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CA 2659944 C 2014/08/26

(11)(21) **2 659 944**

(12) **BREVET CANADIEN**
CANADIAN PATENT

(13) **C**

(22) Date de dépôt/Filing Date: 2009/03/25

(41) Mise à la disp. pub./Open to Public Insp.: 2009/11/20

(45) Date de délivrance/Issue Date: 2014/08/26

(30) Priorité/Priority: 2008/05/20 (US12/124,092)

(51) Cl.Int./Int.Cl. *F28F 7/02* (2006.01), *B64D 33/10* (2006.01), *F28D 21/00* (2006.01), *F28D 9/02* (2006.01), *F28F 21/00* (2006.01)

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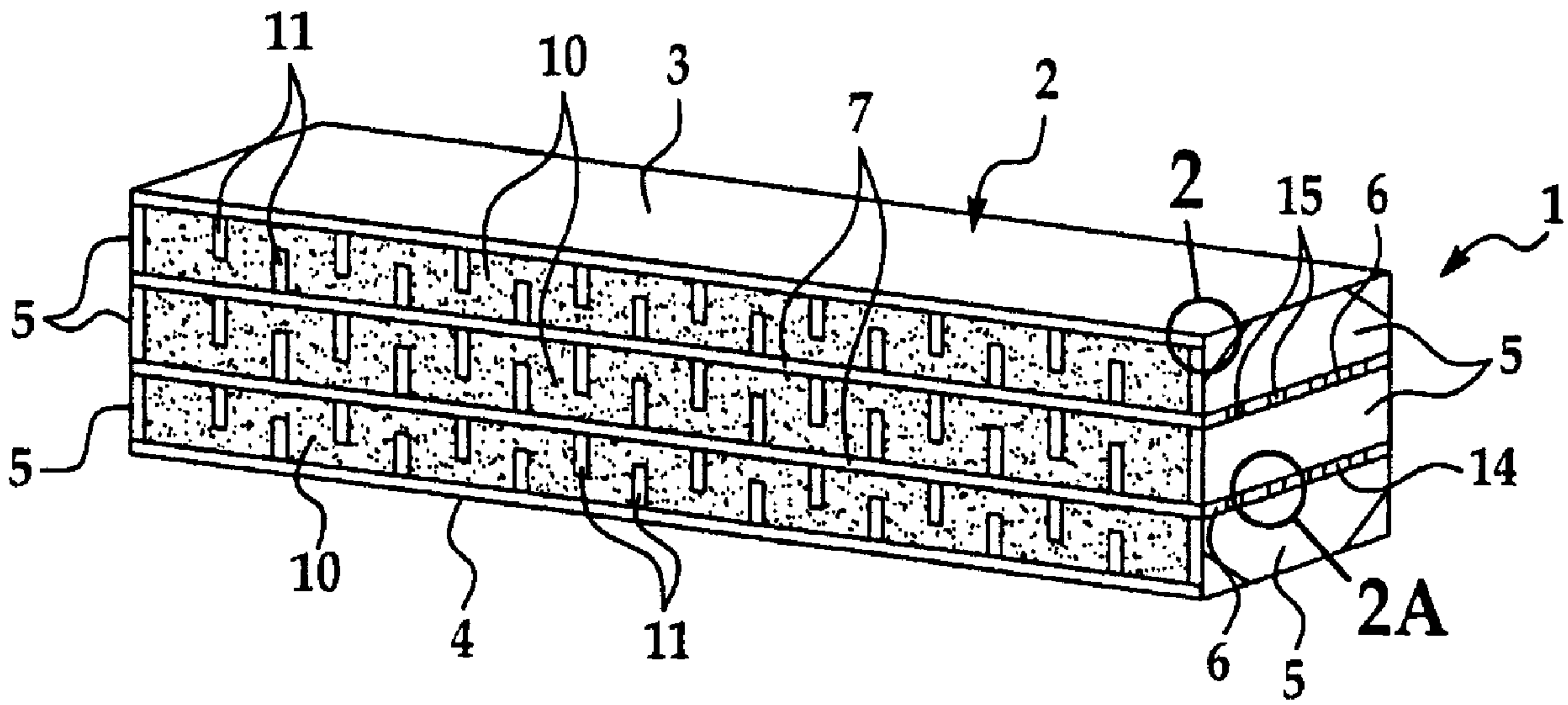
(54) Titre : ECHANGEUR DE CHALEUR A MOUSSE METALLIQUE DE CARBONE MELANGEE
(54) Title: MIXED CARBON FOAM/METALLIC HEAT EXCHANGER



(57) Abrégé/Abstract:
A heat exchanger includes a thermally-conductive fluid barrier having first and second surfaces, at least one first type of foam element placed in thermally-conductive contact with the first surface of the thermally-conductive fluid barrier and having a first coefficient of thermal expansion and at least one second type of foam element placed in thermally-conductive contact with the second surface of the thermally-conductive fluid barrier and having a second coefficient of thermal expansion. The first coefficient of thermal expansion of the first type of foam element and the second coefficient of thermal expansion of the second type of foam element are different by at least a factor of three.

82,000-167
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ABSTRACT OF THE DISCLOSURE

A heat exchanger includes a thermally-conductive fluid barrier having first and second surfaces, at least one first type of foam element placed in thermally-conductive contact with the first surface of the thermally-conductive fluid barrier and having a first coefficient of thermal expansion and at least one second type of foam element placed in thermally-conductive contact with the second surface of the thermally-conductive fluid barrier and having a second coefficient of thermal expansion. The first coefficient of thermal expansion of the first type of foam element and the second coefficient of thermal expansion of the second type of foam element are different by at least a factor of three.

82,000-167
08-0114

MIXED CARBON FOAM/METALLIC HEAT EXCHANGER

TECHNICAL FIELD

[001] The disclosure relates to ram air heat exchangers for aircraft. More particularly, the disclosure relates to a mixed carbon foam/metallic heat exchanger having thermally conductive carbon foam layers which alternate with metal foam layers to allow for the fabrication of heat exchanger cores using materials having vastly different coefficients of thermal expansion (CTE).

BACKGROUND

[002] In the manufacture of ram air heat exchangers using thermally conductive carbon foam as a thermal management material, metallic and carbon elements may be used in fabrication of the heat exchanger core. The metallic and carbon elements used in fabrication of the heat exchanger core may have different coefficients of thermal expansion (CTE). Therefore, during fabrication, high-temperature vacuum brazing processes may generate thermal stresses within the heat exchanger core during the heat-up and cool-down phases of the brazing process.

[003] Therefore, fabrication processes that address thermal stresses caused by mismatched coefficients of thermal expansion (CTE) in a mixed carbon foam/metallic heat exchanger may be desirable.

SUMMARY

[004] The disclosure is generally directed to a heat exchanger. An illustrative embodiment of the heat exchanger includes a thermally-conductive fluid barrier having first and second surfaces, at least one first type of foam element placed in thermally-conductive contact with the first surface of the thermally-conductive fluid barrier and having a first coefficient of thermal expansion and at least one second type of foam element placed in thermally-conductive contact with the second surface of the thermally-conductive fluid barrier and having a second coefficient of thermal expansion. The first coefficient of thermal expansion of the first type of foam element and the second coefficient of thermal expansion of the second type of foam element are different by at least a factor of three.

[005] The disclosure is further generally directed to a mixed carbon foam/metallic foam heat exchanger method. An

illustrative embodiment of the method includes providing a reticulated metal foam layer, providing a thermally conductive carbon foam layer in thermally-conductive contact with the reticulated metal foam layer, distributing a first fluid through the reticulated metal foam layer and distributing a second fluid through the carbon foam layer.

BRIEF DESCRIPTION OF THE ILLUSTRATIONS

[006] FIG. 1 is a perspective view of an illustrative embodiment of the heat exchanger.

[007] FIG. 2 is an enlarged sectional view, taken along section line 2 in FIG. 1, of a reticulated metal foam layer of the heat exchanger.

[008] FIG. 2A is an enlarged sectional view, taken along section line 2A in FIG. 1, of a thermally conductive carbon foam layer of the heat exchanger.

[009] FIG. 2B is a sectional view illustrating a reticulated metal foam layer and a thermally conductive carbon foam layer attached to opposite sides of a thermally-conductive fluid barrier.

[0010] FIG. 3 is an enlarged sectional view illustrating staggered fluid flow channels in the reticulated metal foam layers of the heat exchanger.

[0011] FIG. 4 is an end view of the heat exchanger shown in FIG. 1.

[0012] FIG. 5 is a flow diagram which illustrates an illustrative embodiment of a mixed carbon foam/metallic foam heat exchanger method.

[0013] FIG. 6 is a flow diagram of an aircraft production and service methodology.

[0014] FIG. 7 is a block diagram of an aircraft.

DETAILED DESCRIPTION

[0015] Referring initially to FIGS. 1-4, an illustrative embodiment of the mixed carbon foam/metallic foam heat exchanger, hereinafter heat exchanger, is generally indicated by reference numeral 1 in FIG. 1. The heat exchanger 1 may include a heat exchanger frame 2 which may be aluminum, for example and without limitation, and may include an upper end plate 3; a lower end plate 4 placed in an opposed relationship with respect to the upper end plate

3; and spaced apart end plates 5 at respective ends of the upper end plate 3 and the lower end plate 4. At each end of the heat exchanger frame 2, carbon foam layers 14 may be exposed through plate slots 6 which separate adjacent side bar members 5 from each other.

[0016] At least one ductile thermal management material layer 10 may be provided in the heat exchanger frame 2. As shown in FIG. 2, the ductile thermal management material layer 10 may be reticulated metal foam such as reticulated aluminum foam, for example and without limitation. In certain applications the fluids in the heat exchanger may require the use of other ductile materials such as copper, copper alloys, stainless steels, nickel alloys, etc. At least one thermally conductive carbon foam layer 14 may be provided in the heat exchanger frame 2 in thermally-conductive contact with at least one ductile thermal management material layer 10. The carbon foam may, in certain applications be replaced by other foams, such as a ceramic. The ductile thermal management material layer 10 and the thermally conductive carbon foam layer 14 may have different coefficients of thermal expansion (CTEs), for example the CTEs of the two materials may differ by a factor of three or more. As shown in FIG. 2B, in some embodiments each ductile thermal management material layer 10 may be separated from each carbon foam layer 14 by a thermally-conductive fluid barrier 18. Accordingly, the ductile thermal management material layer 10 may be attached to a first surface 18a and the carbon foam layer 14 may be attached to a second surface 18b of the thermally-conductive fluid barrier 18 according to the knowledge of those skilled in the art. The thermally-conductive fluid barrier 18 may be a metal braze foil layer, for example and without limitation.

[0017] As shown in FIGS. 1 and 3, multiple stress relief blind slots 11 may extend into each ductile thermal management material layer 10. The stress relief blind slots 11 may be placed in generally parallel, staggered relationship with respect to each other and may be oriented in generally perpendicular relationship with respect to a longitudinal axis of the ductile thermal management layer 10. Each stress relief slot 11 may or may not extend across the entire thickness of the ductile thermal management material layer 10. As shown in FIGS. 1 and 4, stress relief blind slots 15 may also be provided in the thermally conductive carbon foam layer 14 and each may or may not extend across the entire thickness of the carbon foam layer 14. The stress relief blind slots 11 and stress relief blind slots 15 may provide stress relief for the heat exchanger 1 during manufacturing and in operation. Furthermore, the stress relief blind slots 11 and stress relief blind slots 15 may provide control of fluid flow losses through the ductile thermal management material layer 10 and the thermally conductive carbon foam layer 14 ,respectively, in operation of the heat exchanger 1.

[0018] As shown in FIGS. 1 and 4, the ductile thermal management material layers 10 and the thermally conductive carbon foam layers 14 may be arranged in the heat exchanger frame 2 in alternating relationship with respect to each other, with each carbon foam layer 14 sandwiched between a pair of ductile thermal management material layers 10. The heat exchanger frame 2 may include multiple side bar members 7 each of which may extend into a plate slot 6 between the end plates 5 at respective ends of the heat exchanger frame 2. Each side bar member 7 may be generally placed between ductile thermal management material layers

10 and generally adjacent to a thermally conductive carbon foam layer 14.

[0019] In some applications of the heat exchanger 1, CTE induced thermal stresses may be a function of length scale. Therefore, as shown in FIGS. 1 and 4, the thermally conductive carbon foam layers 14 may be segmented in multiple sections and tolerance-fitted together in the heat exchanger frame 2. Segmentation of the carbon foam layers 14 may reduce the total length scale between each element of the carbon foam layers 14 and the metallic portions of the heat exchanger 1 such as the various elements of the heat exchanger frame 2, for example and without limitation, to reduce CTE induced thermal stresses between the carbon foam layers 14 and those metallic portions of the heat exchanger 1 during operation of the heat exchanger 1.

[0020] During fabrication of the heat exchanger 1, a vacuum brazing process may be used as is known to those skilled in the art. Accordingly, the ductile thermal management material layers 10 and the thermally conductive carbon foam layers 14, separated by thermally-conductive fluid barriers 18, may be stacked and brazed together during fabrication. It will be appreciated by those skilled in the art that during the vacuum brazing process, the high thermal stresses resulting from thermal expansion and contraction induced in the heat exchanger frame 2 of the heat exchanger 1 may be absorbed by the ductile thermal management material layers 10. The thermal management material layers 10 may not transfer the thermal stresses from the heat exchanger frame 2 to the thermally conductive carbon foam layers 14. This may prevent the application of excessive thermally induced stress on the carbon foam layers 14.

[0021] In application of the heat exchanger 1, a first slot (not shown) may be placed in fluid communication with the ductile thermal management material layers 10 and a second slot (not shown) may be placed in fluid communication with the thermally conductive carbon foam layers 14. A first fluid (not shown) may be distributed from the first slot through the thermal management material layers 10, and a second fluid (not shown) may be distributed from the second slot through the carbon foam layers 14. Accordingly, heat may be transferred by convection and conduction from the hotter to the cooler of the first fluid and the second fluid through the thermally-conductive fluid barrier 18 (FIG. 2B). The high thermal stresses resulting from thermal expansion induced in the heat exchanger 1 by the hotter of the first fluid and the second fluid may be absorbed by the ductile thermal management material 10. This may prevent the application of excessive thermally induced stress on the carbon foam layers 14. The upper end plate 3, lower end plate 4 and side bar members 5 of the heat exchanger frame 2 may prevent loss of fluid from the heat exchanger 1.

[0022] Referring next to FIG. 5, a flow diagram 500 which illustrates an illustrative embodiment of a mixed carbon foam/metallic foam heat exchanger method is shown. In block 502, a reticulated metal foam layer is provided. In block 503, a thermally-conductive fluid barrier is provided in thermally conductive contact with the reticulated metal foam layer. In block 504, a thermally conductive carbon foam layer is provided in thermally-conductive contact with the thermally-conductive fluid barrier. In block 506, a first fluid is distributed through the reticulated metal foam layer. In block 508, a second fluid is distributed through the carbon foam layer. Heat is transferred from the hotter to the cooler of the first fluid and the second fluid. The reticulated metal foam layer may absorb stresses which are induced by thermal expansion during transfer of the heat between the fluids, minimizing or eliminating thermal stresses exerted on the carbon foam layer.

[0023] Referring next to FIGS. 6 and 7, embodiments of the disclosure may be used in the context of an aircraft manufacturing and service method 78 as shown in FIG. 6 and an aircraft 94 as shown in FIG. 7. During pre-production, exemplary method 78 may include specification and design 80 of the aircraft 94 and material procurement 82. During production, component and subassembly manufacturing 84 and system integration 86 of the aircraft 94 takes place. Thereafter, the aircraft 94 may go through certification and delivery 88 in order to be placed in service 90. While in service by a customer, the aircraft 94 may be scheduled for routine maintenance and service 92 (which may also include modification, reconfiguration, refurbishment, and so on).

[0024] Each of the processes of method 78 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 include without limitation any number of aircraft manufacturers and major-system subcontractors; a third party may include without limitation any number of vendors, subcontractors, and suppliers; and an operator may be an airline, leasing company, military entity, service organization, and so on.

[0025] As shown in FIG. 7, the aircraft 94 produced by exemplary method 78 may include an airframe 98 with a plurality of systems 96 and an interior 100. Examples of high-level systems 96 include one or more of a propulsion system 102, an electrical system 104, a hydraulic system 106, and an environmental system 108. Any number of other systems may be included. Although an aerospace example is shown, the principles of the invention may be applied to other industries, such as the automotive industry.

[0026] The apparatus embodied herein may be employed during any one or more of the stages of the production and service method 78. For example, components or subassemblies corresponding to production process 84 may be fabricated or manufactured in a manner similar to components or subassemblies produced while the aircraft 94 is in service. Also, one or more apparatus embodiments may be utilized during the production stages 84 and 86, for example, by substantially expediting assembly of or reducing the cost of an aircraft 94. Similarly, one or more apparatus embodiments may be utilized while the aircraft 94 is in service, for example and without limitation, to maintenance and service 92.

[0027] Although the embodiments of this disclosure have been described with respect to certain exemplary embodiments, it is to be understood that the specific embodiments are for purposes of illustration and not limitation, as other variations will occur to those of skill in the art.

82,000-167
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CLAIMS

What is claimed is:

1. A heat exchanger, comprising:

a heat exchanger frame having a first end plate, a second end plate placed in opposed relationship with respect to said first end plate and at least one side bar member placed at each end of said first end plate and said second end plate;

a thermally-conductive fluid barrier having first and second surfaces provided in said heat exchanger frame;

at least one first type of foam element placed in thermally-conductive contact with said first surface of said thermally-conductive fluid barrier and having a first coefficient of thermal expansion;

at least one second type of foam element placed in thermally-conductive contact with said second surface of said thermally-conductive fluid barrier and having a second coefficient of thermal expansion; and

wherein said first coefficient of thermal expansion of said first type of foam element and said second coefficient of thermal expansion of said second type

82,000-167
08-0114

of foam element are different by at least a factor of three.

2. The heat exchanger of claim 1 wherein said first type of foam element comprises a reticulated metal foam layer.

3. The heat exchanger of claim 2 wherein said reticulated metal foam layer comprises reticulated aluminum foam.

4. The heat exchanger of claim 1 wherein said second type of foam element comprises a thermally conductive carbon foam layer.

5. The heat exchanger of claim 4 wherein said thermally conductive carbon foam layer is segmented in multiple sections.

6. The heat exchanger of claim 1 further comprising a plurality of stress relief blind slots provided in said first type of foam element.

7. The heat exchanger of claim 6 wherein said stress relief blind slots are placed in staggered relationship with respect to each other.

8. The heat exchanger of claim 6 further comprising a plurality of stress relief blind slots provided in said second type of foam element.

9. A method of transferring heat, comprising:

providing a reticulated metal foam layer;

providing a thermally conductive carbon foam layer in thermally-conductive contact with said reticulated metal foam layer;

distributing a first fluid through said reticulated metal foam layer; and

distributing a second fluid through said thermally conductive carbon foam layer.

10. The method of claim 9 wherein said reticulated metal foam layer comprises a reticulated aluminum foam layer.

82,000-167
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11. The method of claim 9 further comprising a plurality of stress relief blind slots in said reticulated metal foam layer.

12. The method of claim 9 further comprising a plurality of stress relief blind spots in said thermally conductive carbon foam layer.

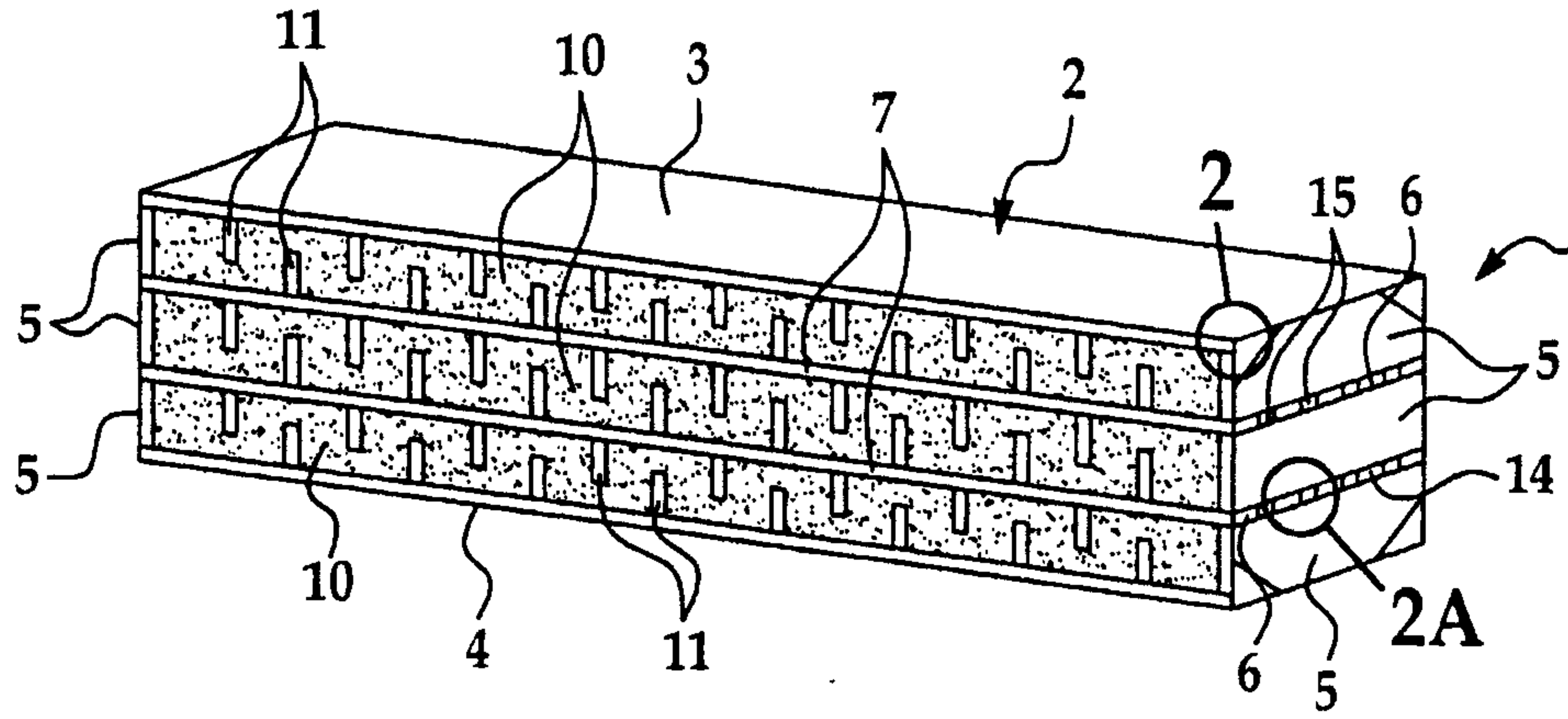


FIG. 1

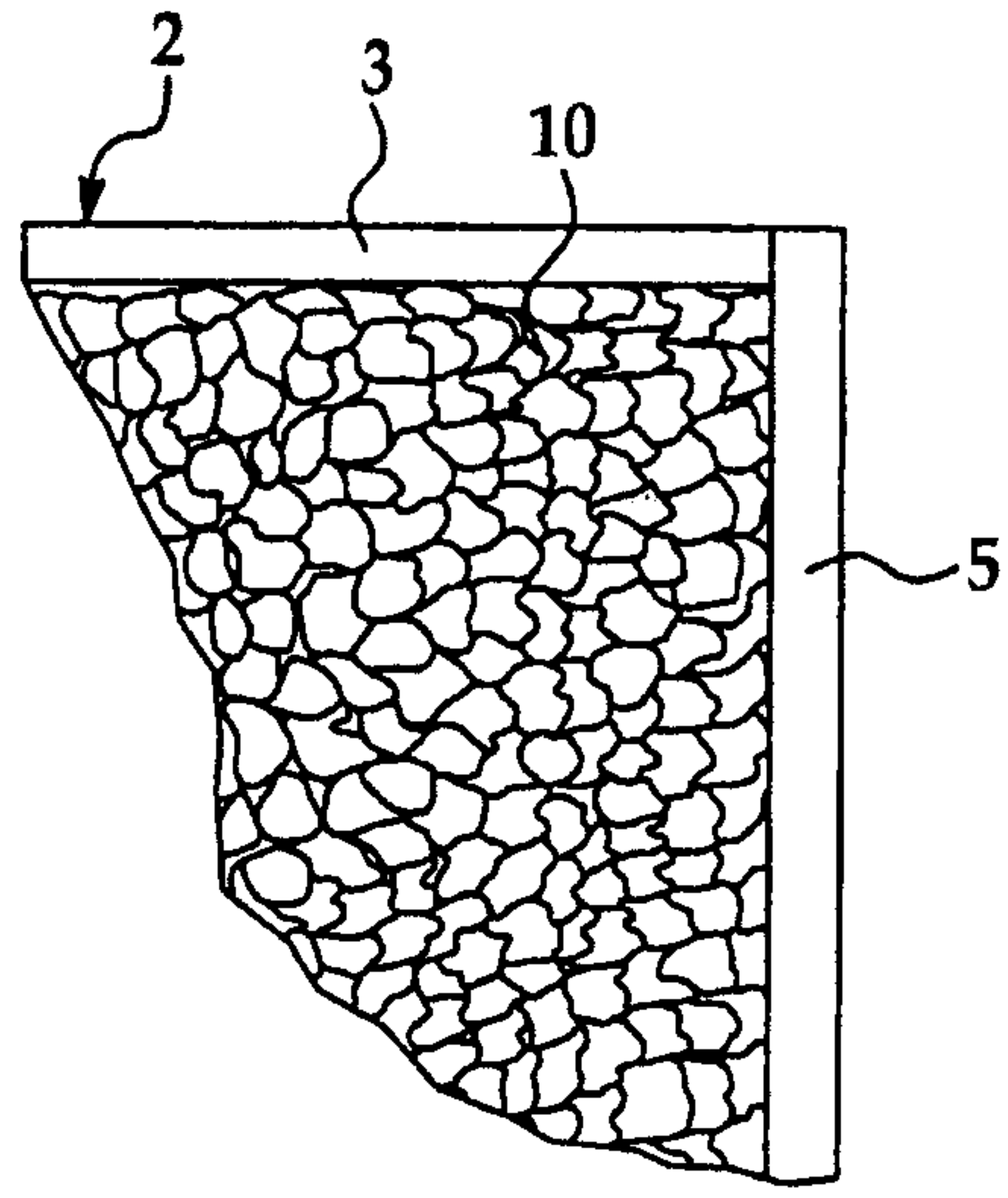


FIG. 2

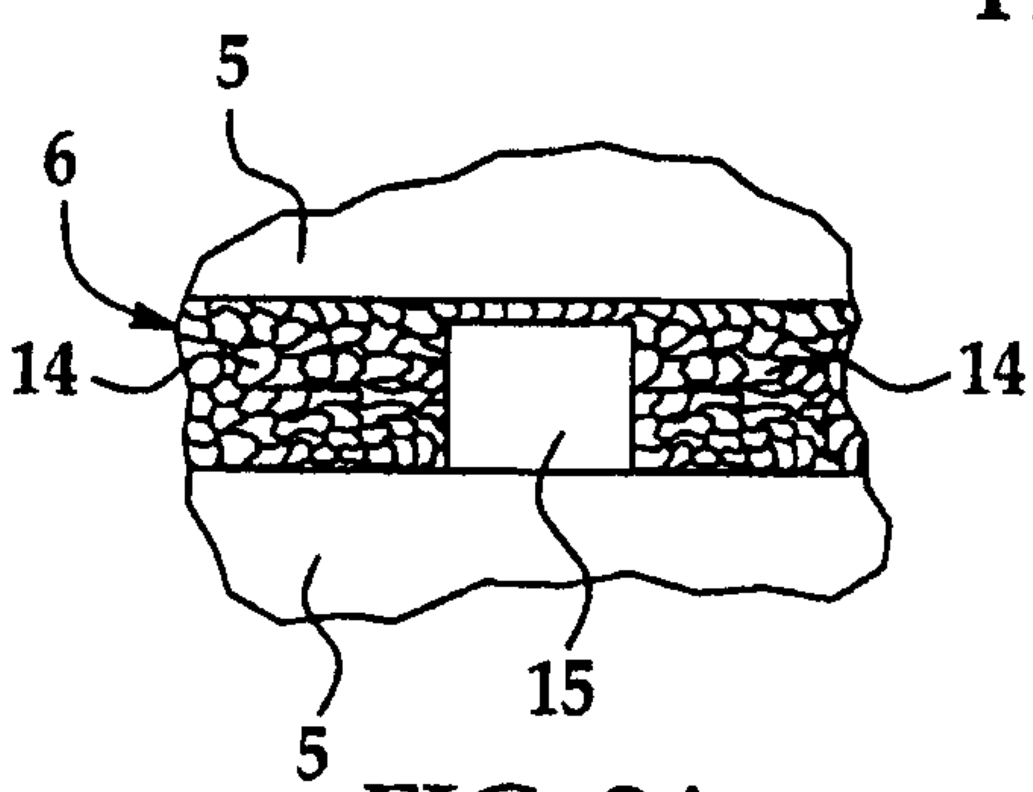


FIG. 2A

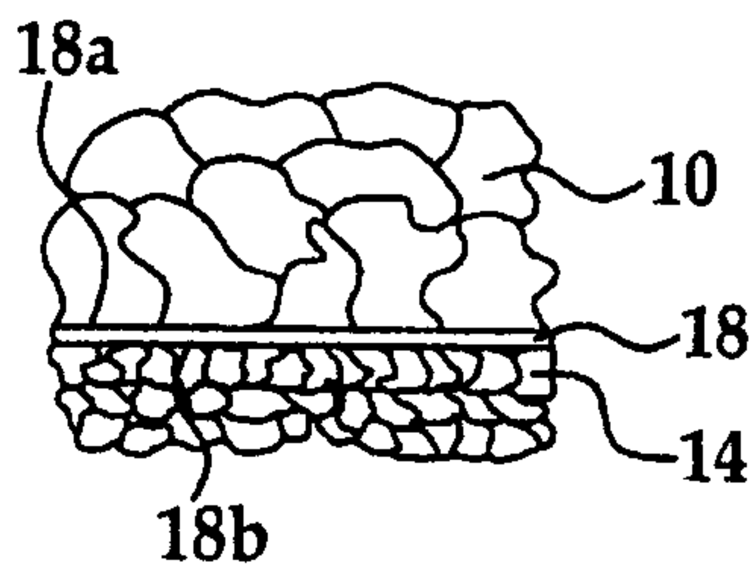


FIG. 2B

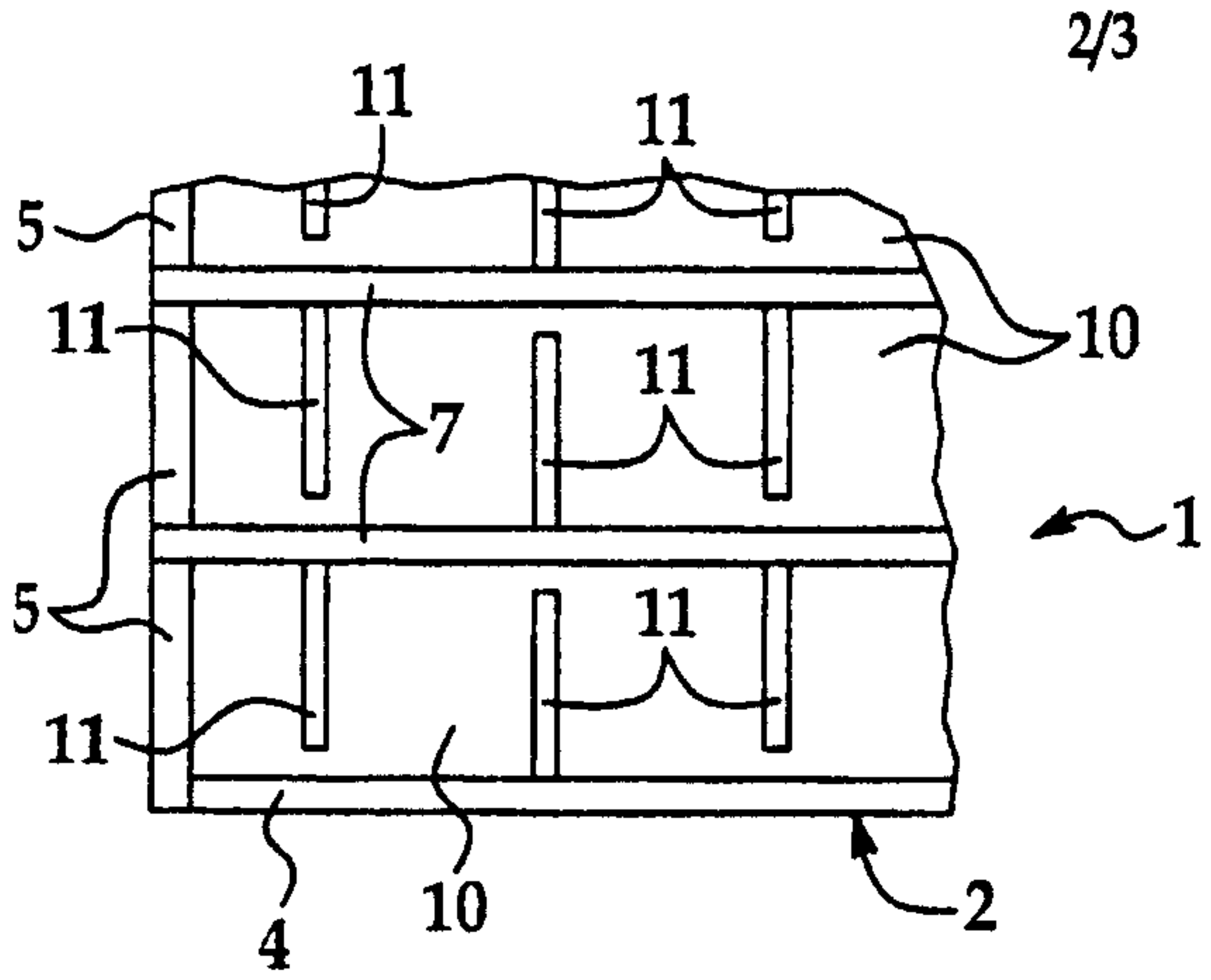


FIG. 3

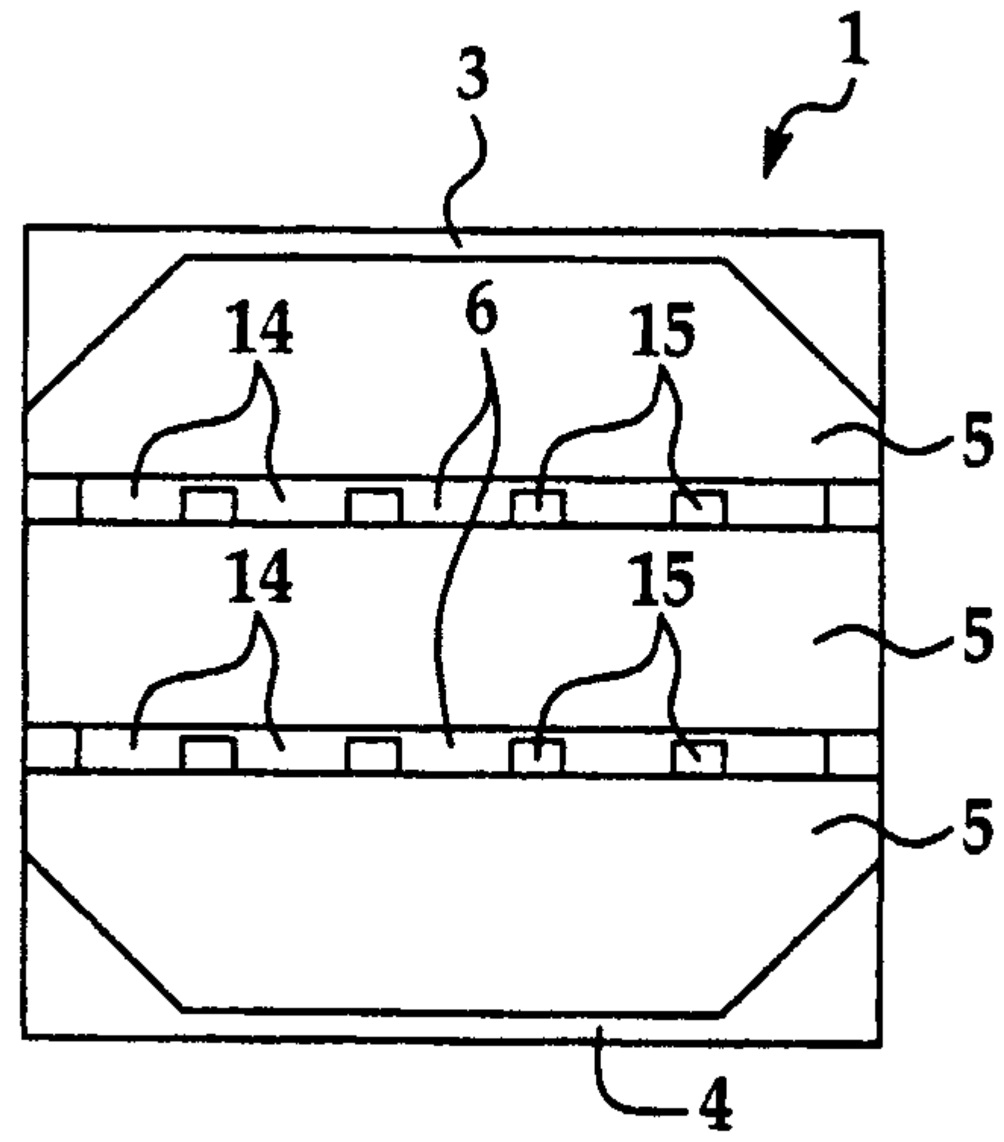


FIG. 4

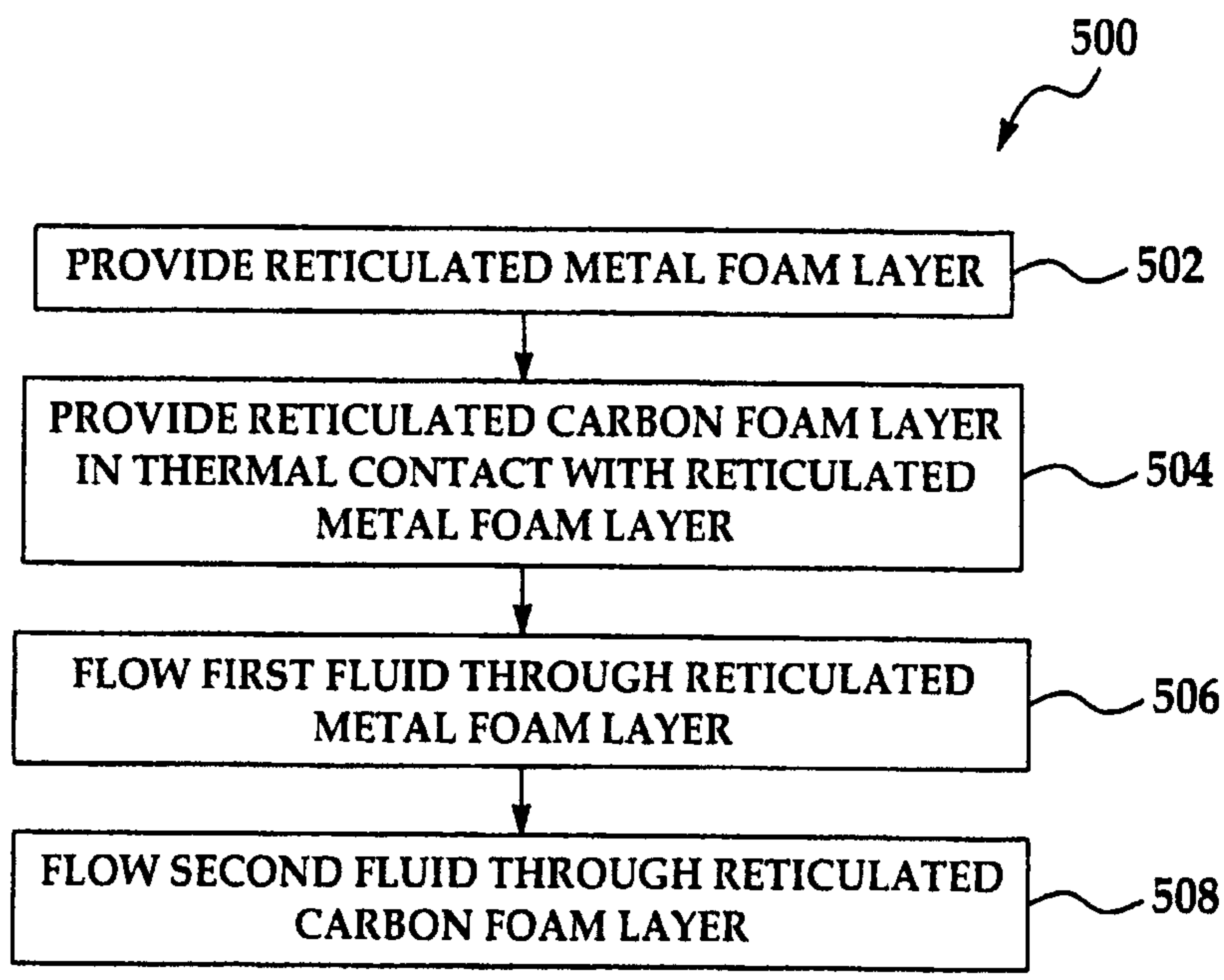


FIG. 5

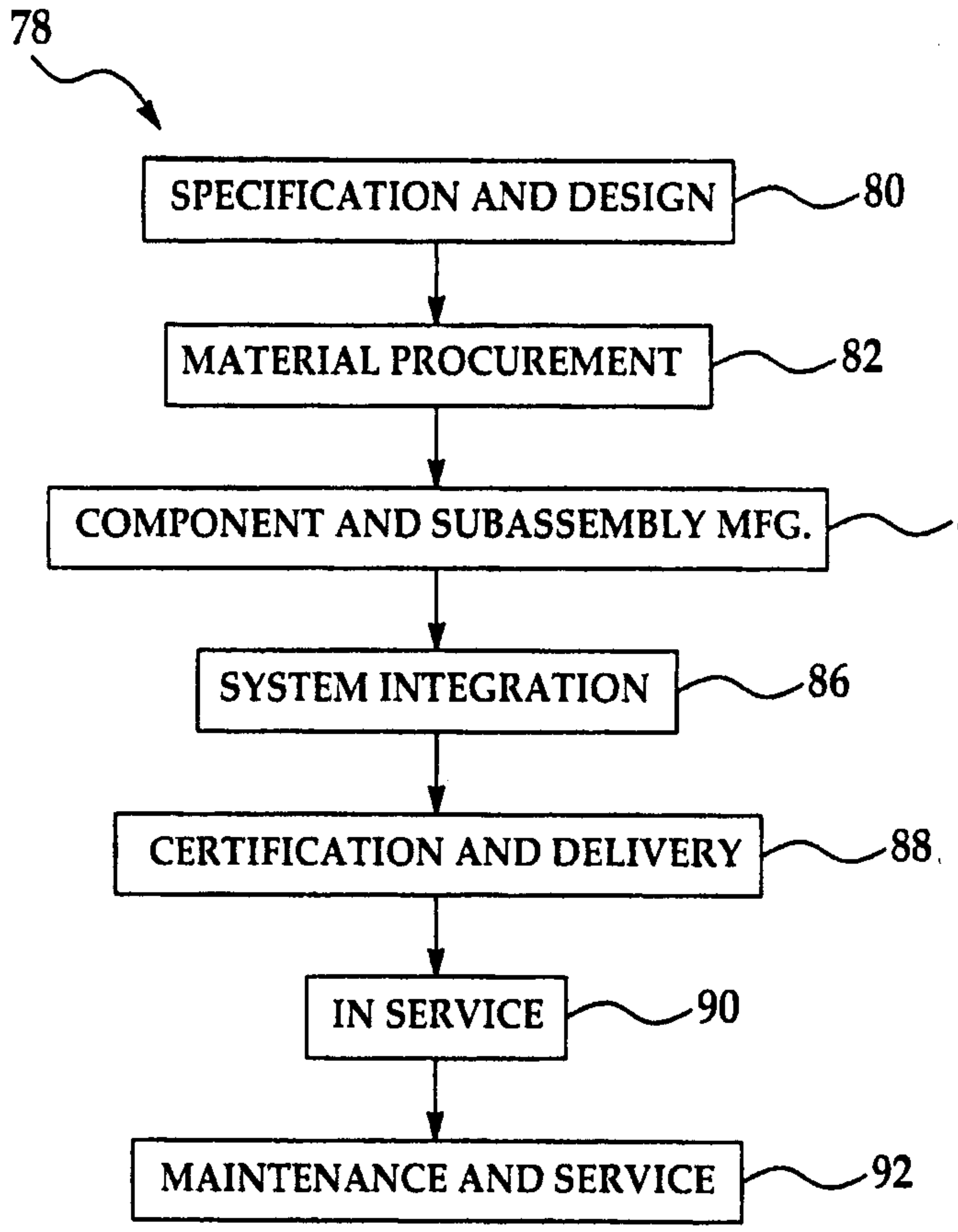
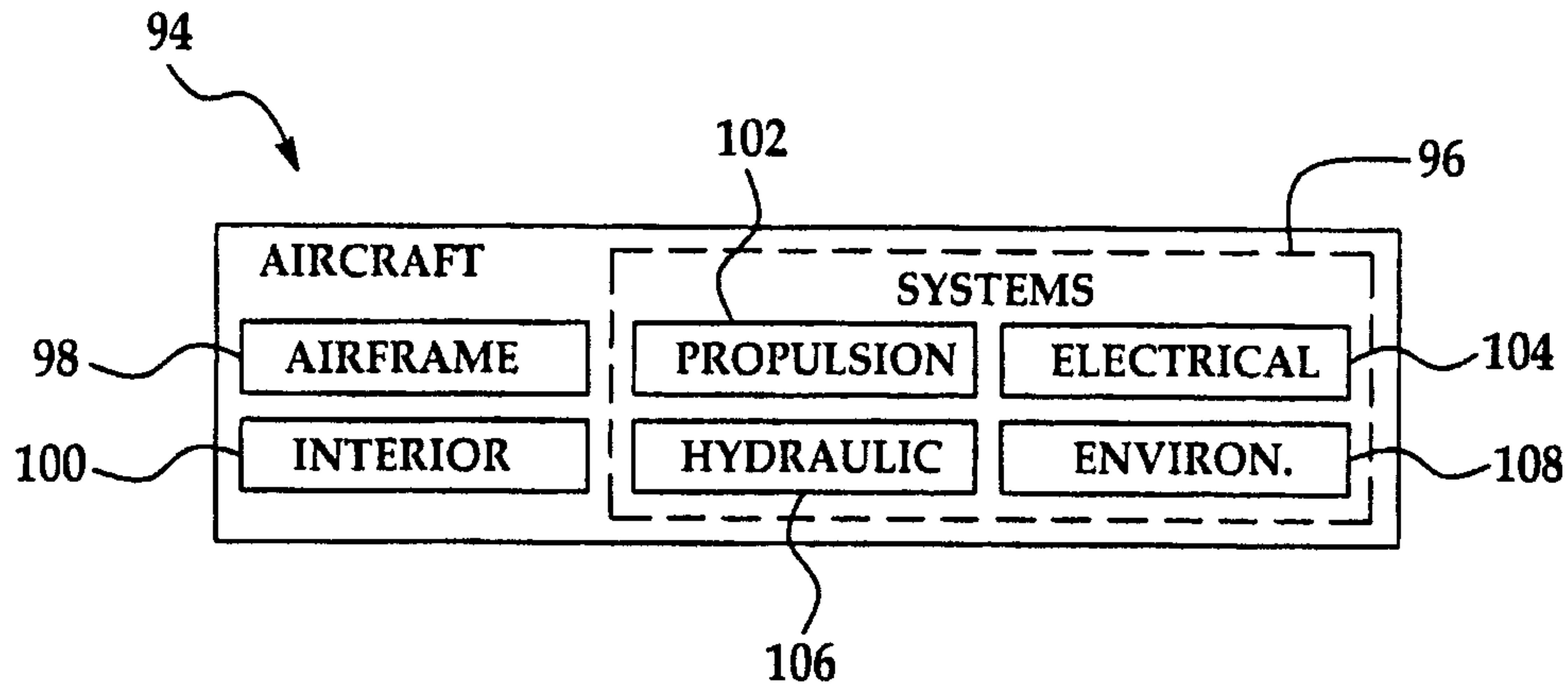

78
SPECIFICATION AND DESIGN
80
MATERIAL PROCUREMENT
82
COMPONENT AND SUBASSEMBLY MFG.
84
SYSTEM INTEGRATION
86
CERTIFICATION AND DELIVERY
88
IN SERVICE
90
MAINTENANCE AND SERVICE
92

FIG. 6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102
96
AIRCRAFT
SYSTEMS
98
AIRFRAME
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100
INTERIOR
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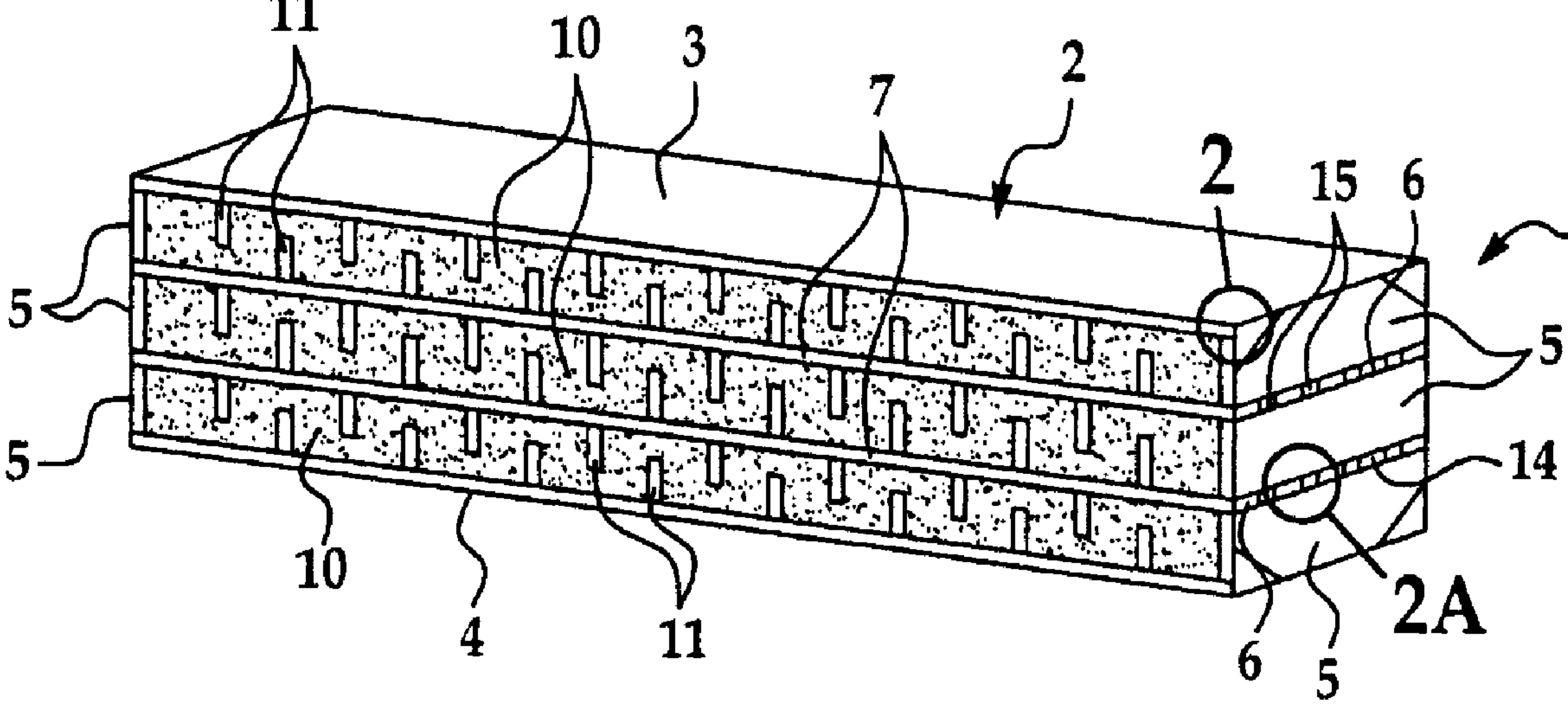
106

FIG. 7



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