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(54) **MICRO-LATTICE CROSS-FLOW HEAT EXCHANGERS FOR AIRCRAFT**

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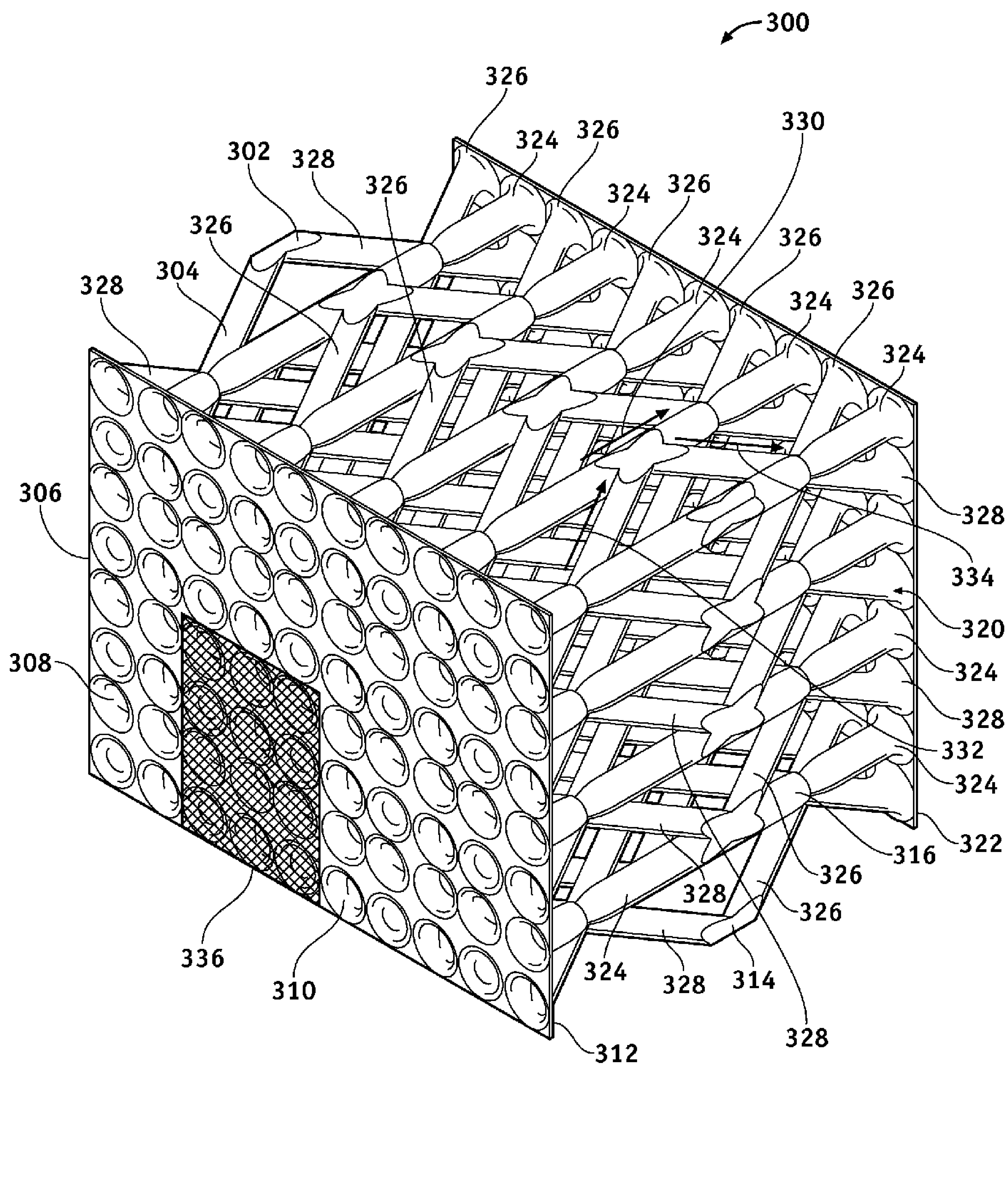
(57) **ABSTRACT**

An aircraft micro-lattice cross-flow heat exchanger and methods are presented. A first aircraft fluid source inlet provides a first fluid from a first aircraft system, and a second aircraft fluid source inlet provides a second fluid from a second aircraft system. A structural body supports aviation induced structural loads and exchanges heat between the first fluid and the second fluid. The structural body comprises hollow channels forming two interpenetrating fluidically isolated volumes that flow the first fluid within the hollow channels and flow the second fluid external to the hollow channels isolated from the first fluid. The hollow channels comprise a hollow three-dimensional micro-truss comprising hollow truss elements extending along at least three directions, and hollow nodes interpenetrated by the hollow truss elements.



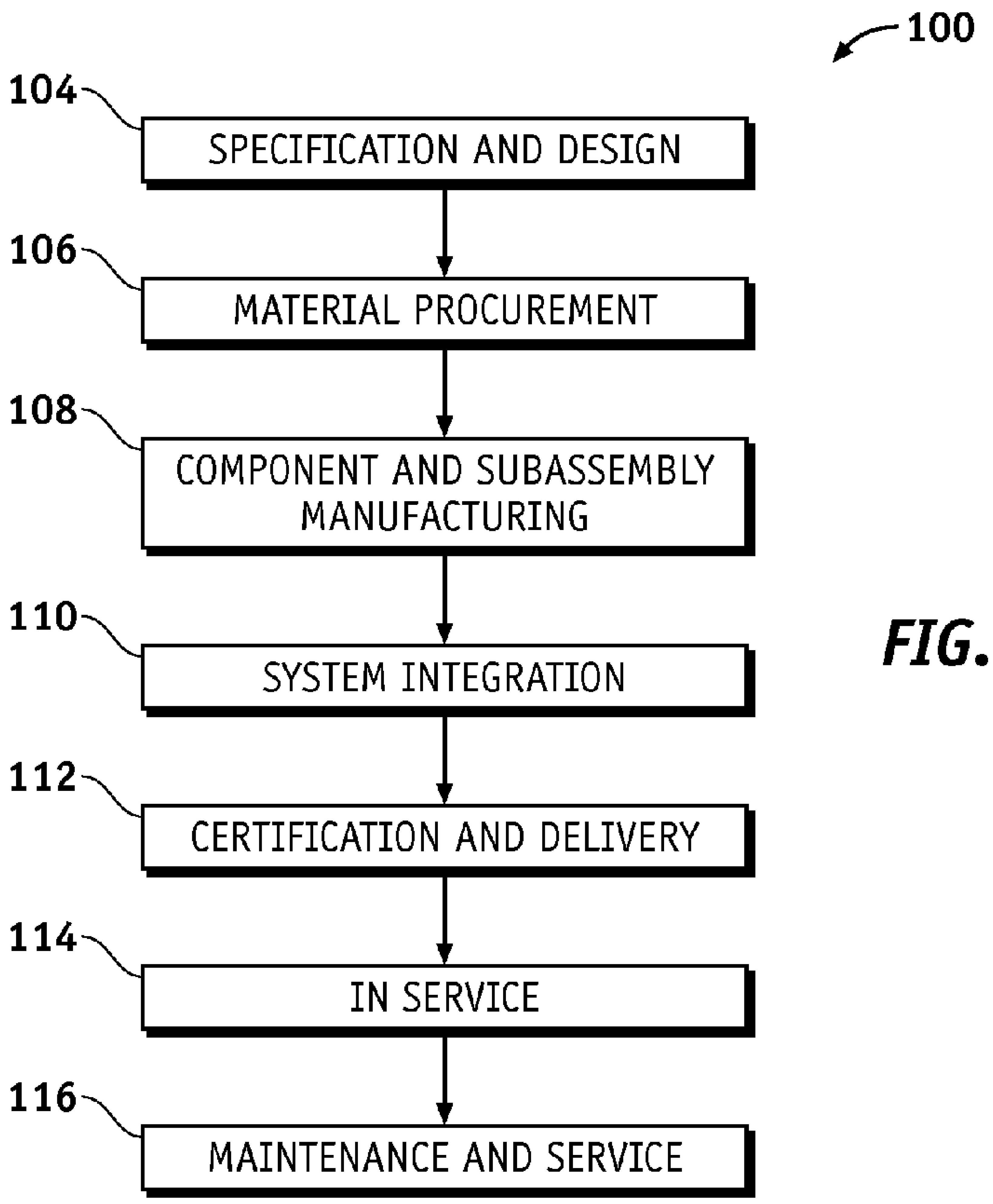

100
104
SPECIFICATION AND DESIGN
106
MATERIAL PROCUREMENT
108
COMPONENT AND SUBASSEMBLY MANUFACTURING
110
SYSTEM INTEGRATION
112
CERTIFICATION AND DELIVERY
114
IN SERVICE
116
MAINTENANCE AND SERVICE

FIG. 1

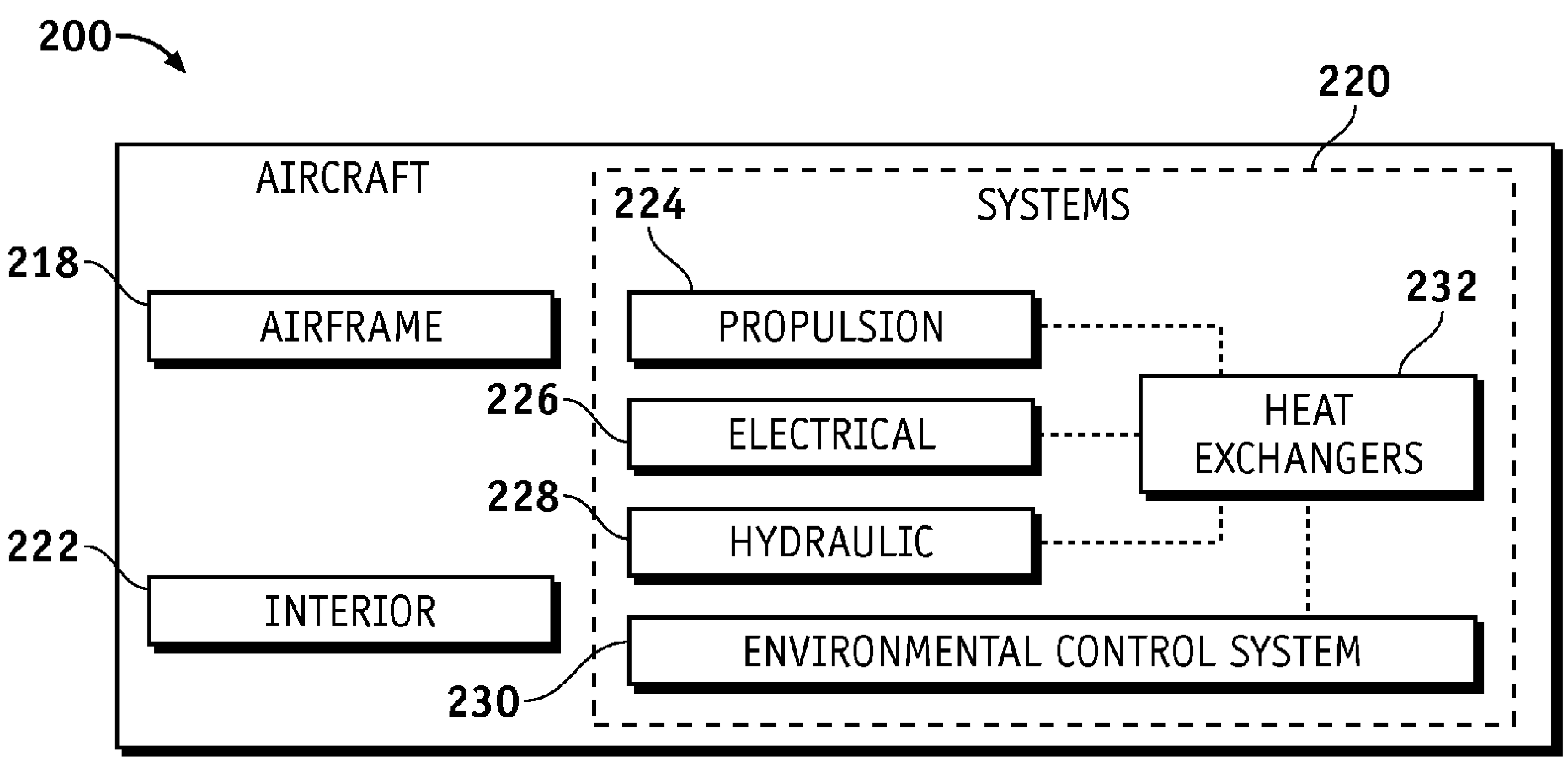
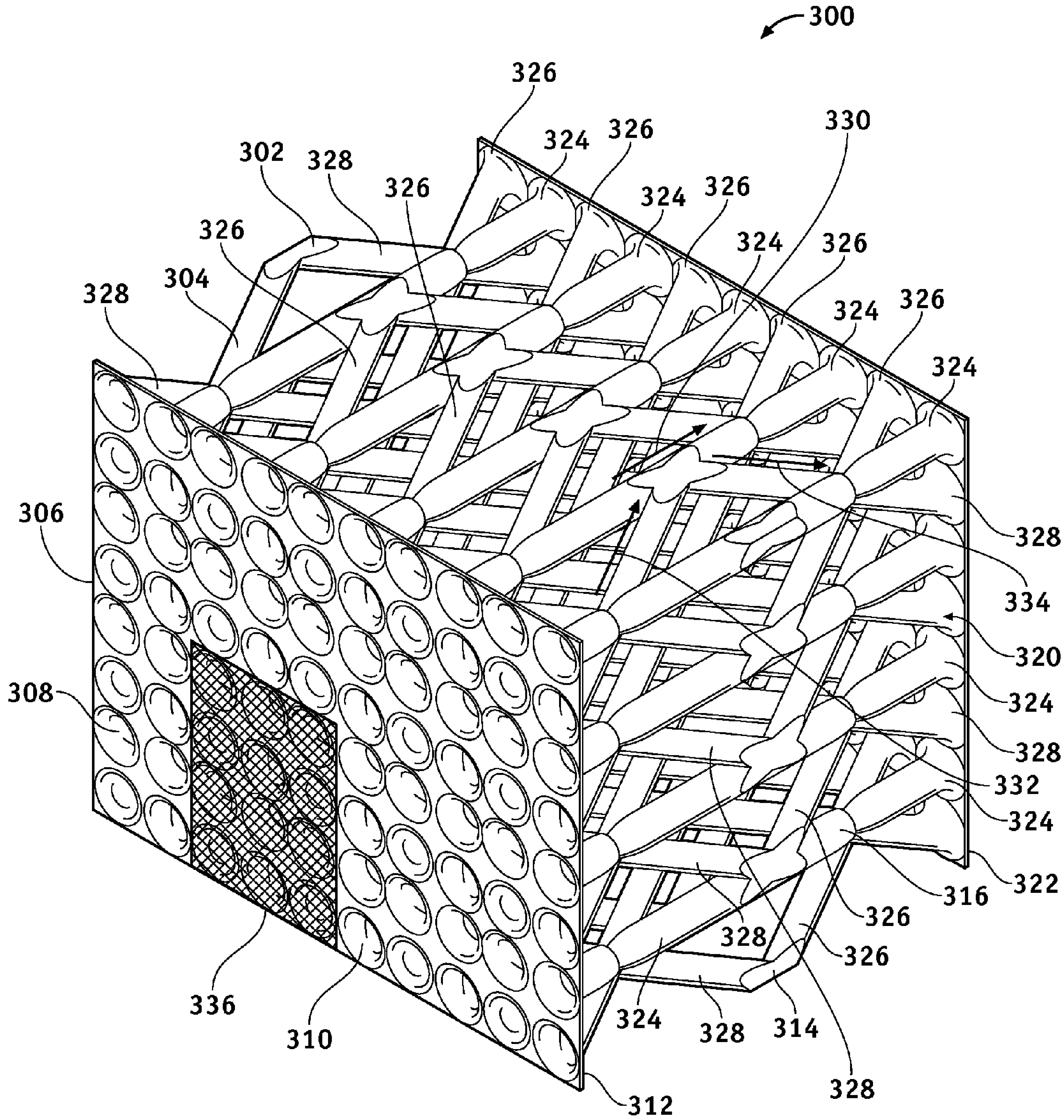

200
220
AIRCRAFT
SYSTEMS
224
218
AIRFRAME
PROPULSION
232
226
ELECTRICAL
HEAT EXCHANGERS
228
HYDRAULIC
222
INTERIOR
ENVIRONMENTAL CONTROL SYSTEM
230

FIG. 2


300
326
324
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302
328
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330
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304
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324
306
328
334
320
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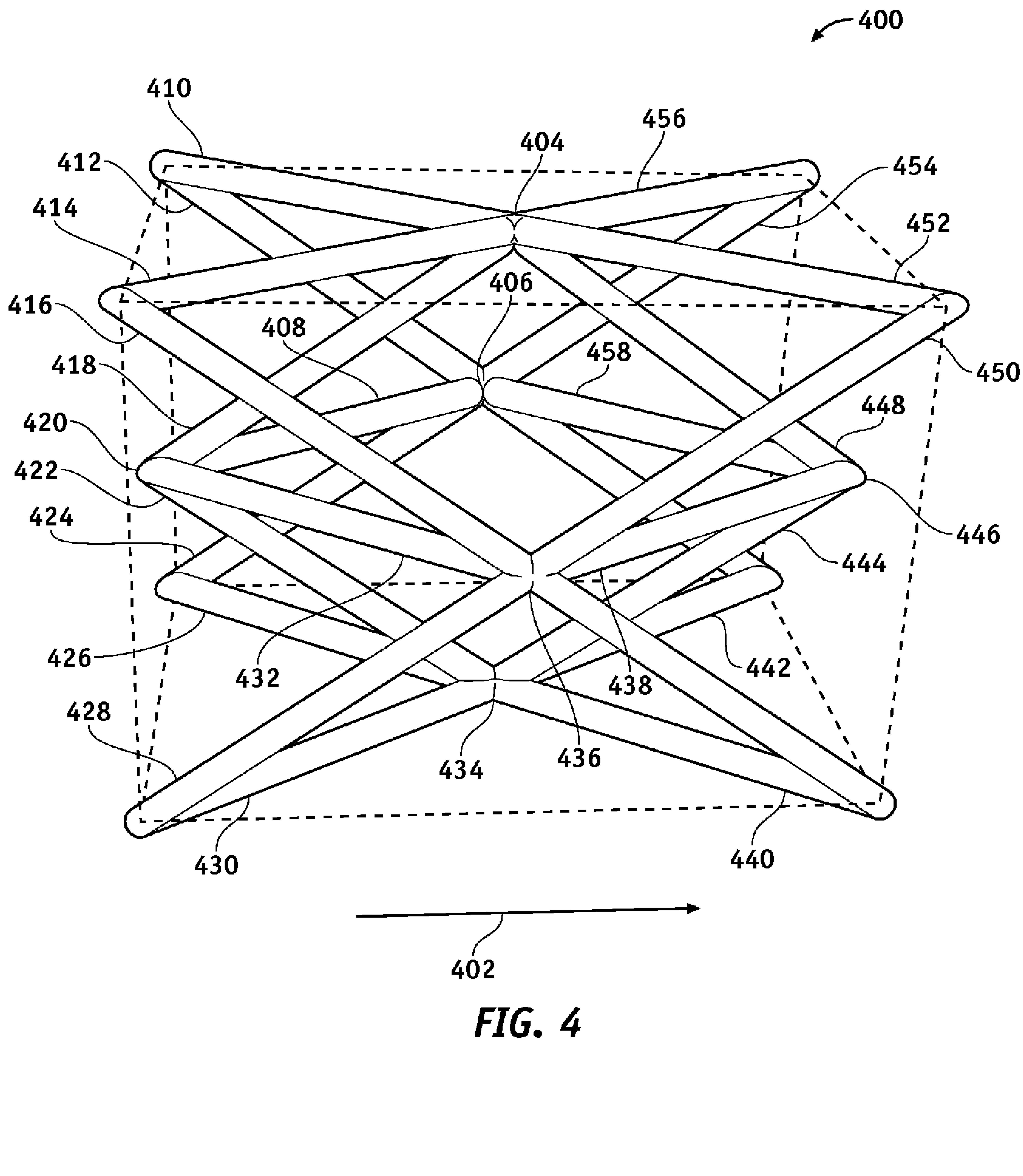
312

FIG. 3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416
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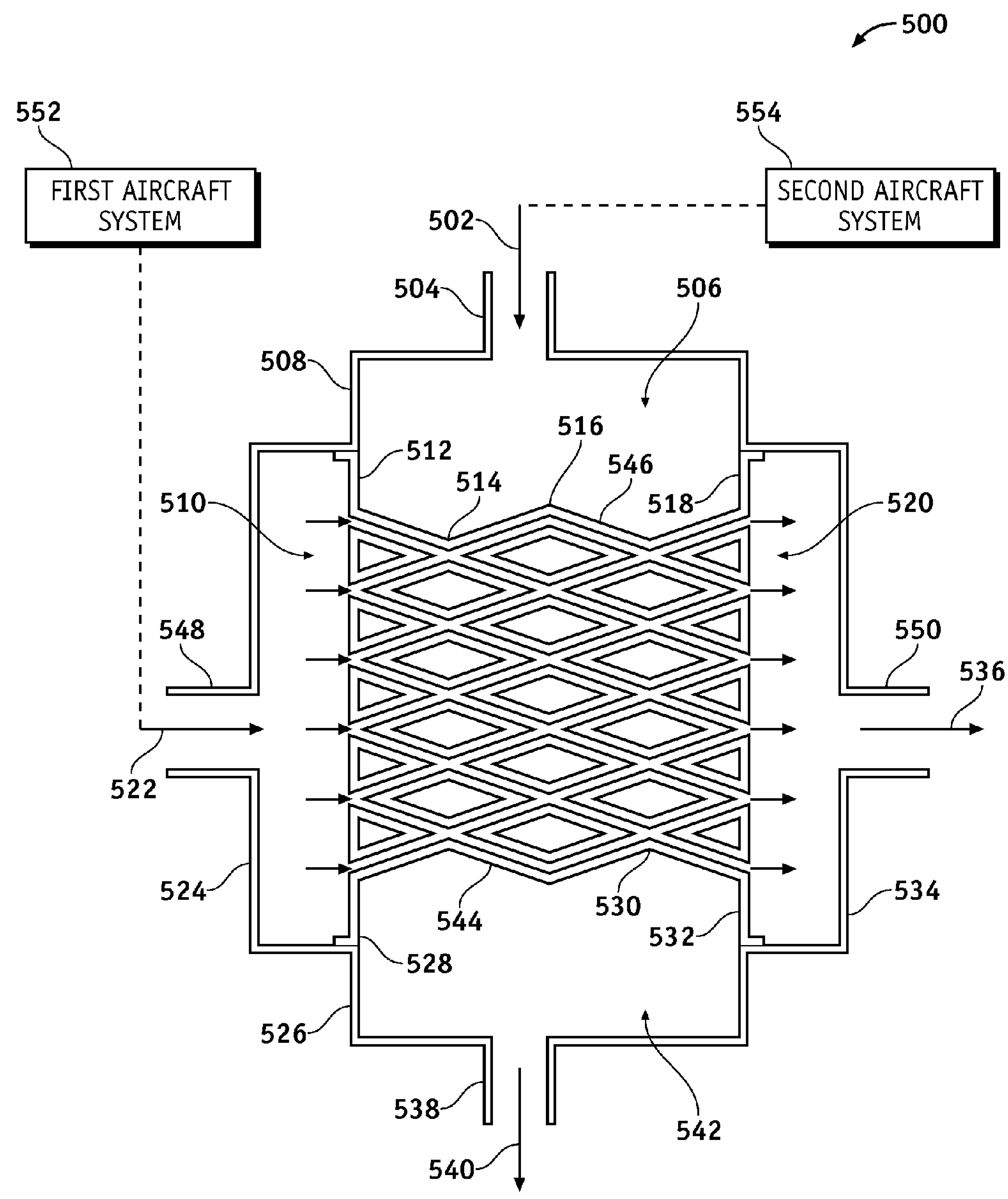
402

FIG. 4


500
552
FIRST AIRCRAFT SYSTEM
554
SECOND AIRCRAFT SYSTEM
502
504
506
508
516
512
546
514
518
510
520
548
550
536
522
524
534
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530
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538
540

FIG. 5

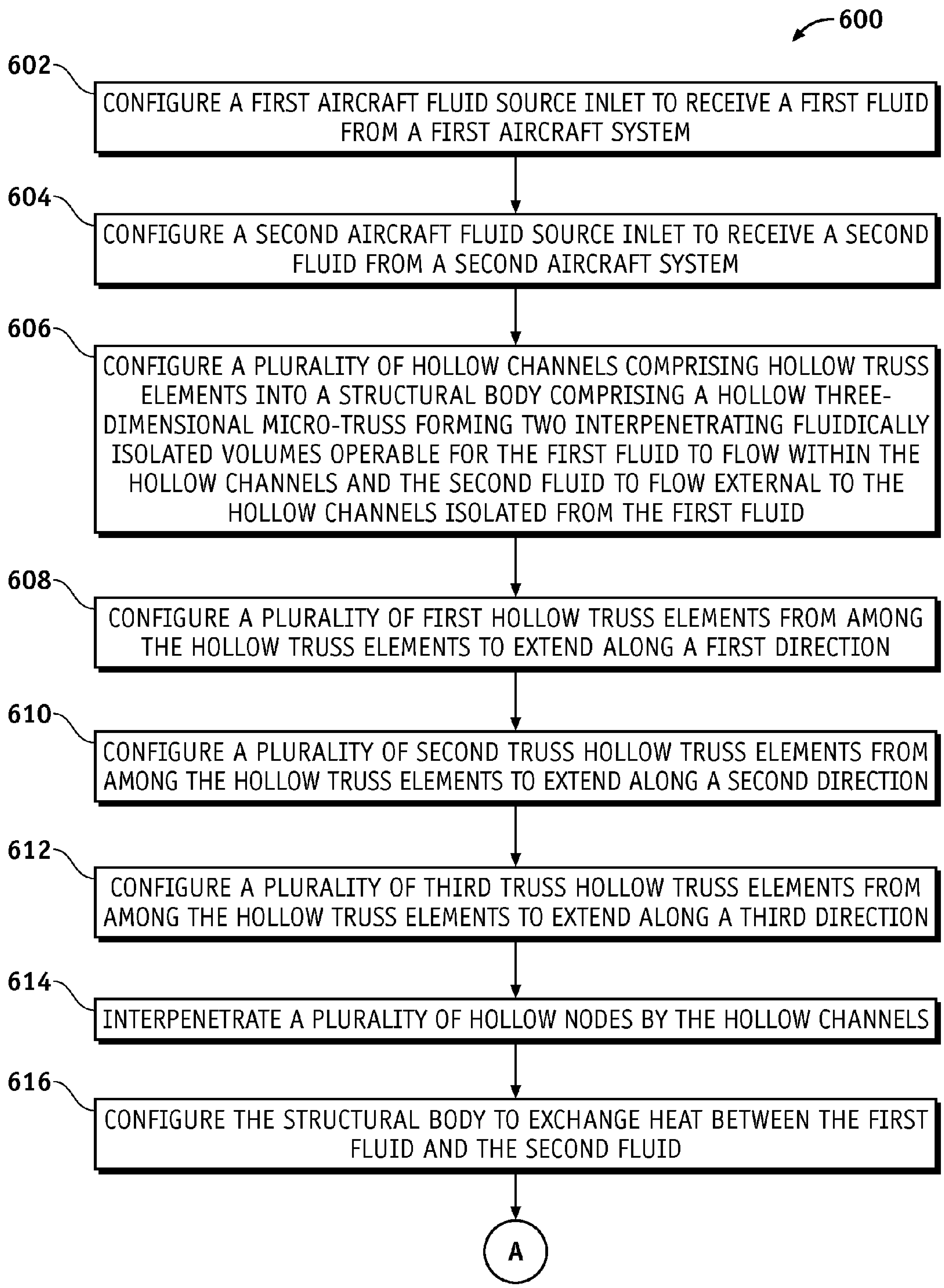
600
602
CONFIGURE A FIRST AIRCRAFT FLUID SOURCE INLET TO RECEIVE A FIRST FLUID FROM A FIRST AIRCRAFT SYSTEM
604
CONFIGURE A SECOND AIRCRAFT FLUID SOURCE INLET TO RECEIVE A SECOND FLUID FROM A SECOND AIRCRAFT SYSTEM
606
CONFIGURE A PLURALITY OF HOLLOW CHANNELS COMPRISING HOLLOW TRUSS ELEMENTS INTO A STRUCTURAL BODY COMPRISING A HOLLOW THREE-DIMENSIONAL MICRO-TRUSS FORMING TWO INTERPENETRATING FLUIDICALLY ISOLATED VOLUMES OPERABLE FOR THE FIRST FLUID TO FLOW WITHIN THE HOLLOW CHANNELS AND THE SECOND FLUID TO FLOW EXTERNAL TO THE HOLLOW CHANNELS ISOLATED FROM THE FIRST FLUID
608
CONFIGURE A PLURALITY OF FIRST HOLLOW TRUSS ELEMENTS FROM AMONG THE HOLLOW TRUSS ELEMENTS TO EXTEND ALONG A FIRST DIRECTION
610
CONFIGURE A PLURALITY OF SECOND TRUSS HOLLOW TRUSS ELEMENTS FROM AMONG THE HOLLOW TRUSS ELEMENTS TO EXTEND ALONG A SECOND DIRECTION
612
CONFIGURE A PLURALITY OF THIRD TRUSS HOLLOW TRUSS ELEMENTS FROM AMONG THE HOLLOW TRUSS ELEMENTS TO EXTEND ALONG A THIRD DIRECTION
614
INTERPENETRATE A PLURALITY OF HOLLOW NODES BY THE HOLLOW CHANNELS
616
CONFIGURE THE STRUCTURAL BODY TO EXCHANGE HEAT BETWEEN THE FIRST FLUID AND THE SECOND FLUID
A

FIG. 6

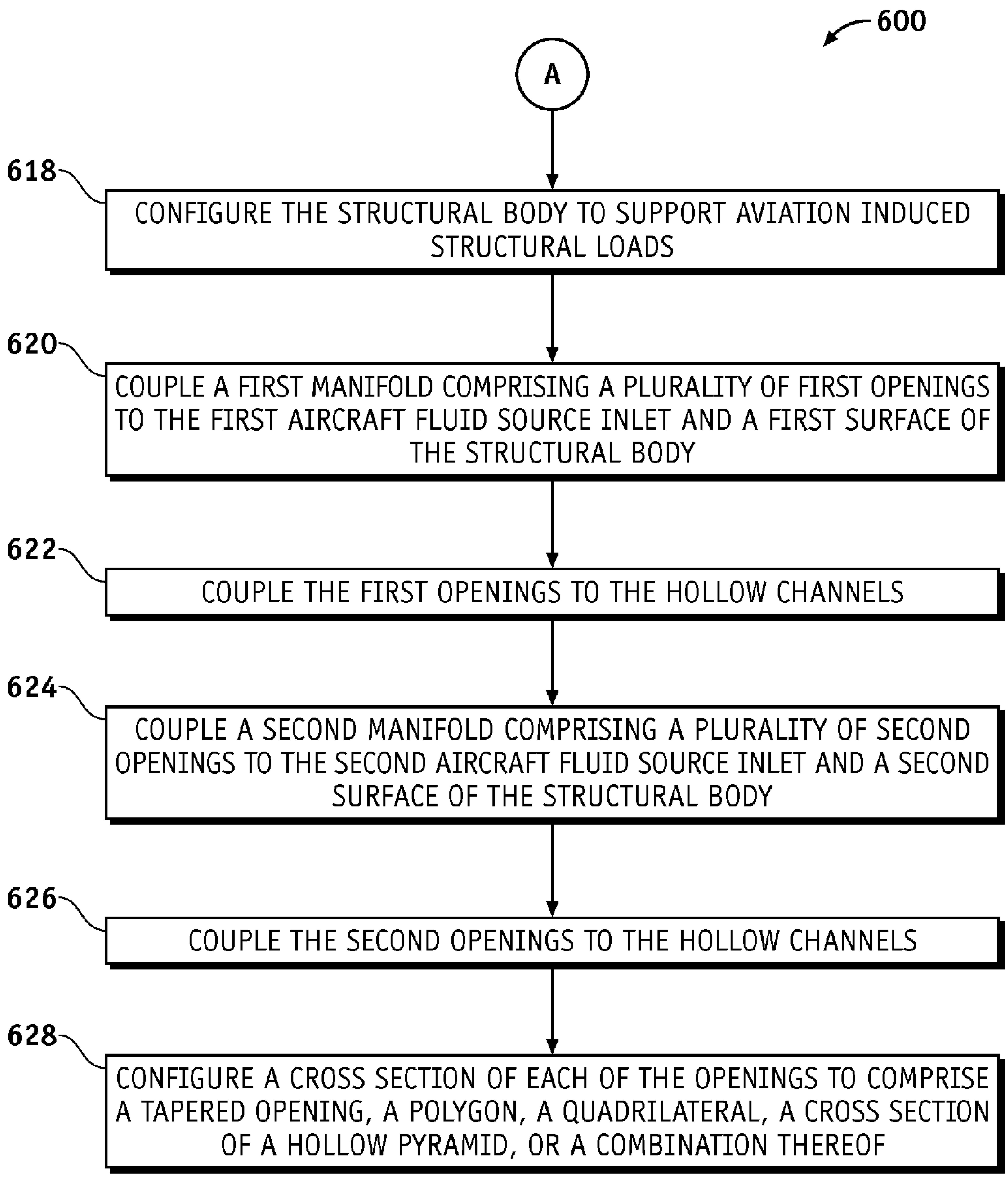
600
A
618
CONFIGURE THE STRUCTURAL BODY TO SUPPORT AVIATION INDUCED STRUCTURAL LOADS
620
COUPLE A FIRST MANIFOLD COMPRISING A PLURALITY OF FIRST OPENINGS TO THE FIRST AIRCRAFT FLUID SOURCE INLET AND A FIRST SURFACE OF THE STRUCTURAL BODY
622
COUPLE THE FIRST OPENINGS TO THE HOLLOW CHANNELS
624
COUPLE A SECOND MANIFOLD COMPRISING A PLURALITY OF SECOND OPENINGS TO THE SECOND AIRCRAFT FLUID SOURCE INLET AND A SECOND SURFACE OF THE STRUCTURAL BODY
626
COUPLE THE SECOND OPENINGS TO THE HOLLOW CHANNELS
628
CONFIGURE A CROSS SECTION OF EACH OF THE OPENINGS TO COMPRISE A TAPERED OPENING, A POLYGON, A QUADRILATERAL, A CROSS SECTION OF A HOLLOW PYRAMID, OR A COMBINATION THEREOF

FIG. 6 cont.

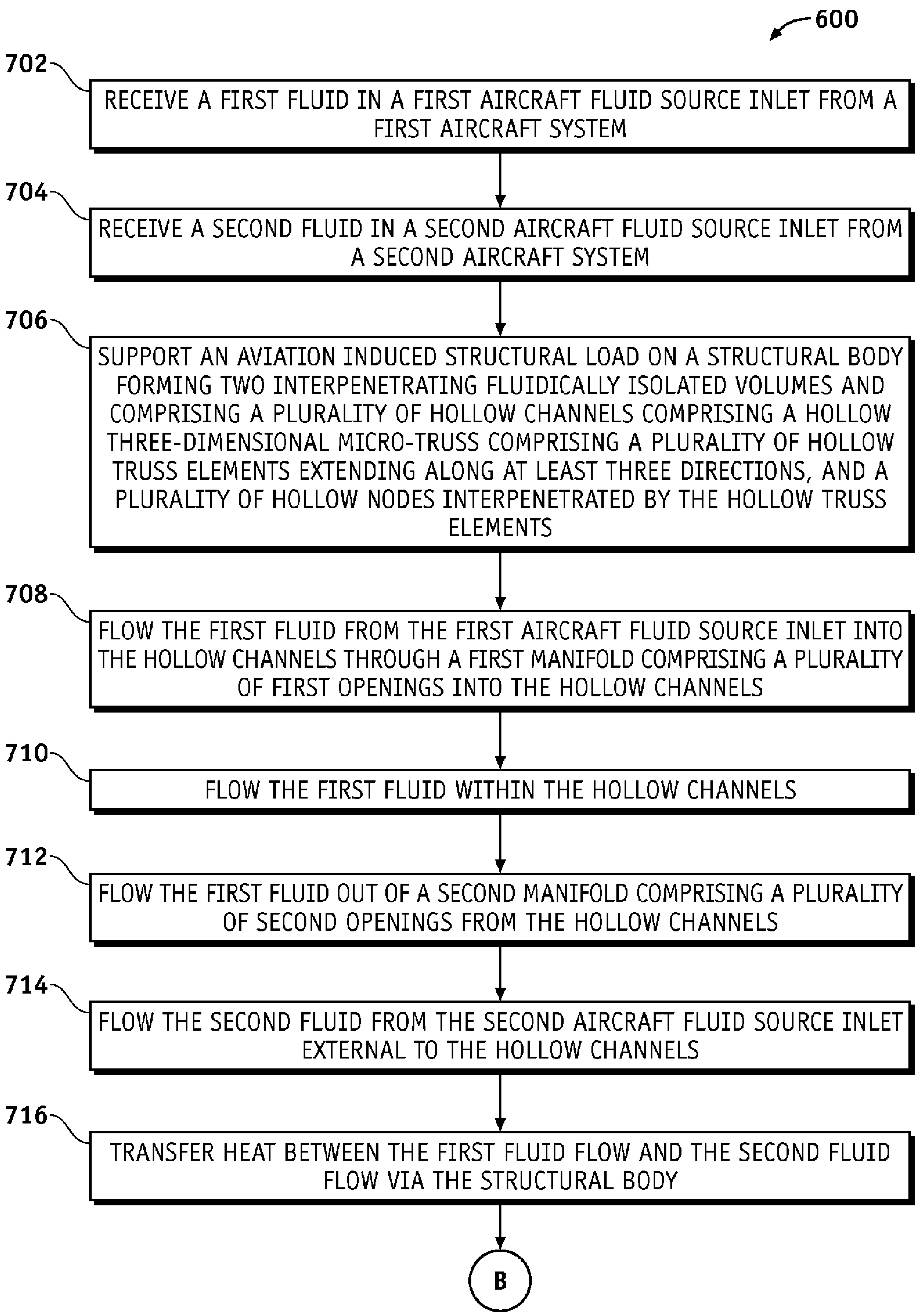
600
702
RECEIVE A FIRST FLUID IN A FIRST AIRCRAFT FLUID SOURCE INLET FROM A FIRST AIRCRAFT SYSTEM
704
RECEIVE A SECOND FLUID IN A SECOND AIRCRAFT FLUID SOURCE INLET FROM A SECOND AIRCRAFT SYSTEM
706
SUPPORT AN AVIATION INDUCED STRUCTURAL LOAD ON A STRUCTURAL BODY FORMING TWO INTERPENETRATING FLUIDICALLY ISOLATED VOLUMES AND COMPRISING A PLURALITY OF HOLLOW CHANNELS COMPRISING A HOLLOW THREE-DIMENSIONAL MICRO-TRUSS COMPRISING A PLURALITY OF HOLLOW TRUSS ELEMENTS EXTENDING ALONG AT LEAST THREE DIRECTIONS, AND A PLURALITY OF HOLLOW NODES INTERPENETRATED BY THE HOLLOW TRUSS ELEMENTS
708
FLOW THE FIRST FLUID FROM THE FIRST AIRCRAFT FLUID SOURCE INLET INTO THE HOLLOW CHANNELS THROUGH A FIRST MANIFOLD COMPRISING A PLURALITY OF FIRST OPENINGS INTO THE HOLLOW CHANNELS
710
FLOW THE FIRST FLUID WITHIN THE HOLLOW CHANNELS
712
FLOW THE FIRST FLUID OUT OF A SECOND MANIFOLD COMPRISING A PLURALITY OF SECOND OPENINGS FROM THE HOLLOW CHANNELS
714
FLOW THE SECOND FLUID FROM THE SECOND AIRCRAFT FLUID SOURCE INLET EXTERNAL TO THE HOLLOW CHANNELS
716
TRANSFER HEAT BETWEEN THE FIRST FLUID FLOW AND THE SECOND FLUID FLOW VIA THE STRUCTURAL BODY
B

FIG. 6

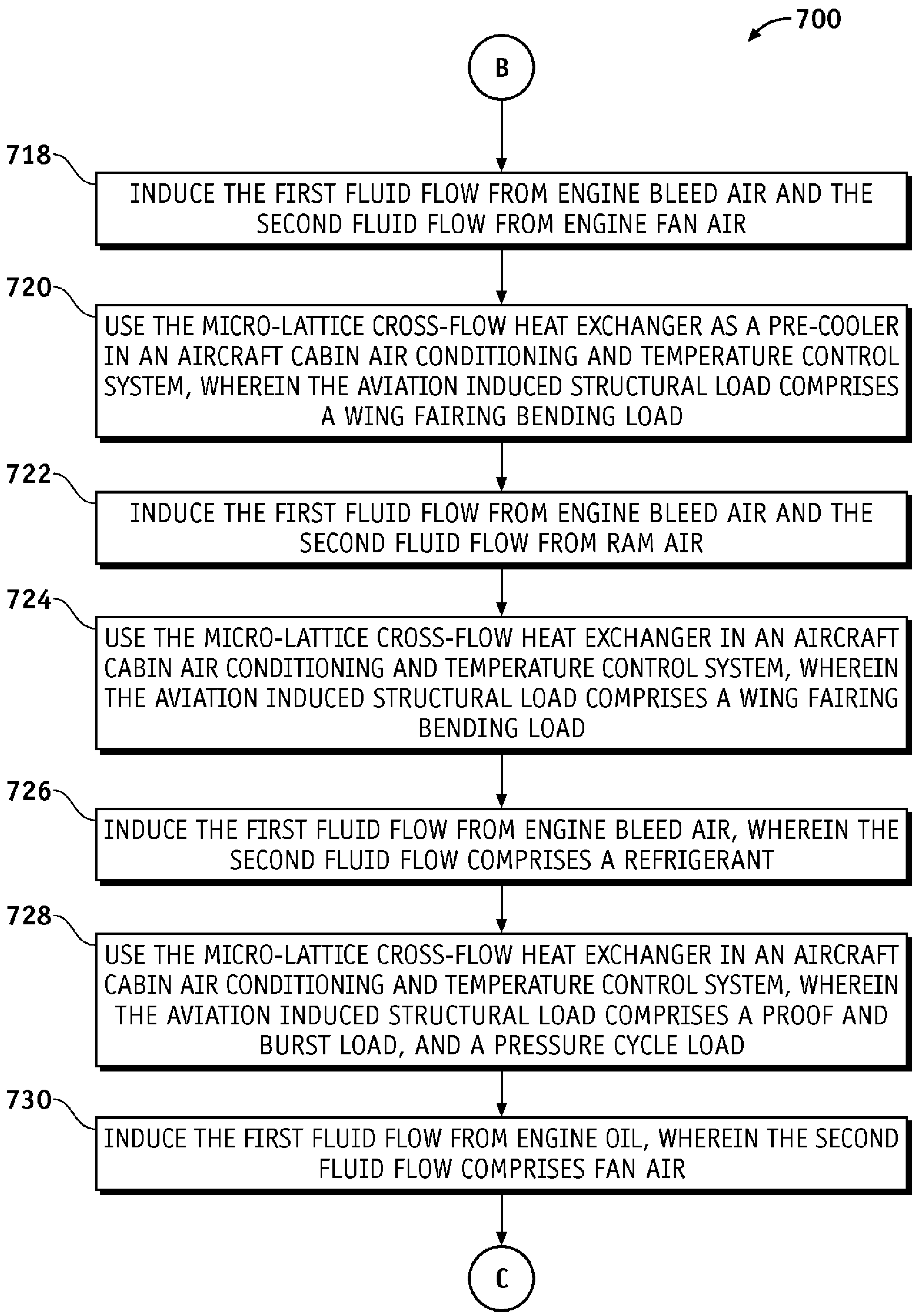
700
B
718
INDUCE THE FIRST FLUID FLOW FROM ENGINE BLEED AIR AND THE SECOND FLUID FLOW FROM ENGINE FAN AIR
720
USE THE MICRO-LATTICE CROSS-FLOW HEAT EXCHANGER AS A PRE-COOLER IN AN AIRCRAFT CABIN AIR CONDITIONING AND TEMPERATURE CONTROL SYSTEM, WHEREIN THE AVIATION INDUCED STRUCTURAL LOAD COMPRISES A WING FAIRING BENDING LOAD
722
INDUCE THE FIRST FLUID FLOW FROM ENGINE BLEED AIR AND THE SECOND FLUID FLOW FROM RAM AIR
724
USE THE MICRO-LATTICE CROSS-FLOW HEAT EXCHANGER IN AN AIRCRAFT CABIN AIR CONDITIONING AND TEMPERATURE CONTROL SYSTEM, WHEREIN THE AVIATION INDUCED STRUCTURAL LOAD COMPRISES A WING FAIRING BENDING LOAD
726
INDUCE THE FIRST FLUID FLOW FROM ENGINE BLEED AIR, WHEREIN THE SECOND FLUID FLOW COMPRISES A REFRIGERANT
728
USE THE MICRO-LATTICE CROSS-FLOW HEAT EXCHANGER IN AN AIRCRAFT CABIN AIR CONDITIONING AND TEMPERATURE CONTROL SYSTEM, WHEREIN THE AVIATION INDUCED STRUCTURAL LOAD COMPRISES A PROOF AND BURST LOAD, AND A PRESSURE CYCLE LOAD
730
INDUCE THE FIRST FLUID FLOW FROM ENGINE OIL, WHEREIN THE SECOND FLUID FLOW COMPRISES FAN AIR
C

FIG. 7 cont.

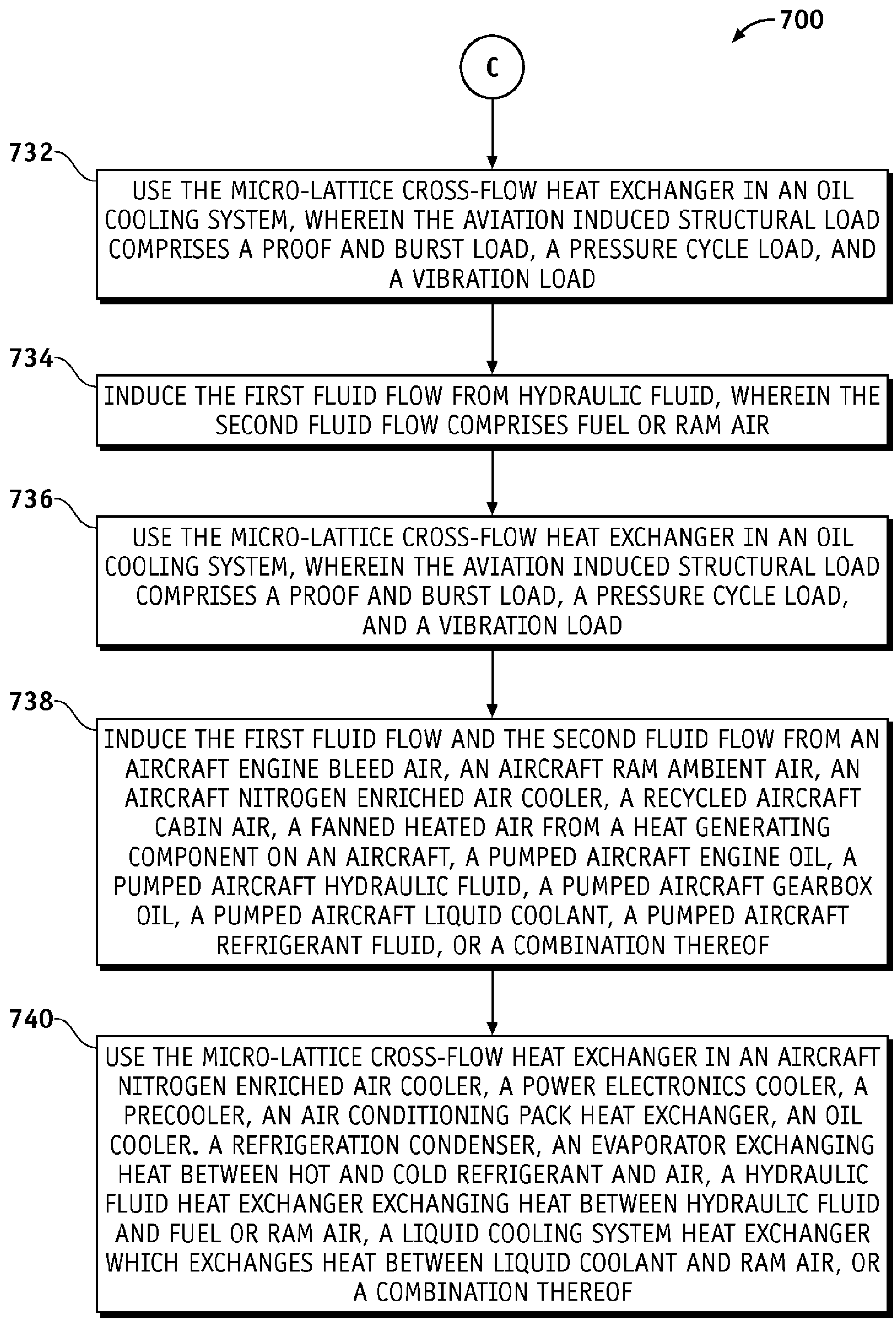
700
C
732
USE THE MICRO-LATTICE CROSS-FLOW HEAT EXCHANGER IN AN OIL COOLING SYSTEM, WHEREIN THE AVIATION INDUCED STRUCTURAL LOAD COMPRISES A PROOF AND BURST LOAD, A PRESSURE CYCLE LOAD, AND A VIBRATION LOAD
734
INDUCE THE FIRST FLUID FLOW FROM HYDRAULIC FLUID, WHEREIN THE SECOND FLUID FLOW COMPRISES FUEL OR RAM AIR
736
USE THE MICRO-LATTICE CROSS-FLOW HEAT EXCHANGER IN AN OIL COOLING SYSTEM, WHEREIN THE AVIATION INDUCED STRUCTURAL LOAD COMPRISES A PROOF AND BURST LOAD, A PRESSURE CYCLE LOAD, AND A VIBRATION LOAD
738
INDUCE THE FIRST FLUID FLOW AND THE SECOND FLUID FLOW FROM AN AIRCRAFT ENGINE BLEED AIR, AN AIRCRAFT RAM AMBIENT AIR, AN AIRCRAFT NITROGEN ENRICHED AIR COOLER, A RECYCLED AIRCRAFT CABIN AIR, A FANNED HEATED AIR FROM A HEAT GENERATING COMPONENT ON AN AIRCRAFT, A PUMPED AIRCRAFT ENGINE OIL, A PUMPED AIRCRAFT HYDRAULIC FLUID, A PUMPED AIRCRAFT GEARBOX OIL, A PUMPED AIRCRAFT LIQUID COOLANT, A PUMPED AIRCRAFT REFRIGERANT FLUID, OR A COMBINATION THEREOF
740
USE THE MICRO-LATTICE CROSS-FLOW HEAT EXCHANGER IN AN AIRCRAFT NITROGEN ENRICHED AIR COOLER, A POWER ELECTRONICS COOLER, A PRECOOLER, AN AIR CONDITIONING PACK HEAT EXCHANGER, AN OIL COOLER. A REFRIGERATION CONDENSER, AN EVAPORATOR EXCHANGING HEAT BETWEEN HOT AND COLD REFRIGERANT AND AIR, A HYDRAULIC FLUID HEAT EXCHANGER EXCHANGING HEAT BETWEEN HYDRAULIC FLUID AND FUEL OR RAM AIR, A LIQUID COOLING SYSTEM HEAT EXCHANGER WHICH EXCHANGES HEAT BETWEEN LIQUID COOLANT AND RAM AIR, OR A COMBINATION THEREOF

FIG. 7 cont.

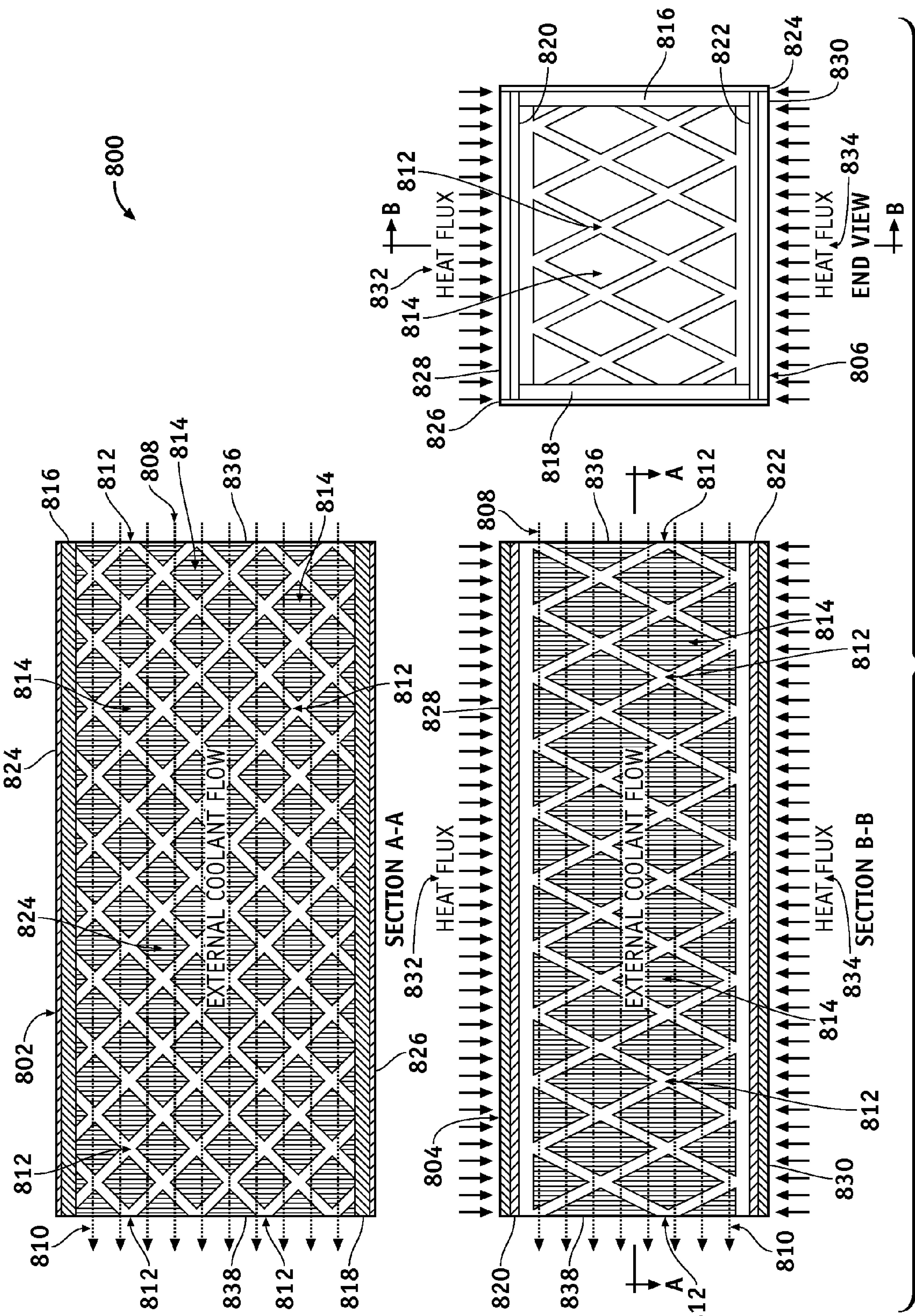
800
SECTION A-A
SECTION B-B
END VIEW
HEAT FLUX
EXTERNAL COOLANT FLOW
802
804
806
808
810
812
814
816
818
820
822
824
826
828
830
832
834
836
838
A
B

FIG. 8

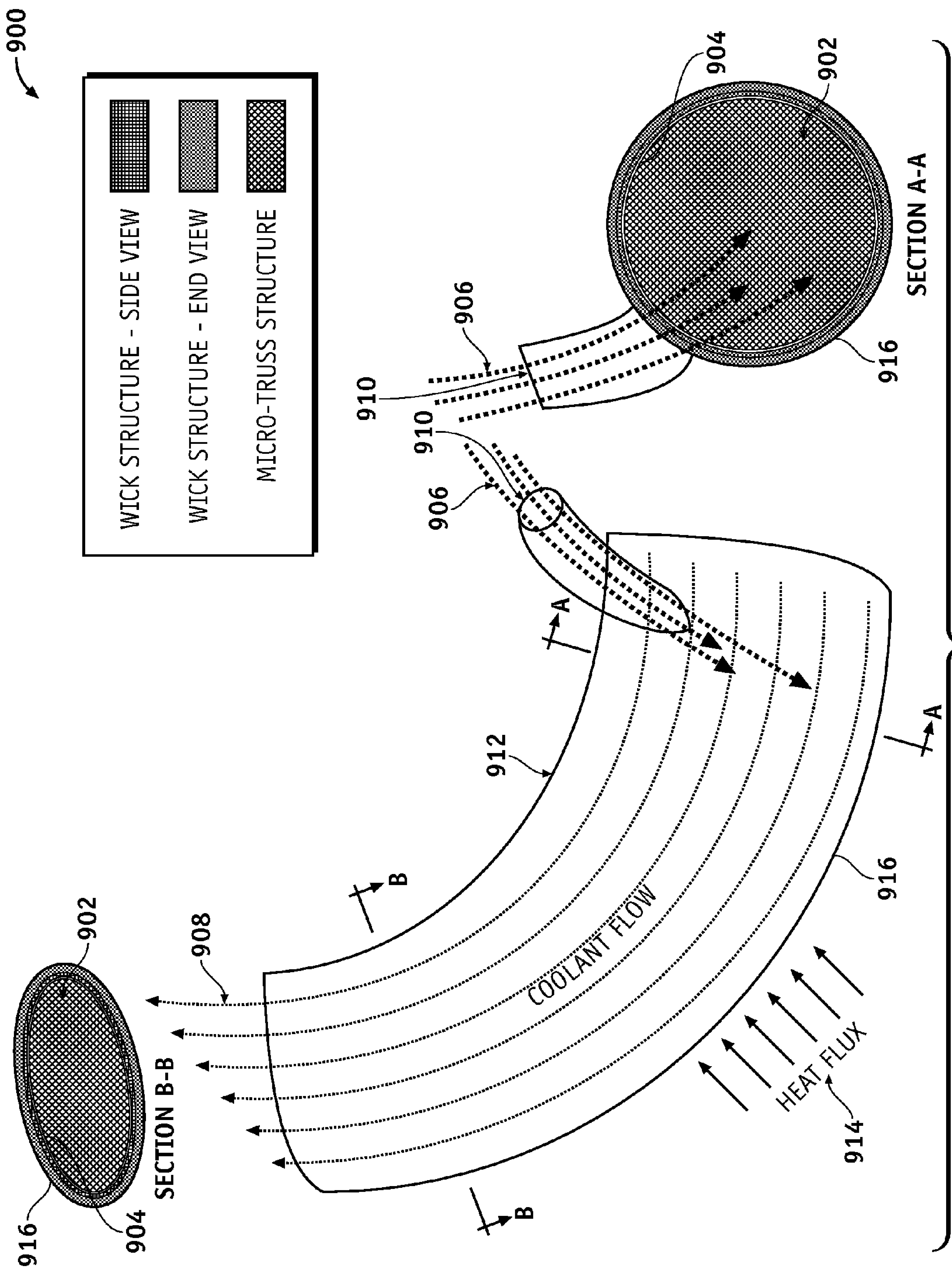
900
WICK STRUCTURE - SIDE VIEW
WICK STRUCTURE - END VIEW
MICRO-TRUSS STRUCTURE
904
902
906
910
910
906
916
SECTION A-A
A
A
912
B
B
908
COOLANT FLOW
HEAT FLUX
914
916
902
916
904
SECTION B-B

FIG. 9

MICRO-LATTICE CROSS-FLOW HEAT EXCHANGERS FOR AIRCRAFT

FIELD

[0001] Embodiments of the present disclosure relate generally to heat exchangers. More particularly, embodiments of the present disclosure relate to aircraft heat exchangers.

BACKGROUND

[0002] Heat exchangers are used in various thermal management applications such as heating, refrigeration, air conditioning, and in systems which create waste heat such as power stations, chemical plants, and petroleum refineries, and in conglomerations of systems, such as aircraft. A heat exchanger generally transfers heat from one medium to another. The media may be separated to never mix or may be in direct contact. Interface pressure loss may represent a significant component consideration. Generally the rate of heat transfer is proportional to the heat exchanger size. Ongoing research is in part focused on development of efficient heat exchanger systems that are light and small in size.

SUMMARY

[0003] An aircraft micro-lattice cross-flow heat exchanger and methods are presented. A first aircraft fluid source inlet provides a first fluid from a first aircraft system, and a second aircraft fluid source inlet provides a second fluid from a second aircraft system. A structural body supports aviation induced structural loads and exchanges heat between the first fluid and the second fluid. The structural body comprises hollow channels forming two interpenetrating fluidically isolated volumes that flow the first fluid within the hollow channels and flow the second fluid external to the hollow channels isolated from the first fluid. The hollow channels comprise a hollow three-dimensional micro-truss comprising hollow truss elements extending along at least three directions, and hollow nodes interpenetrated by the hollow truss elements.

[0004] In this manner, embodiments of the disclosure provide a heat exchanger that also bears structural loads such as system pressures. The heat exchanger comprises enclosed fluid flow interfaces to a hollow porous material that reduce discontinuities and sharp edges and consequently reduce flow disruptions, reduce pressure drops for fluid flowing into the hollow porous material, and/or increases pressure recovery for fluid exiting the hollow porous material.

[0005] In an embodiment, a method for operating a micro-lattice cross-flow heat exchanger for an aircraft receives a first fluid in a first aircraft fluid source inlet from a first aircraft system, and receives a second fluid in a second aircraft fluid source inlet from a second aircraft system. The method further supports an aviation structural load on a structural body forming two interpenetrating fluidically isolated volumes and comprising hollow channels comprising hollow truss elements within a hollow three-dimensional micro-truss. The hollow three-dimensional micro-truss comprises hollow truss elements extending along at least three directions, and a plurality of hollow nodes interpenetrated by the hollow truss elements. The method further flows the first fluid from the first aircraft fluid source inlet into the hollow channels through a first manifold comprising first openings into the hollow channels. The method further flows the first fluid within the hollow channels, and flows the first fluid out of a second manifold comprising second openings from the hollow channels. The method further flows the second fluid external to the hollow channels and transfers heat between the first fluid flow and the second fluid flow via the structural body.

[0006] In another embodiment, a micro-lattice cross-flow heat exchanger for an aircraft comprises a first aircraft fluid source inlet, a second aircraft fluid source inlet, and a structural body. The first aircraft fluid source inlet provides a first fluid from a first aircraft system, and the second aircraft fluid source inlet provides a second fluid from a second aircraft system. The structural body supports aviation induced structural loads and exchanges heat between the first fluid and the second fluid. The structural body comprises hollow channels that form two interpenetrating fluidically isolated volumes configured to flow the first fluid within the hollow channels and flow the second fluid external to the hollow channels and isolated from the first fluid. The hollow channels comprising a hollow three-dimensional micro-truss. The hollow three-dimensional micro-truss comprises hollow truss elements extending along at least three directions, and hollow nodes interpenetrated by the hollow truss elements.

[0007] In a further embodiment, a method for configuring a micro-lattice cross-flow heat exchanger for an aircraft configures a first aircraft fluid source inlet to receive a first fluid from a first aircraft system. The method further configures a second aircraft fluid source inlet to receive a second fluid from a second aircraft system. The method further configures hollow channels comprising hollow truss elements into a structural body comprising a hollow three-dimensional micro-truss forming two interpenetrating fluidically isolated volumes operable for the first fluid to flow within the hollow channels and the second fluid to flow external to the hollow channels isolated from the first fluid. The method further configures first hollow truss elements from among the hollow truss elements to extend along a first direction, and configures second hollow truss elements from among the hollow truss elements to extend along a second direction. The method further configures third hollow truss elements from among the hollow truss elements to extend along a third direction, and interpenetrates hollow nodes by the hollow truss elements. The method further configures the structural body to exchange heat between the first fluid and the second fluid, and configures the structural body to support aviation induced structural loads.

[0008] This summary is provided to introduce a selection of concepts in a simplified form that are further described below in the detailed description. This summary is not intended to identify key features or essential features of the claimed subject matter, nor is it intended to be used as an aid in determining the scope of the claimed subject matter.

BRIEF DESCRIPTION OF DRAWINGS

[0009] A more complete understanding of embodiments of the present disclosure may be derived by referring to the detailed description and claims when considered in conjunction with the following figures, wherein like reference numbers refer to similar elements throughout the figures. The figures are provided to facilitate understanding of the disclosure without limiting the breadth, scope, scale, or applicability of the disclosure. The drawings are not necessarily made to scale.

[0010] FIG. **1** is an illustration of a flow diagram of an exemplary aircraft production and service methodology.

[0011] FIG. **2** is an illustration of an exemplary block diagram of an aircraft.

[0012] FIG. **3** is an illustration of an exemplary micro-lattice cross-flow heat exchanger according to an embodiment of the disclosure.

[0013] FIG. **4** is an illustration of an expanded view of an exemplary micro-lattice cross-flow heat exchanger showing hollow channels entering and leaving hollow nodes according to an embodiment of the disclosure.

[0014] FIG. **5** is an illustration of an exemplary schematic of a micro-lattice cross-flow heat exchanger according to an embodiment of the disclosure.

[0015] FIG. **6** is an illustration of an exemplary flowchart showing a process for configuring micro-lattice cross-flow heat exchanger for an aircraft according to an embodiment of the disclosure.

[0016] FIG. **7** is an illustration of an exemplary flowchart showing a process for operating a micro-lattice cross-flow heat exchanger for an aircraft according to an embodiment of the disclosure.

[0017] FIG. **8** is an illustration of an exemplary schematic of a micro-lattice cross-flow heat exchanger comprising a heat pipe according to an embodiment of the disclosure.

[0018] FIG. **9** is an illustration of an exemplary schematic of a micro-lattice cross-flow heat exchanger comprising a heat pipe according to an embodiment of the disclosure.

DETAILED DESCRIPTION

[0019] The following detailed description is exemplary in nature and is not intended to limit the disclosure or the application and uses of the embodiments of the disclosure. Descriptions of specific devices, techniques, and applications are provided only as examples. Modifications to the examples described herein will be readily apparent to those of ordinary skill in the art, and the general principles defined herein may be applied to other examples and applications without departing from the spirit and scope of the disclosure. Furthermore, there is no intention to be bound by any expressed or implied theory presented in the preceding field, background, summary or the following detailed description. The present disclosure should be accorded scope consistent with the claims, and not limited to the examples described and shown herein.

[0020] Embodiments of the disclosure may be described herein in terms of functional and/or logical block components and various processing steps. It should be appreciated that such block components may be realized by any number of hardware, software, and/or firmware components configured to perform the specified functions. For the sake of brevity, conventional techniques and components related to aircraft, aircraft components, heat exchangers, fluid dynamics, and other functional aspects of the systems (and the individual operating components of the systems) may not be described in detail herein. In addition, those skilled in the art will appreciate that embodiments of the present disclosure may be practiced in conjunction with a variety of structural bodies, and that the embodiments described herein are merely example embodiments of the disclosure.

[0021] Embodiments of the disclosure are described herein in the context of some non-limiting applications, namely, an air conditioning heat exchanger. Embodiments of the disclosure, however, are not limited to such air conditioning applications, and the techniques described herein may also be utilized in other applications. For example, embodiments may be applicable to electronics cooling, battery cooling, liquid-liquid heat exchange, gas-liquid heat exchange, slurry-liquid heat exchange (e.g., slush hydrogen to liquid nitrogen), slurry-gas heat exchange, fuel-coolant heat exchange, Synergistic Air-Breathing Rocket Engines (SABRE), engine precoolers, engine oil coolers, hypersonic precoolers, intercoolers, hydraulic fluid heat exchangers, refrigeration heat exchangers, or other heat exchange applications.

[0022] As would be apparent to one of ordinary skill in the art after reading this description, the following are examples and embodiments of the disclosure and are not limited to operating in accordance with these examples. Other embodiments may be utilized and structural changes may be made without departing from the scope of the exemplary embodiments of the present disclosure.

[0023] Embodiments provide a lightweight, high-performance cross-flow micro-lattice heat exchanger structure for an aircraft, including air to air, liquid to liquid, and liquid to air heat transfer in both single and two-phase flow. Embodiments use a hollow micro-lattice structure as a core structure in the micro-lattice heat exchanger structure for particular applications. A fluid stream is passed through hollow tubes comprising the hollow micro-lattice structure. Another fluid stream passes around the hollow micro-lattice structure. This fluid passage mechanism permits transfer of heat between the two fluid streams without mixing the two fluids. The hollow micro-lattice structure is well-suited for use in multiple places on an aircraft where high heat transfer between two fluid streams, low fluid pressure drop, low mass and low volume is desirable. For example, the micro-lattice heat-exchanger structure may be used to transfer heat from compressed air stream to a RAM air stream, thus providing a source of cabin air at the proper temperature and pressure for passenger comfort.

[0024] Referring more particularly to the drawings, embodiments of the disclosure may be described in the context of an exemplary aircraft manufacturing and service method **100** (method **100**) as shown in FIG. **1** and an aircraft **200** as shown in FIG. **2**. During pre-production, the method **100** may comprise specification and design **104** of the aircraft **200**, and material procurement **106**. During production, component and subassembly manufacturing **108** (process **108**) and system integration **110** of the aircraft **200** takes place. Thereafter, the aircraft **200** may go through certification and delivery **112** in order to be placed in service **114**. While in service by a customer, the aircraft **200** is scheduled for routine maintenance and service **116** (which may also comprise modification, reconfiguration, refurbishment, and so on).

[0025] Each of the processes of method **100** may be performed or carried out by a system integrator, a third party, and/or an operator (e.g., a customer). For the purposes of this description, a system integrator may comprise, for example but without limitation, any number of aircraft manufacturers and major-system subcontractors; a third party may comprise, for example but without limitation, any number of vendors, subcontractors, and suppliers; and an operator may comprise, for example but without limitation, an airline, leasing company, military entity, service organization; and the like.

[0026] As shown in FIG. **2**, the aircraft **200** produced by the method **100** may comprise an airframe **218** with a plurality of systems **220** and an interior **222**. Examples of high-level systems of the systems **220** comprise one or more of a propulsion system **224**, an electrical system **226**, a hydraulic system **228**, an environmental control system **230**, and one or more heat exchanger systems **232**. The one or more heat exchanger systems **232** may be contained in the airframe **218**, the interior **222**, the systems **220** such as the propulsion system **224**, the electrical system **226**, the hydraulic system **228**, and the environmental control system **230** or any system of the aircraft **200**. Any number of other systems may also be included. Although an aerospace example is shown, the embodiments of the disclosure may be applied to other industries.

[0027] It should not be inferred from FIG. **2** that an airplane comprises a single, thermal management or, heat exchanger system that manages waste heat from multiple systems. Rather, each system generally comprises one or more heat exchangers to manage waste heat produced by its components.

[0028] Apparatus and methods embodied herein may be employed during any one or more of the stages of the method **100**. For example, components or subassemblies corresponding to production of the process **108** may be fabricated or manufactured in a manner similar to components or subassemblies produced while the aircraft **200** is in service. In addition, one or more apparatus embodiments, method embodiments, or a combination thereof may be utilized during production stages of the process **108** and the system integration **110**, for example, by substantially expediting assembly of or reducing the cost of an aircraft **200**. Similarly, one or more of apparatus embodiments, method embodiments, or a combination thereof may be utilized while the aircraft **200** is in service, for example and without limitation, to maintenance and service **116**.

[0029] FIG. **3** is an illustration of an exemplary micro-lattice cross-flow heat exchanger **300** according to an embodiment of the disclosure. The micro-lattice cross-flow heat exchanger **300** may comprise a structural body **320**, a manifold **306/322**, and a plurality of hollow nodes **302/314**.

[0030] The structural body **320** comprises a plurality of hollow channels **304/316** configured to flow a first fluid **522** (FIG. **5**) within the hollow channels **304/316** and a second fluid **502** (FIG. **5**) external to the hollow channels **304/316**.

[0031] In one embodiment, the hollow channels **304/316** may be a polymer micro-truss structure in a form of a regular hollow three-dimensional micro-truss of intersecting tubes, configured with hollow nodes **302/314** at the intersections of the hollow channels **304/316**, so that an interior of each of the hollow channels **304/316** is in communication with any other hollow channels **304/316** it intersects. The hollow channels **304/316** comprise hollow truss elements within a hollow three-dimensional micro-truss comprising: first hollow truss elements **324** extending along a first direction **330**, second truss hollow truss elements **326** extending along a second direction **332**, third truss hollow truss elements **328** extending along a third direction **334**.

[0032] The hollow channels **304/316** may comprise, for example but without limitation, a cross-sectional shape that can be elliptical, circular, square, triangular, octagonal, star-shaped, a combination thereof, or other shape. Large aspect ratio elliptical shapes may improve heat transfer, and orientation of an ellipse's major axis may enhance heat transfer and enable better control of a pressure drop incurred by flow of the second fluid. In some embodiments, the hollow channels **304/316** may comprise, for example but without limitation, one or more heat pipes **800** (FIG. **8**).

[0033] Access to an interior fluid volume, formed by connected interiors of the hollow channels **304/316**, may be provided by an architected fluid interface, which may also be referred to as a manifold such as the manifold **306/322**, at each end of the structural body **320**.

[0034] The manifold **306/322** is coupled to a first surface **512** and a second surface **518** (FIG. **5**) of the structural body **320** respectively. The manifold **306/322** each comprises a plurality of openings **308/310** into the hollow channels **304/316**. A cross section (e.g., lateral, longitudinal, or other cross section) of each of the openings **308/310** may comprise, for example but without limitation, a tapered shape (e.g., for a longitudinal cross section), a polygon shape, quadrilateral shape, a cross-section of a hollow pyramid (e.g., for a lateral or longitudinal cross section), or other cross section configuration. The openings **308/310** can be protruding or square-edged, or to reduce pressure drop incurred by the first flow, the openings can be radiused or tapered. The manifold **306/322** may comprise a particulate filter **336**. The particulate filter **336** may be used to decrease a head loss coefficient of a flow encountering the openings **308/310**.

[0035] Each of the hollow channels **304/316** that is at a surface such as the first surface **512** or the second surface **518** where a manifold **306/322** is placed comprises an opening such as the openings **308/310**, but some tube segments of the hollow channels **304/316** may connect two nodes instead of one node and one opening or, as illustrated in FIG. **3**, into groups of hollow channels **304/316**. In the embodiment illustrated in FIG. **3**, the openings **308/310** may be in a form of a funnel or hollow pyramid, with a depth approximately or substantially equal to one half of the length, in a direction of a bore of the funnel, of a unit cell of the hollow three-dimensional micro-truss of hollow channels **304/316**.

[0036] Smooth transitions using the openings **308/310** shaped as described above (e.g., tapered etc.), at an interface between a bulk fluid and a hollow porous material such as the hollow channels **304/316** may result in significantly lower pressure drop for a fluid flowing into the hollow channels **304/316** and higher pressure recovery for a fluid exiting from the hollow channels **304/316** than manifolds having a flat surface with a flush hole for each hollow channels **304/316**. In particular, a head loss coefficient of a flow encountering a right-angle inlet is approximately 0.5, while the head loss coefficient for a filleted inlet is as low as 0.04, representing an improvement of 12.5 times.

[0037] The hollow nodes **302/314** comprise locations at which the hollow channels **304/316** interpenetrate.

[0038] FIG. **4** is an illustration of an expanded view **400** of an exemplary micro-lattice cross-flow heat exchanger **300** showing hollow channels entering and leaving hollow nodes according to an embodiment of the disclosure. For example but without limitation, hollow nodes **404**, **406**, **420**, **434** and **446** comprise various configurations for flow of a fluid in the direction **402**. Hollow node **404** is interpenetrated by hollow truss elements **410**, **414** and **418** bringing fluid into the hollow node **404**, and by hollow truss elements **448**, **452** and **456** receiving fluid from the hollow node **404**. Hollow node **406** is interpenetrated by hollow truss elements **408**, **412** and **424** bringing fluid into the hollow node **406**, and by hollow elements **454**, **458** and **460** receiving fluid from the hollow node **406**. Hollow node **420** is interpenetrated by hollow truss elements (not shown) bringing fluid into the hollow node **420**, and by hollow truss elements **408**, **418**, **422** and **432** receiving fluid from the hollow node **420**. Hollow node **434** is interpenetrated by hollow truss elements **422**, **426** and **430** bringing fluid into the hollow node **434**, and by hollow truss elements

440, **442** and **444** receiving fluid from the hollow node **434**. Node **446** is interpenetrated by hollow truss elements **438**, **444**, **448** and **458** bringing fluid into the hollow node **446**, and by hollow elements (not shown) receiving fluid from the hollow node **446**.

[0039] FIG. **5** is an illustration of an exemplary schematic of a micro-lattice cross-flow heat exchanger **500** according to an embodiment of the disclosure. The micro-lattice cross-flow heat exchanger **500** may comprise a structural body **514** (**320** in FIG. **3**), a first input manifold **524**, a first output manifold **534**, a second input manifold **508**, and a second output manifold **526**.

[0040] The first fluid **522** is flowed into the first input manifold **524** coupled to a surface **512** of the structural body **514**. The structural body **514** is configured for the first fluid **522** to flow into and within a plurality of hollow channels **546**/**544** (**302**/**314** in FIG. **3**). The structural body **514** comprises a plurality of hollow nodes **516**/**530** (**302**/**314** in FIG. **3**) at which the hollow channels **546**/**544** interpenetrate. The first input manifold **524** and the first output manifold **534** comprise a plurality of openings **308**/**310** (see FIG. **3**) into the hollow channels **546**/**544**. The first fluid **522** transfers heat to/from the structural body **514** and exits the first output manifold **534** as a first heat changed fluid **536**.

[0041] The second fluid **502** is flowed into the second input manifold **508** around and external to the hollow channels **546**/**544**. The second fluid **502** transfers heat from/to the structural body **514** and exits the second output manifold **526** as a second heat changed fluid **540**. Thereby, heat is transferred between the first fluid **522** and the second fluid **502** via the structural body **514**.

[0042] In one embodiment, a first aircraft fluid source inlet **548** is configured to provide a first fluid **522** from a first aircraft system **552**. A second aircraft fluid source inlet **504** is configured to provide a second fluid **502** from a second aircraft system **554**. The structural body **320**/**514** is configured to support aviation induced structural loads and exchange heat between the first fluid **522** and the second fluid **502**. The aviation induced structural loads may comprise, for example but without limitation, a proof and burst load, an air pressure cycling load, a vibration load, an inertial load, a thermal cycling load, an airframe structural support load, a wing fairing bending load, a combination thereof, an/or other aviation structural load.

[0043] The structural body **320**/**514** comprises a plurality of the hollow channels **546**/**544** forming two interpenetrating fluidically isolated volumes and configured for flow of the first fluid **522** within the hollow channels **546**/**544** and flow of the second fluid **502** external to the hollow channels **546**/**544** isolated from the first fluid **522**. The hollow channels **546**/**544** comprise a hollow three-dimensional micro-truss such as the micro-lattice cross-flow heat exchanger **300**/**500** comprising hollow truss elements extending along at least three directions, and a plurality of hollow nodes interpenetrated by the hollow truss elements as explained above.

[0044] The micro-lattice cross-flow heat exchanger **300**/**500** may be used in, for example but without limitation, an aircraft nitrogen enriched air cooler, a power electronics cooler, a precooler, an air conditioning pack heat exchanger, an oil cooler, a refrigeration condenser, an evaporator exchanging heat between hot and cold refrigerant and air, a hydraulic fluid heat exchanger exchanging heat between hydraulic fluid and fuel or ram air, a liquid cooling system heat exchanger which exchanges heat between liquid coolant and ram air, and other heat exchange application.

[0045] The first fluid **522** and the second fluid **502** may comprise, for example but without limitation, an aircraft engine bleed air, an aircraft RAM ambient air, an aircraft nitrogen enriched air cooler, a recycled aircraft cabin air, a fanned heated air from a heat generating component on an aircraft, a pumped aircraft engine oil, a pumped aircraft hydraulic oil, a pumped aircraft gearbox oil, a pumped aircraft liquid coolant, a pumped aircraft refrigerant fluid, a vaporized fluid from a heat pipe, and other fluidic source.

[0046] In one embodiment, the micro-lattice cross-flow heat exchanger **500** may use engine bleed air as one fluid (first fluid) and engine fan air as the other fluid (second fluid). This embodiment may be used as a pre-cooler for an aircraft cabin air conditioning and temperature control system.

[0047] In another embodiment, the micro-lattice cross-flow heat exchanger **500** may use compressed air (e.g., engine bleed air) as one fluid (first fluid) and ambient (ram) air as the other fluid (second fluid). This embodiment may be used for the aircraft cabin air conditioning and temperature control system.

[0048] In a further embodiment, the micro-lattice cross-flow heat exchanger **500** may use compressed air (e.g., engine bleed air) as one fluid (first fluid) and refrigerant as the other fluid (second fluid). This application is a subset of an air conditioning and temperature control system of the aircraft cabin.

[0049] FIG. **6** is an illustration of an exemplary flowchart showing a process **600** for configuring a micro-lattice cross-flow heat exchanger for an aircraft according to an embodiment of the disclosure. The various tasks performed in connection with process **600** may be performed mechanically, by software, hardware, firmware, or any combination thereof. For illustrative purposes, the following description of process **600** may refer to elements mentioned above in connection with FIGS. **1**-**5**. In some embodiments, portions of the process **600** may be performed by different elements of the micro-lattice cross-flow heat exchanger **300**/**500** such as the structural body **320**/**514**, the manifold **306**/**322**, the hollow channels **304**/**316**, the hollow nodes **302**/**314**, the first aircraft system **552**, the second aircraft system **554**, etc. Process **600** may have functions, material, and structures that are similar to the embodiments shown in FIGS. **1**-**4**. Therefore common features, functions, and elements may not be redundantly described here.

[0050] Process **600** may begin by configuring a first aircraft fluid source inlet to receive a first fluid from a first aircraft system (task **602**).

[0051] Process **600** may continue by configuring a second aircraft fluid source inlet to receive a second fluid from a second aircraft system (task **604**).

[0052] Process **600** may continue by configuring a plurality of hollow channels comprising hollow truss elements into a structural body comprising a hollow three-dimensional micro-truss forming two interpenetrating fluidically isolated volumes operable for the first fluid to flow within the hollow channels and the second fluid to flow external to the hollow channels isolated from the first fluid (task **606**).

[0053] Process **600** may continue by configuring a plurality of first hollow truss elements from among the hollow truss elements to extend along a first direction (task **608**).

[0054] Process **600** may continue by configuring a plurality of second truss hollow truss elements from among the hollow truss elements to extend along a second direction (task **610**).

[0055] Process **600** may continue by configuring a plurality of third truss hollow truss elements from among the hollow truss elements to extend along a third direction (task **612**).

[0056] Process **600** may continue by interpenetrating a plurality of hollow nodes by the hollow channels (task **614**).

[0057] Process **600** may continue by configuring the structural body to exchange heat between the first fluid and the second fluid (task **616**).

[0058] Process **600** may continue by configuring the structural body to support aviation induced structural loads (task **618**).

[0059] Process **600** may continue by coupling a first manifold comprising a plurality of first openings to the first aircraft fluid source inlet and a first surface of the structural body (task **620**).

[0060] Process **600** may continue by coupling the first openings to the hollow channels (task **622**).

[0061] Process **600** may continue by coupling a second manifold comprising a plurality of second openings to the second aircraft fluid source inlet and a second surface of the structural body (task **624**).

[0062] Process **600** may continue by coupling the second openings to the hollow channels (task **626**).

[0063] Process **600** may continue by configuring a cross section (e.g., lateral, longitudinal, or other cross section) of each of the openings to comprise a tapered opening, a polygon, a quadrilateral, a cross section of a hollow pyramid, or a combination thereof (task **628**).

[0064] A process of forming a hollow porous material such as the hollow channels **304/316** into the structural body **320** is described in U.S. Pat. No. 7,653,276 content of which is incorporated by reference herein in its entirety.

[0065] FIG. **7** is an illustration of an exemplary flowchart showing a process for operating a micro-lattice cross-flow heat exchanger for an aircraft according to an embodiment of the disclosure. The various tasks performed in connection with process **700** may be performed mechanically, by software, hardware, firmware, or any combination thereof. For illustrative purposes, the following description of process **700** may refer to elements mentioned above in connection with FIGS. **1-4**. In some embodiments, portions of the process **700** may be performed by different elements of the micro-lattice cross-flow heat exchanger **300/400** such as the structural body **320/514**, the manifold **306/322**, the hollow channels **304/316**, the hollow nodes **302/314**, the first aircraft system **552**, the second aircraft system **554**, etc. Process **700** may have functions, material, and structures that are similar to the embodiments shown in FIGS. **1-4**. Therefore common features, functions, and elements may not be redundantly described here.

[0066] Process **700** may begin by receiving a first fluid in a first aircraft fluid source inlet from a first aircraft system (task **702**).

[0067] Process **700** may continue receiving a second fluid in a second aircraft fluid source inlet from a second aircraft system (task **704**).

[0068] Process **700** may continue by supporting an aviation structural load on a structural body forming two interpenetrating fluidically isolated volumes and comprising a plurality of hollow channels comprising a hollow three-dimensional micro-truss comprising a plurality of hollow truss elements extending along at least three directions, and a plurality of hollow nodes interpenetrated by the hollow truss elements (task **706**).

[0069] Process **700** may continue by flowing the first fluid from the first aircraft fluid source inlet into the hollow channels through a first manifold comprising a plurality of first openings into the hollow channels (task **708**).

[0070] Process **700** may continue by flowing the first fluid within the hollow channels (task **710**).

[0071] Process **700** may continue by flowing the first fluid out of a second manifold comprising a plurality of second openings from the hollow channels (task **712**).

[0072] Process **700** may continue by flowing the second fluid from the second aircraft fluid source inlet external to the hollow channels (task **714**).

[0073] Process **700** may continue by transferring heat between the first fluid flow and the second fluid flow via the structural body (task **716**).

[0074] Process **700** may continue by inducing the first fluid flow from engine bleed air and the second fluid flow from engine fan air (task **718**).

[0075] Process **700** may continue by using the micro-lattice cross-flow heat exchanger in an aircraft cabin air conditioning and temperature control system, wherein the aviation structural load comprises a wing fairing bending load (task **720**).

[0076] Process **700** may continue by inducing the first fluid flow from engine bleed air and the second fluid flow from ram air (task **722**).

[0077] Process **700** may continue by using the micro-lattice cross-flow heat exchanger in an aircraft cabin air conditioning and temperature control system, wherein the aviation structural load comprises a wing fairing bending load (task **724**).

[0078] Process **700** may continue by inducing the first fluid flow from engine bleed air, wherein the second fluid flow comprises a refrigerant (task **726**). The refrigerant may comprise, for example but without limitation, Freon, Freon replacements (e.g., R134a), water, chlorofluorocarbons, ram air, fan air, or other refrigerant.

[0079] Process **700** may continue by using the micro-lattice cross-flow heat exchanger in an aircraft cabin air conditioning and temperature control system, wherein the aviation structural load comprises a proof and burst load, and a pressure cycle load (task **728**).

[0080] Process **700** may continue by inducing the first fluid flow from engine oil, wherein the second fluid flow comprises fan air (task **730**).

[0081] Process **700** may continue by using the micro-lattice cross-flow heat exchanger in an oil cooling system, wherein the aviation structural load comprises a proof and burst load, a pressure cycle load, and a vibration load (task **732**).

[0082] Process **700** may continue by inducing the first fluid flow from hydraulic fluid, wherein the second fluid flow comprises fuel or ram air (task **734**).

[0083] Process **700** may continue by using the micro-lattice cross-flow heat exchanger in an oil cooling system, wherein the aviation structural load comprises a proof and burst load, a pressure cycle load, and a vibration load (task **736**).

[0084] Process **700** may continue by inducing the first fluid flow and the second fluid flow from an aircraft engine bleed air, an aircraft RAM ambient air, an aircraft nitrogen enriched air cooler, a recycled aircraft cabin air, a fanned heated air from a heat generating component on an aircraft, a pumped aircraft engine oil, a pumped aircraft hydraulic fluid, a pumped aircraft gearbox oil, a pumped aircraft liquid coolant, and a pumped aircraft refrigerant fluid, or a combination thereof (task **738**).

[0085] Process **700** may continue by using the micro-lattice cross-flow heat exchanger in an aircraft nitrogen enriched air cooler, a power electronics cooler, a precooler, an air conditioning pack heat exchanger, an oil cooler. a refrigeration condenser, an evaporator exchanging heat between hot and cold refrigerant and air, a hydraulic fluid heat exchanger exchanging heat between hydraulic fluid and fuel or ram air, a liquid cooling system heat exchanger which exchanges heat between liquid coolant and ram air, or a combination thereof (task **740**).

[0086] FIG. **8** is an illustration of an end view **806**, a section A-A view **802**, and a section B-B view **804** of an exemplary schematic of a micro-lattice cross-flow heat exchanger **800** (heat pipe **800**) according to an embodiment of the disclosure. The micro-lattice cross-flow heat exchanger **800** comprises a heat pipe configuration, thus the micro-lattice cross-flow heat exchanger **800** and the heat pipe **800** may be used interchangeably in this document. The micro-lattice cross-flow heat exchanger **800** may comprise a micro-truss structural body **812** (**320**/**514** in FIGS. **3** and **5**) comprising the hollow channels **304**/**316**/**546**/**544** (FIGS. **3** and **5**). The heat pipe **800** may comprise, for example, a **2**-sided heat pipe interconnected by the micro-truss structural body **812**. The micro-truss structural body **812** functions as a condenser for a heat pipe fluid (not shown) within the micro-truss structural body **812** that is vaporized at sides **828**/**830** that are exposed to a heat load (flux) **832**/**834** respectively. The heat pipe fluid of the heat pipe **800** may comprise, for example but without limitation, water, Freon, a hydrocarbon, an ionic liquid, or other fluid.

[0087] Each side **824**/**826**/**828**/**830** of the micro-lattice cross-flow heat exchanger **800** comprises a wick structure **816**/**818**/**820**/**822** respectively. The wick structure **816**/**818**/**820**/**822** may be configured on a subset of the sides **824**/**826**/**828**/**830** such as, but without limitation, all of the sides **824**/**826**/**828**/**830**, three sides among the sides **824**/**826**/**828**/**830**, a single side among the sides **824**/**826**/**828**/**830**, or other configuration. In some embodiments, a laterally oriented wick structure in all adjacent four of the sides **824**/**826**/**828**/**830** provide return paths of condensed fluid back to a hot spot on one or more of the sides **824**/**826**/**828**/**830**. In various embodiments, the wick structure **816**/**818**/**820**/**822** may comprise, for example but without limitation, a longitudinally oriented wick structure, a laterally oriented wick structure, an omnidirectionally oriented wick structure, or other wick structure.

[0088] In some embodiments, a cooling fluid **808** enters a first side **836** of the micro-lattice cross-flow heat exchanger **800** and flows through and around an exterior **814** of the micro-truss structural body **812**. The cooling fluid **808** may exit a second side **838** of the micro-lattice cross-flow heat exchanger **800**.

[0089] Heat applied to any area of the sides **824**/**826**/**828**/**830** of the micro-lattice cross-flow heat exchanger **800** results in the heat pipe fluid evaporating from point(s) of exposure and a vapor of the heat pipe fluid migrating into the hollow channels **304**/**316** (FIG. **3**) of the micro-truss structural body **812** in closest proximity to the point(s) of exposure. A flow of the cooling fluid **808** through and around the exterior **814** of the micro-truss structural body **812** then absorbs heat from the vapor of the heat pipe fluid and causes it to condense to a condensed refrigerant. The condensed refrigerant flows through the micro-truss structural body **812** (e.g., guided by gravity) to the wick structure **816**/**818**/**820**/**822** in a lowest of the sides **824**/**826**/**828**/**830**. Capillary action in the wick structure **816**/**818**/**820**/**822** then guides the condensed refrigerant back to the hot spot, where the cycle begins again.

[0090] In an embodiment, the first aircraft system **552** comprises a heat pipe surface (not shown) operable to vaporize the heat pipe fluid in response to heating of the heat pipe surface to provide the vaporized heat pipe fluid.

[0091] FIG. **9** is an illustration of an end view, a section A-A view, and a section B-B view of an exemplary schematic of a micro-lattice cross-flow heat exchanger **900** comprising a heat pipe configuration according to an embodiment of the disclosure. The micro-lattice cross-flow heat exchanger **900** may comprise various cross-section shape configurations of a flow body **912** such as, but without limitation, circles, ellipses, triangles, pentagons, polygons, variable cross-sections along their lengths, or a combination thereof. A surface **916** of the micro-lattice cross-flow heat exchanger **900** absorbs a heat flux **914**. The micro-lattice cross-flow heat exchanger **900** comprises longitudinal and lateral wick structures **904**, and a hollow micro-truss structure **902** occupies a center of the micro-lattice cross-flow heat exchanger **900**.

[0092] A cooling fluid **908** enters the micro-lattice cross-flow heat exchanger **900** through a coolant inlet **906** and flows through and around an exterior of the hollow micro-truss structure **902**. The cooling fluid **908** absorbs heat from the hollow micro-truss structure **902** and a vaporized heat pipe fluid (not shown). Thereby, the hollow micro-truss structure **902** serves as a condenser to condense the vaporized heat pipe fluid into a condensed refrigerant (not shown). The wick structures **904** transport the condensed refrigerant from the hollow micro-truss structure **902** back to the wick structures **904** and back to a heated area, thereby enabling continuous evaporation and, in effect, management of a heat load.

[0093] In this manner, embodiments of the disclosure provide a cost-effective fluid flow interface to a hollow porous material, which reduces discontinuities and sharp edges and consequently reduces flow disruption, reduces pressure drop for fluid flowing into the hollow porous material, and/or increases pressure recovery for fluid exiting the hollow porous material.

[0094] While at least one example embodiment has been presented in the foregoing detailed description, it should be appreciated that a vast number of variations exist. It should also be appreciated that the example embodiment or embodiments described herein are not intended to limit the scope, applicability, or configuration of the subject matter in any way. Rather, the foregoing detailed description will provide those skilled in the art with a convenient road map for implementing the described embodiment or embodiments. It should be understood that various changes can be made in the function and arrangement of elements without departing from the scope defined by the claims, which includes known equivalents and foreseeable equivalents at the time of filing this patent application.

[0095] The above description refers to elements or nodes or features being “connected” or “coupled” together. As used herein, unless expressly stated otherwise, “connected” means that one element/node/feature is directly joined to (or directly communicates with) another element/node/feature, and not necessarily mechanically. Likewise, unless expressly stated otherwise, “coupled” means that one element/node/feature is directly or indirectly joined to (or directly or indirectly communicates with) another element/node/feature, and not necessarily mechanically. Thus, although FIGS. **1-5** depict example arrangements of elements, additional intervening elements, devices, features, or components may be present in an embodiment of the disclosure.

[0096] Terms and phrases used in this document, and variations thereof, unless otherwise expressly stated, should be construed as open ended as opposed to limiting. As examples of the foregoing: the term "including" should be read as meaning "including, without limitation" or the like; the term "example" is used to provide exemplary instances of the item in discussion, not an exhaustive or limiting list thereof; and adjectives such as "conventional," "traditional," "normal," "standard," "known" and terms of similar meaning should not be construed as limiting the item described to a given time period or to an item available as of a given time, but instead should be read to encompass conventional, traditional, normal, or standard technologies that may be available or known now or at any time in the future. Likewise, a group of items linked with the conjunction "and" should not be read as requiring that each and every one of those items be present in the grouping, but rather should be read as "and/or" unless expressly stated otherwise. Similarly, a group of items linked with the conjunction "or" should not be read as requiring mutual exclusivity among that group, but rather should also be read as "and/or" unless expressly stated otherwise.

[0097] Furthermore, although items, elements or components of the disclosure may be described or claimed in the singular, the plural is contemplated to be within the scope thereof unless limitation to the singular is explicitly stated. The presence of broadening words and phrases such as "one or more," "at least," "but not limited to" or other like phrases in some instances shall not be read to mean that the narrower case is intended or required in instances where such broadening phrases may be absent.

1. A method for operating a micro-lattice cross-flow heat exchanger for an aircraft, the method comprising:
- receiving a first fluid in a first aircraft fluid source inlet from a first aircraft system;
- receiving a second fluid in a second aircraft fluid source inlet from a second aircraft system;
- supporting an aviation induced structural load on a structural body forming two interpenetrating fluidically isolated volumes and comprising a plurality of hollow channels comprising a hollow three-dimensional micro-truss comprising a plurality of hollow truss elements extending along at least three directions, and a plurality of hollow nodes interpenetrated by the hollow truss elements;
- flowing the first fluid from the first aircraft fluid source inlet into the hollow channels through a first manifold comprising a plurality of first openings into the hollow channels;
- flowing the first fluid within the hollow channels;
- flowing the first fluid out of a second manifold comprising a plurality of second openings from the hollow channels;
- flowing the second fluid from the second aircraft fluid source inlet external to the hollow channels; and
- transferring heat between the first fluid and the second fluid via the structural body.

2. The method of claim **1**, wherein the aviation structural load comprises a proof and burst load, an air pressure cycling load, a vibration load, an airframe structural support load, an inertial load, a thermal cycling load, or a combination thereof.

3. The method of claim **1**, further comprising:
- inducing the first fluid from engine bleed air and the second fluid from engine fan air; and
- using the micro-lattice cross-flow heat exchanger as a pre-cooler in an aircraft cabin air conditioning and temperature control system, wherein the aviation structural load comprises a wing fairing bending load.

4. The method of claim **1**, further comprising:
- inducing the first fluid from engine bleed air and the second fluid from ram air; and
- using the micro-lattice cross-flow heat exchanger in an aircraft cabin air conditioning and temperature control system, wherein the aviation structural load comprises a wing fairing bending load.

5. The method of claim **1**, further comprising:
- inducing the first fluid from engine bleed air, wherein the second fluid comprises a refrigerant; and
- using the micro-lattice cross-flow heat exchanger in an aircraft cabin air conditioning and temperature control system, wherein the aviation structural load comprises a proof and burst load, and a pressure cycle load.

6. The method of claim **1**, further comprising:
- inducing the first fluid from engine oil, wherein the second fluid comprises fan air; and
- using the micro-lattice cross-flow heat exchanger in an oil cooling system, wherein the aviation structural load comprises a proof and burst load, a pressure cycle load, and a vibration load.

7. The method of claim **1**, further comprising:
- inducing the first fluid from hydraulic fluid, wherein the second fluid comprises fuel or ram air; and
- using the micro-lattice cross-flow heat exchanger in an oil cooling system, wherein the aviation structural load comprises a proof and burst load, a pressure cycle load, a vibration load, or a combination thereof.

8. The method of claim **1**, further comprising inducing the first fluid and the second fluid from an aircraft engine bleed air, an aircraft RAM ambient air, an aircraft nitrogen enriched air cooler, a recycled aircraft cabin air, a fanned heated air from a heat generating component on an aircraft, a vaporized fluid from a heat pipe, a pumped aircraft engine oil, a pumped aircraft hydraulic fluid, a pumped aircraft gearbox oil, a pumped aircraft liquid coolant, a pumped aircraft refrigerant fluid, a coolant, or a combination thereof.

9. The method for claim **1**, further comprising using the micro-lattice cross-flow heat exchanger in an aircraft nitrogen enriched air cooler, an electronics cooler, a precooler, an air conditioning pack heat exchanger, an oil cooler. a refrigeration condenser, an evaporator exchanging heat between hot and cold refrigerant and air, a hydraulic fluid heat exchanger exchanging heat between hydraulic fluid and fuel or ram air, a liquid cooling system heat exchanger which exchanges heat between liquid coolant and ram air, or a combination thereof.

10. A micro-lattice cross-flow heat exchanger for an aircraft, comprising:
- a first aircraft fluid source inlet operable to provide a first fluid from a first aircraft system;
- a second aircraft fluid source inlet operable to provide a second fluid from a second aircraft system; and
- a structural body operable to support aviation induced structural loads and exchange heat between the first fluid and the second fluid, and comprising a plurality of hollow channels forming two interpenetrating fluidically isolated volumes and operable for flow of the first fluid

within the hollow channels and flow of the second fluid external to the hollow channels isolated from the first fluid, the hollow channels comprising a hollow three-dimensional micro-truss comprising a plurality of hollow truss elements extending along at least three directions, and a plurality of hollow nodes interpenetrated by the hollow truss elements.

11. The micro-lattice cross-flow heat exchanger of claim **10**, wherein the aviation induced structural loads comprise proof and burst, air pressure cycling, vibration, airframe structural support, an inertial load, a thermal cycling load, or a combination thereof.

12. The micro-lattice cross-flow heat exchanger of claim **10**, further comprising:

a first manifold coupled to the first aircraft fluid source inlet and a first surface of the structural body, and comprising a plurality of first openings into the hollow channels; and

a second manifold coupled to the second aircraft fluid source inlet and a second surface of the structural body, and comprising a plurality of second openings into the hollow channels.

13. The micro-lattice cross-flow heat exchanger of claim **12**, wherein the first manifold and the second manifold further comprise a particulate filter.

14. The micro-lattice cross-flow heat exchanger of claim **12**, wherein a cross section of each of the first openings and the second openings comprises a tapered opening, a polygon, a quadrilateral, a cross section of a hollow pyramid, or a combination thereof.

15. The micro-lattice cross-flow heat exchanger of claim **10**, wherein the first fluid and the second fluid are induced from an aircraft engine bleed air, an aircraft RAM ambient air, an aircraft nitrogen enriched air cooler, a recycled aircraft cabin air, a fan heated air from a heat generating component on an aircraft, a vaporized fluid from a heat pipe, a pumped aircraft engine oil, a pumped aircraft hydraulic fluid, a pumped aircraft gearbox oil, a pumped aircraft liquid coolant, a pumped aircraft refrigerant fluid, a coolant, or a combination thereof.

16. The micro-lattice cross-flow heat exchanger of claim **10**, wherein:

the first fluid comprises a vaporized heat pipe fluid;

the second fluid comprises a cooling fluid;

the first aircraft fluid source inlet comprises a wick structure operable to retain the heat pipe fluid; and

the first aircraft system comprises a heat pipe surface operable to vaporize the heat pipe fluid in response to heating of the heat pipe surface to provide the vaporized heat pipe fluid.

17. The micro-lattice cross-flow heat exchanger of claim **16**, wherein the wick structure comprises, a longitudinally oriented wick structure, a laterally oriented wick structure, an omni-directionally oriented wick structure, or a combination thereof.

18. A method for configuring a micro-lattice cross-flow heat exchanger for an aircraft, the method comprising:

configuring a first aircraft fluid source inlet to receive a first fluid from a first aircraft system;

configuring a second aircraft fluid source inlet to receive a second fluid from a second aircraft system;

configuring a plurality of hollow channels comprising hollow truss elements into a structural body comprising a hollow three-dimensional micro-truss forming two interpenetrating fluidically isolated volumes operable for the first fluid to flow within the hollow channels and the second fluid to flow external to the hollow channels isolated from the first fluid;

configuring a plurality of first hollow truss elements from among the hollow truss elements to extend along a first direction;

configuring a plurality of second truss hollow truss elements from among the hollow truss elements to extend along a second direction; and

configuring a plurality of third truss hollow truss elements from among the hollow truss elements to extend along a third direction;

interpenetrating a plurality of hollow nodes by the hollow truss elements;

configuring the structural body to exchange heat between the first fluid and the second fluid; and

configuring the structural body to support aviation induced structural loads.

19. The method of claim **18**, wherein the aviation induced structural loads comprise: a proof and burst load, an air pressure cycling load, a vibration load, an airframe structural support load, or a combination thereof.

20. The method of claim **18**, further comprising:

coupling a first manifold comprising a plurality of first openings to the first aircraft fluid source inlet and a first surface of the structural body; and

coupling the first openings to the hollow channels.

21. The method of claim **20**, further comprising:

coupling a second manifold comprising a plurality of second openings to the second aircraft fluid source inlet and a second surface of the structural body; and

coupling the second openings to the hollow channels.

22. The method of claim **21**, further comprising configuring a cross section of each of the first openings and the second openings to comprise a tapered opening, a polygon, a quadrilateral, a cross section of a hollow pyramid, or a combination thereof.

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