(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
24 December 2008 (24.12.2008)

PCT

(10) International Publication Number
WO 2008/156505 A1

(51) International Patent Classification:
F16L 9/17 (2006.01) *B29C 53/38* (2006.01)
F16L 9/12 (2006.01) *B29C 65/00* (2006.01)

(21) International Application Number:
PCT/US2007/088674

(22) International Filing Date:
21 December 2007 (21.12.2007)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
11/763,427 14 June 2007 (14.06.2007) US

(71) Applicant *(for all designated States except US)*: **THE BOEING COMPANY** [US/US]; 100 North Riverside Plaza, Chicago, Illinois 60606-2016 (US).

(72) Inventors; and

(75) Inventors/Applicants *(for US only)*: **FRANTZ, Walter, Forrest** [US/US]; 8403 Clear Creek Road, Parkdale, Oregon 97041 (US). **PATEL, Jayant, D.** [US/US]; 21221 Calle Olivia, Lake Forest, California 92630 (US). **MABEN, Douglas, Dean** [US/US]; 805 185th Avenue N.E., Snohomish, Washington 98290 (US). **WHITMAN, Bruce** [US/US]; 3923 Valleyview Drive, Lorain, Ohio 44053 (US). **FREEMAN, Douglas, E.** [US/US]; 1728 North Urban Circle, Lorain, Ohio 44053 (US).

(74) Agents: **TSUDA, Diane, M.** et al.; The Boeing Company, P.O. Box 2515, MC 110-SD54, Seal Beach, California 90740-1515 (US).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, SV, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IS, IT, LT, LU, LV, MC, MT, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:
— *with international search report*
— *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments*

(54) **Title:** LIGHT WEIGHT THERMOPLASTIC FLEX FOAM AND HYBRID DUCT SYSTEM

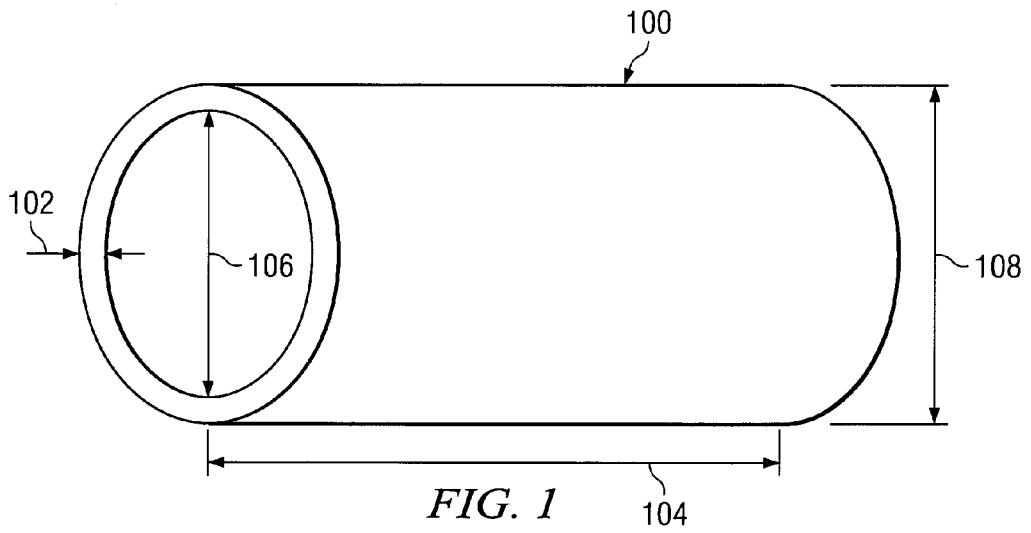


FIG. 1

(57) **Abstract:** An aerospace vessel including a fuselage, a means for causing the fuselage to fly coupled to the fuselage, and an environmental control system within the fuselage. The environmental control system includes a duct made of closed cell thermoplastic foam, such as polyvinylidene fluoride foam.

WO 2008/156505 A1

LIGHT WEIGHT THERMOPLASTIC FLEX FOAM AND HYBRID DUCT SYSTEM

BACKGROUND INFORMATION

1. Field:

The advantageous embodiments described herein relate to closed and semi-closed containers that receive internal or external pressure. More particularly, the advantageous embodiments described herein relate to ducts and methods of making duct systems, and still more particularly, toward duct systems used in aerospace vessels, such as aerospace vessels, helicopters, rockets, space vessels, and others.

2. Background:

Modern aerospace vessels contain numerous ducts of various forms to create a safe environment for people, animals, and equipment in hostile environments found in and around aerospace vessels. For example, in a typical midsize passenger airplane over 500 duct variants can be found. Ducts are used to provide cabin air conditioning, cockpit cooling, ram air cargo heating, water separation, avionic cooling, deicing, air trim, auxiliary power, recirculation systems, exhaust systems, and positive pressure in the cabin to deter the entry of smoke from a cargo fire. Thus, the environmental control duct system of an airplane is complex and adds significant weight to an airplane. Economizing weight is always of great concern to airplane designers because a single pound can impact the value of an aerospace vessel significantly. The weight of the aerospace vessel is important because heavier aerospace vessel intrinsically require more fuel and can carry fewer passengers or cargo relative to lighter aerospace vessel of the same design. These same concerns exist with respect to nearly all aerospace vessels to a greater or lesser degree and the instant invention is seen a solution to these concerns.

The processes and materials for conventional duct manufacturing and assembly can be expensive and possibly ineffective. Conventional ducts, such as metallic ducts, are heavy, costly to tool and fabricate, assemble, maintain, and have difficulty meeting stringent requirements, such as Federal Aviation Administration requirements.

Plastic ducts are used in an environmental control system of an aerospace vessel. However, plastic ducts also have disadvantages in some cases, such as geometry limitations, the potential requirement for flanges for bonding, inconsistent wall thicknesses, weight, and solvent stress factors.

Ducts made of reinforced composite materials are also used in an environmental control system of an aerospace vessel. However, reinforced composites also have several disadvantages. For example, many composites transmit noise and require expensive materials and tools, as well as a great deal of time and labor to process. Composites are also subject to micro damage when handled and stricter alignment tolerances.

SUMMARY

A solution to the problems identified above regarding manufacturing of ducts for aerospace vessels is to manufacture the ducts using thermoplastic foam. As a result, an environmental control system of an aerospace vessel has a lighter weight, is self compensating to accommodate airplane variability, has noise dampening features, lower costs, is damage tolerant, insulated, and is easier to manufacture.

In an advantageous embodiment, a foam duct is provided. The foam duct begins as a thermoplastic foam sheet having properties suitable for use in an environmental control system of an aerospace vessel. The foam duct can also be used in an environmental control system of other aerospace vessels, boats, buildings, automobiles, spacecraft, or other areas where an

environmental control system is established. The thermoplastic foam sheet has a crenulated and beveled first edge and a beveled second edge. The duct is formed by interlocking the crenulated and beveled first edge with the beveled second edge. In alternative embodiments, the first edge and second edge may or may not be crenulated and/or beveled.

In an advantageous embodiment, a vessel is provided. The vessel includes a body or fuselage, and an environmental control system and cabin within the fuselage that provides conditioned air to the equipment and structures that protect people, animals, and equipment from outside elements. The environmental control system includes a duct made of polyvinylidene fluoride (PVDF) foam.

The features, functions, and advantages can be achieved independently in various embodiments of the present invention or may be combined in yet other embodiments in which further details can be seen with reference to the following description and drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

The novel features believed characteristic of the invention are set forth in the appended claims. The invention itself, however, as well as a preferred mode of use, further objectives and advantages thereof, will best be understood by reference to the following detailed description of an advantageous embodiment of the present invention when read in conjunction with the accompanying drawings, wherein:

Figure 1 shows a duct that can be used in an environmental control system of an aerospace vessel, in accordance with an advantageous embodiment;

Figure 2 shows a cross section of the duct shown in **Figure 1**, in accordance with an advantageous embodiment;

Figure 3 shows a bun and a sheet skived from the bun for use in constructing a duct for an environmental control system of an aerospace vessel, in accordance with an advantageous embodiment;

Figure 4 shows the sheet of **Figure 3** after having been skived from the bun, wherein the sheet has been cut to have a beveled and crenulated shape on one edge and a beveled cut on the other edge, in accordance with an advantageous embodiment;

Figure 5 shows an apparatus that uses heat and pressure to make the duct shown in **Figure 1** using a sheet of PVDF foam sheet that has been skived, beveled, and crenulated as shown in **Figure 3** and **Figure 4**, in accordance with an advantageous embodiment;

Figure 6 shows the foam sheet shown in **Figure 4**, wherein, after extraction from the apparatus shown in **Figure 5,** the foam sheet has been formed into a duct with a crenulated-beveled seam, in accordance with an advantageous embodiment;

Figure 7 shows a side view of two beveled edges of a foam sheet overlapped together during formation of a foam duct from the foam sheet, in accordance with an advantageous embodiment;

Figure 8 is a side view of a foam duct seam formed by using heat and pressure at the seam according to the process described with respect to **Figure 7**, in accordance with an advantageous embodiment;

Figure 9 is a side view of a foam duct seam having two edges that are adhesively bonded, in accordance with an advantageous embodiment;

Figure 10 shows side view variants of foam duct seams formed with mitered edges of a foam sheet adhesively bonded together, in accordance with an advantageous embodiment;

Figure 11A shows formation of an angled butt seam, in accordance with an advantageous embodiment;

Figure 11B shows formation of an overlapped butt seam, in accordance with an advantageous embodiment;

Figure 12A shows a simple seam pattern, in accordance with an advantageous embodiment;

Figure 12B shows an interlocking foot pattern seam, in accordance with an advantageous embodiment;

Figure 12C shows an interlocking crenulated seam, in accordance with an advantageous embodiment;

Figure 13 shows a duct that has collapsed on bending;

Figure 14 shows a composite helical wire, in accordance with an advantageous embodiment;

Figure 15 shows a cross section of a composite helical wire for use in forming a helix on a foam duct, in an advantageous embodiment;

Figure 16 shows a mandrel for forming a flex duct, in accordance with an advantageous embodiment;

Figure 17 shows a flex duct formed using the apparatus shown in **Figure 16**, in accordance with an advantageous embodiment;

Figure 18 is a table relating helix and helical pitch relationships to diameters of ducts, in accordance with an advantageous embodiment;

Figure 19 is a table showing numbers of helix revolutions to achieve various duct bend angles, in accordance with an advantageous embodiment;

Figure 20 is a table showing transmission noise reduction versus frequency of sound based on duct construction, in accordance with an advantageous embodiment;

Figure 21 is a table showing transmission noise advantages of thermoplastic foam ducts versus conventional ducts relative to airplane flow for a duct, in accordance with an advantageous embodiment;

Figure 22 shows a cylindrical foam duct being molded into a complex shape, in accordance with an advantageous embodiment;

Figure 23 illustrates a vacuum form tool, in accordance with an advantageous embodiment;

Figure 24 shows two halves of a vacuum-formed foam sheet thermally or adhesively bonded together, in an advantageous embodiment;

Figure 25 shows half of a female mold for use during press formation of a duct, in accordance with an advantageous embodiment;

Figure 26 shows half of a male mold used during press formation of a duct, in accordance with an advantageous embodiment;

Figure 27 shows a molded foam sheet that, when bonded to a complimentary molded foam sheet, forms a foam duct, in accordance with an advantageous embodiment;

Figure 28 shows two thermoplastic foam sheets disposed between molds, in accordance with an advantageous embodiment;

Figure 29 shows a duct being formed using the mold and thermoplastic sheets shown in **Figure 28**, in accordance with an advantageous embodiment;

Figure 30 shows a duct manufactured according to the devices shown in **Figure 28** and **Figure 29**, in accordance with an advantageous embodiment;

Figure 31 illustrates joining of conventional ducts for an aerospace vessel environmental control system using a joining system, in accordance with an advantageous embodiment;

Figure 32 shows two ducts joined by a foam sleeve, in accordance with an advantageous embodiment;

Figure 33 shows a method of joining foam ducts using integral foam sleeves and composite cuffs, in accordance with an advantageous embodiment;

Figure 34 shows a ring clamp disposed around a foam duct, in accordance with an advantageous embodiment;

Figure 35 shows a duct around which is wound a preformed helix wire, in which a pitch bar is used to form the wire into a helix, in accordance with an advantageous embodiment;

Figure 36 is a flowchart illustrating a process of converting a foam bun into a foam duct, in accordance with an advantageous embodiment;

Figure 37 is a flowchart illustrating a process of pressure forming a foam duct into a more complex shape, in accordance with an advantageous embodiment;

Figure 38 is a flowchart illustrating a process of forming a shaped foam duct using vacuum and/or pressure, in accordance with an advantageous embodiment;

Figure 39 is a flowchart illustrating a process of press forming a shaped duct, in accordance with an advantageous embodiment;

Figure 40 is a flowchart illustrating a process of directly forming a duct using a multi-sheet forming process, in accordance with an advantageous embodiment;

Figure 41 is a flowchart illustrating a process of pre-forming a composite helix, in accordance with an advantageous embodiment;

Figure 42 is a flowchart illustrating a process of forming composite wire for use as a helix around foam ducts, in accordance with an advantageous embodiment;

Figure 43 is a flowchart illustrating a process of forming a flex duct by combining foam and a helical wire around a mandrel, in accordance with an advantageous embodiment;

Figure 44 is a flow diagram of aerospace vessel production and service method, in accordance with an advantageous embodiment; and

Figure 45 is a block diagram of an aerospace vessel, in accordance with an advantageous embodiment.

DETAILED DESCRIPTION

The advantageous embodiments described herein provide for use of foam ducts in vessels where people, animals, and equipment need to be protected from the external environment. Particularly, the embodiments described herein are for use in an environmental control system of an aerospace vessel or other aerospace vessel. An aerospace vessel environmental control system formed from all or some of the embodiments described herein is lighter weight, self compensating to accommodate airplane variability, has advantageous noise dampening properties, costs less money, is damage tolerant, self insulating, reduces tooling costs, is flexible during installation and use, can be formed into longer length segments, substantially reduces or eliminates assembly and attachment hardware, and eliminates ECS related scrap and disposal of waste materials.

In an advantageous embodiment, a foam environmental control system can include a combination of different materials layered or co-cured together to achieve a desired product. Layers of the same material can also be co-cured together to achieve a desired product. Additionally, the foam ducts can be formed into helical reinforced ducts to impart flexibility for bending, torsional movement, and axial movement, while simultaneously maintaining desired stiffness.

Figure 1 shows a duct that can be used in an environmental control system of an aerospace vessel, in accordance with an advantageous embodiment. Foam duct **100** is fashioned from foam sheets and can be used in a duct system of an aerospace vessel. Foam duct **100** has a thickness as shown between arrows **102**, a length as shown between arrows **104**, an inner diameter as shown between arrows **106**, and an outer diameter as shown between arrows **108**.

In an advantageous embodiment, foam duct **100** is formed from thermoplastic closed cell foam, such as polyvinylidene fluoride (PVDF). While PVDF foam tubes have been used for insulation covers, known PVDF tubes cannot withstand significant pressure differentials between the inside and outside skins of the vessel without breaking or leaking. Additionally, no known PDVF tube seams are durable enough to withstand prolonged pressure cycling or abuse. Additionally, known PVDF tubes could not be fashioned into some complex shapes commonly used in environmental control system ducts and plenums for use on an aerospace vessel.

Foam duct **100** is formed from a thermoplastic foam sheet having properties suitable for use in an environmental control system of an aerospace vessel. These properties include those properties of ducts required by the Federal Aviation Administration, such as, for example, with regard to flammability. Other properties that render a foam sheet suitable for use in an environmental control system of an aerospace vessel include low weight relative to all possible duct materials, sufficient strength to resist tearing, leak resistance, and resistance to water.

In an advantageous embodiment, foam duct **100** is formed from a sheet sized according to a formula specifically developed to account for engineering tolerances used in environmental control system ducts of an aerospace vessel, particularly with regard to internal pressures and strength of foam duct **100**. The dimensions of the sheet can be defined by equation (1):

$$W=\pi(d + 2t(1 - 0.045d)) + O \quad (1)$$

In equation (1), "W" is the width of the sheet that will ultimately be formed into foam duct **100**. Also in equation one, "d" is the inside diameter of foam duct **100**, which corresponds to the inside diameter shown by arrow **106**. Additionally, "t" is the thickness of the foam duct wall, as shown by arrows **102**.

"O" is the overlap between edges of the sheet once the sheet is wrapped around a mandrel. The value of "O" is typically set to approximately 0.75 inches, though the value of "O" can be greater.

In an advantageous embodiment, foam duct **100** is made of closed cell foam and specifically made of one of PVDF F30 and PVDF F38 grade foams. Other suitable thermoplastic closed cell foams can be used for aerospace vessel environmental control systems, as long as such foams meet Federal Aviation Administration requirements, such as flammability requirements.

Figure 2 shows a cross section of the duct shown in **Figure 1**, in accordance with an advantageous embodiment. Again, arrow **106** shows the inside diameter of foam duct **100**, arrows **102** shows the thickness of foam duct **100**, and arrow **108** shows an outside diameter of foam duct **100**. However, the cross section can represent a single sheet or one or more sheets of foam thermally bonded together to form a single sheet. In this embodiment, a sheet shall mean a single sheet or multiple sheets adhesively or thermally, joined together either partially or fully.

Figure 3 shows a bun and a sheet skived from the bun for use in constructing a duct for an environmental control system of an aerospace vessel, in accordance with an advantageous embodiment. Bun **300** is expanded into foam from a polyvinylidene fluoride (PVDF) sheet. In an advantageous embodiment, a commercial bun is approximately 25.4 millimeters thick along arrows **302**, about two meters long along arrows **304**, and about one meter wide along arrows **306**. However, manufactured buns, such as bun **300**, are also available in different widths, lengths, and thicknesses.

In an advantageous embodiment, bun **300** is skived into one or more sheets. In an advantageous embodiment, sheet **308** is skived from bun **300,** as shown along phantom lines **310** and **312**. Sheet **308** can also be described as being cut from bun **300**; however, sheet **308** can be removed from bun **300** according to any

desired method. In an advantageous embodiment, sheet **308** has a thickness of approximately 0.274 inches for F38 PVDF foam, and approximately 0.292 inches for F30 PVDF foam. However, sheet **308** can have any thickness that is appropriate for the intended use of the final duct product. The thicknesses of 0.274 inches and 0.292 inches are appropriate for the insulating ability specific to PVDF foam thermal properties and the thermal and moisture conditions in an aircraft to prevent moisture condensation on ducts. However, other thicknesses can be used to meet the needs of a duct product.

Figure 4 shows the sheet of **Figure 3** after having been skived from the bun, wherein the sheet has been cut to have a beveled and crenulated shape on one edge and a beveled cut on the other edge, in accordance with an advantageous embodiment. In particular, **Figure 4** shows a top view and a side view of sheet **400** skived from bun **300** of **Figure 3** after having been cut to have the beveled and crenulated shape.

In particular, the edges of foam sheet **400** have been provided with reverse bevels, so that side **440** forms the inside of the duct and side **442** forms the outside of the duct. Additionally, the edges of foam sheet **400** have been provided with a crenulated edge. Thus, for example, as shown in side view of **Figure 4,** bevel **402** is at an angle of about 30 to about 45 degrees, and bevel **404** is approximately parallel to bevel **402**. Thus, foam sheet **400** is wrapped around a mandrel such that bevel **402,** that also contains the crenulated edge, overlaps bevel **404**.

Additionally, as shown in top edge **406,** foam sheet **400** has been provided with a pattern of crenellation teeth, such as crenellation tooth **408**, crenellation tooth **410**, crenellation tooth **412**, and crenellation tooth **414**. In an advantageous embodiment, the opposite side of foam sheet **400,** while beveled, forms a straight edge and is not crenulated. Thus, the crenulated edge is thermally embedded into solid foam, locking

and sealing the seam upon formation of the duct. The determination of whether one or both edges are beveled and/or crenulated depends on a variety of factors. Thus, whether one or both edges of the foam sheet are beveled and/or crenulated varies for the application. A reverse bevel on one or both edges increases peel strength of one or both edges of the seam. Crenellation on one or both edges interlocks the foam together by being thermally pressed into solid foam on one or both sides. If adhesively bonded or taped along the seam using an adhesive tape or thermal tape, the crenellation teeth can be similarly matched, sized, and dimensioned to fit within the alternating recesses in edge **406**. Thus, for example, a crenellation tooth on the opposite edge of foam sheet **400** will fit into recess **416,** and similarly, other crenellation teeth will fit into recesses **418**, **420**, and **422**.

As shown in **Figure 4**, the crenellation teeth and recesses are provided with particular dimensions so that the crenellations will interlock with each other or can be thermally embedded into solid foam once foam sheet **400** is wrapped around itself. In particular, a top end of a particular crenellation tooth, such as crenellation tooth **410** is provided with a radius "r", as shown by arrow **424**. The entire length of crenellation tooth **410** from the bottom of any given recess, such as recess **418** or **420**, is 3.2 times "r", in an advantageous embodiment. Thus, the tips of crenellation teeth **408**, **410**, **412**, and **414** are beveled according to the angle shown in bevel **402,** in the side view of **Figure 4**. The tips of the crenellation teeth correspond to outer edge **426**.

Additionally, the recesses in edge **406** of foam sheet **400** each have an enter radius corresponding to "r" as shown by arrows **428**. The distance along the x coordinates as shown in **Figure 4,** such as, for example, x coordinate phantom line **430** is equal to 1.6 times "r". Similarly, the distance between outer edge **426** and the tangent of the partial circle that forms the

crenellation tooth and the partial circle that forms the recess is 1.6 times "r". The center of radii between a recess and a crenellation tooth along a Y-axis, such as the Y-axis of phantom line **432** is 1.2 times "r". In an advantageous embodiment, "r" is between about 0.1 inches and 0.5 inches. However, all of the values and relative values in this advantageous embodiment can be varied according to the final foam duct that is to be produced. In addition, the recesses can be made of a smaller relative radius in order to compress the interlocking crenulations. In use, foam sheet **400** is wrapped around a mandrel, such that bevel **402** abuts or overlaps bevel **404** and crenellation teeth **408**, **410**, **412**, and **414** are pressed into solid foam or fit within the corresponding edge of foam sheet **400**. The various numbers described above can be varied in other advantageous embodiments.

Figure 5 shows an apparatus that uses heat and pressure to make the duct shown in **Figure 1** using a sheet of PVDF foam sheet that has been skived, beveled, and crenulated as shown in **Figure 3** and **Figure 4**, in accordance with an advantageous embodiment.

Apparatus **500** can be used to create a foam duct, such as foam duct **100** shown in **Figure 1,** by overlapping and thermally bonding opposite edges of a foam sheet. In an advantageous embodiment, an overlap of 0.75 inches is created between beveled edge **402** and beveled edge **404** shown in **Figure 4**. The foam sheet is then subjected to heat at about 300 degrees Fahrenheit for about ten minutes using approximately fifty percent compression. The term "fifty percent compression" means that both overlapped edges of the foam seam are compressed until the resulting seam that began at the thickness of two sheets is now the same thickness as one sheet.

Apparatus **500** includes mandrel **502** about which is wrapped foam sheet **504**. As shown in **Figure 5**, foam sheet **504** includes crenellation teeth **506** and corresponding recesses. Mandrel **502**

is connected to an automated roller in order to rotate mandrel **502** about its central axis.

Mandrel **502** is disposed between bulkheads, in this case, bulkheads **508** and **510**. Bulkheads are locked around mandrel **502** and foam sheet **504** during use. The overlapping edges of foam sheet **504** are heated and pressed between. Bulkhead **510** and mandrel **502** are used to produce the thermally bonded seam **602** of duct **600** shown in **Figure 6**. Thereafter, the resulting duct is cooled. After a suitable cooling period, bulkheads **508** and **510** are opened and the resulting duct is released from the mandrel.

Apparatus **500** also includes one or more heating elements, not shown, in order to heat foam sheet **504** and the overlapping edges of foam sheet **504**. In order to hold bulkheads **508** and **510** in place while compressing the foam seam from two ply thickness to one ply thickness, apparatus **500** also includes a locking mechanism, such as C-clamps, to keep the bulkheads in place while heat is applied to the seam of foam sheet **504**.

Mandrel **502** is shown disposed in a trough. A spacer ring (not shown) wraps around mandrel **502** at a position towards the outer end of mandrel **502**. The spacer assists in maintaining pressure on foam sheet **504** and also provides a mechanism for releasing the finished duct from the mandrel by using air pressure between the finished duct and mandrel **502**.

The manufacturing process shown in **Figure 5** creates a continuous cylindrical duct without adding stiffness, deformation, or a seam that can be easily separated. The splicing design shown can also be fabricated using two other processes, a water jet process and a laser machining process. Both processes are fast, precise, and efficient.

Figure 6 shows the foam sheet shown in **Figure 4**, wherein after extraction from the apparatus shown in **Figure 5,** the foam sheet has been formed into a duct with a crenulated-beveled seam, in accordance with an advantageous embodiment. Foam duct **600** corresponds to foam duct **100** shown in **Figure 1**, foam duct

200 shown in **Figure 2**, and is the product of the process performed on foam sheet **504** shown in **Figure 5**.

In particular, foam duct **600** shows crenulated seam **602** that is formed when beveled and crenulated edges are brought together. As shown in **Figure 6**, a wavy line is formed along crenulated seam **602**. Crenulated seam **602** is fused from the two edges of foam sheet **504** of **Figure 5**. Thus, after the duct formation process shown in **Figure 5**, duct **600** is a continuous cylindrical duct.

However, duct **600**, as shown elsewhere herein, can be forced into many different shapes. Therefore, the circular or oval cross sectional shape of foam duct **600** is only an example of the ducts that can be formed by the process described elsewhere herein. Seam **602**, as shown elsewhere herein, can be formed by other thermal and pressure processes as described, by adhesive bonding, or by adhesive of thermal taping.

Figure 7 shows a side view of two beveled edges of a foam sheet overlapped together during formation of a foam duct from the foam sheet, in accordance with an advantageous embodiment. Foam sheet **700** shown in **Figure 7** can be used to form a foam duct, such as foam duct **100** shown in **Figure 1,** using apparatus **500** shown in **Figure 5**. Foam duct **700** can be formed from bun **300** shown in **Figure 3**. The configuration of foam sheet **700** shown in **Figure 7** is especially useful for the formation of foam ducts during a thermal fusion process.

Foam sheet **700** is formed into a right circular cylindrical duct; however, foam sheet **700** can be used with regards to any shaped duct. As shown in **Figure 7**, beveled end **702** overlaps beveled end **704** in overlapping region **706**. Beveled end **702** and beveled end **704** can have a straight or crenulated edge, such as those edges shown in **Figure 4**, though neither beveling or crenellation is necessarily required depending on anticipated duct stresses, anticipated duct abuse, and the type of foam used.

In the advantageous embodiment shown in **Figure 7**, surface **708** forms the outer surface of the duct and surface **710** forms the inner surface of the duct. As shown further with respect to **Figure 8**, beveled end **702** and beveled end **704** are pressed into solid foam and heated in region **702**, **704**, and **706** to form a continuous seam of a duct, such as seam **602** shown in **Figure 6**.

Figure 8 is a side view of a foam duct seam formed by using heat and pressure at the seam according to the process described with respect to **Figure 7**, in accordance with an advantageous embodiment. Thus, foam duct **800** corresponds to foam duct **700** shown in **Figure 7**.

As shown in **Figure 8**, seam **802** is formed as beveled edge **702** and beveled edge **704** are pressed together. Thereafter, while beveled edge **702** and beveled edge **704** are pressed together, heat is applied and seam **802** is sealed. In this manner, a foam duct is formed.

Figure 9 is a side view of a foam duct seam having two edges that are adhesively bonded, in accordance with an advantageous embodiment. Foam sheet **900** includes edge **902** and edge **904**. Foam sheet **900** overlaps at seam **906** in the vicinity of edge **902** and edge **904**. In an advantageous embodiment, an adhesive can be applied in the area of seam **906** to form a foam duct. Thus, the process shown in **Figure 9** can be used to repair ducts or can be used for alternative embodiments. Ultimately, foam sheet **900** will form a duct having outer face **908** and inner face **910**.

Figure 10 shows side view variants of foam duct seams formed with mitered edges of a foam sheet adhesively bonded together, in accordance with an advantageous embodiment. In particular, **Figure 10** shows a side view of a seam of foam duct **900** of **Figure 9**. The two edges are then bonded together with adhesive that is applied along the seam. Thus, foam sheet **900** in **Figure 10** is formed into a duct having outer face **908** and inner face **910**. The duct formed from foam sheet **900** can be a

right circular cylinder duct, such as that shown in **Figure 1**, but can also be any particular shape.

In an advantageous embodiment, flarings **1002** can be added to outer face **908** and inner face **910** of foam sheet **900** in order to stop seam breakage or localized fracture of foam cells that leads to dissolution due to abuse or pressure cycles. Flarings **1002** allow attachments, seams, and adhesive to flex together, versus pealing apart or inducing stress concentrations. In an advantageous embodiment, flarings **1002** are formed by applying adhesive over a seam such that the edges are thin. Flarings **1002** can also be formed by thinning the edges of stiff metal or composite attachments in a straight edge or crenulated edge. Flarings **1002** allow for the use of stronger adhesives that do not have the flexibility of normal foam adhesives.

Figures 11A and **11B** show a side view of alternative seams formed by adhesively bonding the edges of a foam sheet together, in accordance with an advantageous embodiment. In particular, **Figure 11A** and **11B** shows formation of an angled butt seam, in accordance with an advantageous embodiment, and **Figure 11A** and **11B** shows formation of an overlapped butt seam, in accordance with an advantageous embodiment. As shown in **Figure 11A** and **11B**, foam sheet **900** is the same as foam sheet **900** shown in **Figure 9**.

In **Figure 11A** and **11B**, foam sheet **900** has been pressed together in angle-butt seam **1100**. End **902** and end **904** form a single line, as shown. If desired, flaring **1102** can be added. Flaring **1102** can be an adhesive to make the seam more durable once foam sheet **900** has been formed into a duct. Seam **1100** is perpendicular to outer face **908** and inner face **910**.

The edges of the foam sheet shown in **Figure 11A** and **11B** have been pressed together in overlapped-butt seam **1104**. End **902** and end **904** form a single line, as shown. If desired, flaring **1102** can be added. Flaring **1102** can be an adhesive to

make the seam more durable once foam sheet **900** has been formed into a duct. Overlapped-butt seam **1104** is shaped, as shown.

Figure 12A through **Figure 12C** show top views of geometric variants of the seams shown in **Figure 7** through **Figure 11A** and **11B**, wherein the foam sheet has been formed into a duct, in accordance with an advantageous embodiment. **Figure 12A** through **Figure 12C** show three of many possible different seam patterns for foam ducts. In particular, **Figure 12A** shows a simple seam pattern, in accordance with an advantageous embodiment. Simple seam pattern **1200** shows a straight seam that is also perpendicular to outer face **908**, as shown with respect to **Figure 9**.

Figure 12B shows an interlocking foot pattern seam, in accordance with an advantageous embodiment. To form interlocking foot pattern seam **1202**, the two edges of foam sheet **900** are each provided with a similar, but offset foot pattern. A saw-tooth in one edge will fit into a similar shaped recess of another edge of the foam sheet. Thus, interlocking foot pattern seam **1202** is similar to crenulated seam **602** shown in **Figure 6**. Interlocking foot pattern seam **1202** is stronger and more durable than simple seam pattern **1200** shown in **Figure 12A**.

Figure 12C shows an interlocking crenulated seam, in accordance with an advantageous embodiment. Crenulated seam **1204** corresponds to crenulated seam **602** shown in **Figure 6**. Crenulated seam **1204** is formed from the crenulated edges shown in **Figure 4**. When thermally or adhesively bonded, the foam sheet becomes a duct, such as duct **600** shown in **Figure 6**. Crenulated seam **1204** is stronger than simple seam pattern **1200** shown in **Figure 12A**.

Figure 13 shows a duct that has collapsed on bending. When a foam duct is bent beyond a certain radius, the foam duct will buckle in one or more places, as shown in **Figure 13**. Tube **1300** has kink **1302**. Kink **1302** causes tube **1300** to be choked. Choking changes the intended duct shape and can prevent a duct

from delivering conditioned air or other fluids. A prolonged choked condition can result in damage to subsequent systems in different aerospace vessel components. Loss of some systems could result in severe consequences, such as premature landing, loss of an airplane, an airplane being out-of-service, and passenger discomfort. All of these consequences can result to loss of profit for the airline carrier.

Figure 14 shows a composite helical wire, in accordance with an advantageous embodiment. Helical wire **1400** can be wrapped around a duct in order to improve the strength of a duct, particularly with respect to kinking or choking, as shown in **Figure 13**. Helical wire **1400** is a thermoplastic wire formed into a helical shape using a heating process. However, any suitable wire can be applied to a duct to form a helical shape onto the duct.

Figure 15 shows a cross section of a composite helical wire for use in forming a helix on a foam duct, in an advantageous embodiment. Helical wire **1500** shown in **Figure 15** can be a wire, such as helical wire **1400** shown in **Figure 14**. Helical wire **1500** includes a hollow area **1502**, though hollow area **1502** is not necessarily required for every application. Additionally, the cross section of helical wire **1500** need not be round. The cross section of helical wire **1500** can be a partial circle, polygon, or other irregular shape, as desired for the particular application.

Helical wire **1500** can be formed from a variety of thermoplastic materials, such as, but not limited to polyetherimide, polyetheretherketone, polyphenylsulfone, and polyvinylidene fluoride (PVDF). Helical wire **1500** can also be made from other materials, such as PEI glass, PEEK glass, and various composite materials. These materials are chosen according to the properties that are desired for the final duct product.

In an advantageous embodiment, helical wire **1500** is formed from materials, such as polyetherimide or polyetheretherketone, which results in providing superior stiffness, strength, and bonding with less weight and cost. Helical wire **1500** is secured to a foam duct by thermal bonding, though adhesive bonding can also be used in other advantageous embodiments. Thermal bonding has the advantage that air pockets do not form at the edges between helical wire **1500** and a duct.

In advantageous embodiments, helical wire **1500** can be bonded to a foam duct, such as foam duct **100** shown in **Figure 1**. Helical wire **1500** is a duct that forms a flex duct. Flex ducts are resistant to kinking. Helical wire **1500** can be bonded to a foam duct using a variety of means. In an advantageous embodiment, helical wire **1500** is thermally bonded to the duct in the same or similar manner that a seam is bonded together, as shown with respect to **Figure 4** through **Figure 12C**. Other bonding means can also be used, such as, but not limited to glues or resins, or a combination of glues and thermal bonding.

Figure 16 shows a mandrel for forming a flex duct, in accordance with an advantageous embodiment. **Figure 16** shows a device that can be used in conjunction with helical wire **1400** of **Figure 14** to form a flex duct.

In particular, apparatus **1600** includes mandrel **1602** and spindle **1604**. In an advantageous embodiment, air nozzle attachment **1606** is provided in order to allow air from a hose to be forced into mandrel **1602**. Thus, using a burst of air pressure, a foam duct on mandrel **1602** can be removed from mandrel **1602** easily and without breaking or tearing the duct. The same air can be used to help pleat the foam duct after the helix is formed.

In other advantageous embodiments, apparatus **1600** can be adjusted. For example, mandrel **1602** can be lengthened to accommodate different lengths of ducts. If mandrel **1602** is

sufficiently long, then mandrel **1602** can be supported at the end opposite spindle **1604**.

A design consideration for manufacturing ducts for use in airplanes is the desire to avoid creation of stresses within a duct. Many of these stresses can be avoided by avoiding embrittlement of a flex duct. In particular, embrittlement of the wire forming the helix of the flex duct is to be avoided.

Steps that can be taken to avoid embrittlement of the wire forming the helix include restricting the pulling of the extruded profile immediately after an exit cycle to retain the density of the wire. Additionally, the common practice of adjusting the profile shape of the wire is avoided after exiting the die. Furthermore, dies for the wire are developed to minimize undesired scoring and shaping of the wire. Additionally, caging of the initial fifteen feet of wire material can be performed to prevent sudden cooling shock and to minimize stress build up. Additionally, gradual and controlled cooling can be used to avoid absorption of residual stress. The factory temperature and humidity should also be controlled, and the use of regrind or recycled materials should be forbidden. In conventional duct making practices, use of regrind or recycled materials is common. However, such practice should be avoided when constructing ducts for use in aerospace vessels.

A process for relieving stress and for screening a helical coil is described below for the thermoplastic PEI. First, the extruded profile of a PEI coil is exposed to a temperature near a glass transition temperature for the thermoplastic. In an advantageous embodiment, such a temperature for PEI is in a range of about 380 degrees Fahrenheit to about 400 degrees Fahrenheit for approximately four or more hours. The extruded profile of the PEI coil is gradually cooled in an oven until the temperature is about 180 degrees Fahrenheit or less. The coil is then screened against a bright light, such as sunlight or a bright artificial light, to detect voids. The light creates a

sharp glow in the duct, revealing flaws in the material. Flawed or defective material is rejected.

Another method to detect flaws is to apply a clean cloth wrap along the helical coil and moisten the cloth with MEK and Tricholoroathane. The cloth is kept moist so that fluid and vapor are in contact with the coil for about 25 to about 30 minutes. The solvent is sprayed frequently onto the cloth to replace evaporated solvent. The coil is then blot dried to avoid white filming and the part is examined for cracks. If the part exhibits cracks, then the part is discarded.

In the advantageous embodiment described above, helical or flex ducts are fabricated by attaching a wire over a preformed duct. However, an alternative process for forming helical ducts or flex ducts can also be used. This additional process is described below.

First, the mandrel is thoroughly cleaned with a lint-free wiper and solvent. The mandrel is positioned on a fabrication machine and the mandrel is wiped with the solvent using a lint-free wiper saturated with the solvent. The mandrel is then wiped dry with the lint-free wiper. Next, TEFLON® (polytetrafluoroethylene), a suitable release tape, or some other release agent is applied to the mandrel. A PVDF foam sheet is then turned to the desired size using the formula described above in order to ensure adequate material for the type of splice. A thin, transparent adhesive tape can be incorporated to enhance the adhesion strength of the splice. The foam sheet is positioned and rolled on the mandrel, and secured approximately every four to eight inches with PVA tape.

The foam duct body is heated at about 180 degrees for about twenty minutes to build a shape memory in the foam duct. The next step is to pressure wrap the foam overlaps at the center of the duct and work towards the ends. This technique ensures uniformity of splice overlap along the full length of the duct.

The PVA tape wrap pressure is kept firm throughout the overall length of the foam by slightly compressing the foam.

Next, an extra ply of foam is applied to the cuff areas, if required by the design. A reinforcing ply layer may be added to enhance tear resistance and to aid in installation of a clamp during installation in an aerospace vessel.

Next, the cuff areas are pressure wrapped with a PVA sheet or tape. The overlap areas are thermally fused or welded at 300 degrees Fahrenheit plus or minus about 10 degrees for about 12 to about 15 minutes.

Next, a helix size and shape is selected based on the desired performance. Polyetherimide helixes can be used to meet aviation requirements. Next, a small piece of thermal-setting fiberglass tape is placed at the initiation of the wire to protect the foam interface from abrasion damage. The wire is applied using a pitch bar in order to apply uniform spacing of a desired helical pitch while the mandrel is rotating. The pitch bar helps ensure that the helix is free of twists and that the wire is cleaned as the wire is fed. The pitch bar also controls the pitch of the helix.

Next, fiberglass tape is applied to the underside of the termination of the helix to protect the foam. The terminated ends are secured by applying a full rotational wrap.

Next, a mixture of HYSOL U-10FL and acetone at a ratio of two parts adhesive to one part acetone by volume is prepared. The mixture is applied over the helix at an ambient temperature of about 50 degrees Fahrenheit to about 80 degrees Fahrenheit. Finally, the assembly is force cured at 200 degrees Fahrenheit for about 45 to about 60 minutes.

Figure 17 shows a flex duct formed using the apparatus shown in **Figure 16**, in accordance with an advantageous embodiment. If pleated, duct **1700** can be referred to as an accordion duct because duct **1700** can be compressed or expanded along its length.

During airplane assembly, often the last duct in the final assembly is either too long or too short. However, this problem can be addressed using a flex duct as shown in **Figure 17**. Thus, using duct **1700**, custom duct fitting, readjustment, or realignment of an entire environmental control system duct assembly can be avoided. Additionally, special tools and parts do not need to be created in order to finish connecting an environmental control system in an aerospace vessel.

Duct **1700** is also useful in areas where the degree of flexion is to be minimized in order to decrease noise generated from bending airflow around corners. Using a single helix that is heat molded to the duct, a specific degree of flexibility can be achieved for the helical flex duct. For example, for a sidewall riser duct of an aerospace vessel, the initial turns can be flexible. However, as the turn comes closer to the passenger deck, the flex section of the duct can be made less flexible and quieter. In an advantageous embodiment, PVDF foam ducts can usually bend, without collapse, to the radius of a large fuselage without the use of a helix wire.

Figure 18 is a table relating helix and helical pitch relationships to diameters of ducts, in accordance with an advantageous embodiment. Table **1800** can be used to select a diameter of a wire wrapped around a duct and to select a corresponding pitch of the helix, as the wire used to make the helix is wrapped around a duct. Generally, as the hose or duct diameter increases, the diameter and pitch of the wire also increase as shown. For a polyetherimide wire, the wire properties do not significantly vary between whether or not the wire is hollow or solid. Whether the wire is hollow or solid also does not significantly affect the pitch of the helix. However, hollow wires are lighter and are more flexible, whereas solid wires are stiffer and provide greater protection against duct choking.

Figure 19 is a table showing numbers of helix revolutions to achieve various duct bend angles, in accordance with an advantageous embodiment. Table **1900** can be used to determine the amount of wire needed when wrapping a helix around a duct. In particular, table **1900** can be used to determine the amount of wire needed when wrapping a wire around a duct that has a cross-section of a circle or near circle. The amount of wire depends on bends in the duct. Depending on the nominal bend angle and the maximum bend angle, a minimum number of helix revolutions are used. Given the number of helix revolutions needed and given the radius of the duct, the amount of wire needed can be determined.

Figure 20 is a table showing transmission noise reduction versus frequency of sound based on duct construction, in accordance with an advantageous embodiment. Table **2000** shows that the pitch of the helix wrapped around a foam duct changes the noise dampening effects of the duct. Noise dampening is of great concern in aerospace vessel construction due to the noise created when the airplane is operational.

As shown in table **2000**, the best noise attenuation is achieved depending on both the width of the helix pitch and the frequency of noise that is to be attenuated. For example, in the frequency range of approximately 1000 hertz, a wide helical pitch produces the best noise attenuation. However, at about 7000 hertz, a narrow helical pitch provides the best noise dampening. Thus, depending upon the particular use to which a duct is to be put, and depending on the noise frequency expected from fluid flowing through the duct, the helical pitch can be adjusted to maximize frequency attenuation.

Additionally, thermoplastic foams, such as PVDF foams, exhibit superior acoustic dampening properties compared with traditional metal or plastic ducts. Thus, in conjunction with selected helical pitches, thermoplastic foam ducts can substantially decrease the noise volume emitted from ducts

during airflow through a duct. In an advantageous embodiment, a decrease of 2.5 decibels per duct foot can be achieved. Higher or lower decibel attenuations can also be achieved. A foam duct can also be wrapped in a thin composite layer to provide the same breakout noise attenuation found in composite ducts. Further, the frequency of noise attenuation can be tuned by changing the helix pitch along the length of the duct.

In an advantageous example, before air is sent from the lower lobe of an aerospace vessel to the upper lobe, engineers want the ducts to have high flow noise attenuation because the risers taking the air into the upper lobe are in the side walls next to the ears of passengers. Thus, for this application, untreated foam is used in the lower lobe to attenuate noise flow generated from fans and bending the air up the side wall of the aerospace vessel. Then, a helix, thin composite layer, tape, or a combination of these can be used around the duct close to where a passenger ear is located in order to attenuate breakout noise. Thus, a duct can be provided with a partial helix, in the sense that the helix does not extend the entire length of the duct.

Additionally, noise attenuation characteristics of foam ducts are dependent on helical angle as well as helical pitch. A wide helix angle dampens low to mid frequency noise, whereas a narrow helix angle dampens high frequency noise. Therefore, duct noise attenuation at a desired frequency regime can be obtained by varying helical characteristics, such as angle and pitch. The dampening of low to mid frequency is very significant, as low frequency noise reductions are more difficult to attenuate. Conventional techniques for attenuating low frequency noise are generally achieved by adding significant undesirable weight to the aerospace vessel.

Figure 21 is a table showing transmission noise advantages of thermoplastic foam ducts versus conventional ducts relative to airflow thru a duct, in accordance with an advantageous

embodiment. Table **2100** shows that the noise in a duct depends on the flow rate in feet per minute of fluid, such as air, through the duct. As shown in table **2100**, foam ducts produce less flow-generated noise than hard ducts. Thus, again, in conjunction with table **2000** of **Figure 20**, foam ducts have been shown to have superior noise attenuation qualities.

Figure 22 shows a cylindrical foam duct being molded into a complex shape, in accordance with an advantageous embodiment. Foam duct **2200** can be foam duct **100** shown in **Figure 1** and **Figure 2**, or foam duct **600** shown in **Figure 6**. Similarly, foam duct **2200** could also be foam duct **1700** shown in **Figure 7**.

As shown in **Figure 22**, foam duct **2200** is placed into the bottom half of mold **2202**. The ends are plugged with end-caps **2204** and **2206** and then the top half of mold **2202** is secured over foam duct **2200**. Mold **2202** has the desired shape of the final foam duct product. In an advantageous embodiment, foam duct **2200** is pressurized by blowing air in one or more ends, such as end-cap **2206**.

After internal pressurization to what will be two or more atmospheres at final temperature, depending on the need for shape change and geometric definition of the part, foam duct **2200** is heated to a temperature near or above the glass transition temperature of the thermoplastic. For PVDF foam, the filled apparatus is heated to about 300 to about 400 degrees Fahrenheit for a time of about 5 to about 20 minutes. Thereafter, foam duct **2200** is cooled and then depressurized. Foam duct **2200** is then removed from mold **2202** and is ready for use or for further processing.

Thus, the advantageous embodiment shown in **Figure 22** can be used to transform straight or cylindrical foam ducts into ducts having complex shapes. In particular, foam duct **2200** can assume a shape having sharp changes in direction, necking, or other complex shapes. Additionally, if the size of mold **2202** is

somewhat larger than foam duct **2200**, then the size of foam duct **2200** can be increased by the process described above.

In another advantageous embodiment, one or more additional molds can be used to increase or slightly decrease the diameter of foam duct **2200**. For example, an additional mold can be inserted into foam duct **2200**, wherein the additional mold has a diameter slightly larger than the diameter of foam duct **2200**. Thus, during processing the diameter of foam duct **2200** can be increased in size.

Figure 23 and **Figure 24** illustrate a process for forming a duct having a complex shape. In particular, **Figure 23** and **Figure 24** illustrate a process of foaming a duct through the use of a vacuum formation process.

Figure 23 illustrates a vacuum form tool, in accordance with an advantageous embodiment. Vacuum form tool **2300** is in a shape corresponding to a desired shape for the final foam duct product. Vacuum form tool **2300** is provided with a number of small holes or apertures, such as apertures **2302**. In an advantageous embodiment, a foam sheet, such as foam sheet **302** shown in **Figure 3**, is placed over vacuum form tool **2300**. Air is drawn out through apertures **2302** as heat is applied, thereby creating a vacuum suction that draws the softened foam sheet close over vacuum form tool **2300**. Heat is applied near glass transition temperature to the foam sheet for a specified period of time. In an advantageous embodiment the PVDF foam sheet is held under about 1 atmosphere of vacuum pressure at 300 degrees Fahrenheit for about 10 minutes. Thereafter, the foam sheet is cooled and removed from vacuum form tool **2300**.

Figure 24 shows two halves of a vacuum-formed foam sheet thermally or adhesively bonded together, in an advantageous embodiment. Duct **2400** is made from two foam sheets molded using vacuum form tool **2300** in **Figure 23** and a similar vacuum form tool not shown. After individually forming each sheet using vacuum form tool **2300** in **Figure 23**, the two sheets are bonded

together using thermal bonding or adhesive bonding, as described previously herein. As a result, duct **2400** is created. As can be seen, duct **2400** has an unusual shape.

In an advantageous embodiment, individual molded pieces of foam can be adhesively fixed to each other using an adhesive, such as BAC5010 type 70, as shown in **Figures 9** through **Figure 11A** and **11B,** or thermally bonded as described with respect to **Figure 4** through **Figure 8**. Adhesive BAC5010 type 70 is known to meet flammability and strength requirements, as set forth by the Federal Aviation Administration. In an advantageous embodiment, the application of an adhesive avoids thick layers or buildup and avoids non-flexible stress points that can cause foam fracture. Additionally, ducts can be joined to each other using cuffs or sleeves.

In another advantageous embodiment, two halves of a molded sheet are pressed together to form a duct around a tool, such as a mandrel. By forcing the molded sheets together around the tool, the two halves of the foam sheet can be pressed into a shape representing the final shape of the finished foam duct.

In an advantageous embodiment, two C-shaped hotplates are placed around the tool. The ends of the duct are placed against the C-shaped hotplates. The C-shaped hotplates are simultaneously heated to bring the ends of the PVDF foam ducts to about 300 degrees Fahrenheit. The C-shaped hotplates are held together for approximately 20 seconds under gentle pressure. Then, the C-shaped hotplates are quickly re-tracked and the ends forced together. In an advantageous embodiment, thermally active tape or pressure sensitive tape may be wrapped around a joint or foam duct as added reinforcement for protection of the foam duct.

Figure 25 shows a female mold for use during press formation of a duct, in accordance with an advantageous embodiment. **Figure 26** shows the male mold used during press formation of a duct, in accordance with an advantageous

embodiment. **Figure 27** shows a molded foam sheet that, when bonded to a complimentary molded foam sheet, forms a foam duct, in accordance with an advantageous embodiment. **Figure 25** through **Figure 27** together illustrate a press mold and a process which can be used to form a component of a foam duct or to form a whole foam duct, particularly for foam ducts having non-cylindrical shapes or a curved axis.

In particular, foam sheet **2700** in a flat state is placed between female mold **2500** of **Figure 25** and male mold **2600** of **Figure 26**. Male mold **2600** includes bulge **2602** having a desired shape for one side of the final foam duct product. Female mold **2500** includes depression **2502** that has the shape for the other side of the final foam duct. Female mold **2500** is approximately offset from bulge **2602** when pressed together, with the offset being about the thickness of foam sheet **2700**. Foam sheet **2700** is then heated to near glass transition temperature. In an advantageous embodiment, PVDF foam is heated to approximately 300 degrees Fahrenheit for about 20 seconds and then placed between female mold **2500** and male mold **2600** when the molds are completely separated. The molds are then quickly pressed together in proximity to each other to about the approximate thickness of foam sheet **2700**.

The pressure applied to foam sheet **2700** during the heating process can vary depending on the foam and need for geometric definition. In an advantageous embodiment, a pressure of about 5 pounds per square inch is applied, and a heat of about 300 degrees Fahrenheit is applied for about 10 minutes.

Thereafter, the molds are allowed to cool, female mold **2500** and male mold **2600** are separated and foam sheet **2700** is removed. Foam sheet **2700** has assumed a shape of the mold, as shown by shape **2702**. Foam sheet **2700** can then be bonded to one or more additional foam sheets to form a foam duct or some other component. In another advantageous embodiment, foam sheet **2700**

can be attached to other components, such as plastic ducts or other parts or metal ducts or other parts.

Figure 28 through **Figure 30** show a method of making a duct. In particular, the method shown in **Figure 28** through **Figure 30** can be used to create a foam duct, such as foam duct **100** shown in **Figure 1**.

In particular, **Figure 28** shows two heated thermoplastic foam sheets disposed between molds, in accordance with an advantageous embodiment. The process begins by placing a first foam sheet, such as foam sheet **2800**, and a second foam sheet, such as foam sheet **2802**, between upper mold block **2804** and lower mold block **2806**. Upper mold block **2804** includes depression **2808**, into which foam sheet **2800** will be forced. Lower mold block **2806** contains depression **2810** into which foam sheet **2802** will be forced. Foam sheet **2800** and foam sheet **2802** can be made of PVDF F30 or F38 foam; however, foam sheet **2800** and foam sheet **2802** could be made of any foam suitable for use in the targeted environmental control system.

Figure 29 shows a duct being formed using the mold and thermoplastic sheets shown in **Figure 28**, in accordance with an advantageous embodiment. **Figure 29** shows that upper mold block **2804** and lower mold block **2806** have been pressed together, such that foam sheet **2800** and foam sheet **2802** shown in **Figure 28** have been pressed together in flange region **2900** and flange region **2902**. In an advantageous embodiment, air is forced between foam sheet **2800** and foam sheet **2802**, such that foam sheet **2800** is forced into depression **2808** and foam sheet **2802** is forced into depression **2810**.

Optionally, in another advantageous embodiment, holes **2904** and **2906** can be provided in mold blocks **2804** and **2806**, such that a vacuum or negative pressure can be applied through mold blocks **2804** and **2806**. In an advantageous embodiment, holes **2904** and **2906** are between about 1/8″ in diameter and about 1/6″ in diameter, but the hole sizes can be either larger or smaller.

The vacuum or negative pressure can be applied to force foam sheet **2800** into depression **2808** and foam sheet **2802** into depression **2810**.

Before and while foam sheet **2800** and foam sheet **2802** are forced into the configuration shown in **Figure 29**, heat is applied to foam sheet **2800** and foam sheet **2802**, including flange region **2900** and flange region **2902**. In an advantageous embodiment, upper mold block **2804** and lower mold block **2806** are brought together while foam sheet **2800** and foam sheet **2802** are hot. In this manner, foam sheet **2800** and foam sheet **2802** are fused together at flange regions **2900** and **2902**. This process can be used to form a duct or ducts having any particular shape. In an advantageous embodiment, a foam duct in the shape of a tube is formed.

In an advantageous embodiment, foam sheet **2800** and foam sheet **2802** are heated at about 300 degrees Fahrenheit, at about 1 atmosphere of pressure with an internal part pressure of approximately 25 PSI (pounds per square inch). The pressure applied between upper mold block **2804** and lower mold block **2806**, in an advantageous embodiment, should be sufficient to achieve about a 50% seam compression in flange region **2900** and flange region **2902**. In an advantageous embodiment, pressure should be applied with heat for approximately thirty to forty seconds. Different times, temperatures, and pressures can also be used.

Figure 30 shows a duct manufactured according to the devices shown in **Figure 28** and **Figure 29**, in accordance with an advantageous embodiment. **Figure 30** shows foam duct **3000** with flange regions **2900** and **2902**. Foam duct **3000** corresponds to a fusion between foam sheet **2800** and foam sheet **2802** in **Figure 28** and **Figure 29**.

After fusing foam sheet **2800** and foam sheet **2802** as shown in **Figure 29**, foam duct **3000** is allowed to cool. Upper mold block **2804** and lower mold block **2806** are separated from foam duct **3000**. In an advantageous embodiment, upper mold block **2804**

and lower mold block **2806** can be separated from foam duct **3000** while foam duct **3000** is below glass transition temperature. In another advantageous embodiment, flange region **2900** and flange region **2902** can be trimmed from foam duct **3000**, as shown by phantom line **3002**. Similarly, flange region **2902** can be trimmed from foam duct **3000**, as shown by phantom line **3004**. In another advantageous embodiment, one or both of flange area **2900** and flange area **2902** can be left on foam duct **3000**, or partially trimmed, in order to accommodate a particular part to be manufactured.

Figure 31 illustrates joining of conventional ducts for an aerospace vessel environmental control system using a joining system, in accordance with an advantageous embodiment. Silicone sleeve **3100** is slid over the ends of duct **3102** and duct **3104**. Beads **3106** disposed around ducts **3102** and **3104** help secure ducts **3102** and **3104** to the sleeves and then the sleeves to other ducts. Silicone sleeve **3100** is disposed over beads **3108**. Beads **3106** and **3108** are typically shaped like a ring, thin on the edges, thick in the middle, and wrap around the duct end. Additionally, clamps **3110** and **3112** are used to further secure silicone sleeve **3100** to ducts **3102** and **3104**. Clamps **3110** and **3112** can be traditional metal clamps or plastic clamps. Beads can add significant weight, manufacturing costs, and difficulty. Clamps, especially metal clamps, also add significant weight.

Figure 32 shows two ducts joined by a foam sleeve, in accordance with an advantageous embodiment. Foam sleeve **3200** is a fraction of the weight of a silicone sleeve and eliminates half of the beads and clamps. Foam sleeve **3200** is made an integral part of duct **3202** by thermal welding or adhesive bonding, using similar techniques described above. In the advantageous embodiment of **Figure 32**, foam sleeve **3200** is made of the same foam material as duct **3202**, though foam sleeve **3200** can be made from a different thermoplastic material.

Sleeve end **3204** extends over duct **3206**, which adjoins duct **3202**. Bead **3208** on duct **3206** aids in securing sleeve end **3204** to duct **3206**. Though often not needed, clamp **3210** can be secured around sleeve end **3204** in order to more securely attach sleeve **3204** to duct **3206**. Even if clamp **3210** is required for a particular product, no clamp is needed for the one end of duct **3202**.

Thus, at a minimum, at least half of the clamps in an environmental control system of an aerospace vessel can be avoided, relative to previously known systems for attaching ducts to the environmental control system of an aerospace vessel. This avoidance advantageously decreases the weight of the airplane and reduces the cost of manufacturing the airplane. Furthermore, foam is self-insulating. Therefore, for many applications in the environmental control system of an aerospace vessel, additional insulation is not needed. Accordingly, additional weight can be saved.

Overall, approximately 100 pounds of weight can be removed from the environmental control system of a 250 passenger aerospace vessel. Thus, the value of the plane increases by many thousands of dollars and the cost of producing the plane is decreased due to the use of less expensive materials and manufacturing techniques associated with the advantageous embodiments described herein.

Note that second sleeve **3212** is thermally or adhesively bonded to duct **3206**. Thus, a third duct can be attached to duct **3206** in the same or similar manner that duct **3206** is attached to duct **3202**.

With respect to both advantageous embodiments shown in **Figure 32**, a wire can be wrapped around foam sleeve **3200** in a helical pattern. The resulting helix can reduce noise from airflow through duct **3202** and duct **3206**. Additionally, the wire helix can increase a structural strength of foam sleeve **3200**.

In another advantageous embodiment, a cloth can be placed around foam sleeve **3200**. The cloth acts to stiffen the area around foam sleeve **3200**. In another advantageous embodiment, the cloth can be replaced with an open weaved carrier, such as TEDLAR® (polyvinyl fluoride), polyester, fiberglass, or other suitable fabric. Such materials provide resistance to tearing and ballooning at higher pressures. Other materials, such as a Nextel fabric, can be used to protect the foam sleeve from high temperatures.

Figure 33 shows a method of joining foam ducts using integral foam sleeves and composite cuffs, in accordance with an advantageous embodiment. The method shown in **Figure 33** is another advantageous embodiment for joining ducts, relative to the methods shown in **Figure 31** and **Figure 32**.

Figure 33 shows foam duct **3300** disposed around composite cuff **3302** and foam duct **3304** disposed around composite cuff **3306**. In an advantageous embodiment, the composite cuffs are only a few inches long and are bonded inside the ends of the foam ducts so that a solid structure exists around which a clamp can be placed to join foam ducts together. Thus, composite cuff **3302** has end **3308** and end **3310**, shown at the respective phantom lines, with composite cuff **3302** shown as phantom lines inside foam duct **3300** and foam duct **3304**. Similarly, composite cuff **3306** has end **3312** and end **3314**, shown at the respective phantom lines, with the portion of composite cuff **3306** disposed inside foam duct **3304**. Additionally, foam duct **3300** has end **3316** and end **3318**, shown at the respective phantom lines. Similarly, foam duct **3304** has end **3318** and end **3320**, shown at the respective phantom lines. Thus, foam duct **3300** abuts foam duct **3304** at end **3318** shown at the corresponding phantom line.

Bead **3322** on composite cuff **3302** assist in holding foam duct **3304** in place around composite cuff **3302**. Similarly, clamp **3324** assists in holding foam duct **3304** on composite cuff **3302** by compressing the foam behind bead **3322** on composite cuff **3302**.

Note that bead **3326** on composite cuff **3306** can be used to assist in joining a third foam duct to composite cuff **3306** and foam duct **3304**. Other techniques for bonding foam ducts, other than the technique shown in **Figure 33**, can be used to bond a foam duct to a composite cuff or to bond a foam duct to a second foam duct.

For all of the advantageous embodiments of foam ducts or sleeves described above, a finely woven thin thermoplastic wire impregnated with a suitable resin matrix can be added to the interior part of a foam duct. In this case, foam for high temperature applications can be silicon based, as opposed to PVDF based. The resin matrix can be elastomeric for flexible ducts and rigid for hybrid ducts. A layer of ceramic membrane may be sandwiched between the inner wire and foam to further diffuse temperature.

Some environmental control system ducts have branch-offs to connect to secondary systems or to customer-specific systems. These branch-offs are often in the shape of a 'T' or '+' cross-section and can be of varied angles. A tool can be provided to create and insert these branch-offs. The tool is in a similar T-shape or '+' cross-section shape corresponding to the branch-offs to be connected. A segmented tool similar to a jigsaw puzzle is used to fabricate parts and then unscrew segments of the tool to release the part.

The foam sleeve and foam duct assemblies shown above avoid a common problem in known duct assemblies. In particular, because the foam used to make the sleeves and ducts are hydrophobic (meaning that the foam does not retain water) foam ducts and sleeves resist sweating or condensation. Thus, addition of insulation systems, which are expensive and heavy, can be avoided in many cases. Sweating or condensation on ducts can produce unpleasant effects in a passenger cabin of an aerospace vessel, such as blowing a fine mist of water onto the

passengers through the environmental control system. This effect is considered to be undesirable and is to be avoided.

Figure 34 shows a ring clamp disposed around a foam duct, in accordance with an advantageous embodiment. Clamp **3400** can be used to join duct **3402** and duct **3404** together. As shown, duct **3402** and duct **3404** are joined at phantom line **3403**. Clamp **3400** self-adjusts to the demanded applied pressure, requires no tools to fashion, and is lightweight and inexpensive. Clamp **3400** can be referred to as a "Patel clamp."

Clamp **3400** is made from a composite, non-hydroscopic material, such as Nylon 12 (polyamide) or polypropylene so that when used in humid conditions, the clamp does not cause material relaxation. For this reason, clamp **3400** can replace steel clamps in an environmental control system of an aerospace vessel. Clamp **3400** has a minimum inner diameter, as shown by arrows **3406**. The minimum inner diameter corresponds to about an outside diameter of duct **3402**. Clamp **3400** has a maximum inside diameter as shown by arrows **3408**.

Clamp **3400** has two different sections for purposes of description. Namely, full ring **3410** is a ring that is sized and dimensioned to wrap fully around the diameter of duct **3402**. Partial ring **3412** is attached to full ring **3410**, though in an advantageous embodiment partial ring **3412** is an integral, continuous part of full ring **3410**. Partial ring **3412** has an outwardly flaring radius along the direction shown by arrows **3416**. Thus, partial ring **3412** forms part of a frustro-conical shape. Angle **3418** defines the steepness of frustro-conical partial ring **3412** and also defines the angle between full ring **3410** and partial ring **3412**. In an advantageous embodiment, angle **3418** can be about 30 degrees, though angle **3418** can vary between about 0 degrees to about 180 degrees.

Bulge **3420** is a bulge in the foam sleeve or duct due to a bead on a composite cuff disposed inside foam duct **3402** and duct **3404**. Thus, one manner of calculating the maximum inside

diameter of full ring **3410** is by adding the outside diameter of the bead plus two times the foam thickness, less two times the compression of foam required to prevent the sleeve from slipping off the duct.

In use, the shape of clamp **3400** facilitates pulling clamp **3400** over a duct. Specifically, partial ring **3412** forms a handle, guide, and stop used when placing clamp **3400** over ducts **3402** and **3404**. In an advantageous embodiment, clamp **3400** is pulled over duct **3402** in the direction shown by arrow **3416**. Additionally, partial ring **3412** snugly abuts bulge **3420** when clamp **3400** is fully engaged. In this manner, when forces act to pull the ducts apart, partial ring **3412** abuts the bead, digging full ring **3410** into the foam ducts, making the ring tighter. This configuration acts like a "finger trap." Note that clamp **3400** has an inside diameter that is larger than the bead so clamp **3400** can be installed from any end of the duct. Thus, for example, clamp **3400** can be pulled over duct **3402** when duct **3404** and composite cuff **3422** are difficult to reach. In this manner, clamp **3400** can be used to join duct **3402** to duct **3404**, wherein duct **3402** has an integral cuff bonded to its end.

This configuration can be repeated to join multiple ducts together. For example, composite cuff **3422** is bonded to the end of duct **3404**. A third foam duct can be joined to duct **3404** using a second foam clamp, similar to clamp **3400**, that is slipped over composite cuff **3422**. In an advantageous embodiment, duct **3402** and duct **3404** can be foam ducts.

Clamp **3400** in an advantageous embodiment has a thickness of approximately 0.03 inches and a width of approximately 0.5 inches. In other advantageous embodiments, these dimensions can be increased or reduced as desired for the intended use of clamp **3400**.

In an advantageous embodiment, clamp **3400** is made of a single piece of non-hydroscopic (non-water retaining) composite, so that when clamp **3400** is applied to a duct, clamp **3400** is

light weight and does not relax with moisture or temperatures common to aircraft ducts. Clamp **3400** can be injection molded for low cost.

In another advantageous embodiment, the entire assembly of clamp **3400**, duct **3402**, and duct **3404** can be subjected to heat and/or pressure for a predetermined period, thereby thermally welding clamp **3400** to ducts **3402** and **3404** and permanently sealing the two ducts together. In this manner, the bond between duct **3402** and duct **3404** can be made resistant to tearing, breaking, or leaking.

In some advantageous embodiments, where the duct and sleeve combination are expected to handle lower-end loads, a reinforced foam sleeve slid over a bead provides sufficient clamping force to eliminate entirely the need for a clamp. Thus, this advantageous embodiment further reduces the weight added to the environmental control system of an aerospace vessel. Optionally, a bead can be reshaped to better trap a foam sleeve once the foam sleeve is passed the bead or bead radius. For example, the shape of a bead can be varied from the quarter circle a full D-shape, an O-shape, or any other desired shape.

Figure 35 shows a duct around which is wound a preformed helix wire, in which a pitch bar is used to form the wire into a helix, in accordance with an advantageous embodiment. Thus, **Figure 35** illustrates a method of applying a helix to all or part of a foam duct, such as foam duct **3500** or the foam ducts shown in the preceding figures.

Wire **3502** is wrapped around foam duct **3500** using pitch tool **3504** to form a helix around foam duct **3500**. Pitch tool **3504** ensures that the pitch of the helix is uniform. The pitch of the helix is the distance between any two coils of the helix, such as the distance shown between arrows **3506**.

In an advantageous embodiment, wire **3502** is formed from materials such as polyetherimide or polyetheretherketone, which results in providing superior stiffness, strength, and bonding

with less weight and cost. Wire **3502** is secured to foam duct **3500** by thermally bonding wire **3502** to foam duct **3500**, though adhesive bonding can also be used in other advantageous embodiments. Thermal bonding has the advantage that air pockets do not form at the edges between wire **3502** and foam duct **3500**.

Additionally, the configuration shown in **Figure 35** eliminates any requirement for an outer-ply or additional layer of reinforced elastomeric wires, or incorporation of a cord to contain the helix. Thus, this configuration aids in preventing stress failures in foam duct **3500**.

In an advantageous embodiment, foam duct **3500** is rotated about a spindle or on a mandrel in order to facilitate the layering of wire **3502** using pitch tool **3504**. In an advantageous embodiment, after wire **3502** is completely disposed around foam duct **3500** and along the length of foam duct **3500**, the entire part is placed into an oven and cured. The curing process fuses wire **3502** to foam duct **3500**.

Figure 36 is a flowchart illustrating a process of converting a foam bun into a foam duct, in accordance with an advantageous embodiment. The process shown in **Figure 36** can be implemented using an apparatus, such as apparatus **500** shown on **Figure 5**.

The process begins as a foam bun is received (step **3600**). The bun is skived into a sheet (step **3602**). The sheet is then cut to a size and seam type (step **3604**). The seam type can be one of numerous seam types, such as those shown in **Figure 6** through **Figure 12C**.

Next, the sheet is rolled around a mandrel, such that seam edges overlap to form a splice (step **3606**). Heat and pressure are applied to the seam and duct for a period of time (step **3608**). The sheet is cooled (step **3610**), and removed from the mandrel (step **3612**). At this point, the sheet is now a duct tube. Other post-processes can be applied to the foam duct after this point.

Figure 37 is a flowchart illustrating a process of pressure forming a foam duct into a more complex shape, in accordance with an advantageous embodiment. The process shown in **Figure 37** can be implemented using an apparatus or mold such as the apparatus and mold shown in **Figure 5**.

The process begins as an existing formed foam duct is placed into a shaped tool or mold (step **3700**). The foam duct ends are then sealed with an airtight seal (step **3702**). The inside of the foam duct is pressurized (step **3704**), and then the foam duct is heated (step **3706**). After a time, the foam duct is cooled (step **3708**) and then removed from the tool or mold (step **3710**). Other post processes are possible from this point to further shape the foam duct.

Figure 38 is a flowchart illustrating a process of forming a shaped foam duct using heat, vacuum, and/or pressure, in accordance with an advantageous embodiment. The process begins by placing a sheet over a mold and applying heat (step **3800**). A vacuum is then applied through the mold and to the sheet (step **3802**).

A decision is then made whether more detail is needed in the foam sheet (step **3804**). If more detail is desired ('yes' output to step **3804**), then gas pressure is applied on the non-tool side of the foam sheet (step **3806**). After this step, or if no more detail is desired ('no' output to step **3804**), then the sheet is cooled (step **3808**). The cooled sheet is then removed from the mold (step **3810**). A determination is then made as to whether the molded sheet is attached to a second molded sheet (step **3812**). If the molded sheet is attached to a second molded sheet ('yes' output to step **3812**), the process forms a new shape (step **3814**), with the process terminating thereafter. If the molded sheet is not attached to a second molded sheet ('no' output to step **3812**), the process terminates.

Figure 39 is a flowchart illustrating a process of press forming a shaped duct, in accordance with an advantageous

embodiment. The process begins by heating the sheet (step **3900**) and placing the heated sheet over a heated mold (step **3902**). The sheet is then pressed over a mold (step **3904**) and cooled (step **3906**). A determination is then made as to whether the molded sheet is attached to a second molded sheet (step **3908**). If the molded sheet is attached to a second molded sheet ('yes' output to step **3908**), the process forms a new shape (step **3910**) and terminates thereafter. If the molded sheet is not attached to a second molded sheet ('no' output to step **3908**), the process terminates.

Figure 40 is a flowchart illustrating a process of directly forming a duct using a multi-sheet forming process, in accordance with an advantageous embodiment. The process begins by heating the molds and pre-heating a foam sheet (step **4000**), and then placing a first foam sheet inside a hollow mold (step **4002**). A second heated foam sheet is placed inside the hollow mold opposite the first foam sheet (step **4004**). The mold is then sealed (step **4006**). A vacuum can be applied between the hollow mold and the foam sheets (step **4008**). Alternatively or in addition to the application of a vacuum, gas pressure can be applied between the foam sheets to force compliance of the first and second foam sheets with the mold (step **4010**). After a time, the first and second sheets are cooled (step **4012**). The new foam duct is then removed from the mold (step **4014**).

If flash or flanges are created during this process, a determination is then made as to whether to retain the flash or flanges (step **4016**). If no flash or flanges are created, then step **4016** is skipped and the process terminates. If flash or flanges are formed, and if flash or flanges are to be retained (a 'yes' output to step **4016**), the flash and flanges are retained (step **4018**), with the process terminating thereafter. However, if flash or flanges are not to be retained (a 'no' output to step **4016**), the flash and flanges are removed (step **4020**), with the process terminating thereafter.

Figure 41 is a flowchart illustrating a process of pre-forming a composite helix, in accordance with an advantageous embodiment. The process begins by wrapping a wire in a helical pattern of determined pitch around a foam duct (step **4100**). The wire is made of a thermoplastic material, though the wire can be made of any suitable material such as foam, plastic, or metal in other advantageous embodiments. The foam duct is then heated (step **4102**) and, after a time, cooled (step **4104**), with the process terminating thereafter.

Figure 42 is a flowchart illustrating a process of forming composite wire for use as a helix around foam ducts, in accordance with an advantageous embodiment. The process begins by wrapping a wire in a helical pattern of determined pitch around a foam duct (step **4200**). The wire is made of a thermoplastic material, though the wire can be made of any suitable material such as foam, plastic or metal in other advantageous embodiments. The foam duct is inserted into die (step **4202**) and extruded into a coil (step **4204**). The coil is heated (step **4206**) and gradually cooled (step **4208**).

A determination is then made as to whether to quality check the coil (step **4210**). If no quality check is to be made of the coil ('no' output to step **4210**), the process terminates. If the coil is to be quality checked ('yes' output to step **4210**), a determination is made as to whether to utilize the light method (step **4212**). If the light method is selected ('yes' output to step **4212**), the opposite side of the coil wall is exposed to strong light and examined for voids (step **4214**). A determination is made as to whether a void has been detected (step **4216**). If a void has not been detected ('no' output to step **4216**), the coil is retained (step **4218**), with the process terminating thereafter. If a void has been detected ('yes' output to step **4216**), the coil is rejected (step **4220**), with the process terminating thereafter.

Returning now to step **4212**, if the light method is not selected ('no' output to step **4212**), a cloth is applied to the coil (step **4222**) and moistened with MEK and Tricholoroathane for a determined time (step **4224**). The coil is then blow-dried (step **4226**), and a determination is made as to whether cracks are found in the coil (step **4228**). If cracks are found in the coil ('yes' output to step **4228**), the coil is rejected (step **4220**), with the process terminating thereafter. If no cracks are found in the coil ('no' output to step **4228**), the coil is retained (step **4230**), with the process terminating thereafter.

Figure 43 is a flowchart illustrating a process of forming a flex duct by combining foam and a helical wire around a mandrel, in accordance with an advantageous embodiment. The process begins by applying a release agent to the clean mandrel (step **4300**). The foam sheet is trimmed to size according to a formula (step **4302**). A release agent is applied to the mandrel (step **4304**). A release agent can be release tape, Teflon® (polytetrafluoroethylene), or some other release liquid or solid suitable for assisting in releasing a foam sheet or duct from the mandrel. Then, the foam sheet is positioned and secured to the mandrel (step **4306**).

A pressure-wrap sheet overlaps at the center of the formed duct, and the duct is worked towards the ends (step **4308**). Optionally, an extra ply of foam is applied on the cuff or sleeve or on other areas of the foam duct (step **4310**). The cuff areas are pressure-wrapped with an additional sheet or with tape (step **4312**) and the overlaps are heat welded (step **4314**).

The helix size and type are selected (step **4316**) and thermofitting fiberglass tape is applied at the initiation of the helix (step **4318**). The helix is applied using a pitch bar to determine the pitch of the helix (step **4320**). Thermofitting fiberglass tape is then applied to the underside of the termination of the helix (step **4322**) and the helix ends are secured by applying a rotation wrap (step **4324**). A mixture of

HYSOL U-10FL and acetone is applied over the helix (step **4326**). Finally, the duct is force cured (step **4328**), with the process terminating thereafter.

Figure 44 is a flow diagram of aerospace vessel production and service method, in accordance with an advantageous embodiment. **Figure 45** is a block diagram of an aerospace vessel, in accordance with an advantageous embodiment. The advantageous embodiments described herein may be further described in the context of an aerospace vessel manufacturing and service method **4400** as shown in **Figure 44** and in the context of aerospace vessel **4502** as shown in **Figure 45**.

During pre-production, exemplary service method **4400** may include specification and design **4404** of the aerospace vessel **4502** and material procurement **4406**. During production, component and subassembly manufacturing **4408** and system integration **4410** of the aerospace vessel **4502** takes place. Thereafter, the aerospace vessel **4502** may go through certification and delivery **4412** in order to be placed in service **4414**. While in service by a customer, the aerospace vessel **4502** is scheduled for routine maintenance and service **4416** (which may include modification, reconfiguration, refurbishment, and so on).

Each of the processes of service method **4400** may be performed or carried out by a system integrator, a third party, and/or an operator, such as a customer, as indicated by the "X" in the grid to the right of the flow diagram of **Figure 44**. For the purposes of this description, a system integrator may include without limitation any number of aerospace vessel manufacturers and major-system subcontractors; a third party may include without limitation any number of venders, subcontractors, and suppliers; and an operator may be an airline, leasing company, military entity, service organization, and so on.

As shown in **Figure 45**, the aerospace vessel **4502** produced by exemplary service method **4400** may include an airframe **4518** with a plurality of systems **4520** and an interior **4522**. Examples of high-level systems **4520** include one or more of a propulsion system **4524**, an electrical system **4526**, a hydraulic system **4528**, and an environmental system **4530**. Environmental system **4530** can be an environmental control system, as described with respect to the advantageous embodiments provided herein. The aerospace vessel further comprises wings, turbine engines, jets, rocket engines, gas, helicopter blades, or other means for flying **4532** that can cause the aerospace vessel to fly. Means for flying **4532** can also be means for causing a fuselage to fly.

The apparatuses and methods embodied herein may be employed during any one or more of the stages of the production and service method **4400**. For example, components or subassemblies corresponding to component and subassembly manufacturing **4408** may be fabricated or manufactured in a manner similar to components or subassemblies produced while the aerospace vessel **4502** is in service. Also, one or more apparatus embodiments, method embodiments, or a combination thereof may be utilized during production stages **4408** and **4410**, for example, by substantially expediting assembly or reducing the cost of an aerospace vessel **4502**. Similarly, one or more apparatus embodiments, method embodiments, or a combination thereof may be utilized while the aerospace vessel **4502** is in service, for example and without limitation, to maintenance and service **4416**.

The description of the present invention has been presented for purposes of illustration and description, and is not intended to be exhaustive or limited to the invention in the form disclosed. Many modifications and variations will be apparent to those of ordinary skill in the art. Further, different advantageous embodiments may provide different advantages as compared to other advantageous embodiments. The embodiment or embodiments selected are chosen and described in

order to best explain the principles of the invention, the practical application, and to enable others of ordinary skill in the art to understand the invention for various embodiments with various modifications as are suited to the particular use contemplated.

CLAIMS:

What is claimed is:

1. A duct (100) comprising:

a thermoplastic foam sheet (400) having properties suitable for use in an environmental control system;

a crenulated first edge of the thermoplastic foam;

a second edge of the thermoplastic foam, wherein the duct is formed by interlocking the crenulated first edge with the second edge.

2. The duct of claim 1 wherein the first edge and the second edge are beveled (402, 404).

3. The duct of claim 1 further comprising:

a wire (1400) wrapped around the duct (100), wherein the wire is comprised of a thermoplastic material, and wherein the wire is wrapped in the shape of a helix.

4. The duct of claim 3 wherein the helix is welded to the duct using one of applied heat, an adhesive, and both applied heat and an adhesive.

5. The duct of claim 3 wherein the duct is pleated (1700).

6. The duct of claim 3 wherein a pitch of the helix is selected to dampen a noise of a given frequency range.

7. The duct of claim 3 wherein an angle of the helix is selected to dampen a noise of a given frequency range.

8. The duct of claim 1 wherein the duct is formed by wrapping the thermoplastic foam sheet around a mandrel (502).

9. The duct of claim 8 wherein wrapping the thermoplastic foam sheet around a mandrel (502) defines an internal shape of the thermoplastic foam sheet, wherein an outside tool (2300) is applied against overlapping edges of the thermoplastic foam sheet to compress the overlapping edges together, and wherein heat is applied to the duct.

10. The duct of claim 1 wherein the duct is post-formed to a different shape.

11. The duct of claim 10 wherein the duct is post-formed into a complex shape by heating the duct and pressing the duct into a mold.

12. The duct of claim 11 wherein the duct is post-formed by injected gas inside the duct while applying heat.

13. The duct of claim 10 wherein the duct has a shape selected from the group consisting of a tube, a branch-off, and an unusual shape.

14. An aerospace vessel (4502) comprising:
a fuselage (4518);
a means for causing the fuselage to fly (4532); and
an environmental control system (4530) within the fuselage, wherein the environmental control system comprises a first duct (100) comprising polyvinylidene fluoride foam.

15. The aerospace vessel of claim 14 wherein the environmental control system further comprises a second duct and wherein the first duct and the second duct are coupled using a foam sleeve (3100) comprising a polyvinylidene fluoride foam.

16. The aerospace vessel of claim 15 wherein the first duct and the foam sleeve are coupled using a clamp (3400)comprising a first section (3410) in the shape of a ring and a second section (3412) comprising a partial frustro-conical shape attached to the first section.

17. The aerospace vessel of claim 15 wherein the first duct, the second duct, and the foam sleeve are coupled using an adhesive.

18. The aerospace vessel of claim 15 wherein the clamp (3400) comprises a material selected from the group consisting of a thermoplastic foam, a composite material, and a plastic material.

19. The aerospace vessel of claim 15 wherein the first duct and the second duct are coupled to a third duct comprising a material selected from the group consisting of a metal, a composite, and a plastic material.

20. The aerospace vessel of claim 14 wherein a sheet width, "W", is sized and dimensioned according to an equation that is a function of "d", a perimeter of a controlled tool surface of the duct; "t", a thickness of a wall of the duct; and "O", a total overlap of all edges that come together to form one or more seams.

21. The aerospace vessel of claim 14 further comprising:
a helix (1400) wrapped around the first duct.

22. The aerospace vessel of claim 21 wherein the helix comprises a thermoplastic wire and wherein the helix is welded to the duct using applied heat.

23. The aerospace vessel of claim 14 wherein the duct further comprises a flex duct (1700).

24. The aerospace vessel of claim 21 wherein the duct further comprises a helical flex duct.

25. The aerospace vessel of claim 21 wherein a pitch of the helix is selected to dampen a noise of a given frequency.

26. The aerospace vessel of claim 21 wherein an angle of the helix is selected to dampen a noise of a given frequency.

27. A method for manufacturing a duct, the method comprising:

cutting a sheet of thermoplastic foam to form a first crenulated edge and a second edge;

placing the sheet around a mandrel such that the first crenulated edge overlaps and interlocks with the second edge;

sealing the first crenulated edge to the second edge, wherein a duct is formed by sealing.

28. The method of claim 27 wherein sealing comprises:

applying heat and pressure to the first crenulated edge and to the second edge.

29. The method of claim 27 further comprising:

placing the duct in a mold; and

curing the duct such that the duct permanently takes on the shape of the mold.

30. The method of claim 29 wherein curing comprises:

applying at least one of heat and pressure to the duct while the duct is in the mold.

31. The method of claim 29 further comprising:

before curing, applying a vacuum through the mold to force the duct to assume a shape of the mold.

32. The method of claim 27 further comprising:

wrapping a wire in a helical pattern of a pre-determined pitch around the foam duct.

33. The method of claim 32 further comprising:

inserting the duct into a die;

extruding the duct into a coil; and

heating the coil;

34. The method of claim 33 further comprising:

applying a cloth to the coil for a pre-determined time, wherein the cloth is moistened with methyl ethyl ketone and trichloroethane; and

drying the coil by blowing air onto the coil.

35. The method of claim 34 further comprising:

examining the coil for cracks;

responsive to detecting a crack, discarding the coil; and

responsive to a failure to detect the crack, retaining the coil.

36. The method of claim 33 further comprising:

exposing an opposite side of the coil to a light;

examining the coil for voids;

responsive to detecting a void, discarding the coil; and

responsive to a failure to detect the void, retaining the coil.

37. The method of claim 32 further comprising:

before curing and after wrapping the wire, applying to the helical wire a mixture of acetone and a urethane adhesive comprising a polyisocyanate resin and a polyol hardener.

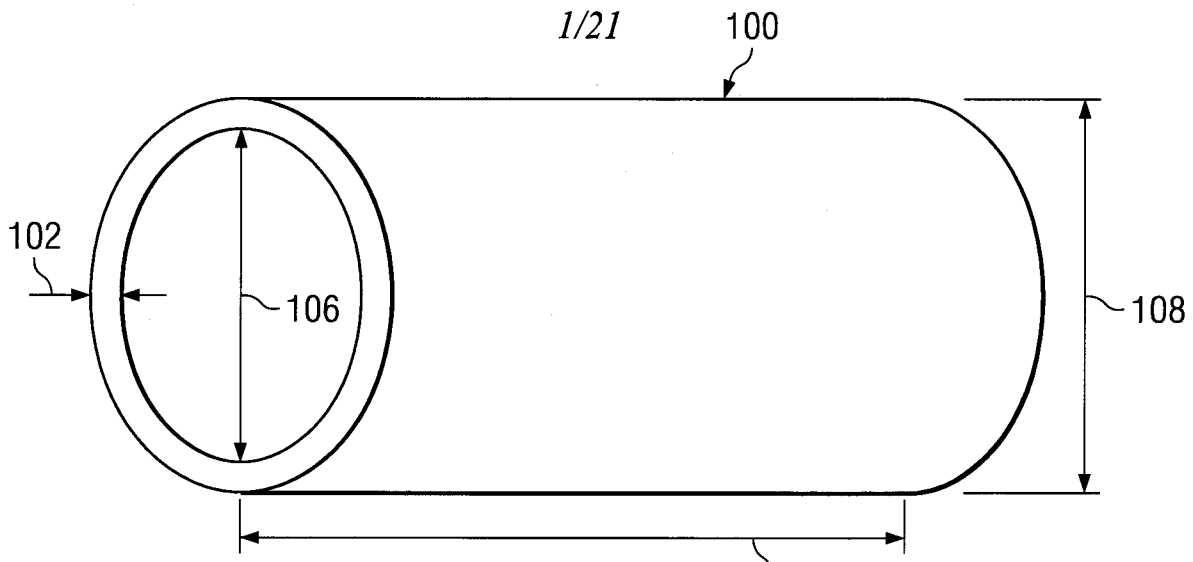


FIG. 1

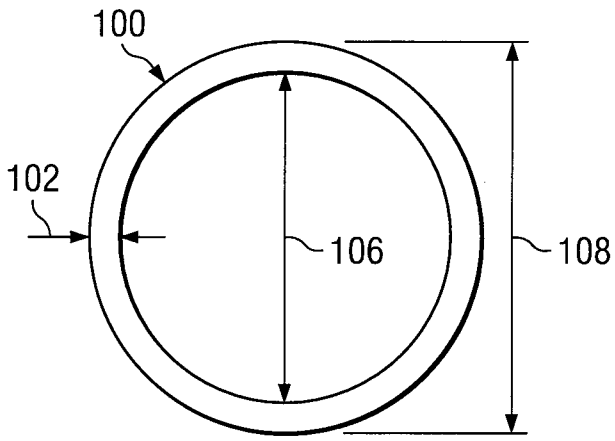


FIG. 2

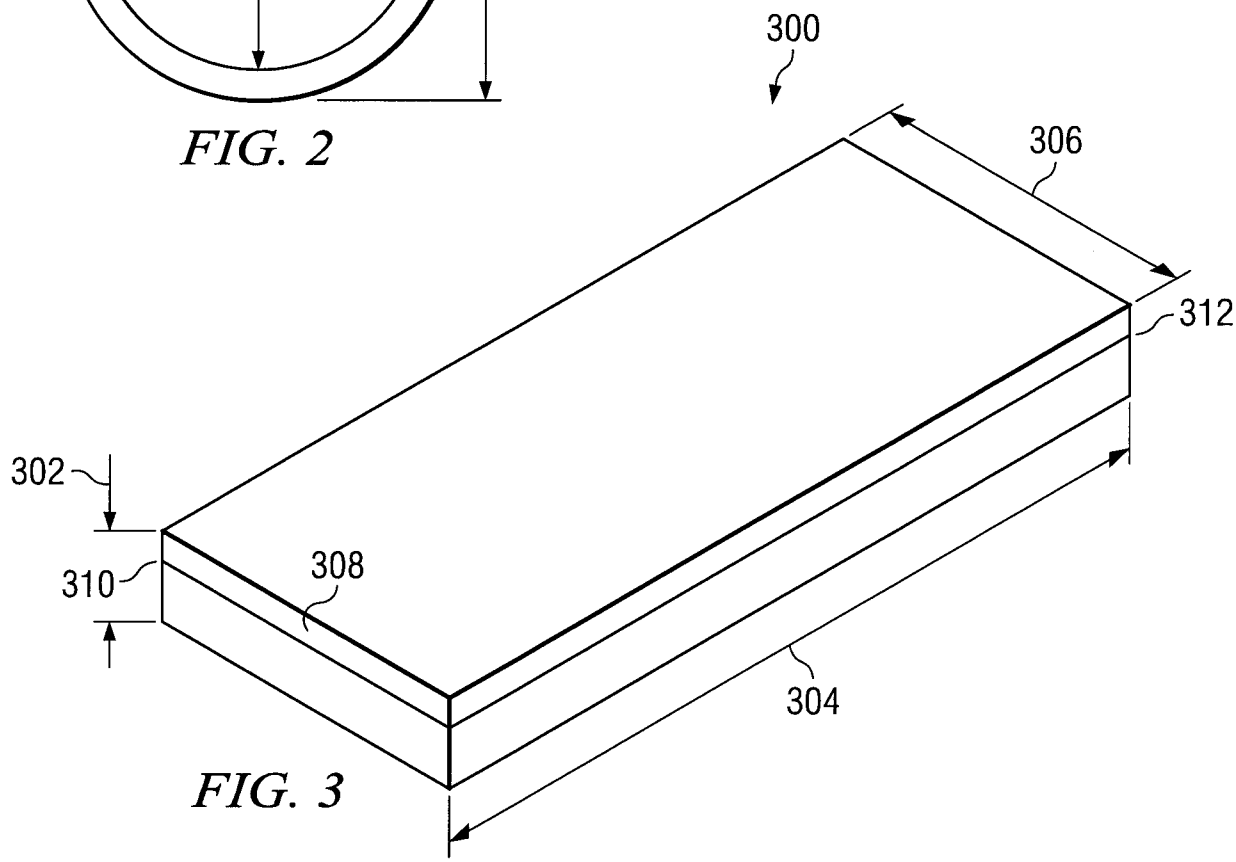


FIG. 3

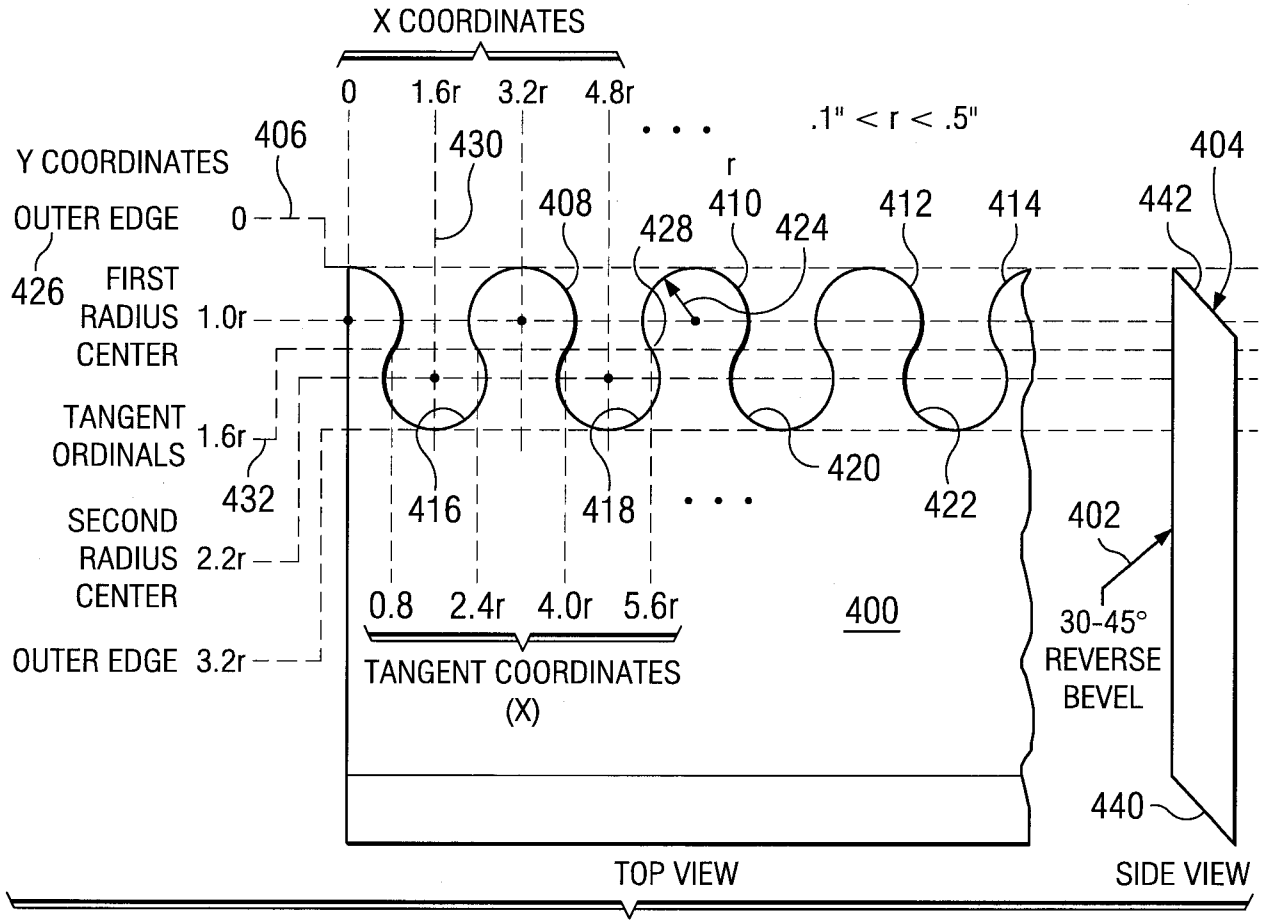

X COORDINATES
0
1.6r
3.2r
4.8r
.1" < r < .5"
406
430
404
Y COORDINATES
OUTER EDGE
0
408
428
410
424
412
414
442
426
FIRST
RADIUS
CENTER
1.0r
TANGENT
ORDINALS
1.6r
420
432
416
418
422
402
SECOND
RADIUS
CENTER
2.2r
0.8
2.4r
4.0r
5.6r
400
30-45°
REVERSE
BEVEL
OUTER EDGE
3.2r
TANGENT COORDINATES
(X)
440
TOP VIEW
SIDE VIEW

FIG. 4

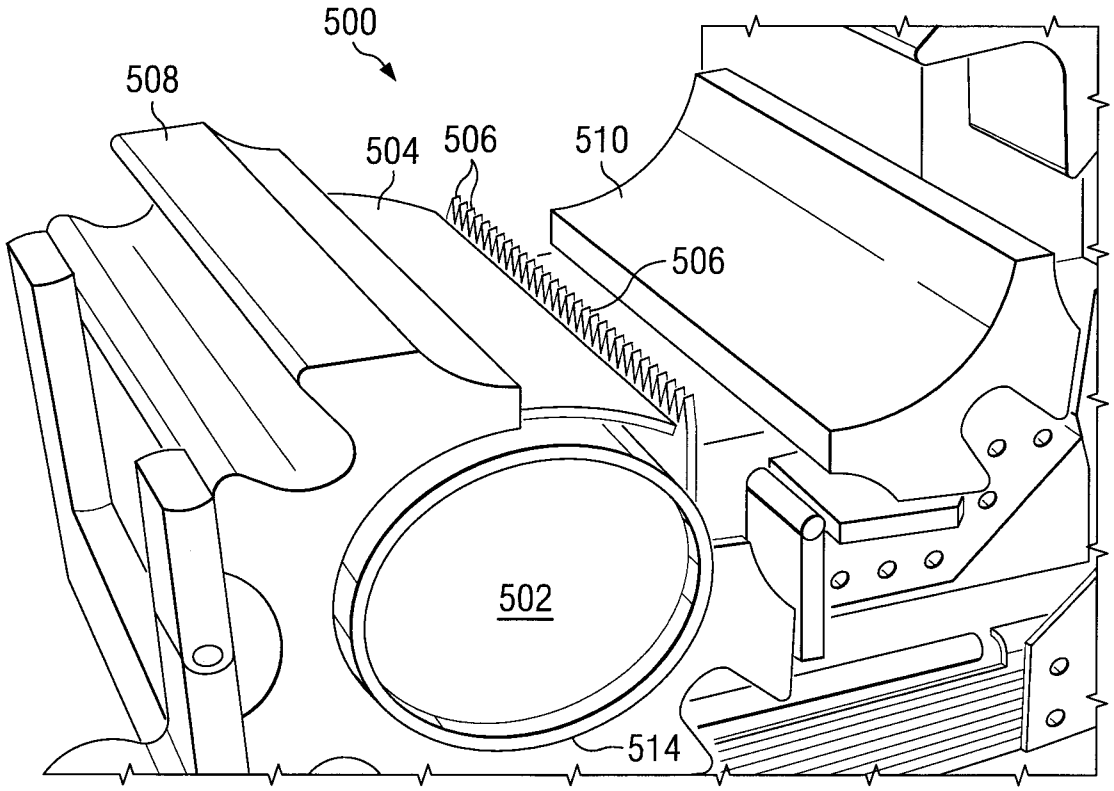

500
508
504
506
510
506
502
514

FIG. 5

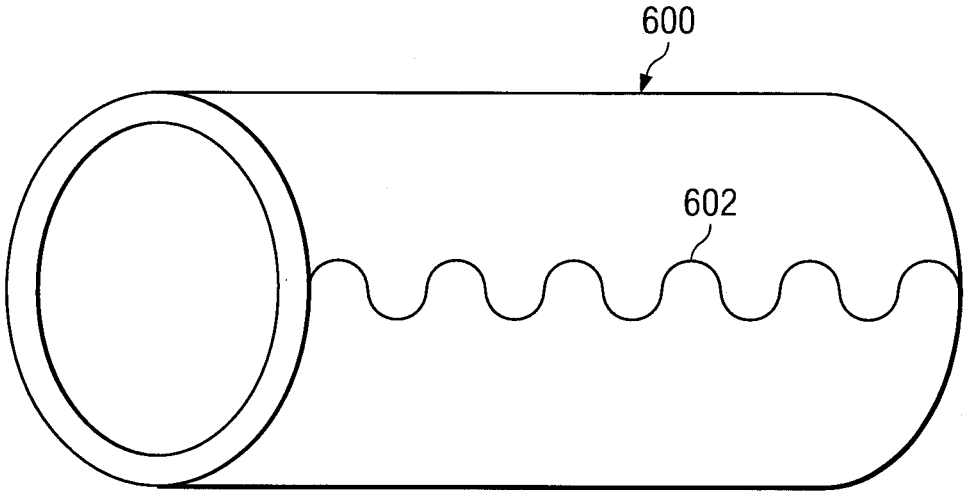


FIG. 6

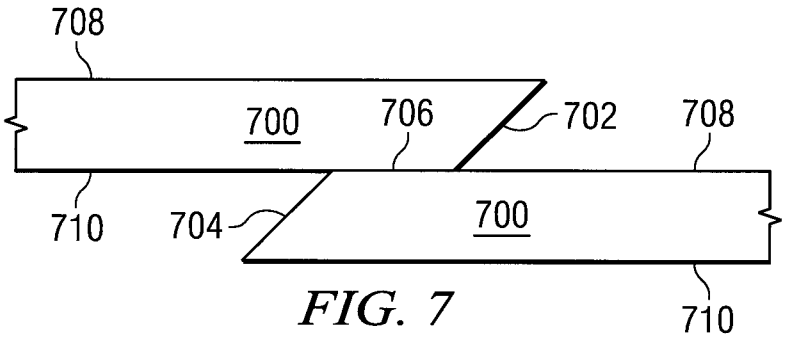


FIG. 7

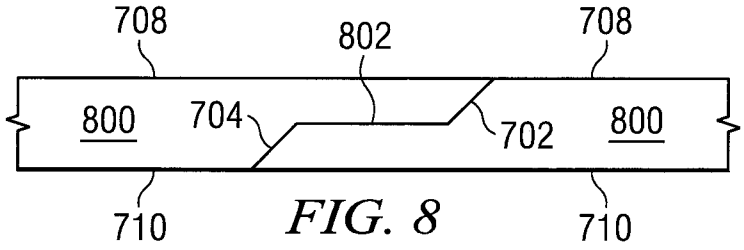


FIG. 8

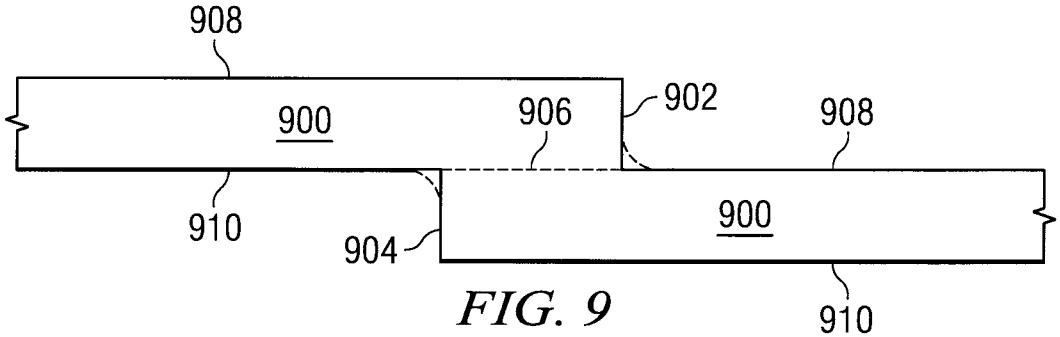


FIG. 9

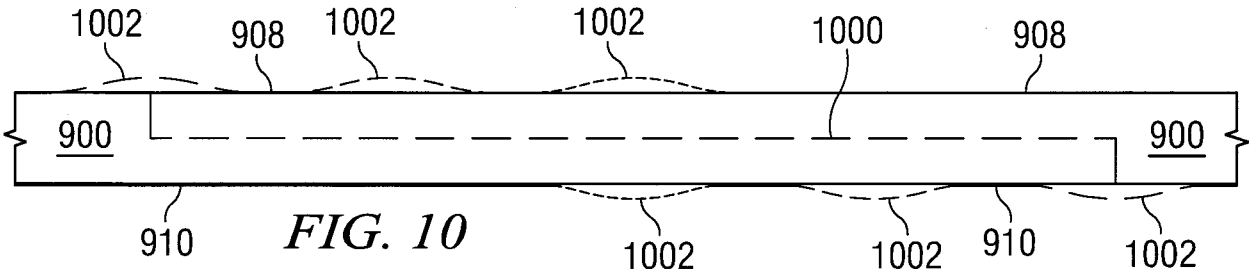


FIG. 10

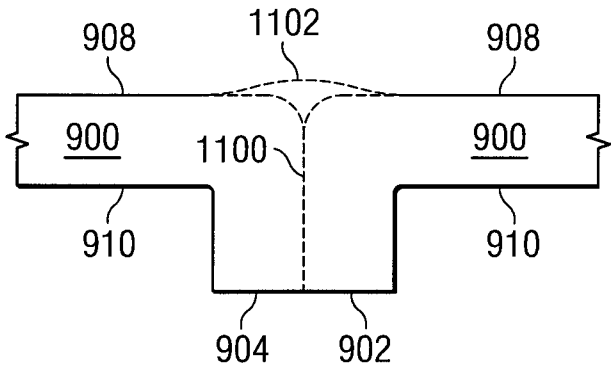


FIG. 11A

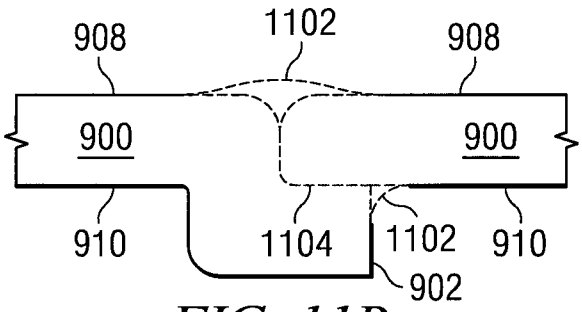


FIG. 11B

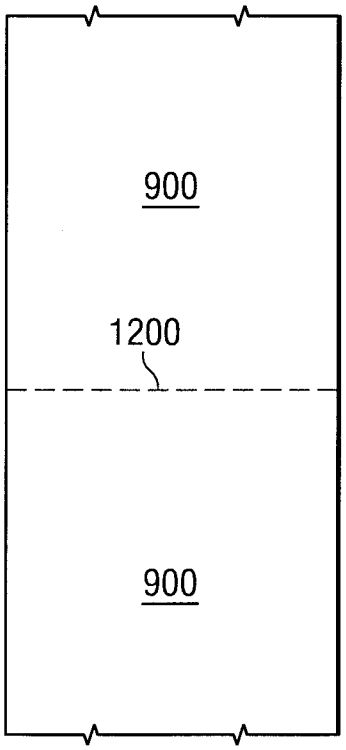


FIG. 12A

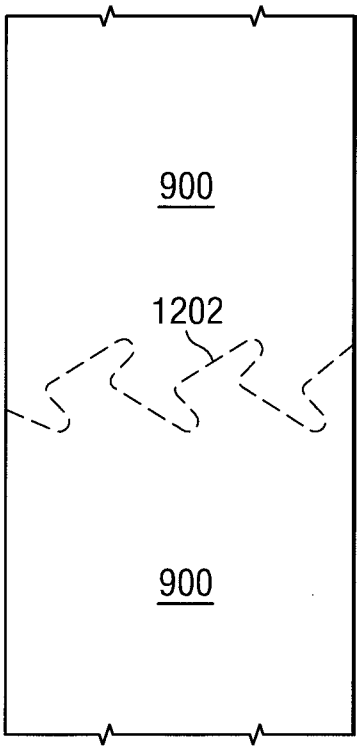


FIG. 12B

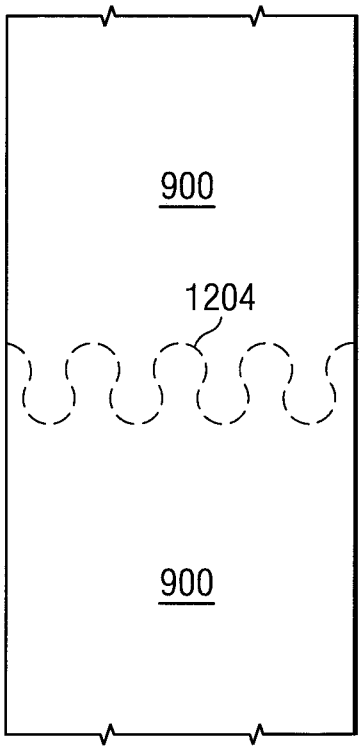


FIG. 12C

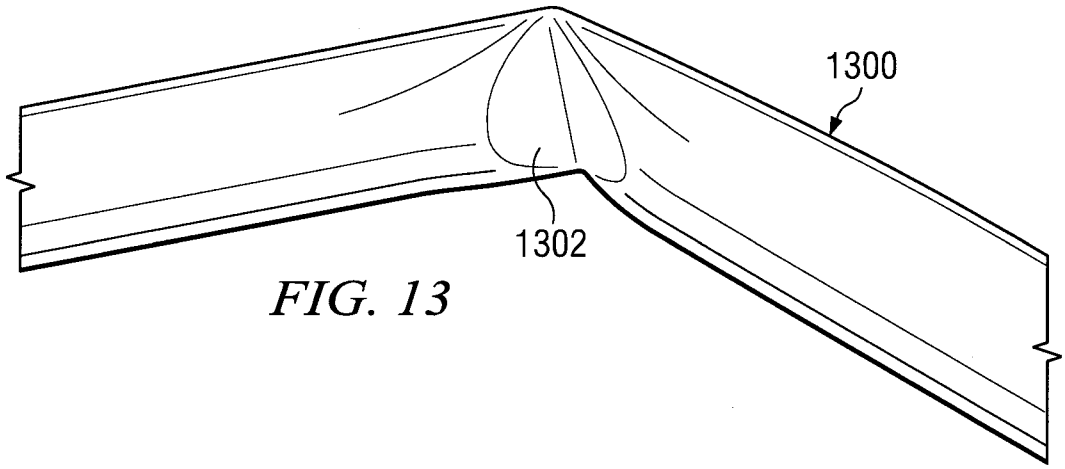


FIG. 13

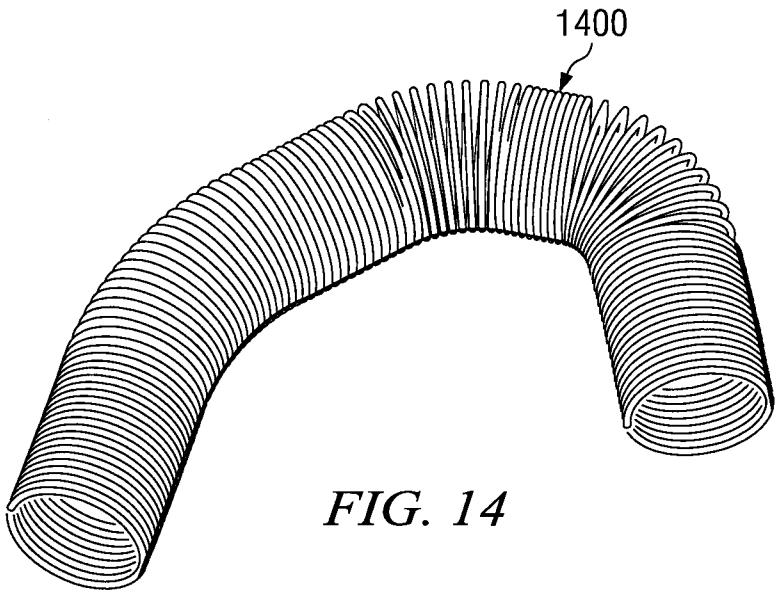


FIG. 14

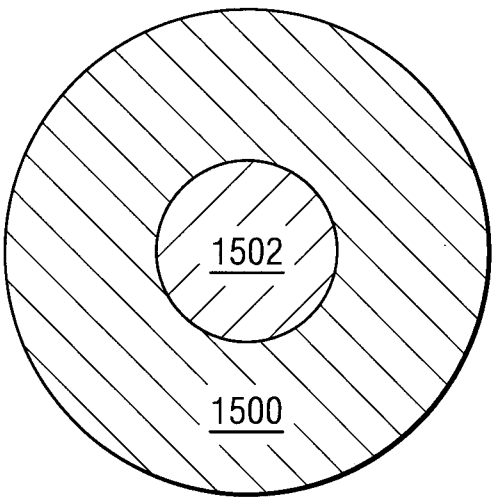


FIG. 15

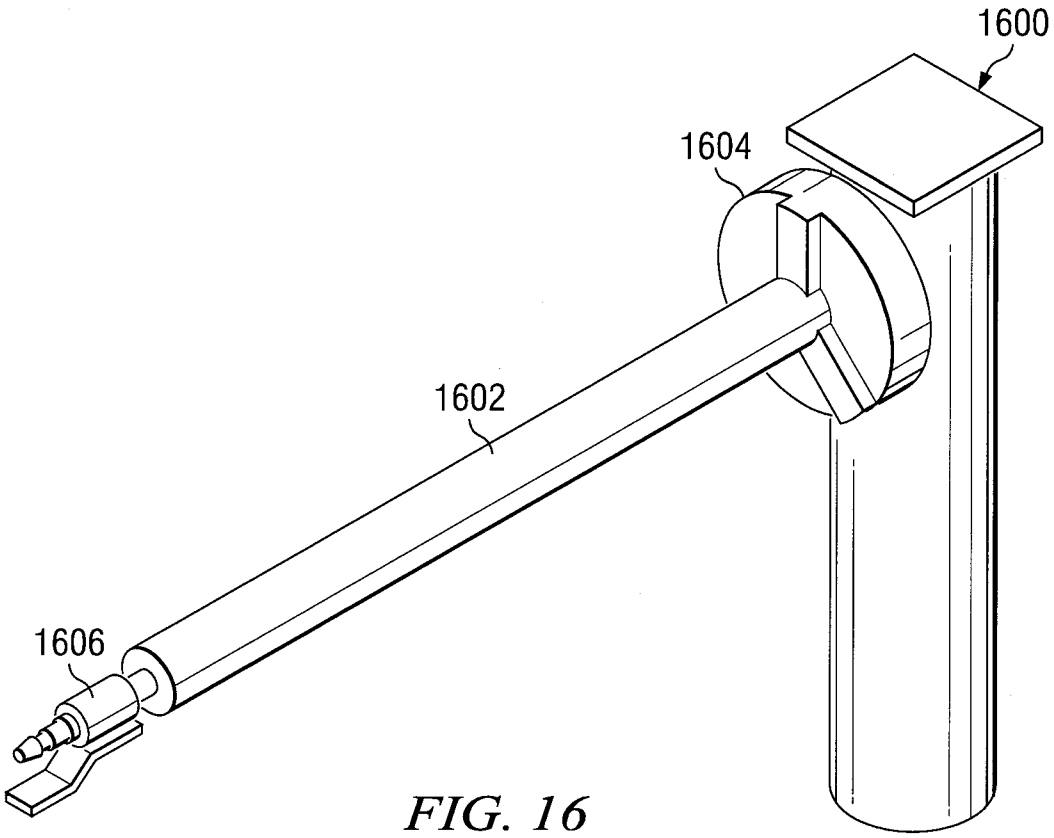


FIG. 16

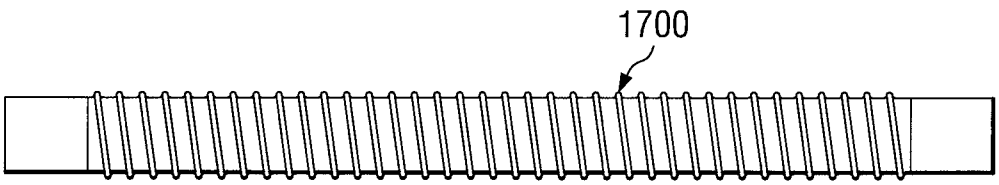


FIG. 17

1800

HOSE DIAMETER (INCHES)	POLYETHERIMIDE (ULTEM) (INCHES)		PITCH (INCHES)	
	HOLLOW	SOLID	HOLLOW	SOLID
0.75		0.06	0.25	0.25
1.00-1.25		0.06	0.25	0.25
1.50	0.08	0.08	0.25	0.25
1.75-2.50	0.09	0.09	0.25/0.37	0.25/0.37
3.00	0.09	0.09	0.37	0.37
3.50-4.00	0.09	0.09	0.37/0.50	0.37/0.50
4.50-5.50	0.09/0.12	0.09/0.12	0.50	0.50
5.50-7.50	0.12	0.12	0.62/0.75	0.62/0.75
8.00-9.00	0.15	0.15	0.75/0.87	0.75/0.87
9.50-12.00	0.15/0.18	0.15/0.18	0.95	0.95

FIG. 18

1900

BEND ANGLE NOMINAL	BEND ANGLE MAX	MINIMUM NUMBER OF HELIX REVOLUTIONS
15°	20°	5
30°	38°	6
45°	55°	7
90°	120°	9

FIG. 19

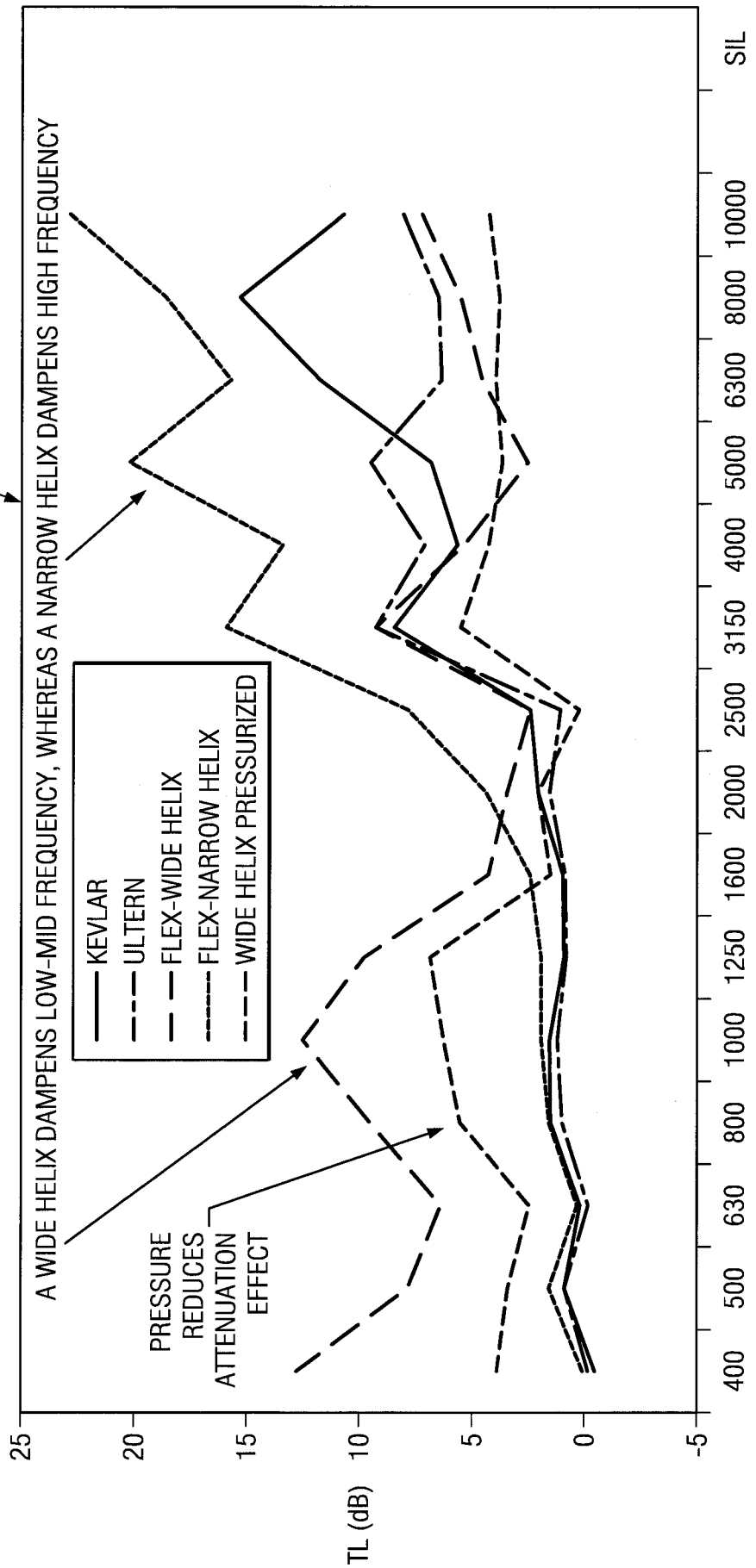

2000
A WIDE HELIX DAMPENS LOW-MID FREQUENCY, WHEREAS A NARROW HELIX DAMPENS HIGH FREQUENCY
PRESSURE REDUCES ATTENUATION EFFECT
KEVLAR
ULTERN
FLEX-WIDE HELIX
FLEX-NARROW HELIX
WIDE HELIX PRESSURIZED
TL (dB)
25
20
15
10
5
0
-5
400
500
630
800
1000
1250
1600
2000
2500
3150
4000
5000
6300
8000
10000
SIL
FREQUENCY (Hz)

FIG. 20

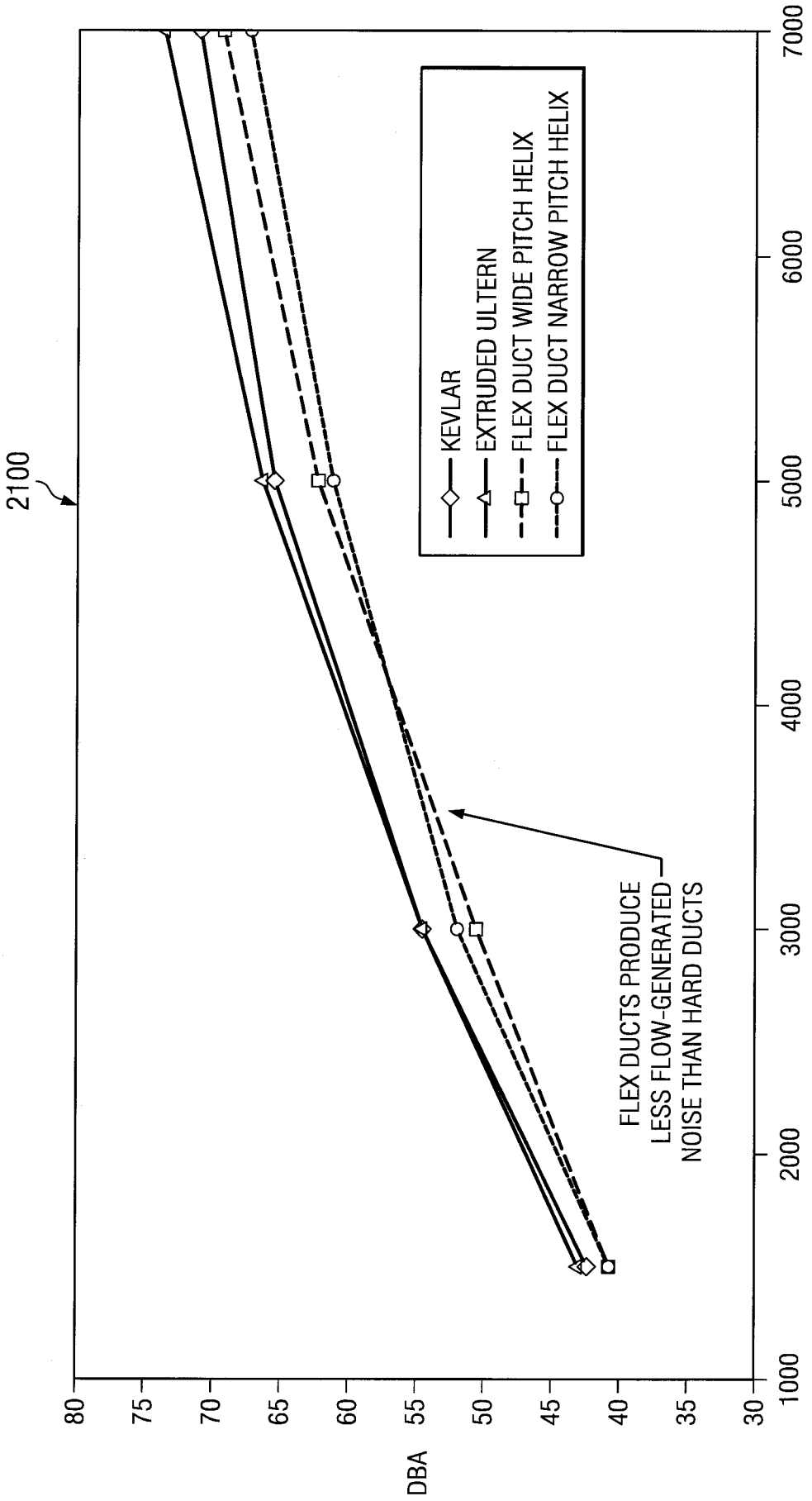

2100
KEVLAR
EXTRUDED ULTERN
FLEX DUCT WIDE PITCH HELIX
FLEX DUCT NARROW PITCH HELIX
FLEX DUCTS PRODUCE
LESS FLOW-GENERATED
NOISE THAN HARD DUCTS
DBA
80
75
70
65
60
55
50
45
40
35
30
1000
2000
3000
4000
5000
6000
7000
FLOW (FEET/MIN)

FIG. 21

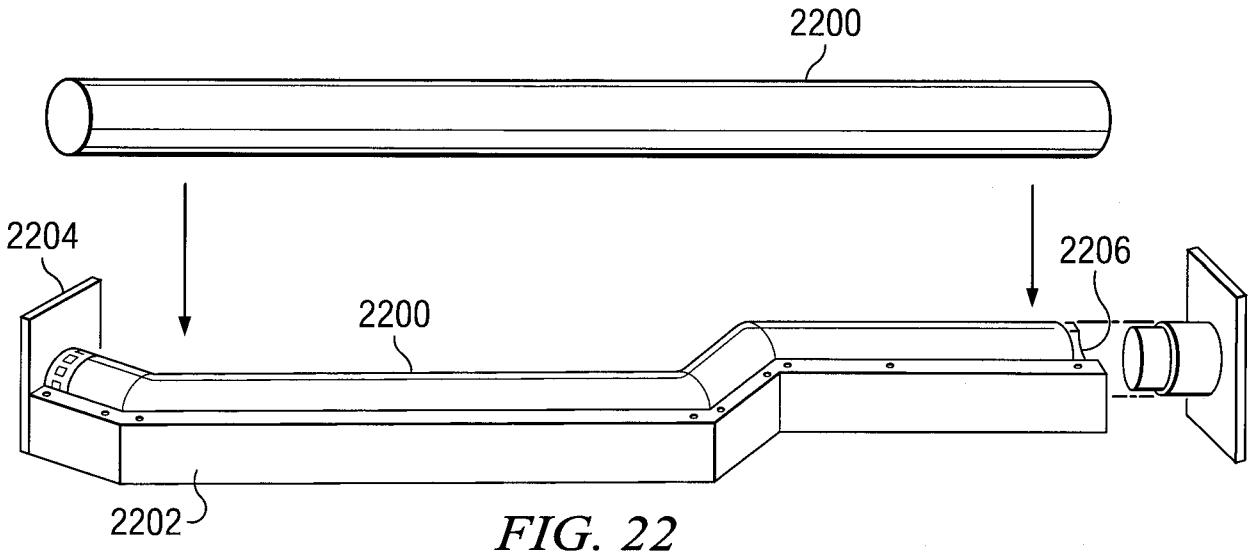


FIG. 22

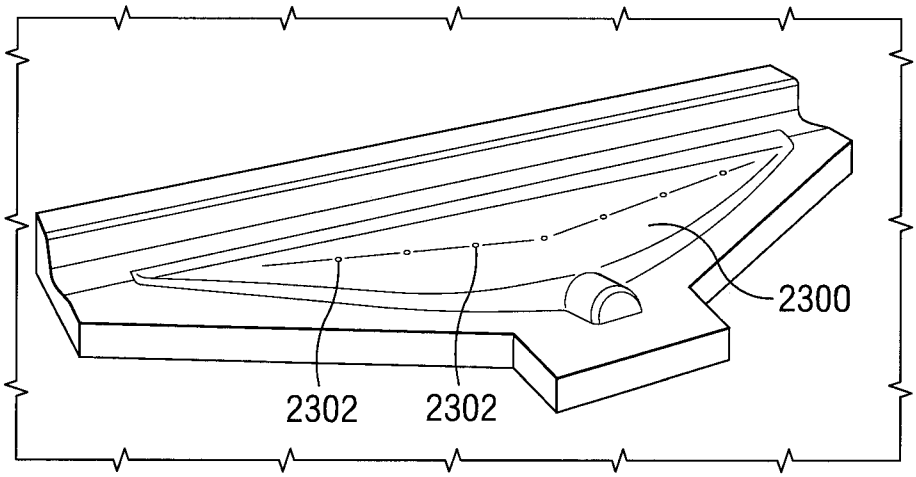


FIG. 23

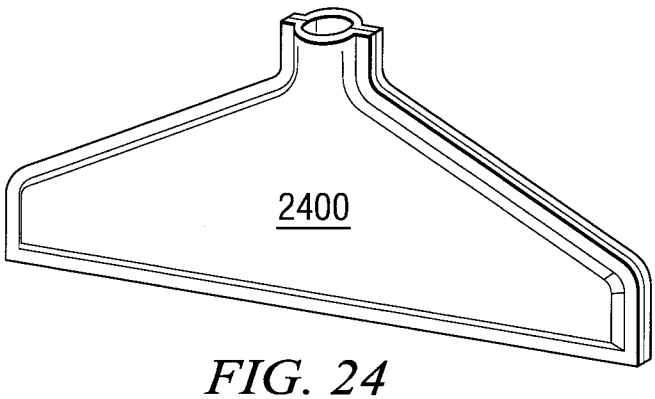


FIG. 24

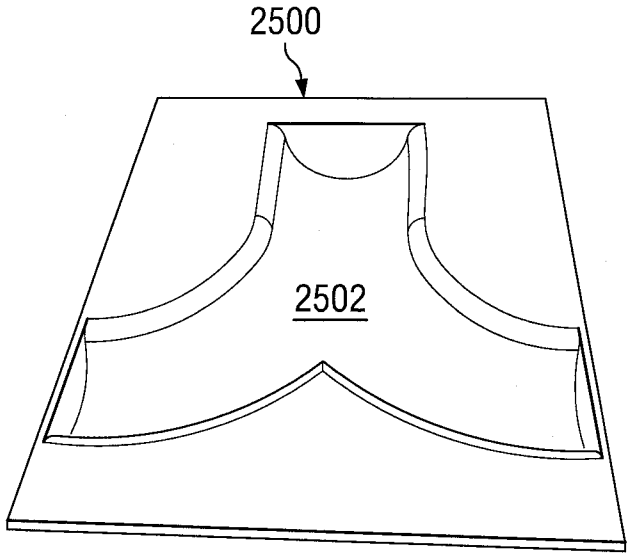


FIG. 25

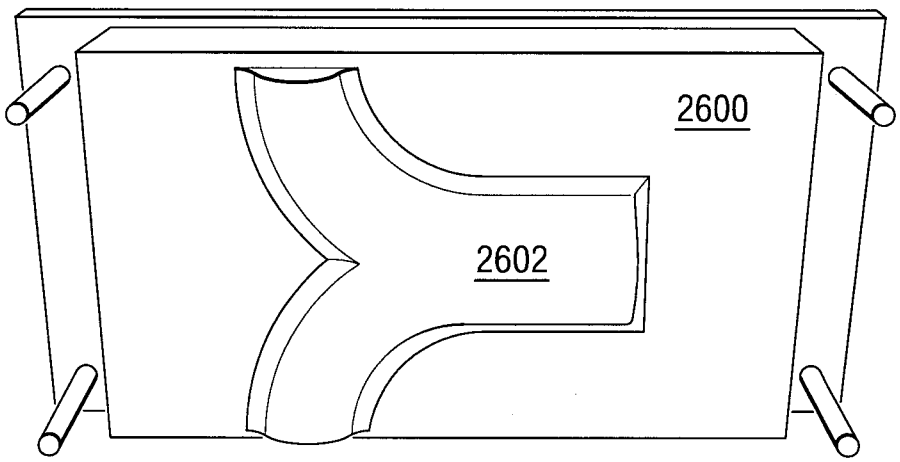


FIG. 26

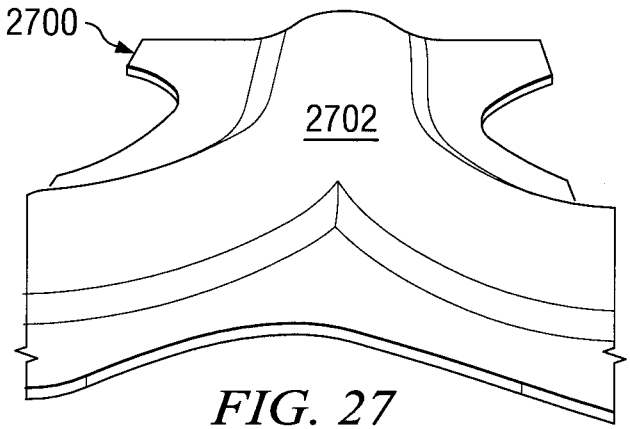


FIG. 27

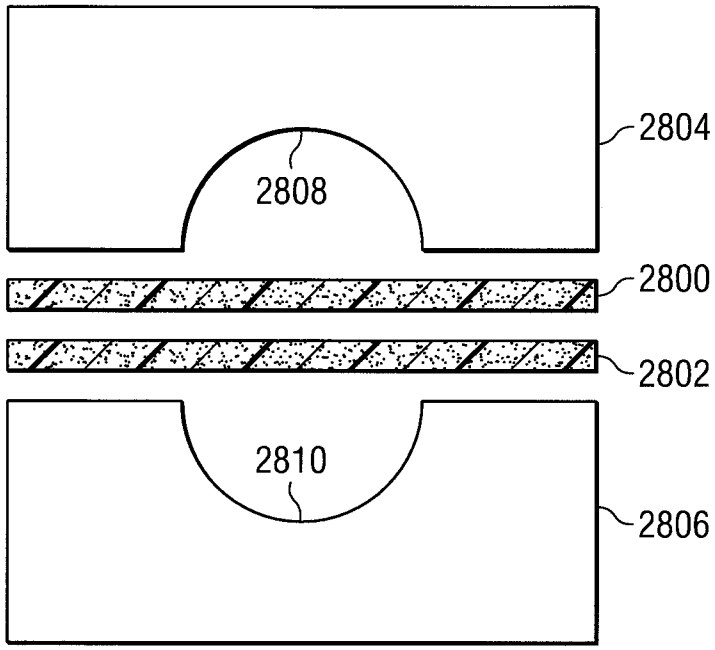


FIG. 28

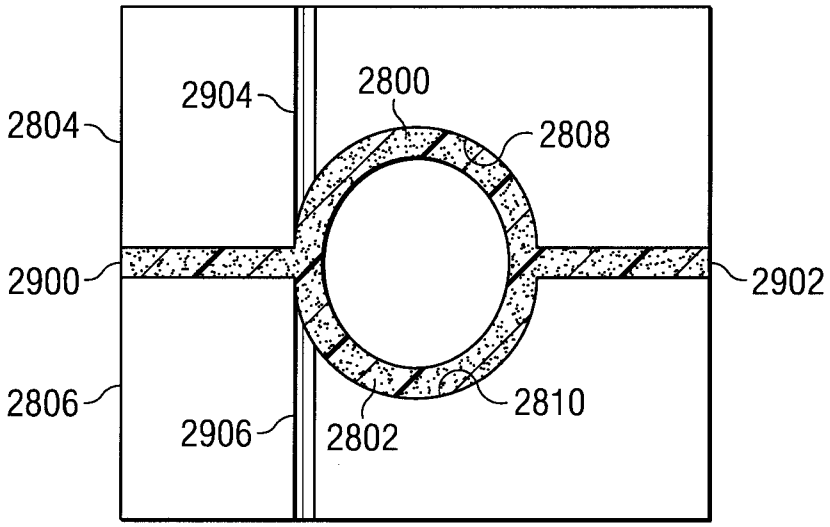


FIG. 29

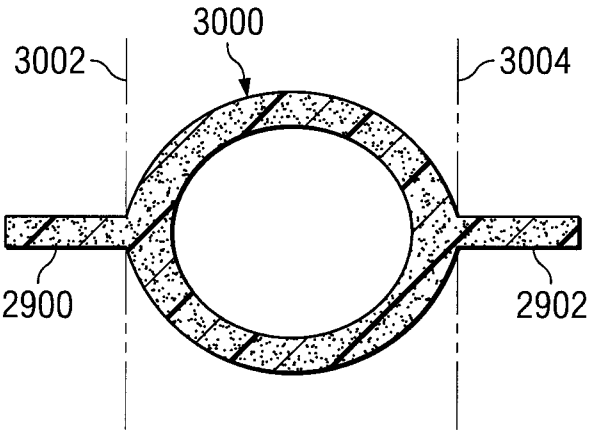


FIG. 30

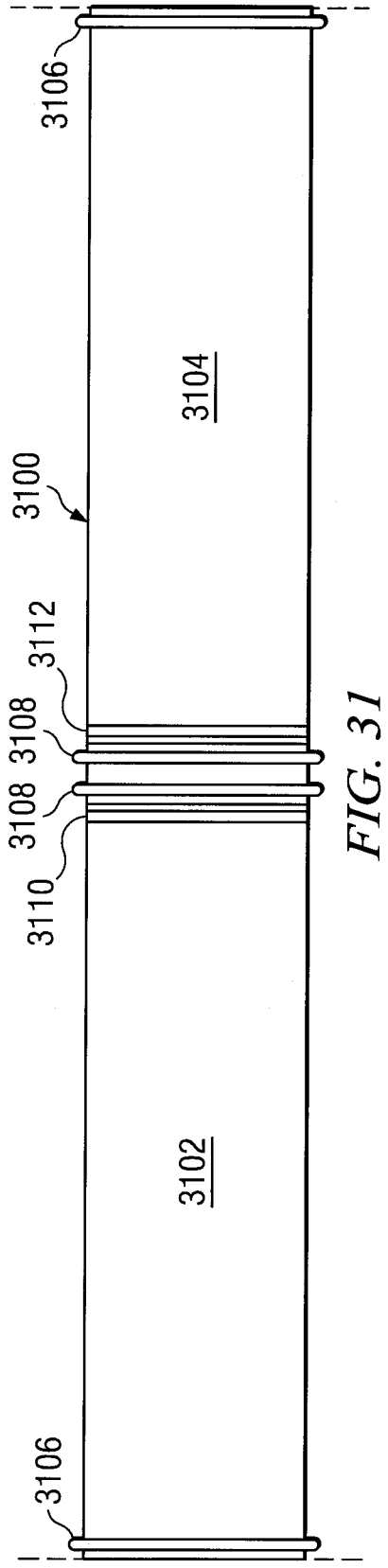

3106
3104
3100
3112
3108
3108
3110
3102
3106

FIG. 31

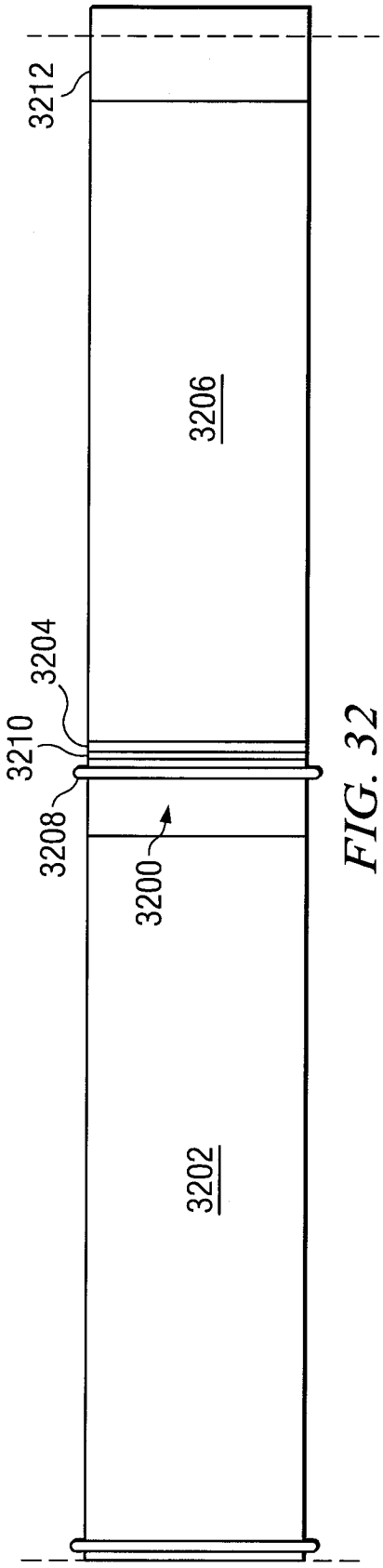

3212
3206
3204
3210
3208
3200
3202

FIG. 32

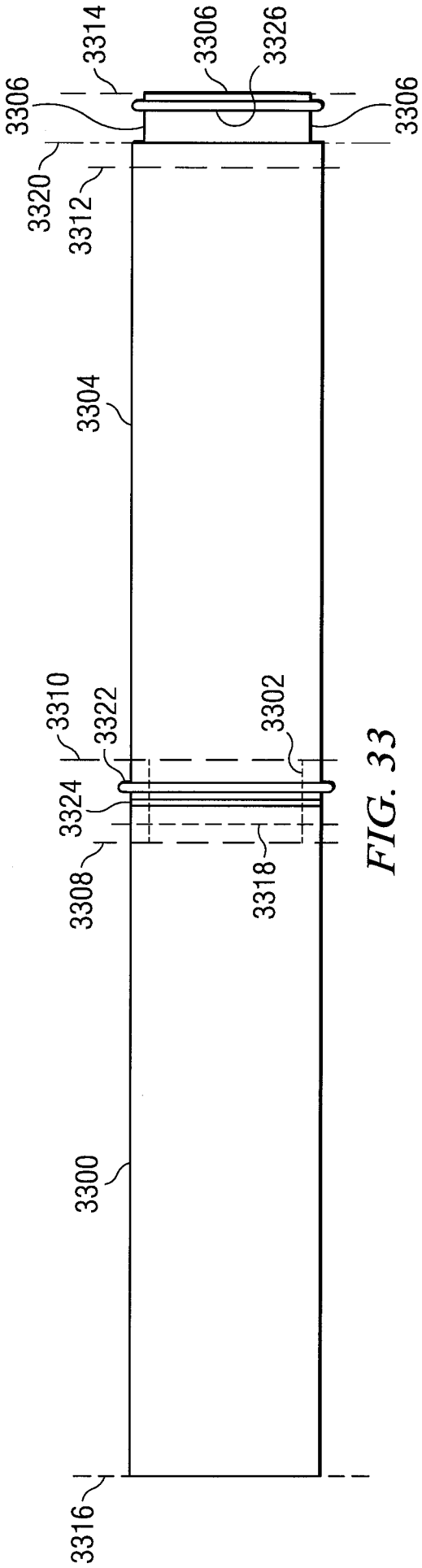

3314
3306
3326
3306
3306
3320
3312
3304
3310
3322
3302
3324
3308
3318
3300
3316

FIG. 33

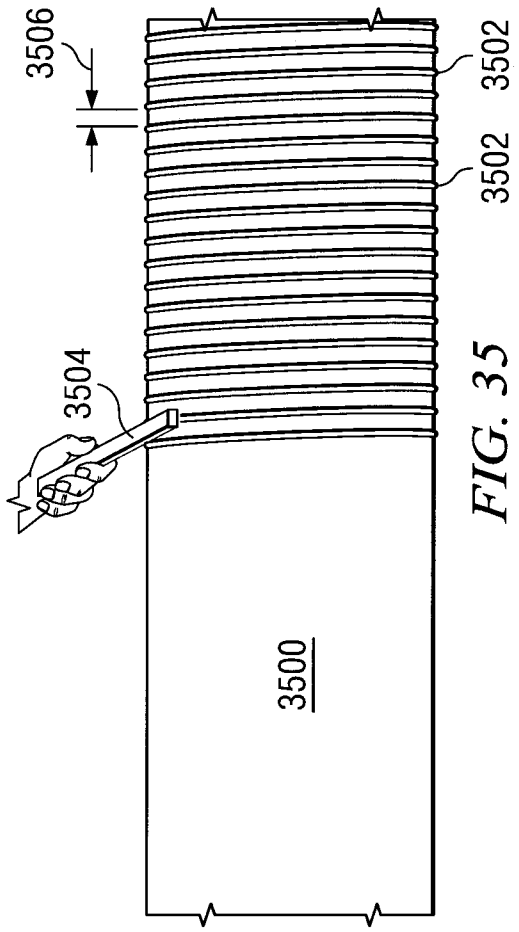

3506
3502
3502
3504
3500

FIG. 35

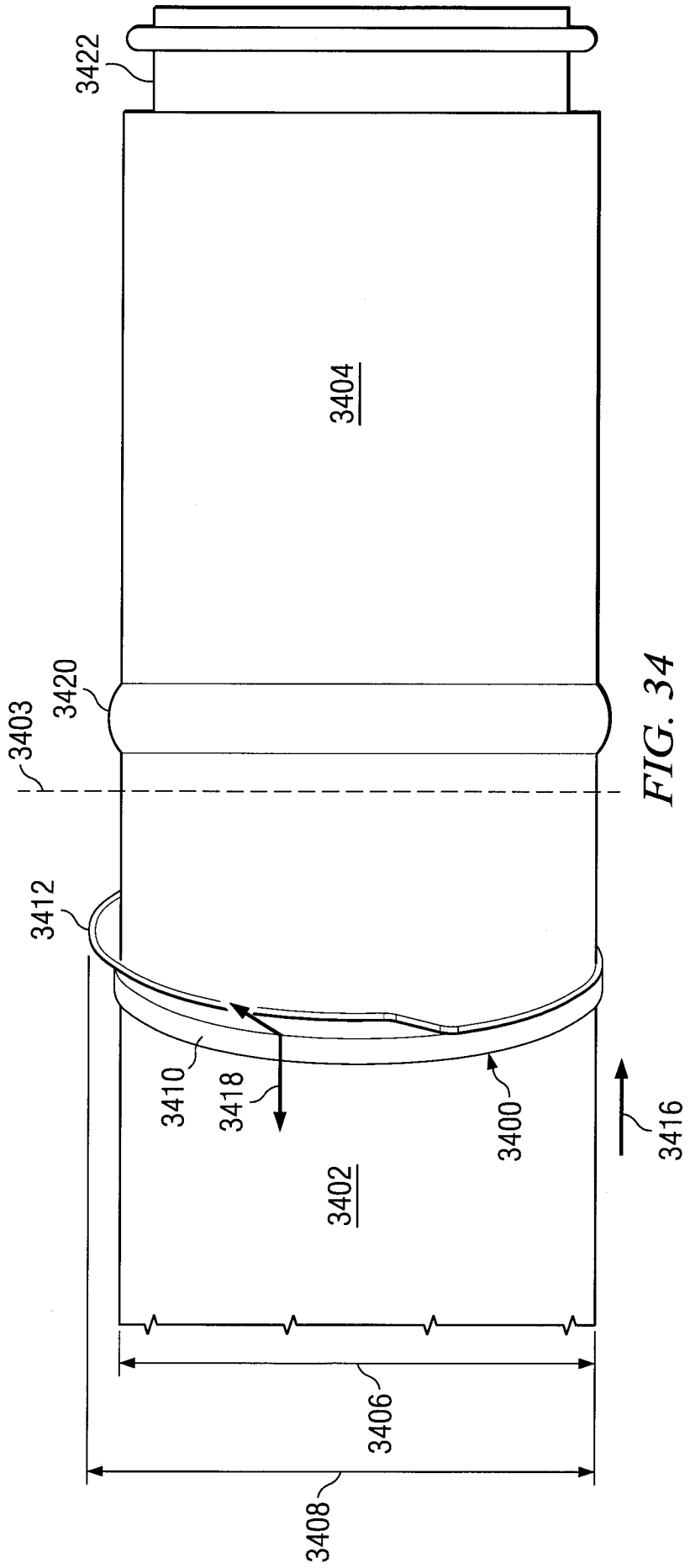


FIG. 34

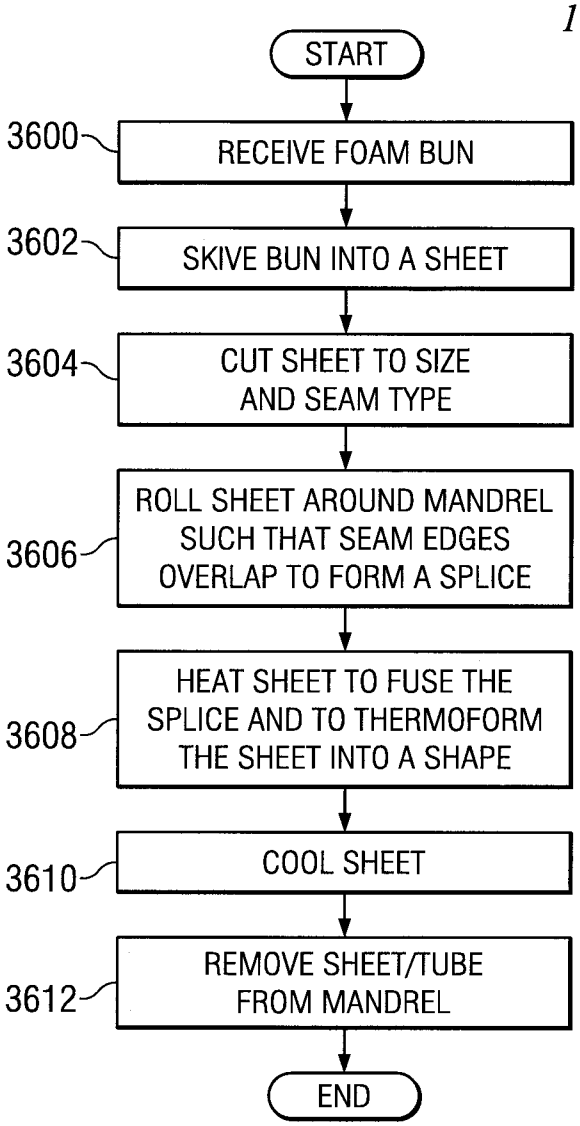

START
3600
RECEIVE FOAM BUN
3602
SKIVE BUN INTO A SHEET
3604
CUT SHEET TO SIZE AND SEAM TYPE
3606
ROLL SHEET AROUND MANDREL SUCH THAT SEAM EDGES OVERLAP TO FORM A SPLICE
3608
HEAT SHEET TO FUSE THE SPLICE AND TO THERMOFORM THE SHEET INTO A SHAPE
3610
COOL SHEET
3612
REMOVE SHEET/TUBE FROM MANDREL
END

FIG. 36

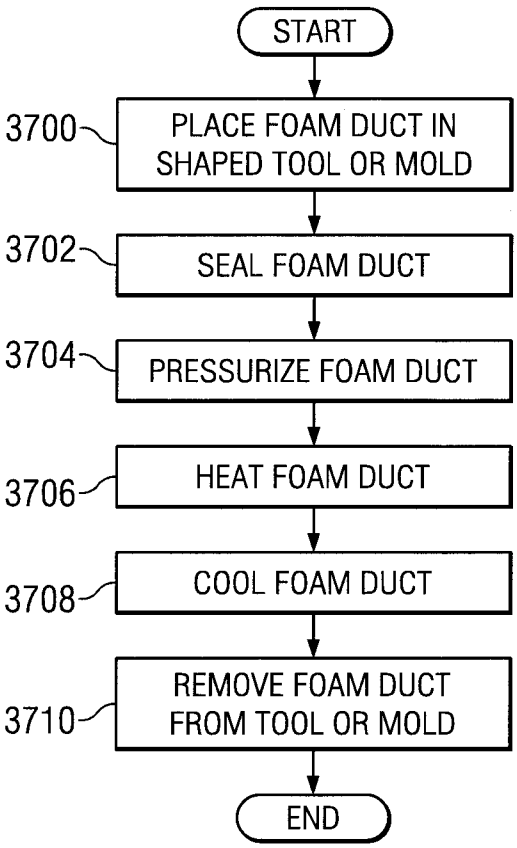

START
3700
PLACE FOAM DUCT IN SHAPED TOOL OR MOLD
3702
SEAL FOAM DUCT
3704
PRESSURIZE FOAM DUCT
3706
HEAT FOAM DUCT
3708
COOL FOAM DUCT
3710
REMOVE FOAM DUCT FROM TOOL OR MOLD
END

FIG. 37

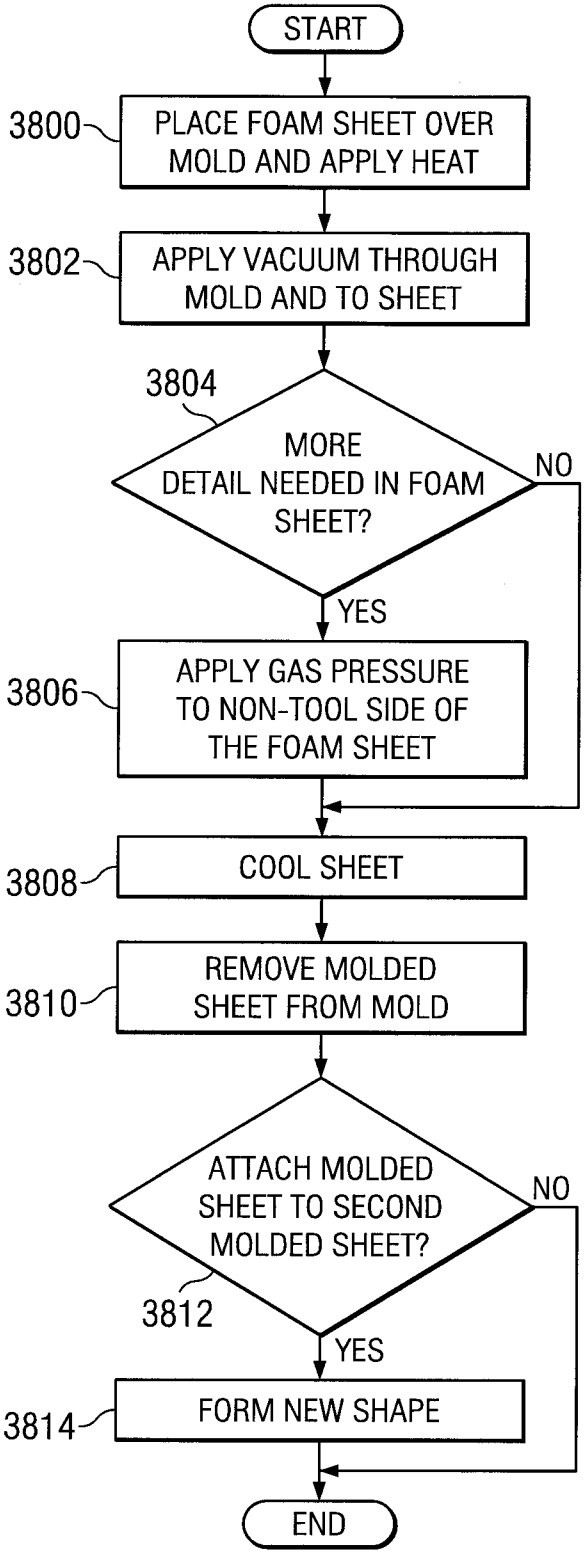

START
3800
PLACE FOAM SHEET OVER MOLD AND APPLY HEAT
3802
APPLY VACUUM THROUGH MOLD AND TO SHEET
3804
MORE DETAIL NEEDED IN FOAM SHEET?
NO
YES
3806
APPLY GAS PRESSURE TO NON-TOOL SIDE OF THE FOAM SHEET
3808
COOL SHEET
3810
REMOVE MOLDED SHEET FROM MOLD
ATTACH MOLDED SHEET TO SECOND MOLDED SHEET?
NO
3812
YES
3814
FORM NEW SHAPE
END

FIG. 38

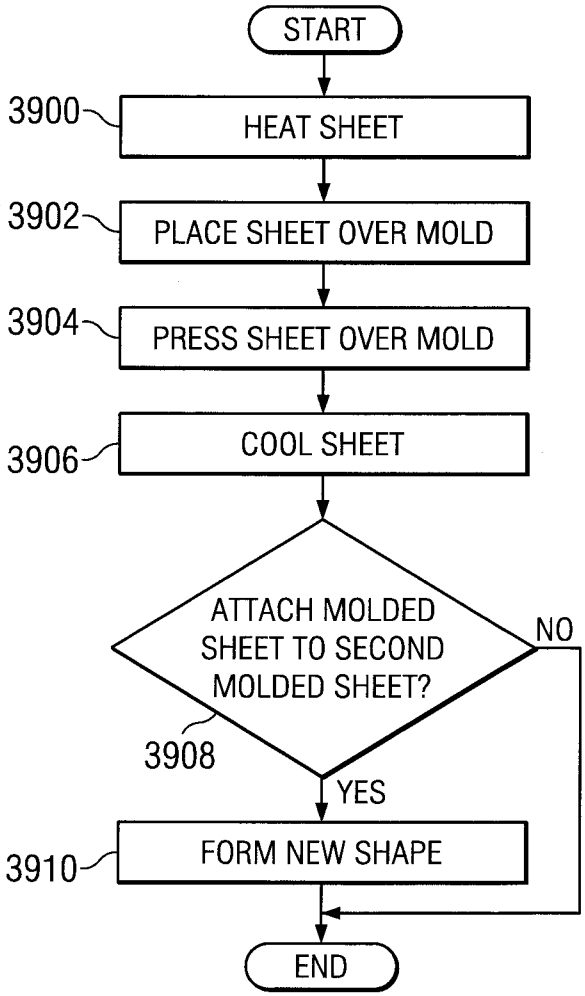

START
3900
HEAT SHEET
3902
PLACE SHEET OVER MOLD
3904
PRESS SHEET OVER MOLD
3906
COOL SHEET
ATTACH MOLDED SHEET TO SECOND MOLDED SHEET?
NO
3908
YES
3910
FORM NEW SHAPE
END

FIG. 39

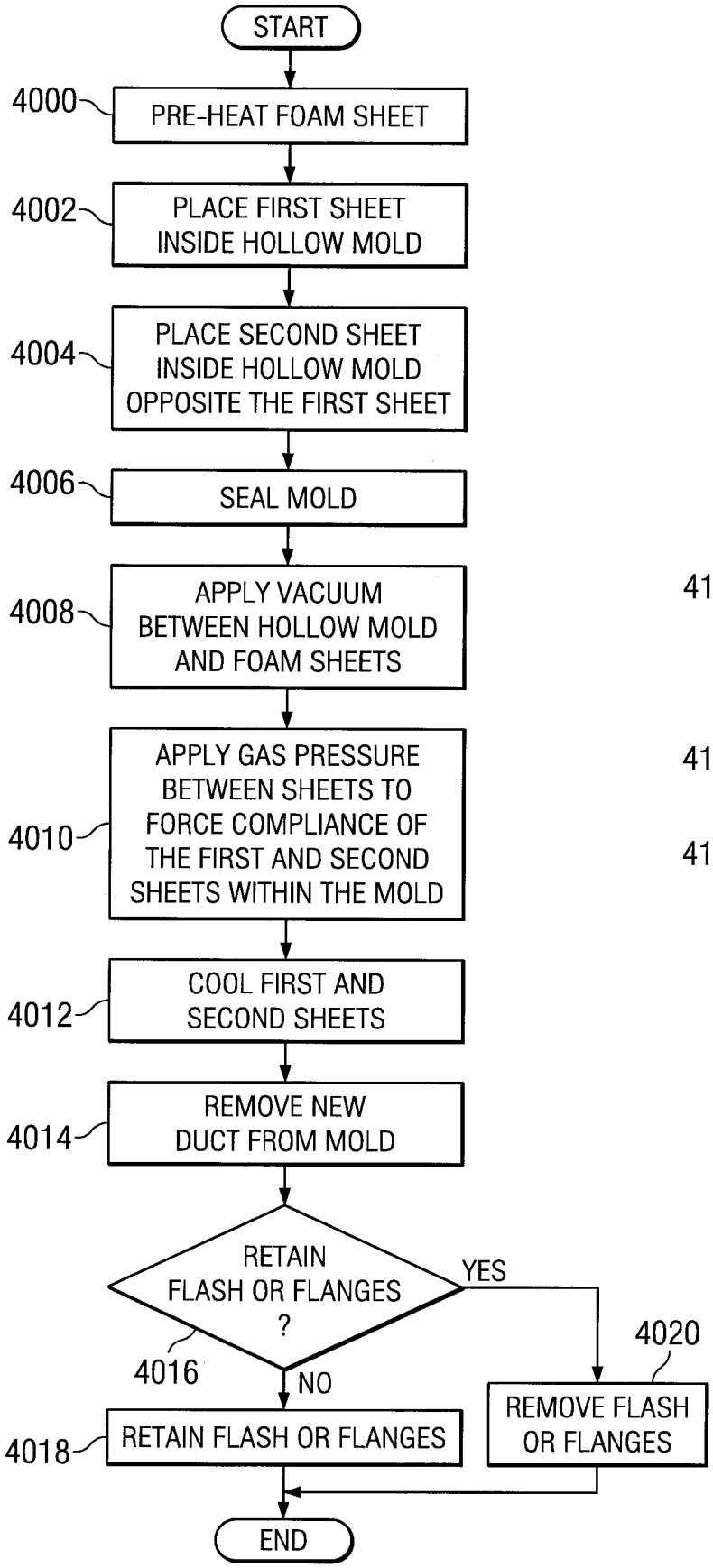

START
4000
PRE-HEAT FOAM SHEET
4002
PLACE FIRST SHEET INSIDE HOLLOW MOLD
4004
PLACE SECOND SHEET INSIDE HOLLOW MOLD OPPOSITE THE FIRST SHEET
4006
SEAL MOLD
4008
APPLY VACUUM BETWEEN HOLLOW MOLD AND FOAM SHEETS
4010
APPLY GAS PRESSURE BETWEEN SHEETS TO FORCE COMPLIANCE OF THE FIRST AND SECOND SHEETS WITHIN THE MOLD
4012
COOL FIRST AND SECOND SHEETS
4014
REMOVE NEW DUCT FROM MOLD
RETAIN FLASH OR FLANGES ?
4016
YES
NO
4018
RETAIN FLASH OR FLANGES
4020
REMOVE FLASH OR FLANGES
END

FIG. 40

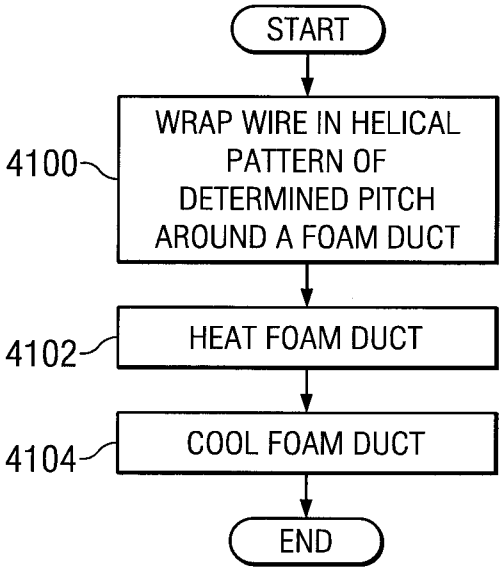

START
4100
WRAP WIRE IN HELICAL PATTERN OF DETERMINED PITCH AROUND A FOAM DUCT
4102
HEAT FOAM DUCT
4104
COOL FOAM DUCT
END

FIG. 41

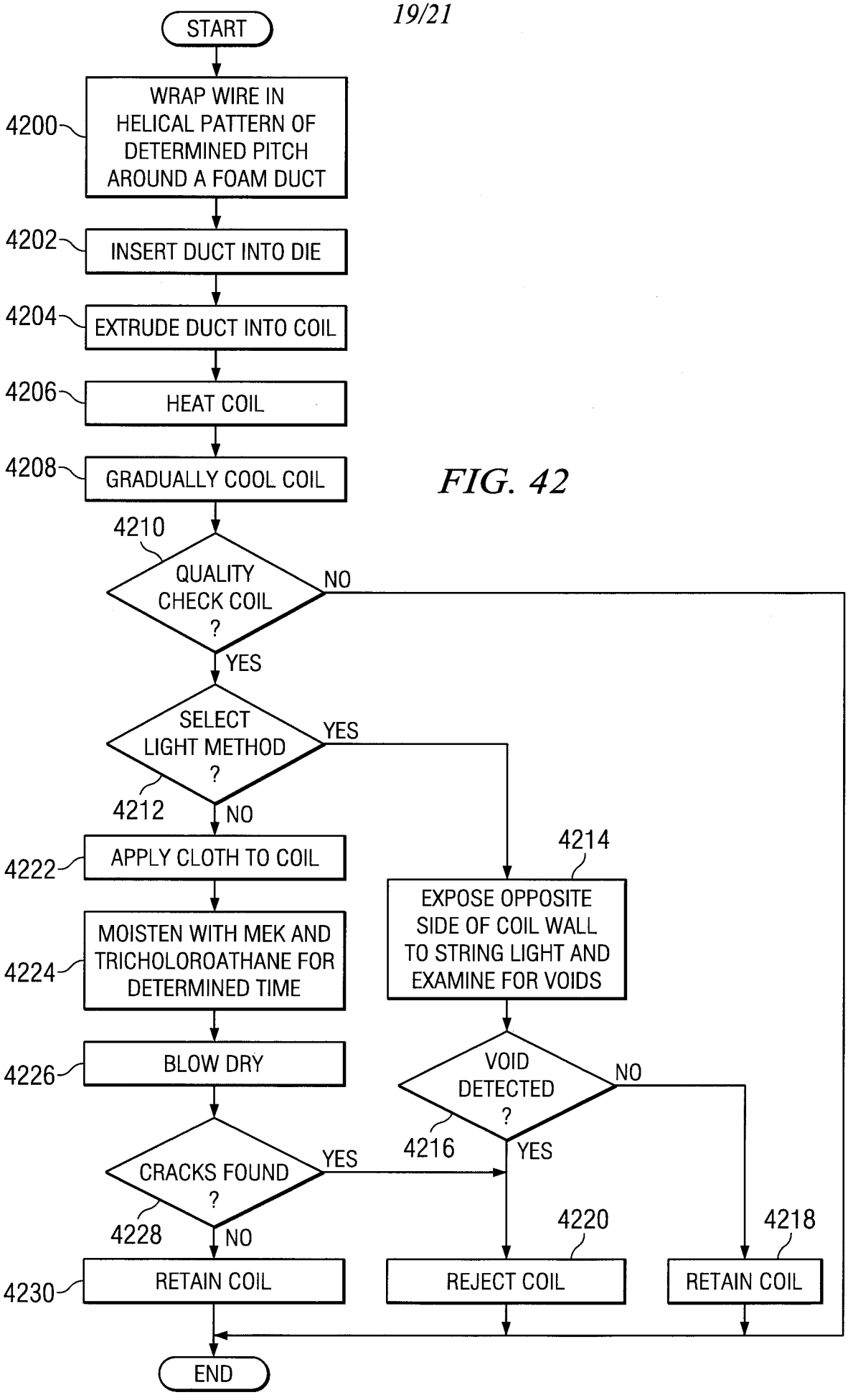

START
WRAP WIRE IN HELICAL PATTERN OF DETERMINED PITCH AROUND A FOAM DUCT
4200
INSERT DUCT INTO DIE
4202
EXTRUDE DUCT INTO COIL
4204
HEAT COIL
4206
GRADUALLY COOL COIL
4208
4210
QUALITY CHECK COIL ?
NO
YES
SELECT LIGHT METHOD ?
YES
4212
NO
APPLY CLOTH TO COIL
4222
4214
EXPOSE OPPOSITE SIDE OF COIL WALL TO STRING LIGHT AND EXAMINE FOR VOIDS
MOISTEN WITH MEK AND TRICHOLOROATHANE FOR DETERMINED TIME
4224
BLOW DRY
4226
VOID DETECTED ?
NO
4216
YES
CRACKS FOUND ?
YES
4228
NO
4220
4218
RETAIN COIL
4230
REJECT COIL
RETAIN COIL
END

FIG. 42

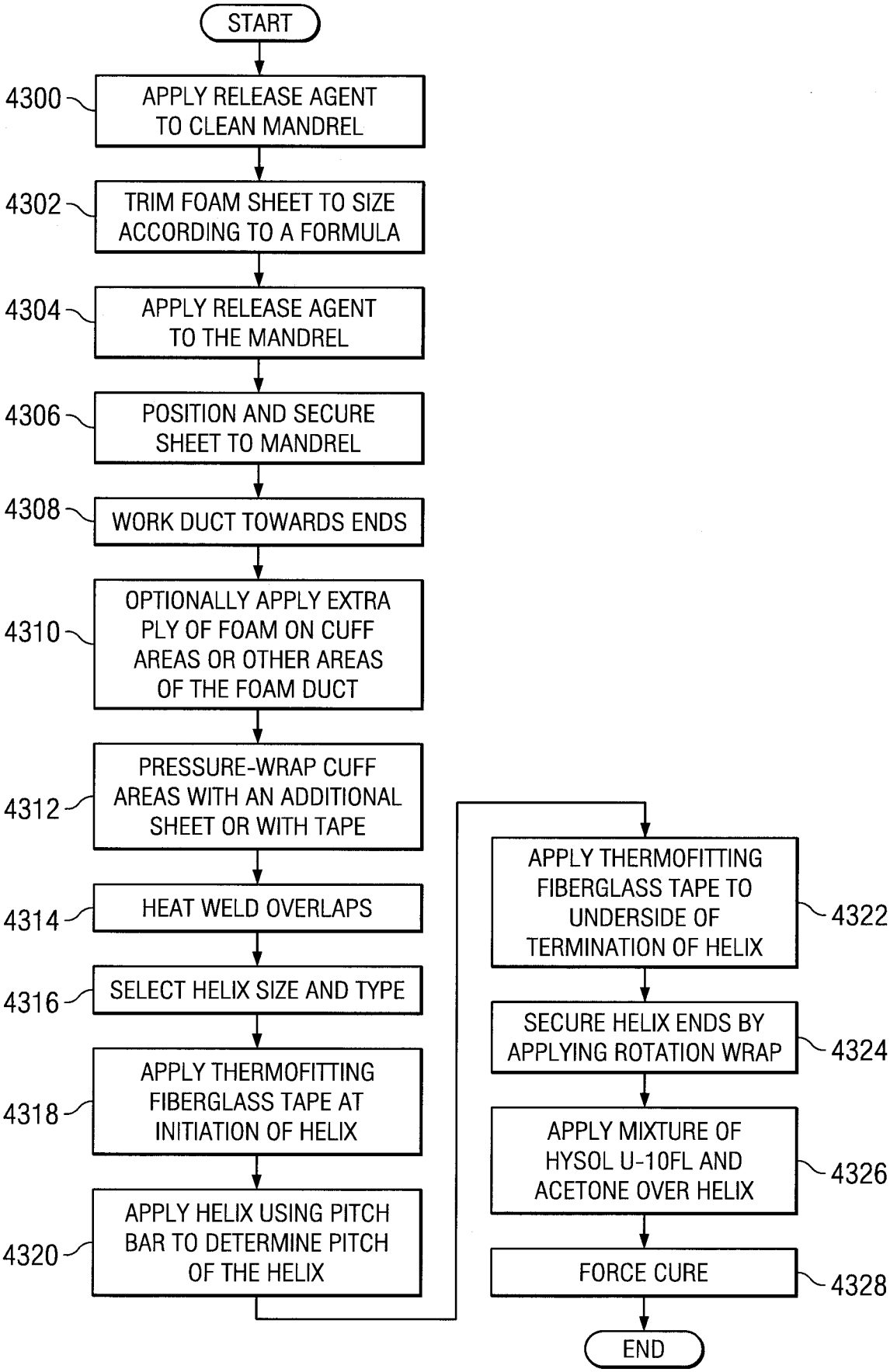

START
4300
APPLY RELEASE AGENT TO CLEAN MANDREL
4302
TRIM FOAM SHEET TO SIZE ACCORDING TO A FORMULA
4304
APPLY RELEASE AGENT TO THE MANDREL
4306
POSITION AND SECURE SHEET TO MANDREL
4308
WORK DUCT TOWARDS ENDS
4310
OPTIONALLY APPLY EXTRA PLY OF FOAM ON CUFF AREAS OR OTHER AREAS OF THE FOAM DUCT
4312
PRESSURE-WRAP CUFF AREAS WITH AN ADDITIONAL SHEET OR WITH TAPE
4314
HEAT WELD OVERLAPS
4316
SELECT HELIX SIZE AND TYPE
4318
APPLY THERMOFITTING FIBERGLASS TAPE AT INITIATION OF HELIX
4320
APPLY HELIX USING PITCH BAR TO DETERMINE PITCH OF THE HELIX
4322
APPLY THERMOFITTING FIBERGLASS TAPE TO UNDERSIDE OF TERMINATION OF HELIX
4324
SECURE HELIX ENDS BY APPLYING ROTATION WRAP
4326
APPLY MIXTURE OF HYSOL U-10FL AND ACETONE OVER HELIX
4328
FORCE CURE
END

FIG. 43

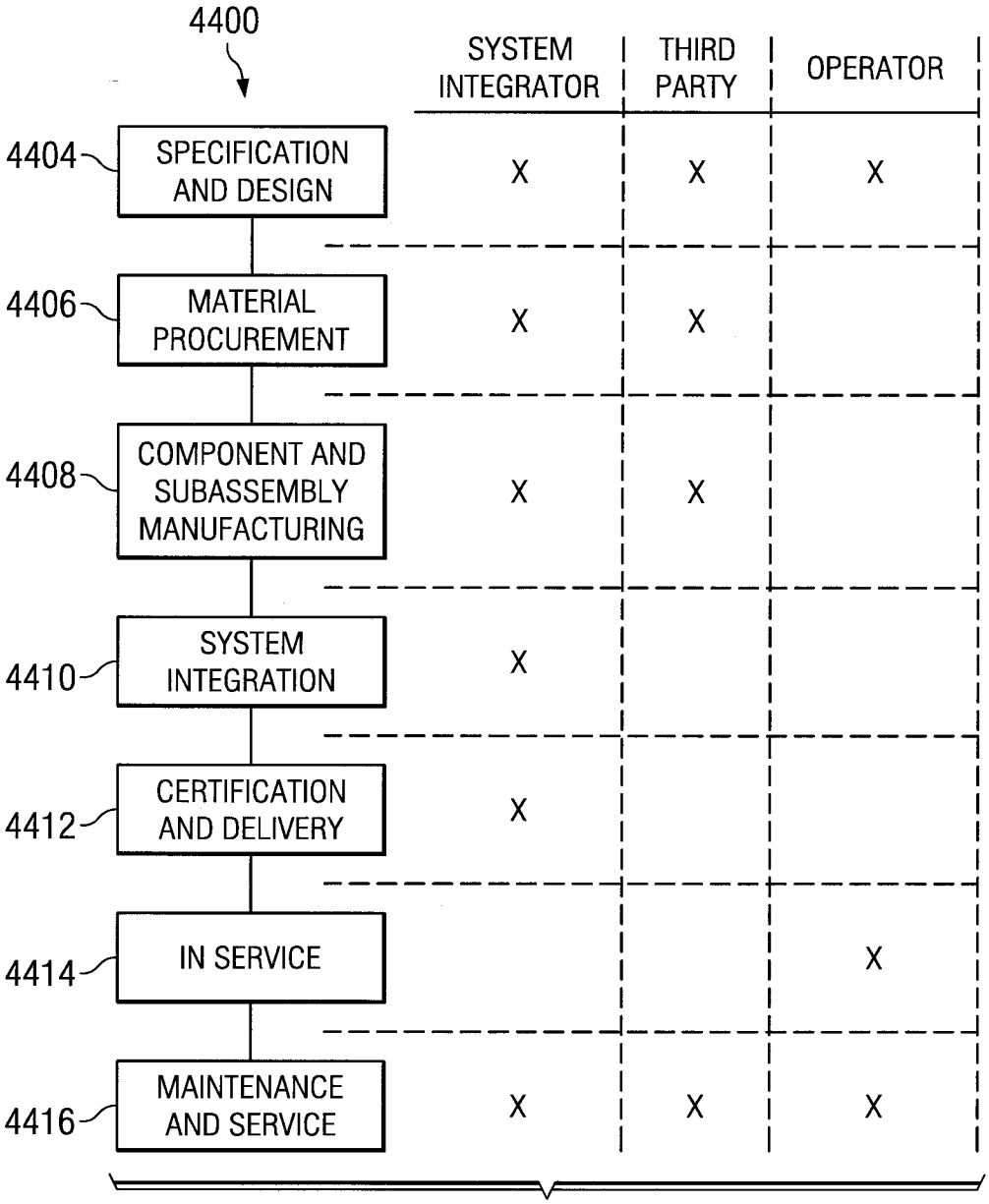

4400
SYSTEM INTEGRATOR
THIRD PARTY
OPERATOR
4404
SPECIFICATION AND DESIGN
X
X
X
4406
MATERIAL PROCUREMENT
X
X
4408
COMPONENT AND SUBASSEMBLY MANUFACTURING
X
X
4410
SYSTEM INTEGRATION
X
4412
CERTIFICATION AND DELIVERY
X
4414
IN SERVICE
X
4416
MAINTENANCE AND SERVICE
X
X
X

FIG. 44

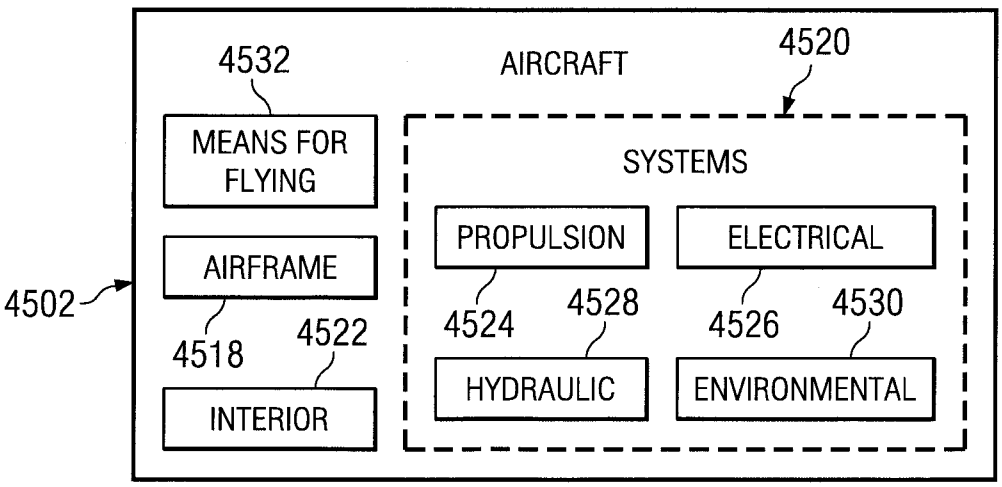

4532
AIRCRAFT
4520
MEANS FOR FLYING
SYSTEMS
PROPULSION
ELECTRICAL
AIRFRAME
4502
4524
4528
4526
4530
4518
4522
HYDRAULIC
ENVIRONMENTAL
INTERIOR

FIG. 45

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2007/088674

A. CLASSIFICATION OF SUBJECT MATTER
INV. F16L9/17 F16L9/12 B29C53/38
ADD. B29C65/00

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)
B29C F16L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)
EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 250 002 A (MARQUET & CIE NOEL [BE]) 23 December 1987 (1987-12-23) claim 1; figure 1	1-13, 27-37
X	DE 20 2004 011025 U1 (EATON FLUID POWER GMBH [DE]) 9 September 2004 (2004-09-09) paragraph [0007]; figures 1,4	1-13, 27-37
A	US 5 393 105 A (PETTERSON BART [US] ET AL) 28 February 1995 (1995-02-28) column 3, lines 14,15; claim 1	1-13, 27-37
A	US 2 784 129 A (STEPHENS JOSEPH F) 5 March 1957 (1957-03-05) figures 1,2	1-13, 27-37

-/--

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
27 May 2008	10/10/2008

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Dupuis, Jean-Luc

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2007/088674

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 3 095 337 A (ASCHER CHASE) 25 June 1963 (1963-06-25) claim 1; figure 1	1-13, 27-37
A	US 3 289 702 A (SHERBURNE PHILIP C) 6 December 1966 (1966-12-06) figures 12-14	1-13, 27-37
A	WO 2004/110738 A (BELL HELICOPTER TEXTRON INC [US]; HETHCOCK JAMES DONN [US]; JONES RODN) 23 December 2004 (2004-12-23) claim 1; figures 1,2	1-13, 27-37

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2007/088674

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers allsearchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search reportcovers only those claims for which fees were paid, specifically claims Nos.:

4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

1-13, 27-37

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-13,27-37

Product claims 1-13 and corresponding method claims 27-37 address a duct and corresponding manufacturing method comprising a thermoplastic foam sheet having properties suitable for use in an environmental control system a crenulated first edge of the thermoplastic foam, a second edge of the thermoplastic foam, wherein the duct is formed by interlocking the crenulated first edge with the second edge.

---

2. claims: 14-26

Claims 14-26 address an aerospace vessel comprising a fuselage, a means for causing the fuselage to fly and an environmental control system within the fuselage, wherein the environmental control system comprises a first duct comprising PVDF foam.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2007/088674

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP 0250002 A	23-12-1987	DE 3620791 A1	23-12-1987
DE 202004011025 U1	09-09-2004	NONE	
US 5393105 A	28-02-1995	NONE	
US 2784129 A	05-03-1957	NONE	
US 3095337 A	25-06-1963	NONE	
US 3289702 A	06-12-1966	NONE	
WO 2004110738 A	23-12-2004	CA 2515180 A1	23-12-2004
		CN 1750921 A	22-03-2006
		DE 04775802 T1	18-05-2006
		EP 1597053 A2	23-11-2005