sub-spar tools 61, blade lay-ups (not shown) of pre-pregs inserted within stiffener and fastener lay-ups, noodles and other suitable components constituting an

assembly. The assembly and female tool 53 have been bagged, wherein air suction is performed for sucking eventual air from the pre-preg ply interfaces, thus compacting the lay-ups and preparing the assembly for a proper co-curing. After the bagging procedure, the assembly is inserted into the autoclave 60. The autoclave 60 provides that the integral lay-up
5 17 co-cures in hot air temperature and under high over pressure. Thereafter, the female tool 53 is removed together with the co-cured laminate from the autoclave 60 for demoulding, wherein box tools 33 are removed from the co-cured laminate. Fig. 6e illustrates a demoulding procedure, wherein a robot arm 63 removes components and tools from the finished laminate. After curing, the torsion-box type skin composite structure is moved to a manufacture station in
10 production line 45 where an automatic inspection is performed of the structure. Also gaps in between stiffener element 11 and fastener element 13 are filled with plastic in purpose to achieve strength. At the same manufacture station a machining is performed for trimming, drilling etc. of the composite laminate. Bore holes (not shown) are drilled by an automatic drilling machine (preferably orbital drilling) through the fastener elements 13 in bore holes
15 flanges.

Figs. 7a to 7b illustrate a part of the principle of the present invention, where Fig. 7a shows prior art principle. Fig. 7a illustrates prior art. The skins made of a thick aluminium sheet metal. Stringers made of composite have been attached to the skin S inner side. Rib feet R holding
20 the skin S to the sub-structure are mounted. The rib feet R are riveted to the skin S. During use of the prior art skin S a tension occur forcing the skin S away within an area of an end portion of the rib foot R. This means that a torque T will act on the joint between the rib foot R and the skin S, wherein one end portion will be subject to tensile force and the other end portion will be subject to compression force. This phenomenon can occur for all type of skins, i.e. peel forces
25 occurring on a composite skin and rib foot joint. Such torque is thus critical.

Fig. 7b illustrates one aspect of the invention. The skin 9 comprises a co-cured composite substrate skin ply 9'. Onto the substrate skin 9' lay-up are the flanges 40 of the stiffener lay-ups 12 applied. The flanges 40 extend to such extent that they abut A (or almost abut) each
30 other at their edges, so that the substrate skin 9' lay-up fully is covered by said flanges 40. In such way the stringers will be an integrated part of the skin component 9, wherein the flanges 40 of the stringers 11 will increase the skin 9 component strength. Such integrated stringer flange 40 and skin substrate 9' will save weight, which is important for aircraft industry. This also implies less fuel consumption of an aircraft, which is environmental friendly. Fig. 7b
35 illustrates the principle of arranging a train (chain) TR of fastener elements 13 in a line extending over the skin 9 component inside surface in chord wise direction. Such train of rib feet, interlocked by also the web stringer material (thickness) seen chord wise (transverse to

the longitudinal direction of the stringer elements 11), will promote a rigidity to the structure, but primary it will gain the strength of the structure 3 regarding peel forces and shear forces between rib feet 13 and skin 9.

5 Fig. 8 illustrates one aspect of the present invention. Rib feet 13' are integrated with the skin 9 and stringers 12' by co-curing. Upper flanges 21' of the rib feet 13' are attached by means of the co-curing procedure to upper flanges 21' of the stringers 12' having a Z-profile. Also lower flanges 23' of the rib feet 13' are attached to the skin 9 during the same co-curing step.

10 Figs. 9a to 9c illustrate fiber mats cut into a suitable shape for the fastener elements shown in Fig. 8. The mats are injected during one injection step with resin.

Fig. 10a illustrates a flow chart of the method for manufacture of a torsion-box type skin composite structure, according to one aspect o the invention. The method starts in a Step 301.
15 In Step 302 is provided a method for manufacture of the composite structure, mountable on a main sub-structure. In Step 303 the method fulfilled. The step 302 thus comprises the steps of: providing a forming tool; providing a skin lay-up onto the forming tool; positioning a stiffener lay-up and a fastener lay-up to the skin lay-up for forming an integral lay-up; and co-curing the integral lay-up.

20 Fig. 10b illustrates a flow chart of the method for manufacture of a torsion-box type skin composite structure, according to one aspect o the invention. Step 401 corresponds to a starting (start-up) of a production line. Step 402 defines the providing a curved male and a corresponding female skin forming tool. Step 403 defines the application of a lay-up onto the
25 male skin forming tool for forming an inner surface. Step 404 defines the application of the skin lay-up on the female skin forming tool for forming an outer surface of the skin lay-up by introducing male skin forming tool carrying skin lay-up into female skin forming tool. Step 405 defines the removal of the male skin forming tool from the skin lay-up applied to the female skin forming tool. Step 406 defines the introduction of a module box forming tool, on which a
30 second lay-up has been pre-formed, into and in proper position relative the female skin forming tool in such way that the second lay-up contacts the skin lay-up. Step 407 defines the sealing of the female skin forming tool and introduced module box forming tool positioning the skin lay-up and the second lay-up within a vacuum bag for evacuation. Step 408 defines the bagging of the female skin forming tool and introduced module box forming tool comprising the lay-ups
35 within a vacuum bag for evacuation. Step 409 defines a co-curing of the lay-ups in an autoclave. Step 410 defines a demoulding procedure wherein the box tools are removed from the co-cured laminate. Step 411 defines a stop in production line. Alternatively, the finished

article can be transported to a work-shop for mounting the article to the main sub-structure of an aircraft wing, wherein the fastening elements are bonded to the main sub-structure.

Fig. 11 illustrates a device 900 according to one aspect of the invention. The control unit 200 of the production line 45 described in Fig. 6a-6e may comprise the device 900. The device 900 comprises a non-volatile memory NVM 920 which is a computer memory that can retain stored information even when the computer is not powered. The device 900 further comprises a processing unit 910 and a read/write memory 950. The NVM 920 comprises a first memory unit 930. A computer program (which can be of any type suitable for any operational data base) is stored in the first memory unit 930 for controlling the functionality of the device 900 as a part of e.g. the production line shown in Figs. 6a to 6f.

Furthermore, the device 900 comprises a bus controller (not shown), a serial communication port (not shown) providing a physical interface through which information transfers separately in two directions. The device 900 also comprises any suitable type of I/O module (not shown) providing input/output signal transfer, an A/D converter (not shown) for converting continuously varying signals from detectors (not shown) and other monitoring units (not shown) of the production line into binary code suitable for the computer.

The device 900 also comprises an input/output unit (not shown) for adaption to time and date. The device 900 also comprises an event counter (not shown) for counting the number of event multiples that occur from independent events in the production line. Furthermore the device 900 includes interrupt units (not shown) associated with the computer for providing a multitasking performance and real time computing in said production line. The NVM 920 also includes a second memory unit 940 for external controlled operation.

A data medium storing program P comprising driver routines adapted for drivers (not shown) and provided for operating the device 900 for performing the present method described herein. The data medium storing program P comprises routines for causing in a production line an automatic or semi-automatic manufacture of a torsion-box type skin composite structure mountable to a main sub-structure. The data medium storing program P comprises a program code stored on a medium, which is readable on the computer, for causing the control unit 200 to perform the method steps of: providing a forming tool; providing a skin lay-up onto the forming tool; positioning a stiffener lay-up and a fastener lay-up to the skin lay-up for forming an integral lay-up; and co-curing the integral lay-up.

The data medium storing program P further may be stored in a separate memory 960 and/or in

a read/write memory 950. The data medium storing program P is in this embodiment stored in executable or compressed data format.

It is to be understood that when the processing unit 910 is described to execute a specific function this involves that the processing unit 910 executes a certain part of the program stored in the separate memory 960 or a certain part of the program stored in the read/write memory 950.

The processing unit 910 is associated with a data port 999 for communication via a first data bus 915. The non-volatile memory NVM 920 is adapted for communication with the processing unit 910 via a second data bus 912. The separate memory 960 is adapted for communication with the processing unit 910 via a third data bus 911. The read/write memory 950 is adapted to communicate with the processing unit 910 via a fourth data bus 914. The data port 999 is preferably connectable to e.g. data links L201, L202, L203, L204 and L205 of the production line shown in Figs. 6a to 6f.

When data is received by the data port 999, the data will be stored temporary in the second memory unit 940. After that the received data is temporary stored, the processing unit 910 will be ready to execute the program code, according to the above-mentioned procedure.

Preferably, the signals (received by the data port 999) comprise information about operational status of the production line, such as operational status regarding the ATL performance for producing the proper lay-up in correspondence with designer drawings. It could also be operational data regarding the positioning of the lay-ups relatively the forming tools and the monitoring of such positioning. According to one aspect, signals received by the data port 999 may contain information about curing temperature and over pressure of the autoclave. The received signals at the data port 999 can be used by the device 900 for controlling and monitoring a semi-automatic or automatic production line for manufacture of manufacture of the torsion-box type skin composite structure mountable to a main sub-structure in a cost-effective way. The signals received by the data port 999 can be used for automatically moving and positioning the box tools into position against the semi-cured skin lay-up for adherence to the different lay-ups in the production line by means of robot arms. The information is preferably measured by means of suitable sensor members arranged in each automatic apparatus of the production line. The information can also be manually fed to the control unit 200 via a suitable communication device, such as a personal computer display.

Parts of the methods can also be executed by the device 900 by means of the processing unit 910, which processing unit 910 runs the data medium storing program P being stored in the

separate memory 960 or the read/write memory 950. When the device 900 runs the data medium storing program P, the method steps disclosed herein will be executed.

The present invention is of course not in any way restricted to the preferred embodiments described above, but many possibilities to modifications, or combinations of the described
5 embodiments, thereof should be apparent to a person with ordinary skill in the art without departing from the basic idea of the invention as defined in the appended claims. The definition of lay-up may include the meaning of dry fiber mats injected with resin later on in a resin injection step or the meaning of with resin pre-impregnated fiber mats which is semi-cured or
10 not cured at all. The definition of lay-up may include the meaning of only resin filled with nano fiber-like reinforcement elements or combinations with CFRP. The lay-up can be applied in different ways, having different fiber orientations in each ply, and may have a fiber mat which is infused with resin. The lay-ups may comprise a pre-preg tape such as unidirectional pre-impregnated fiber plies, fibers being of woven carbon fiber pre-preg fabrics or glass, Kevlar,
15 spectra pre-preg tapes and fabrics etc. Thereby a laminate stack can be built by means of an ATL-apparatus, which is cost-effective. Examples of suitably composite materials include carbon fibers, aramid fibers, glass fibers, combinations of carbon and glass fibers or combinations of carbon, aramid and glass fibers. The skins and the substructure may be provided by laminating multiple sheets or layers having the fibers of respective sheet oriented
20 in different directions. Each skin ply may comprise large fibers, such as carbon fibers, graphite fibers and/or carbon nano tubes oriented in different directions. For example, a ply with span wise oriented carbon fibers could be laid onto and adjacent a ply with chord wise oriented carbon fibers and upon this one a further ply having 45 degrees oriented fibers relative the span wise direction. Each ply can also comprise large fibers and/or carbon nano tubes or the
25 like. The laminate materials may be achieved by resin transfer moulding (RTM) in an automated operation that combines compression, moulding, and transfer moulding processes. The mould may be loaded with layers of dry fibers and the resin being injected or drawn into the mould. Some of the elongated reinforcement fiber-like elements are oriented transverse to the laminate surface. Preferably, the resin is heated and pressure is applied. After curing, the
30 structure is removed, suitably trimmed, ID-marked and stored. The integral fastener element is suitably defined as an integral attachment of the fastener element to both the stiffener element (e.g. stringer) and the skin component (skin). The integral attachment to the skin component is preferably made via the flanges of the stiffener element, which flanges in turn are attached (co-cured) to a skin substrate component. The thickness of said flanges and that of the skin
35 substrate component defines the skin component overall thickness. The definition of stiffener flanges may in this application therefore be also part of the skin component. The skin lay-up will suitably after co-curing together with the stiffener flanges lay-up constitute a part of the

composite skin. Of course, a first surface of the fastener lay-up to be attached to stringer lay-up and a second surface of the fastener lay-up to be attached to skin lay-up is preferably formed with an angle about 90 degrees to the plane of the flange portion of the fastener lay-up, which will be attached to the rib foot. Of course the surfaces can be arranged so that, such

5 angle can be 70-80 degrees (or other) depending upon application. Of course can the second surface be used for attachment to the rib foot and the flange portion co-cure with the skin lay-up. The definition of herein regarding the term "composite" means a plastic material being reinforced with fiber like material and the composite may comprise several plies with different fiber orientations.

CLAIMS

1. A method for manufacture of a torsion-box type skin composite structure (3) mountable to a main sub-structure (6), the torsion-box type skin composite structure (3) comprises a skin component (9), a stiffener element (11), a fastener element (13) for bonding the torsion-box type skin composite structure (3) to the main sub-structure (6), the method comprises the step of:
 - providing a forming tool (31);
 - providing a skin lay-up (10) onto the forming tool (31);
 - positioning a stiffener lay-up (12) and a fastener lay-up (14) to the skin lay-up (10) for forming an integral lay-up (17); and
 - co-curing the integral lay-up (17).
2. The method according to claim 1, wherein the step of positioning the stiffener (12) and the fastener lay-up (14) is performed after forming said stiffener (12) and fastener lay-ups (14) over a box tool (33, 34).
3. The method according to claim 1 or 2, wherein the step of positioning the stiffener (12) and the fastener lay-up (14) is performed such that a first portion (21) of the fastener lay-up (14) joins the stiffener lay-up (12).
4. The method according to any of claims 1 to 3, wherein the step of positioning the stiffener (12) and the fastener lay-up (14) is performed such that a second portion (23) of the fastener lay-up (14) joins the skin lay-up (10).
5. The method according to any of the preceding claims, wherein the step of positioning the stiffener (12) and fastener lay-up (14) to the skin lay-up (10) is made after the application of an adhesive to a joining area between said lay-ups (10, 12, 14).
6. The method according to claim 5, wherein said adhesive comprises fiber-like reinforcement elements.
7. The method according to any of the preceding claims, wherein the step of co-curing the integral lay-up (17) is made in an autoclave (60).
8. A torsion-box type skin composite structure mountable to a main sub-structure (6), the torsion-box type skin composite structure (3) comprises a skin component (9), a stiffener

element (11), a fastener element (13) for bonding the torsion-box type skin composite structure (3) to the main sub-structure (6), **characterized by** that the fastener element (13) exhibits a first portion (21), which is firmly integrated with the stiffener element (11).

- 5 9. The structure according to claim 8, **wherein** the stiffener element (11) exhibits a second portion (23), which is firmly integrated with the skin component (9).
10. The structure according to claim 8 or 9, **wherein** the fastener element (13) exhibits a third portion (F1), which comprises at least one bore hole (15).
- 10 11. The structure according to any of claims 8 to 10, **wherein** the fastener element (13) is configured as a three-wall laminate co-cured with the stiffener element (11) and the skin component (9).
- 15 12. An aircraft wing comprising a torsion-box type skin composite structure (3) according to any of the preceding claims 8-11, **wherein** the torsion-box skin composite structure (3) is releasable mounted to a main sub-structure (6) via the integral fastener elements (13).
- 20 13. A production line for the manufacture of a torsion-box type skin composite structure (3) mountable to a main sub-structure (6), the torsion-box type skin composite structure (3) comprises a skin component (9), a stiffener element (11), a fastener element (13) for bonding the torsion-box type skin composite structure (3) to the main sub-structure (6), the production line comprises:
- an apparatus for providing a forming tool (33, 51, 53);
 - 25 -an apparatus (47) for providing a skin lay-up (10) onto the forming tool (33, 51, 53);
 - an apparatus (55) for positioning a stiffener lay-up (12) and a fastener lay-up (14) to the skin lay-up (10) for forming an integral lay-up (17); and
 - an apparatus (60) for co-curing the integral lay-up.
- 30 14. A data medium storing program (P) for causing in a production line (45) according to claim 13 an automatic or semi-automatic manufacture of a torsion-box type skin composite structure (3), wherein said program (P) comprises a program code stored on a medium, which is readable on a computer, for causing a control unit (200, 200') to perform the method steps of:
- 35 -providing a forming tool (33, 51, 53);
- providing a skin lay-up (10) onto the forming tool (51, 53);

-positioning a stiffener lay-up (12) and a fastener lay-up (14) to the skin lay-up (10) for forming an integral lay-up (17); and
-co-curing the integral lay-up (17).

- 5 15. A data medium storing program product comprising a program code stored on a medium, which is readable on a computer, for performing the method steps according to any of claims 1 to 7, when a data medium storing program (P) according to claim 14 is run on a control unit (200).

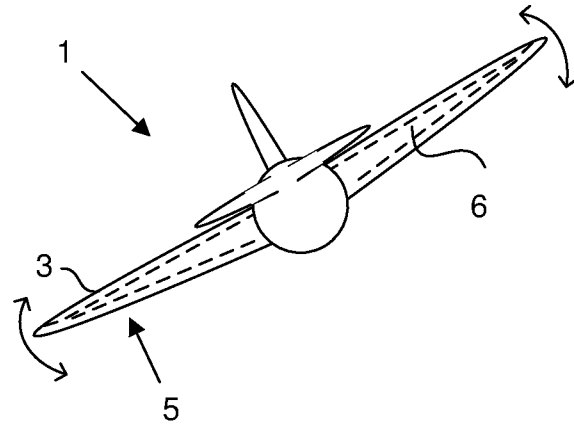


FIG. 1

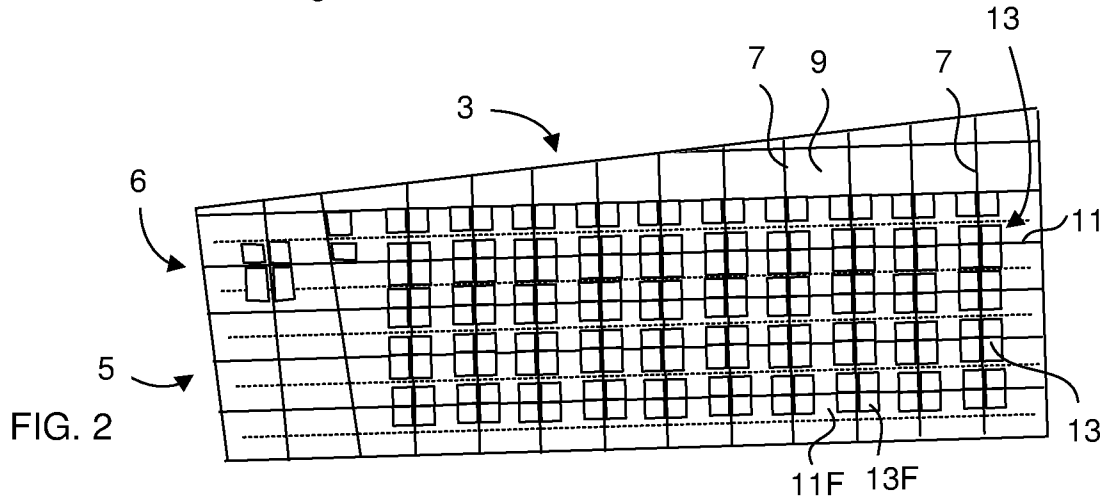


FIG. 2

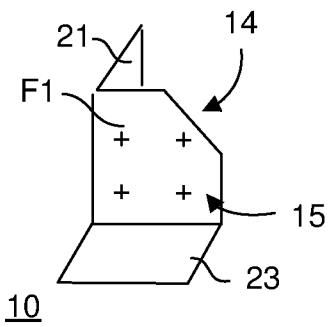


FIG. 3a

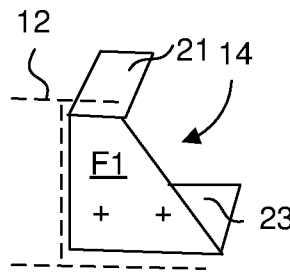


FIG. 3b

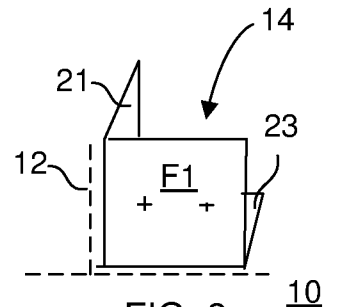


FIG. 3c

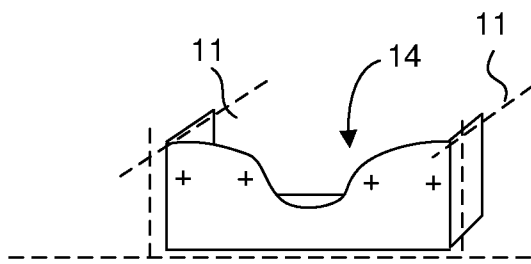


FIG. 3d

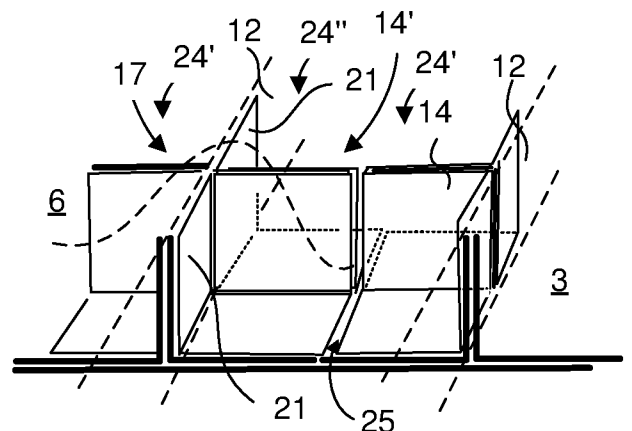


FIG. 3e

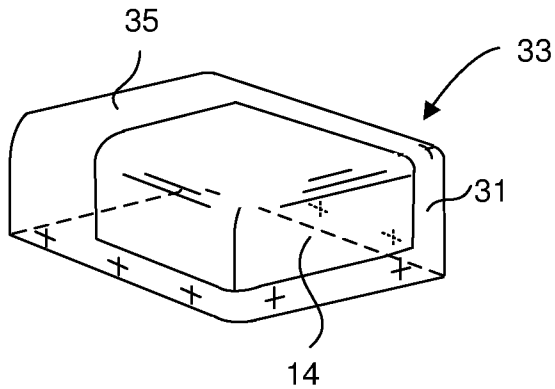


FIG. 5a

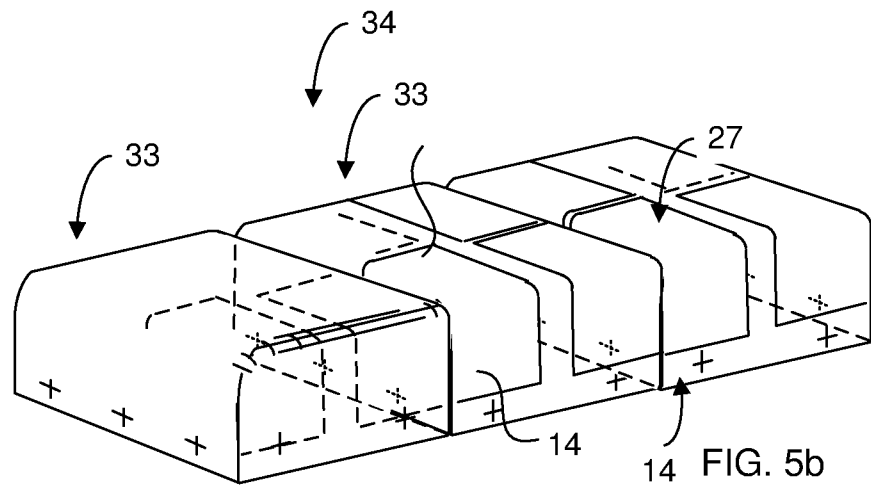
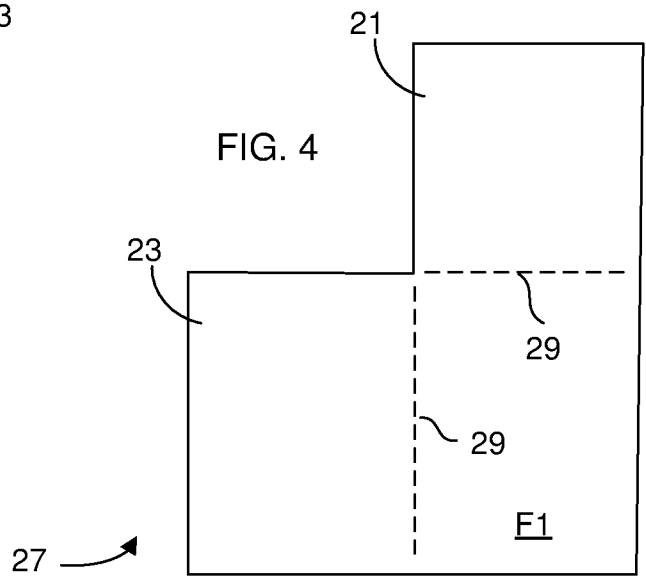


FIG. 5b

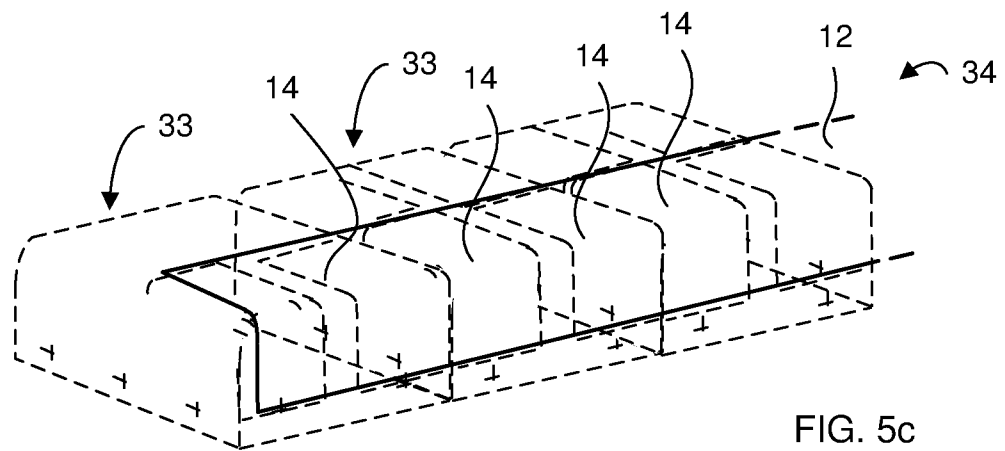


FIG. 5c

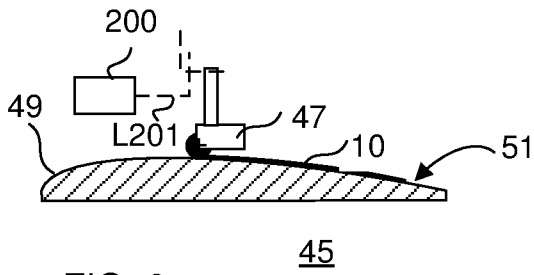


FIG. 6a

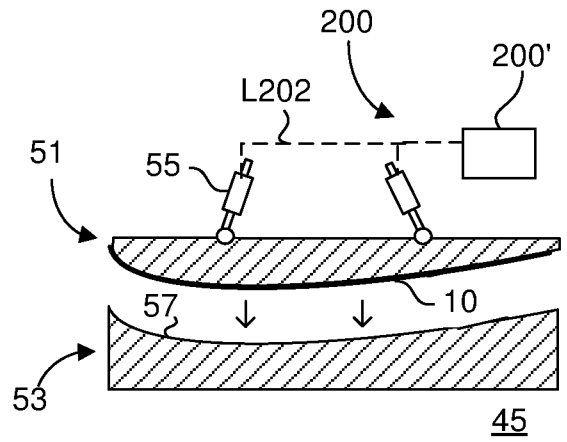


FIG. 6b

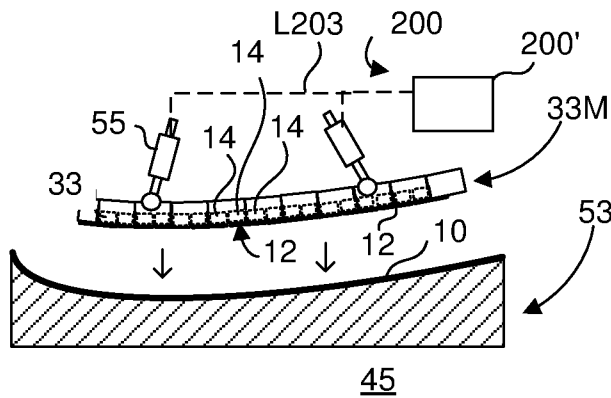


FIG. 6c

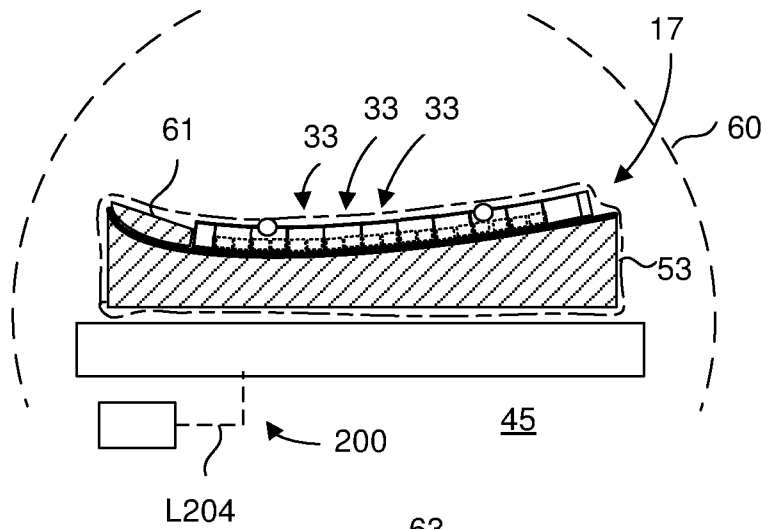


FIG. 6d

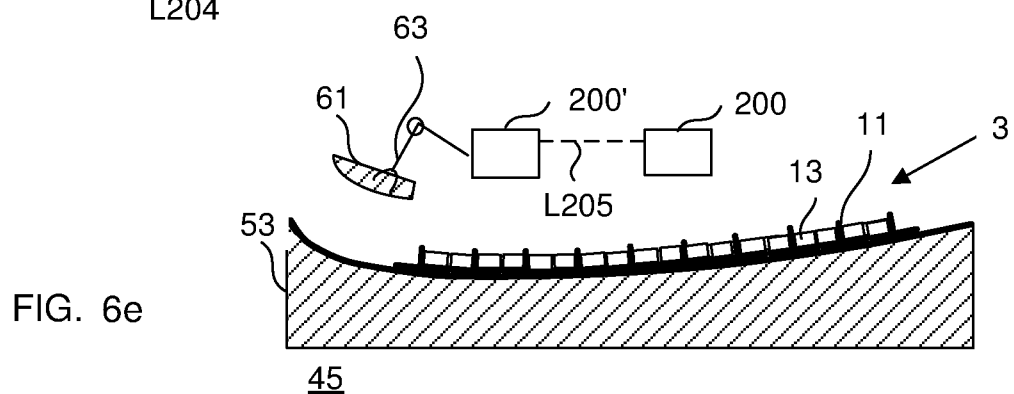


FIG. 6e

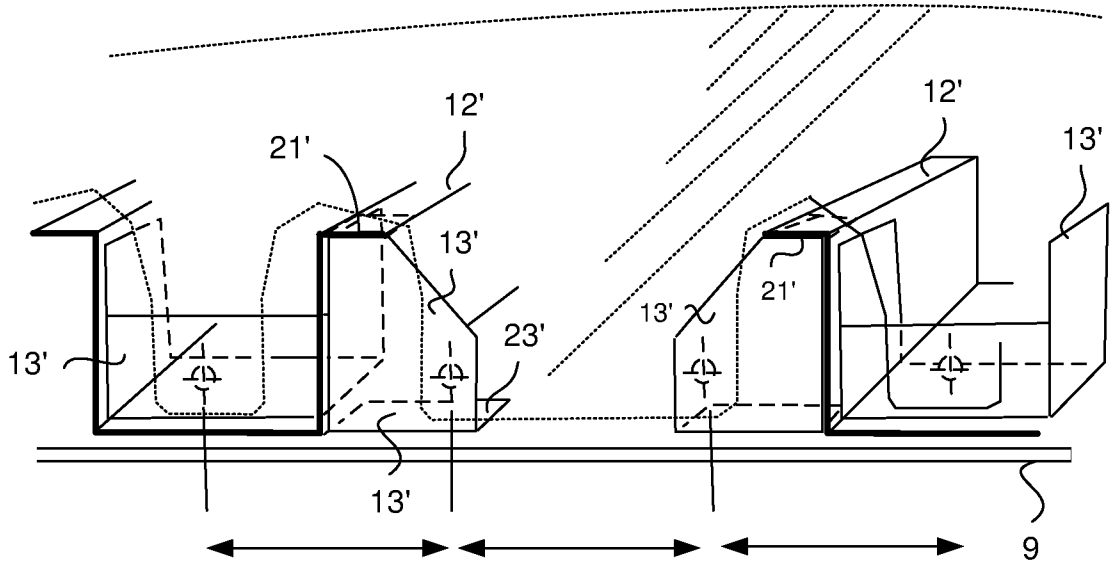


FIG. 8

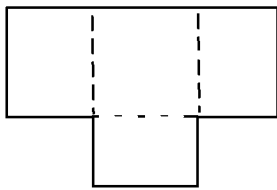


FIG. 9a

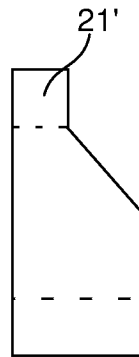


FIG. 9b

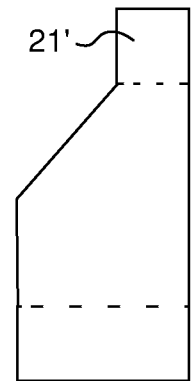


FIG. 9c

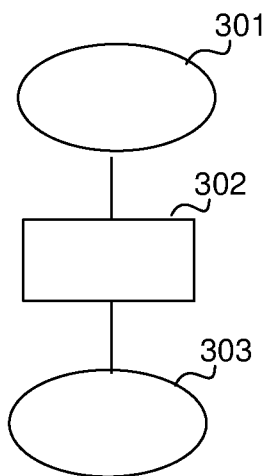


FIG. 10a

FIG. 10b

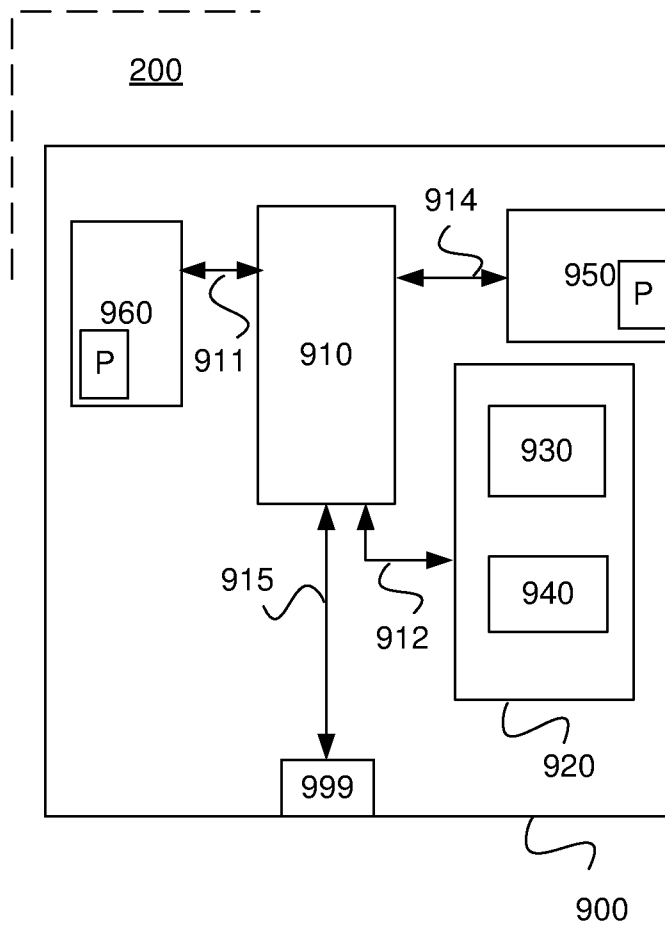
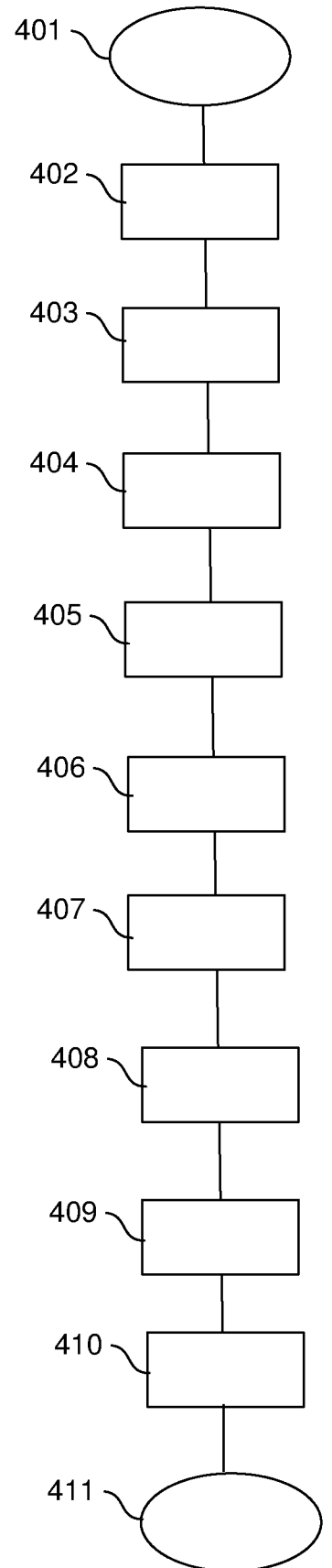


FIG. 11

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE2013/050457

A. CLASSIFICATION OF SUBJECT MATTER		
IPC: see extra sheet		
According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED		
Minimum documentation searched (classification system followed by classification symbols)		
IPC: B29C, B29D, B64C		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched		
SE, DK, FI, NO classes as above		
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)		
EPO-Internal, PAJ, WPI data		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
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A	US 20090320398 A1 (GOUVEA ROBERTO PATON), 31 December 2009 (2009-12-31); paragraphs [0030], [0031]; figures; claim 14 --	1-15
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Date of the actual completion of the international search		Date of mailing of the international search report
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INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE2013/050457

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International Patent Classification (IPC)

- B64C 3/20** (2006.01)
- B29C 70/30** (2006.01)
- B64C 1/12** (2006.01)
- B64C 3/18** (2006.01)
- B64C 3/26** (2006.01)

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