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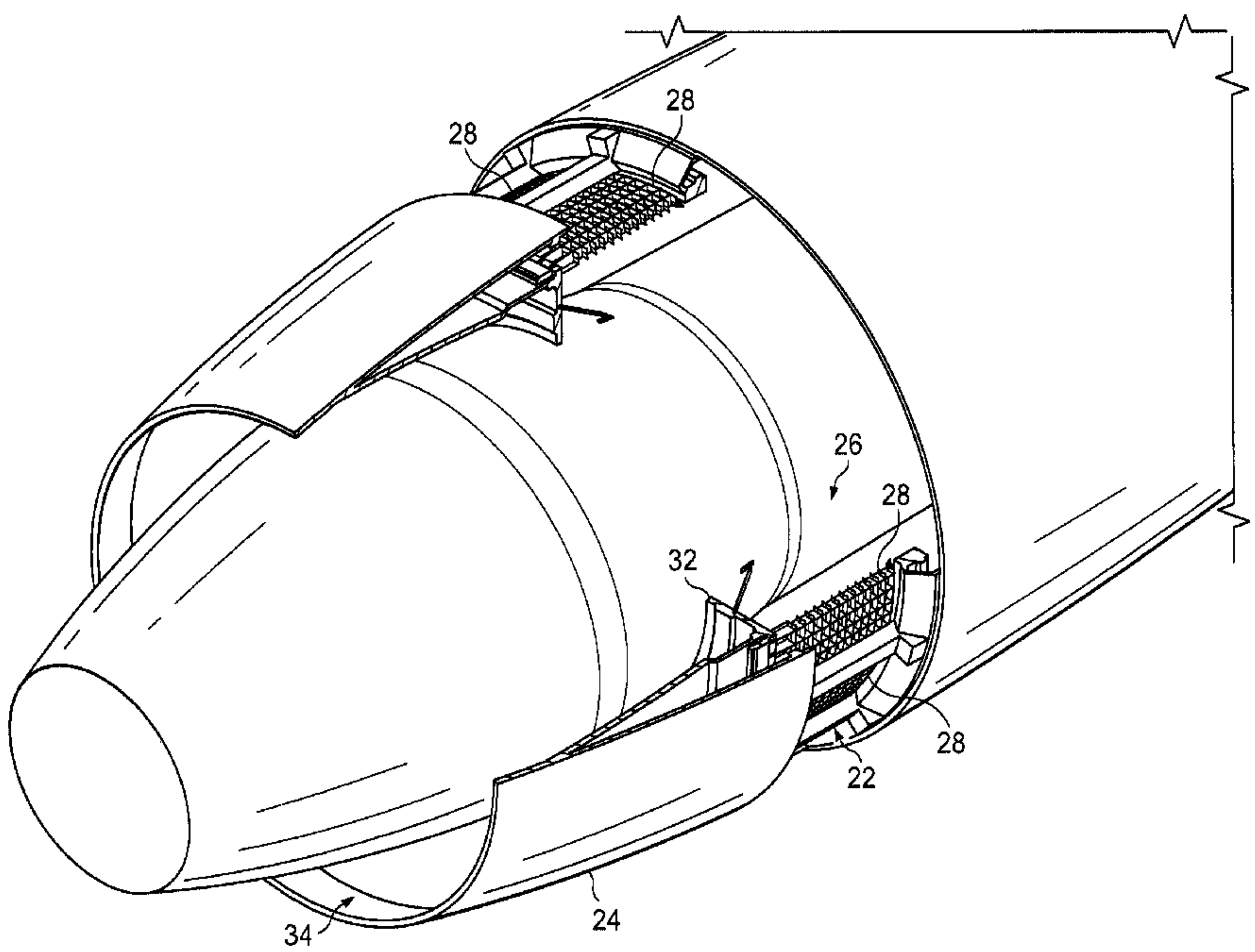



(57) Abrégé/Abstract:
A cascade for a jet engine thrust reverser is fabricated by co-consolidating pre-consolidated thermoplastic strongbacks and vanes. The strongbacks are reinforced with continuous fibers, and the vanes are reinforced with discontinuous fibers.

## ABSTRACT

A cascade for a jet engine thrust reverser is fabricated by co-consolidating pre-consolidated thermoplastic strongbacks and vanes. The strongbacks are reinforced with continuous fibers, and the vanes are reinforced with discontinuous fibers.

# THERMOFORMED CASCADES FOR JET ENGINE THRUST REVERSERS

## BACKGROUND

### 1. Field

The present disclosure generally relates to thrust reversers for jet engines, and deals more particularly with cascade type thrust reversers, as well as a method of fabricating cascades.

### 2. Background

Airplanes with jet engines are often equipped with thrust reversers that increase drag on the airplane during landings, thereby reducing the speed of the aircraft. A thrust reverser increases drag by effectively reversing the flow of exhaust gases through the jet engine. In one type of thrust reverser, referred to as a cascade-type, a transcowl on the jet engine nacelle translates rearwardly to expose a cascade formed by multiple open grid panels. Closing of a blocker door causes a bypass portion of the airflow through the engine to be diverted through series of circumferentially arranged cascade vanes in the grid panels which are oriented to redirect the airflow forwardly and thereby produce reverse thrust.

The fabrication of cascade grid panels is time consuming, labor intensive and therefore expensive. Current cascade grid panels are fabricated using fiber reinforced thermoset resins which require many processing steps and specialized equipment. For example, use of thermosets require thawing of prepreg, pre-curing of strongbacks, hand layup of the individual vanes, compression molding to co-cure the strongbacks to the vanes, and post curing.

Accordingly, there is a need for a cascade for a jet engine thrust reverser that is simple in construction and is less expensive to produce. There is also a need for a low cost method of fabricating the cascade which reduces touch labor and requires fewer processing steps as well as less processing equipment.

## SUMMARY

The disclosed embodiments provide a light weight cascade for use in thrust reversers that is simple to manufacture and requires fewer processing steps to produce. Complex, three-dimensional, all thermoplastic composite cascades can be rapidly manufactured using continuous fiber strongbacks co-consolidated with discontinuous long fiber thermoplastic composite grid panels. The strongbacks may be fabricated separately from the grid panels, thereby improving manufacturing flow. The strongbacks and the vanes in the grid panels may be molded to any desired shape in order to redirect the bypass air in any desired direction. The grid panels may be fabricated either individually or in modular subassembly groups. Because the pre-consolidated strongbacks and grid panels can be fabricated as individual pieces, they can be combined into a final, high-temperature consolidation tooling with open slots to accurately index the rigid strongbacks in relationship to the vanes of the individual grid panels. The desired indexing may be achieved using a combination of alternating hard tool inserts and soluble mandrels.

According to one disclosed embodiment, a cascade is provided for a jet engine thrust reverser. The cascade comprises a plurality of strongbacks co-consolidated with a plurality of vanes. Each of the strongbacks is formed of a polymer resin having a continuous fiber reinforcement. Each of the vanes is formed of a polymer resin, such as a thermoplastic, having a discontinuous fiber reinforcement. The vanes may be arranged in a plurality of modular vane assemblies. The discontinuous fiber reinforcement includes randomly oriented, chopped fibers. The strongback assembly and the vanes are pre-consolidated prior to being consolidated with each other. The strongback assembly is reinforced with continuous fibers.

According to another disclosed embodiment, a method is provided of fabricating a cascade grid panel for a jet engine thrust reverser. The method comprises fabricating a plurality of thermoplastic vanes, fabricating a plurality of thermoplastic strongbacks, and co-consolidating the vanes and the strongbacks. Fabricating the thermoplastic vanes may be performed by compression molding a thermoplastic resin reinforced with discontinuous fibers. Fabricating the strongbacks may be performed by continuous compression molding a thermoplastic resin reinforced with continuous fibers. The co-consolidation is performed by loading the thermoplastic vanes and the thermoplastic strongbacks into compression mold tooling, heating each of the thermoplastic vanes and thermoplastic strongbacks, and co-consolidating the vanes and the strongbacks using the compression mold tooling to compress the thermoplastic vanes against the thermoplastic strongbacks. Loading the thermoplastic vanes and the thermoplastic strongbacks into the compression mold tooling includes placing a set of hard tool inserts into a first set of vane cavities, and placing a set of expandable soluble mandrels into a second set of vane cavities. The method may further comprise cooling the vanes and the strongbacks after they have been co-consolidated and removing the cascade grid panel from the compression mold tooling, including dissolving the soluble mandrels. The method may also include indexing the vanes relative to the strongbacks within the compression mold tooling. Indexing the vanes includes inserting a set of hard tool inserts into cavities formed by the vanes.

According to still another embodiment, an apparatus is provided for co-consolidating a plurality of strongbacks and a plurality of vanes. The apparatus comprises a tool including a plurality of hard tool inserts fixed in relationship to each other and capable of being inserted into a first set of cavities formed by the vanes. The apparatus further comprises a plurality of mandrels capable of being individually inserted into a second set of cavities formed by the vanes. The mandrels may be soluble. The tool includes a tool base and the plurality of hard tool inserts are fixed to the tool base.

In one embodiment there is provided a cascade for a jet engine thrust reverser, including a plurality of strongbacks each formed of a polymer resin having a continuous fiber reinforcement and a plurality of vanes joined to the strongbacks and each formed of a polymer resin having a discontinuous fiber reinforcement.

The polymer resin may be a thermoplastic resin.

The strongbacks and the vanes may be co-consolidated.

The plurality of vanes may be arranged in a plurality of modular vane assemblies co-consolidated with the plurality of strongbacks.

The discontinuous fiber reinforcement may include randomly oriented, chopped fibers.

In another embodiment there is provided a cascade for a jet engine thrust reverser, including a pre-consolidated thermoplastic strongback assembly and, pre-consolidated thermoplastic vanes co-consolidated with the strongbacks.

The strongback assembly may be reinforced with continuous fibers.

The vanes may be reinforced with discontinuous fibers.

The vanes may be arranged as a plurality of vane assemblies, each of the vane assemblies including a plurality of the vanes and located between and consolidated with the strongbacks.

In another embodiment there is provided a method of fabricating a cascade grid panel for a jet engine thrust reverser, involving fabricating a plurality of thermoplastic vanes, fabricating a plurality of thermoplastic strongbacks and co-consolidating the vanes and the strongbacks.

Fabricating a plurality of thermoplastic vanes may be performed by compression molding a thermoplastic resin reinforced with discontinuous fibers.

Fabricating a plurality of thermoplastic strongbacks may be performed by continuous compression molding a thermoplastic resin reinforced with continuous fibers.

Co-consolidating the thermoplastic vanes and the thermoplastic strongbacks may involve loading the thermoplastic vanes and the thermoplastic strongbacks into compression mold tooling, heating each of the thermoplastic vanes and thermoplastic strongbacks, and co-consolidating the vanes and the strongbacks using the compression mold tooling to compress the thermoplastic vanes against the thermoplastic strongbacks.

Loading the thermoplastic vanes and the thermoplastic strongbacks into the compression mold tooling may involve placing a set of hard tool inserts into a first set of vane cavities, and placing a set of expandable soluble mandrels into a second set of vane cavities.

The method may further involve cooling the vanes and the strongbacks after they have been co-consolidated and removing the cascade grid panel from the compression mold tooling, including dissolving the soluble mandrels.

The method may further involve indexing the vanes relative to the strongbacks within the compression mold tooling.

Indexing the vanes may include inserting a set of hard tool inserts into cavities formed by the vanes.

In another embodiment there is provided an apparatus for co-consolidating a plurality of strongbacks and a plurality of vanes. The apparatus includes a tool including a plurality of hard tool inserts fixed in relationship to each other and capable of being inserted into a first set of cavities formed by the vanes and, a plurality of mandrels capable of being individually inserted into a second set of cavities formed by the vanes.

The mandrels may be soluble.

The tool may include a tool base and the plurality of hard tool inserts may be fixed to the tool base.

The discontinuous fiber reinforcement may include at least one of carbon, metal, glass, and ceramic fiber.

The continuous fiber reinforcement may include at least one of carbon, metal, glass, and ceramic fiber.

The continuous fiber reinforcement may include multiple lamina having different fiber orientations.

The plurality of strongbacks may be spaced apart and extend generally parallel to each other.

The plurality of vanes may extend between adjacent spaced apart strongbacks.

The cascade may include fore and aft mounting flanges for mounting the cascade to jet engine, and the plurality strongbacks may extend between the fore and aft mounting flanges.

The plurality of strongbacks may be formed integrally with the fore and aft mounting flanges.

The plurality of stongbacks and plurality of vanes may be each formed from one of a polyetherimide, polyphenylene sulphide, polyethersulfone, polyetheretherketone, polyetherketoneketone, and polyetherketoneketone-fc grade polymer resin.

The features, functions, and advantages can be achieved independently in various embodiments of the present disclosure 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 illustrative embodiments are set forth in the appended claims. The illustrative embodiments, 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 illustrative embodiment of the present disclosure when read in conjunction with the accompanying drawings, wherein:

Figure **1** is an illustration of a side elevational view of an airplane jet engine, a transcowl having shifted rearwardly to expose a cascade-type thrust reverser.

Figure **2** is an illustration of a perspective view of the aft end of the jet engine shown in Figure **1**.

Figure **3** is a longitudinal sectional view of a portion of the jet engine shown in Figures **1** and **2**, illustrating airflow through the thrust reverser.

Figure **4** is an illustration of a top, perspective view of a cascade grid panel forming part of the thrust reverser.

Figure **5** is an illustration of the area designated as FIG. **5** in Figure **4**.

Figure **5**A is an illustration of the area designated as FIG. **5**A in Figure **5**.

Figure **5**B is an illustration of the area designated as FIG. **5**B in Figure **5**.

Figure **6** is an illustration of a perspective view of a strongback assembly.

Figure **7** is an illustration of a perspective view of a modular vane assembly.

Figure **8** is an illustration of a perspective view of an alternate embodiment of a vane assembly, showing the installation of individual vanes subassemblies.

Figure **9** is an illustration of a cross-sectional view showing a cascade grid panel about to be placed on hard tooling.

Figure **10** is an illustration similar to Figure **9** but showing the cascade grid panel having been located on the hard tooling.

Figure **11** is an illustration similar to Figure **10** but showing expandable soluble mandrels about to be inserted into open vane cavities in the cascade grid panel.

Figure **12** is illustration similar to Figure **11** but showing the expandable soluble mandrels having been inserted into the open vane cavities.

Figure **13** is an illustration of a top plan view showing the pre-consolidated vanes having been assembled with the pre-consolidated strongback assembly in preparation for co-consolidation.

Figure **14** is an illustration similar to Figure **13**, but showing the alternating locations of hard tool inserts and expandable soluble mandrels having been inserted into the vane cavities.

Figure **15** is an illustration of a block diagram broadly showing the components of tooling used to co-consolidate the pre-consolidated vanes and the pre-consolidated strongback assembly.

Figure **16** is an illustration of a flow diagram broadly showing the steps of a method of fabricating the cascade grid panels.

Figure **17** is an illustration of a flow diagram of aircraft production and service methodology.

Figure **18** is an illustration of a block diagram of an aircraft.

## DETAILED DESCRIPTION

Referring first to Figures **1-3**, an aircraft jet engine **20** includes an engine nacelle **22** and a transcowl **24** that translates rearwardly to expose a cascade-type thrust reverser **26**. The thrust reverser **26** comprises a plurality of circumferentially arranged, thrust reversing cascade grid panels **28**, sometimes referred to as cascade baskets.

During normal flying operations, the transcowl **24** is in a closed, forward position, joining the transcowl **24** with the nacelle **22**, and thereby covering the cascade grid panels **28**. During landing, the transcowl **24** is moved from its closed position to its open, rearwardly extended position (shown in Figures **1–3**) by means of actuator rods **30**. Opening the transcowl **24** exposes the cascade grid panels **28** to the surrounding environment. With the transcowl **24** having been shifted to its open position, the thrust reverser **26** is activated by closing circumferentially located blocker doors **32**. Closing the blocker doors **32** prevents the bypass exhaust from flowing in its normal direction out of the nozzle **34**, forcing the exhaust through the cascade grid panels **28**, as shown by the arrows **36** in Figure **3**. Each of the cascade grid panels **28** includes vanes **46** that direct the flow of the exhaust forward, and optionally radially outward, producing a reversal in the direction of the exhaust flow. This reversal of the exhaust flow results in a reversal of thrust that assists in slowing down the aircraft.

Attention is now directed to Figures **4** and **5** which illustrate additional details of one of the cascade grid panel **28**, along with a related coordinate system **25** showing the axial-forward direction, the radial-up direction and the side-circumferential direction. The cascade grid panel **28** is curved in the side-circumferential direction, and comprises a plurality of axially extending strongbacks **44**, a plurality of vanes **46** extending between the strongbacks **44**, and fore and aft mounting flanges **40**, **42** respectively. The mounting flanges **40**, **42** allow the cascade grid panels **28** to be mounted side-by-side in a circumferential arrangement around the engine nacelle **22**.

The strongbacks **44** are designed to react the majority of the load on the cascade grid panel **28**, while the vanes **46** are designed to react relatively minimal loads during a reverse thrust procedure. The strongbacks **44** include a later discussed a continuous fiber reinforcement, while the vanes **46** include a discontinuous fiber reinforcement. The strongbacks **44**, together with the vanes **46**, form a plurality of vane cavities **48** through which the bypass air flows and is redirected.

The strongbacks **44** extend generally parallel to each other and are spaced apart in the side-circumferential direction. In the disclosed embodiment, each of the strongbacks **44** is planar and is aligned with the radial-up direction, however in other embodiments, the strongbacks **44** may be not be planar and/or may be inclined a desired degree in order to direct the airflow in the side–circumferential direction. As will be discussed below in more detail, the strongbacks **44** are formed integral with the mounting flanges **40**, **42**. The vanes **46** are spaced apart from each other in the axial-forward direction and each may be inclined relative to the radial-up direction or be cup shaped (see Figure **5**) in order to redirect the bypass airflow in the axial-forward direction to produce reverse thrust.

Referring now particularly to Figures **5**, **5**A and **5**B, the strongbacks **44** and the vanes **46** may comprise a polymer resin such as a suitable fiber reinforced thermoplastic resin including, but not limited to PEI (polyetherimide) PPS (polyphenylene sulphide), PES (polyethersulfone), PEEK (polyetheretherketone), PEKK (polyetherketoneketone), and PEKK-FC (polyetherketoneketone-fc grade). As shown in Figure **5**A, the vanes **46** are reinforced with discontinuous long fibers **35** that may be randomly oriented. The discontinuous fibers **35** may include one or more of carbon, metal, glass or ceramic fibers, having lengths that are suitable for the application. For example, in one embodiment, the fibers **35** may be chopped flakes having a width and length of **1/2** inch X **1/2** inch respectively, while in another embodiment the width and length may be **1/16** inch X **1/2** inch respectively. The fibers **35** may have differing lengths and may have the same or different fiber thicknesses or diameters. The volume of the fibers relative to the thermoplastic matrix may vary with the performance requirements of the particular application. The selected thermoplastic composite material may be in the form of fabrics, tape semi-preg or other forms.

As shown in Figure **5**B, the strongbacks **44** along with the flanges **40**, **42** may be reinforced with continuous unidirectional fibers **45** which may be the same as, or different from the material than the discontinuous fibers **35** used to reinforce the vanes **46**. The strongbacks **44** and the flanges **40**, **42** may be of multiple lamina having differing fiber orientations that are pre-consolidated together. As will be discussed below, the vanes **46** may be pre-consolidated and then later co-consolidated with the pre-consolidated strongbacks **44** in a compression molding operation.

Referring now to Figure **6**, the thermoplastic strongbacks **44** along with the flanges **40**, **42** may be fabricated as a single, pre-consolidated thermoplastic strongback assembly **56** using a suitable thermoforming forming process such as without limitation, continuous compression molding. The strongback assembly **56** is formed with open, strongback slots **58** between adjacent strongbacks **44** which extend in the axial direction. As previously discussed, the strongbacks **44** may be inclined in order to direct the bypass airflow toward the side-circumferential direction.

Referring to Figure **7**, the pre-consolidated thermoplastic vanes **46** may be fabricated as a plurality of unitary, pre-consolidated modular vane assemblies **50** each of which comprises a plurality of individual vanes **46** that are joined to spaced apart sidewalls **54** connected together at their ends by and end walls **52**. The modular vane assemblies **50** have a geometry and dimensions that are substantially the same as the strongback slots **58**. The modular vane assemblies **50** may be produced as unitary modules by compression molding a thermoplastic composite resin, including any of the fiber reinforced thermoplastics described earlier. In order to assemble the vane assemblies **50** with the strongback assembly **56**, each of the vane assemblies **50** is placed in one of the strongback slots **58** and loaded into later discussed tooling that is used to co-consolidate the vane assemblies **50** and the strongback assemblies **56**.

Attention is now directed to Figure **8** which illustrates an alternate method of installing individual vanes **46** between adjacent strongbacks **44**. In this embodiment, individual vane subassemblies **60** may be fabricated by compression molding or other thermoforming techniques. The individual vane subassemblies **60** are placed at the desired locations within the strongback slots **58** and indexed within suitable tooling to maintain the positions of the vane subassemblies **60** in relationship to the strongback assembly **56**. Each of the vane subassemblies **60** includes a vane **46** having integrally molded sidewalls **54** which contact contacts and becomes co-consolidated with the strongbacks **44**. Each of the vane subassemblies **60** is a pre-consolidated thermoplastic reinforced with discontinuous long fibers, as previously discussed.

Referring now to Figures **9-12**, the strongback assembly **56** and the vane subassemblies **60** (or modular vane assemblies **50**) are co-consolidated using a combination of hard tooling **70** and dissolvable tool inserts in the form of expandable soluble mandrels **78**. The expandable soluble minerals **78** may be formed of conventional materials that may be dissolved and washed away after the consolidation process is completed, as by subjecting the mandrels **78** to a dissolving liquid such as water. The expandable soluble mandrels **78** reduce tooling costs, however in some embodiments, the mandrels **78** may be hard tools, rather than soluble. The hard tooling **70** includes hard tool inserts **72** fixed on a tool base **74**. The hard tool inserts **72** and the expandable soluble mandrels **78** have a cross-sectional geometry substantially matching that of the vane cavities **48**. When heated either in an oven, a press or an autoclave, the tool inserts **72**, **78**, expand and thereby compress the sidewalls **54** of the vane subassemblies **60** against the strongbacks **44**. The tooling and the pre-consolidated strongback assembly **56** and vane subassemblies **60** may be assembled using any of various techniques.

For example, as shown in Figure **9**, the cascade grid panel assembly **66** may be preassembled, following which, as shown in Figure **9** the hard tool inserts **72** are inserted **68** into alternating ones of the vane cavities **48**. Figure **10** shows the hard tool inserts **72** having been inserted into the vane cavities **48**, and the cascade grid panel assembly **66** resting on the tool base **74**. Next, as shown in Figure **11**, the expandable soluble minerals **78** are inserted into the remaining open vane cavities **48**, following which, as shown in Figure **12**, all of the vane cavities **48** have tool inserts therein and the assembly of the tooling and the grid panel assembly **66** is ready to be placed in a compression molding apparatus (not shown) to carry out the final co-consolidation process. Other techniques for assembling the components of the grid panel assembly **66** with the tooling are possible.

Figure **13** illustrates a portion of the assembled prior to the tool inserts **72**, **78** being inserted into the vane cavities **48**. In one embodiment, as shown in Figure **14**, the tool inserts **72**, **78** may be arranged to be placed in an alternating manner in the vane cavities **48**. During the assembly of the tooling with the components of the grid panel assembly **66**, the hard tool inserts **72** function to index the vane subassemblies **60** relative to each other and relative to the strongback assembly **56**.

Referring now to Figure **15**, with the tool inserts **72** and soluble mandrels **78** having been inserted into alternating ones of the vane cavities **48** of the cascade grid assembly **66**, the cascade grid assembly **66** may be placed in a consolidation tool and loaded into a compression press **75**, which applies pressure **P** to the cascade grid assembly **66** using a top tool **80**, a bottom tool **82** and side tools **84**, **86**. The use of alternating hard tool inserts **72** and soluble mandrels **78** assists in locating the components of the grid panel **28** prior to co-consolidation to provide repeatability and accurate placement, and help assure that the components do not float, move or re-melt during the final co-consolidation phase.

Figure **16** broadly illustrates the overall steps of a method of fabricating cascade grid panels **28** of the type described above. At **88**, the vanes **46** may be fabricated by compression molding a suitable thermoplastic resin reinforced with discontinuous long fibers **35**. Similarly, in step **90** the strongbacks **44** may be fabricated by continuous compression molding a suitable thermoplastic resin reinforced with continuous fibers **45**, such as unidirectional prepreg. With the vanes **46** and the strongbacks **44** having been separately pre-consolidated in steps **88** and **90**, steel compression mold tooling is provided at step 92 which includes hard tool cavity inserts **72**. At step **94**, the pre-consolidated vanes **46** and strongbacks **44** are loaded into compression mold tooling, where the hard tool inserts **72** act as indexing or locating features that properly locate the vanes **46** relative to each other and relative to the strongbacks **44**.

Next, at step **96**, the second set of tool inserts the form of expandable soluble mandrels **78** are inserted into the remaining open vane cavities that are not already filled with hard tool inserts **72** in order to fill these open vane cavities. At step **98**, the tooling is heated in an oven, a heated hydraulic press and/or an autoclave to the melting temperature of the thermoplastic, in preparation for final consolidation. At **100**, heat and pressure are used to co-consolidate the strongbacks **44** and the vanes **46** into a homogeneous cascade grid panel assembly **28**, during which the hard tool inserts **72** and the mandrels **78** expand to exert pressure against the vanes **46**.

The pressure applied against the vanes **46** presses the vanes **46** outward against the IML (inner mold line) of the strongback assembly **56**, thereby co-consolidating the vanes **46** and the strongbacks **44** into a homogeneous continuous fiber and discontinuous fiber, all thermoplastic composite cascade grid panel **28**. With the vanes **46** and the strongbacks **44** fully co-consolidated, then, at **102** the tooling is cooled down, thereby cooling the vanes **46** and the strongbacks **44**. Then the consolidated cascade grid panel **28** is removed from the tooling and the mandrels **78** are washed away. At **104**, the consolidated cascade grid panel assembly **28** is trimmed, as necessary.

Embodiments of the disclosure may find use in a variety of potential applications, particularly in the transportation industry, including for example, aerospace, marine, automotive applications and other application where grid-type panels may be used. Thus, referring now to Figures **17** and **18**, embodiments of the disclosure may be used in the context of an aircraft manufacturing and service method **106** as shown in Figure **17** and an aircraft **108** as shown in Figure **18**. Aircraft applications of the disclosed embodiments may include, for example, without limitation, thrust reversers for jet engines. During pre-production, exemplary method **106** may include specification and design **110** of the aircraft **108** and material procurement **112**. During production, component and subassembly manufacturing **114** and system integration **116** of the aircraft **108** takes place. Thereafter, the aircraft **108** may go through certification and delivery **118** in order to be placed in service **120**. While in service by a customer, the aircraft **108** is scheduled for routine maintenance and service **122**, which may also include modification, reconfiguration, refurbishment, and so on.

Each of the processes of method **106** may be performed or carried out by a system integrator, a third party, and/or an operator (e.g., a customer). For the purposes of this description, a system integrator may include without limitation any number of aircraft manufacturers and major-system subcontractors; a third party may include without limitation any number of vendors, subcontractors, and suppliers; and an operator may be an airline, leasing company, military entity, service organization, and so on.

As shown in Figure **18**, the aircraft **108** produced by exemplary method **106** may include an airframe **124** with a plurality of systems **126** and an interior **128**. Examples of high-level systems **126** include one or more of a propulsion system **130**, an electrical system **132**, a hydraulic system **134** and an environmental system **136**. Any number of other systems may be included. Although an aerospace example is shown, the principles of the disclosure may be applied to other industries, such as the marine and automotive industries.

Systems and methods embodied herein may be employed during any one or more of the stages of the production and service method **106**. For example, components or subassemblies corresponding to production process **114** may be fabricated or manufactured in a manner similar to components or subassemblies produced while the aircraft **108** is in service. Also, one or more apparatus embodiments, method embodiments, or a combination thereof may be utilized during the production stages **114** and **116**, for example, by substantially expediting assembly of or reducing the cost of an aircraft **108**. Similarly, one or more of apparatus embodiments, method embodiments, or a combination thereof may be utilized while the aircraft **108** is in service, for example and without limitation, to maintenance and service **122**.

The description of the different illustrative embodiments has been presented for purposes of illustration and description, and is not intended to be exhaustive or limited to the embodiments in the form disclosed. Many modifications and variations will be apparent to those of ordinary skill in the art. Further, different illustrative embodiments may provide different advantages as compared to other illustrative embodiments. The embodiment or embodiments selected are chosen and described in order to best explain the principles of the embodiments, the practical application, and to enable others of ordinary skill in the art to understand the disclosure for various embodiments with various modifications as are suited to the particular use contemplated.

**THE EMBODIMENTS OF THE INVENTION IN WHICH AN EXCLUSIVE PROPERTY OR PRIVILEGE IS CLAIMED ARE DEFINED AS FOLLOWS:**

**1.** A cascade for a jet engine thrust reverser, comprising:

a plurality of strongbacks each formed of a polymer resin having a continuous fiber reinforcement; and

a plurality of vanes joined to the strongbacks and each formed of a polymer resin having a discontinuous fiber reinforcement.

**2.** The cascade of claim **1**, wherein the polymer resin is a thermoplastic resin.

**3.** The cascade of claim **1** or **2**, wherein the strongbacks and the vanes are co-consolidated.

**4.** The cascade of any one of claims **1** to **3**, wherein the plurality of vanes are arranged in a plurality of modular vane assemblies co-consolidated with the plurality of strongbacks.

**5.** The cascade of any one of claims **1** to **4**, wherein the discontinuous fiber reinforcement includes randomly oriented, chopped fibers.

**6.** The cascade of any one of claims **1** to **5**, wherein the discontinuous fiber reinforcement comprises at least one of carbon, metal, glass, and ceramic fiber.

**7.** The cascade of any one of claims **1** to **6**, wherein the continuous fiber reinforcement comprises at least one of carbon, metal, glass, and ceramic fiber.

**8.** The cascade of any one of claims **1** to **7**, wherein the continuous fiber reinforcement comprises multiple lamina having different fiber orientations.

**9.** The cascade of any one of claims **1** to **8**, wherein the plurality of strongbacks are spaced apart and extend generally parallel to each other.

**10**. The cascade of claim **9**, wherein the plurality of vanes extend between adjacent spaced apart strongbacks.

**11**. The cascade of any one of claims **9** to **10**, further comprising fore and aft mounting flanges for mounting the cascade to jet engine, and wherein the plurality strongbacks extend between the fore and aft mounting flanges.

**12**. The cascade of claim **11**, wherein the plurality of strongbacks are formed integrally with the fore and aft mounting flanges.

**13**. The cascade of any one of claims **1** to **12**, wherein the plurality of stongbacks and plurality of vanes are each formed from one of a polyetherimide, polyphenylene sulphide, polyethersulfone, polyetheretherketone, polyetherketoneketone, and polyetherketoneketone-fc grade polymer resin.

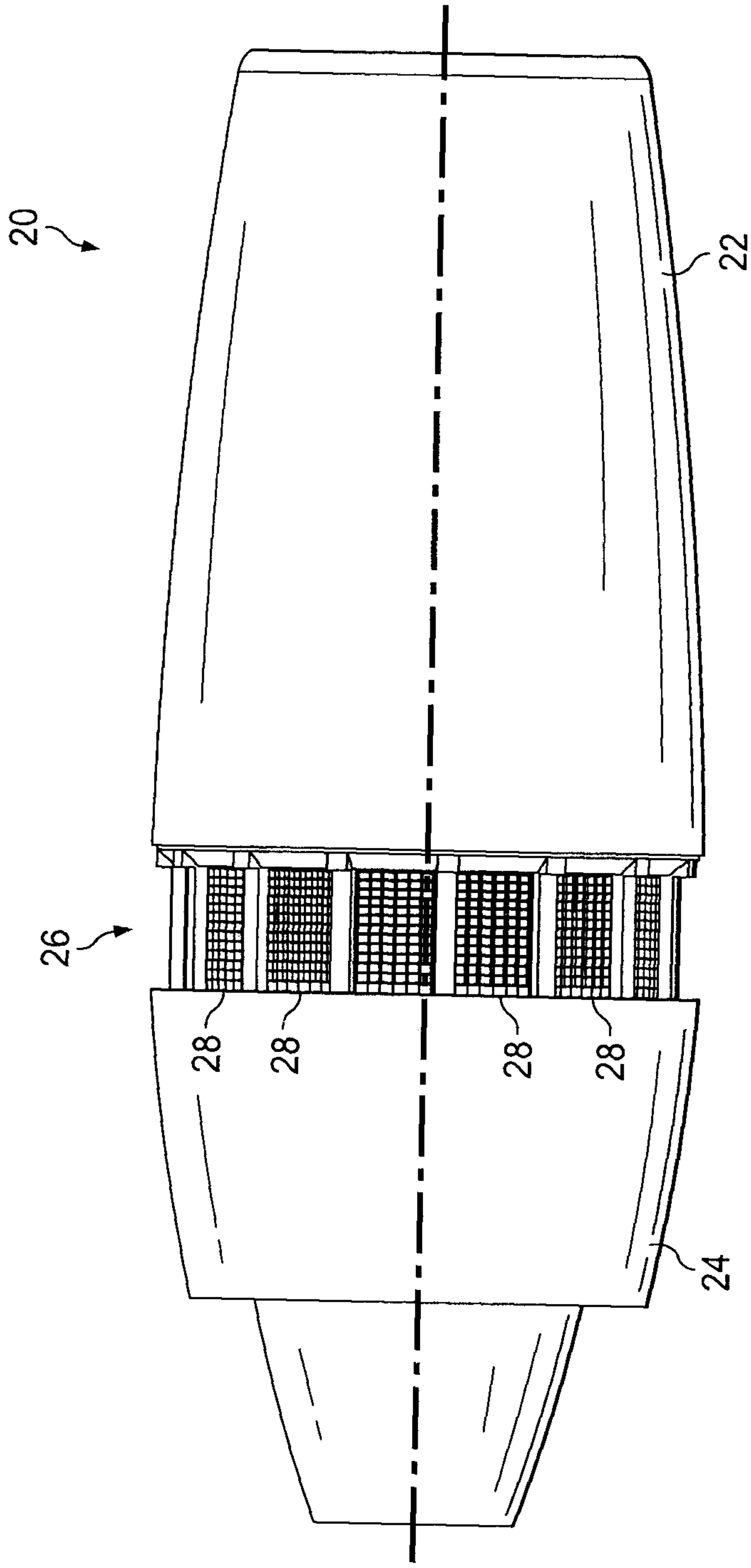



FIG. 1

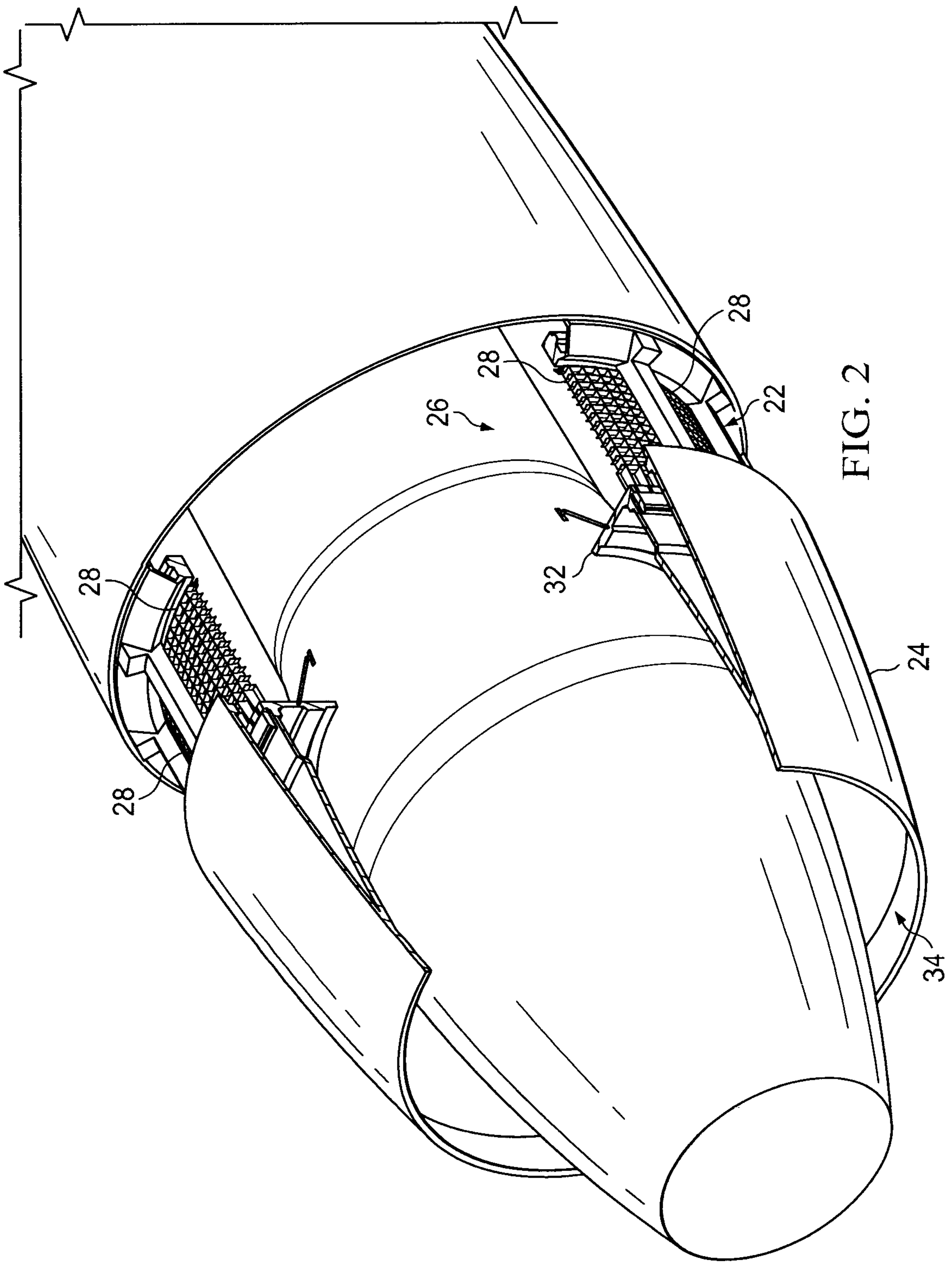



FIG. 2

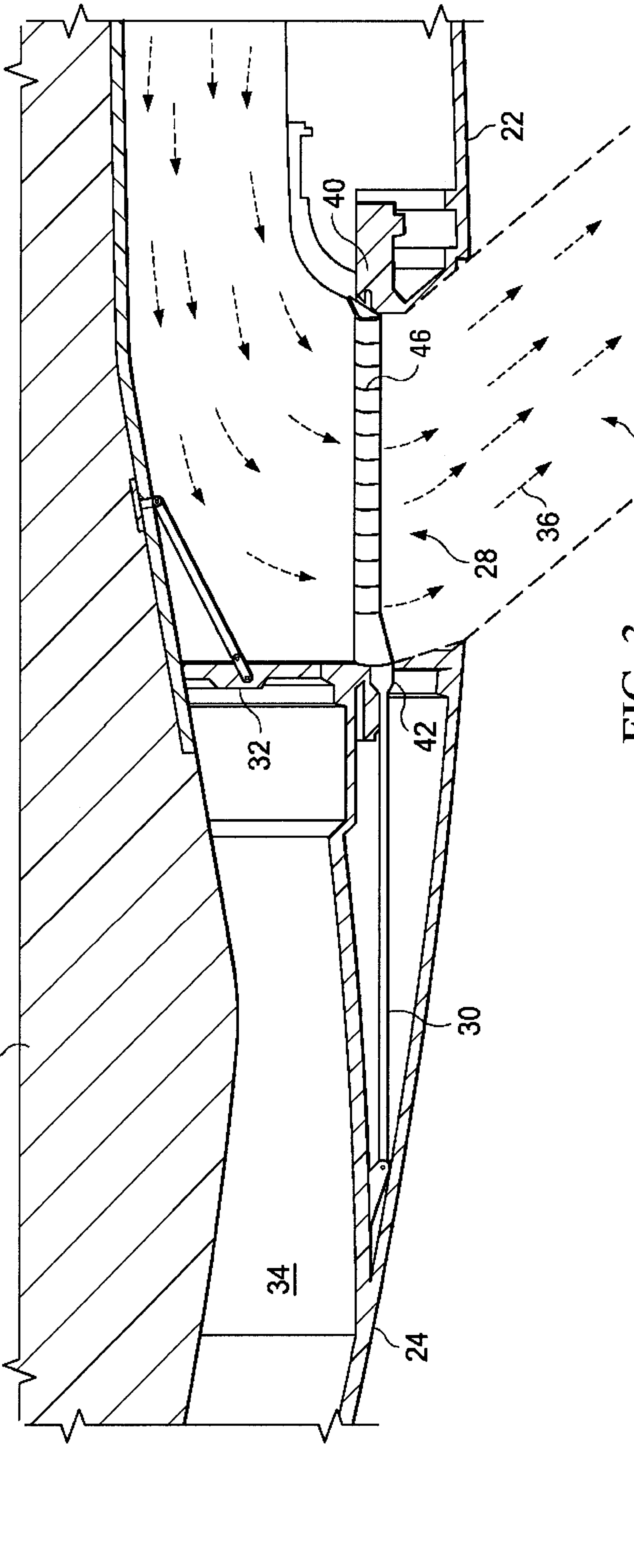



FIG. 3

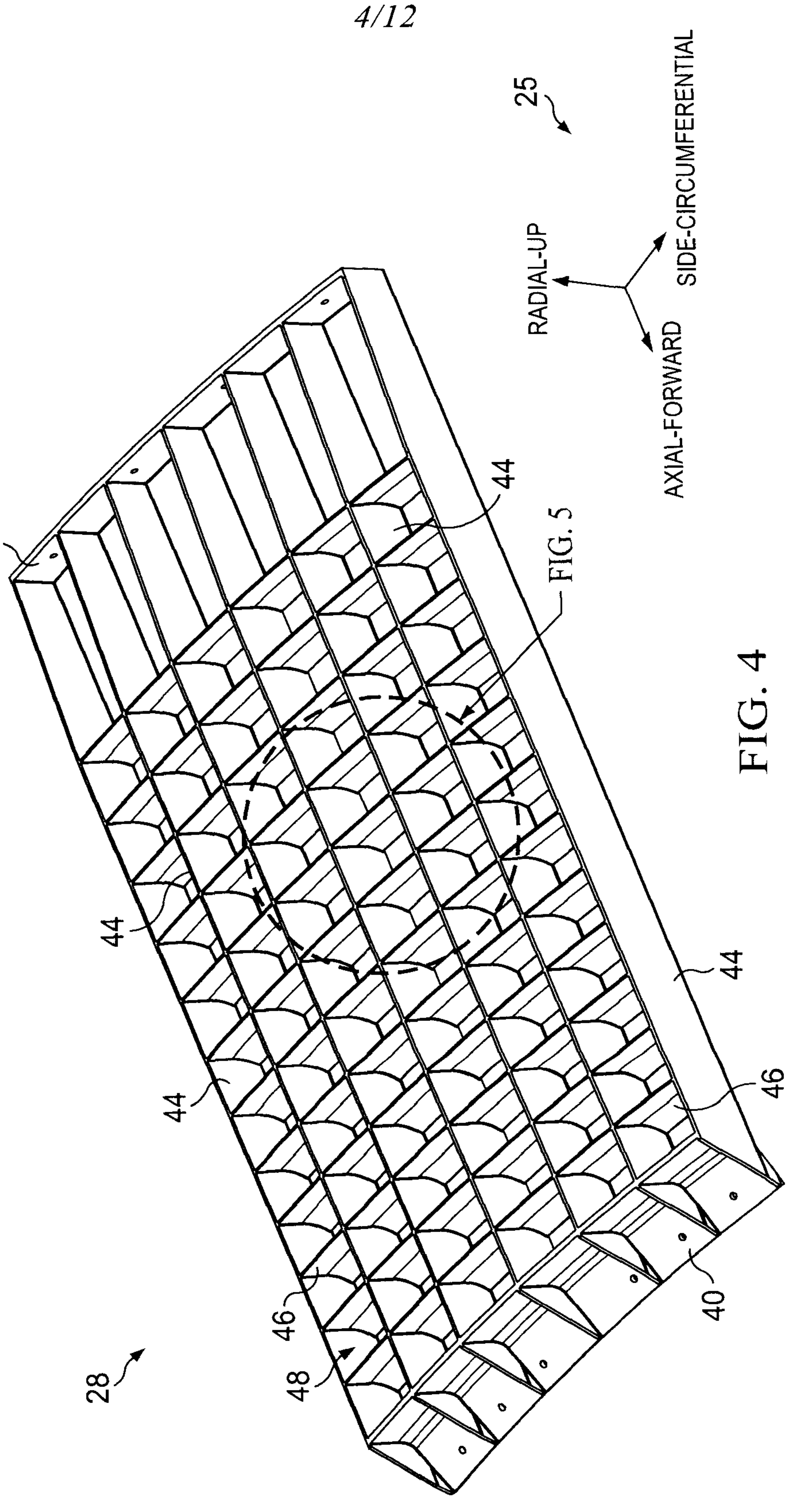

25
RADIAL-UP
SIDE-CIRCUMFERENTIAL
AXIAL-FORWARD
42
44
FIG. 5
44
44
44
46
46
48
28
40

FIG. 4

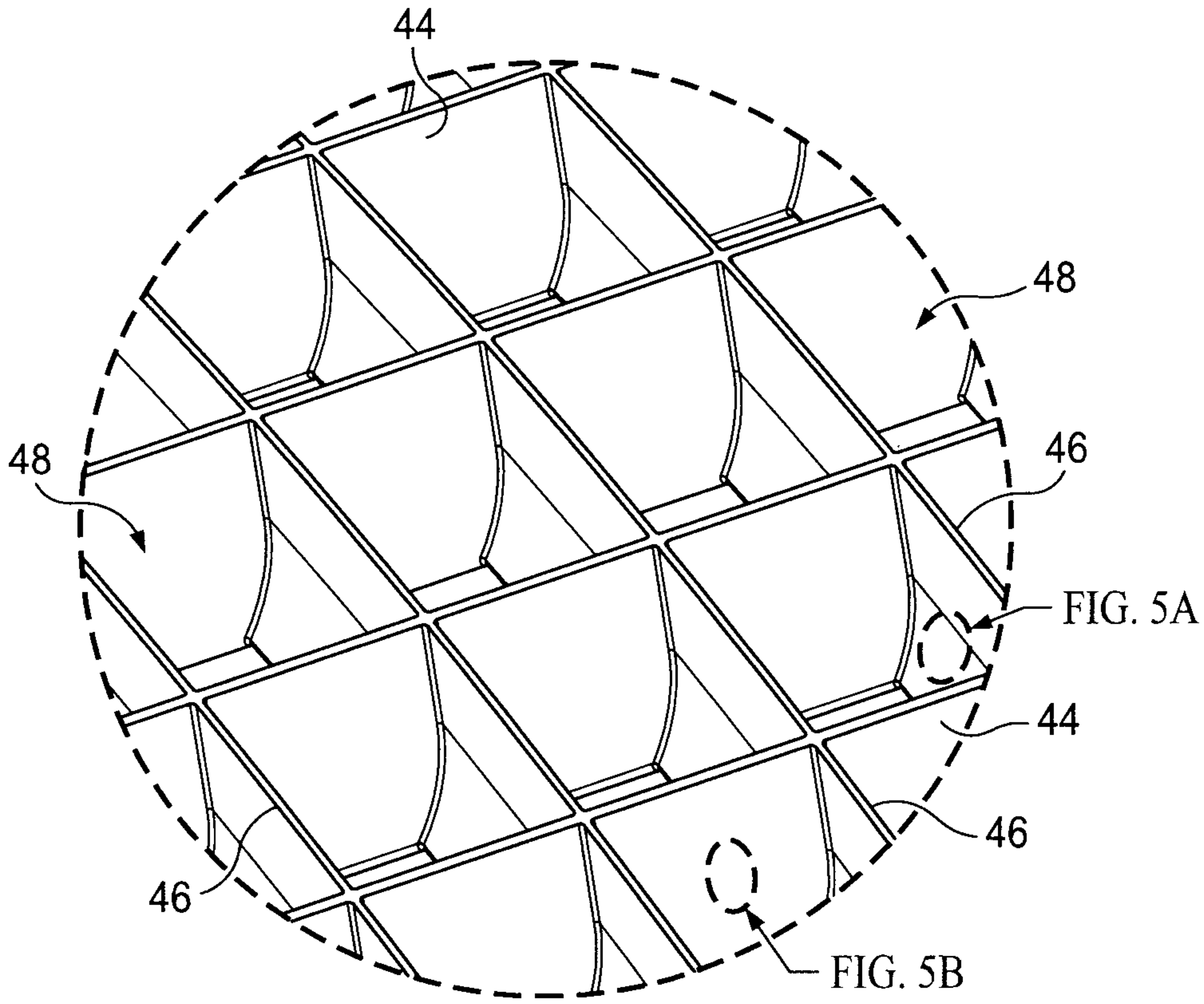



FIG. 5

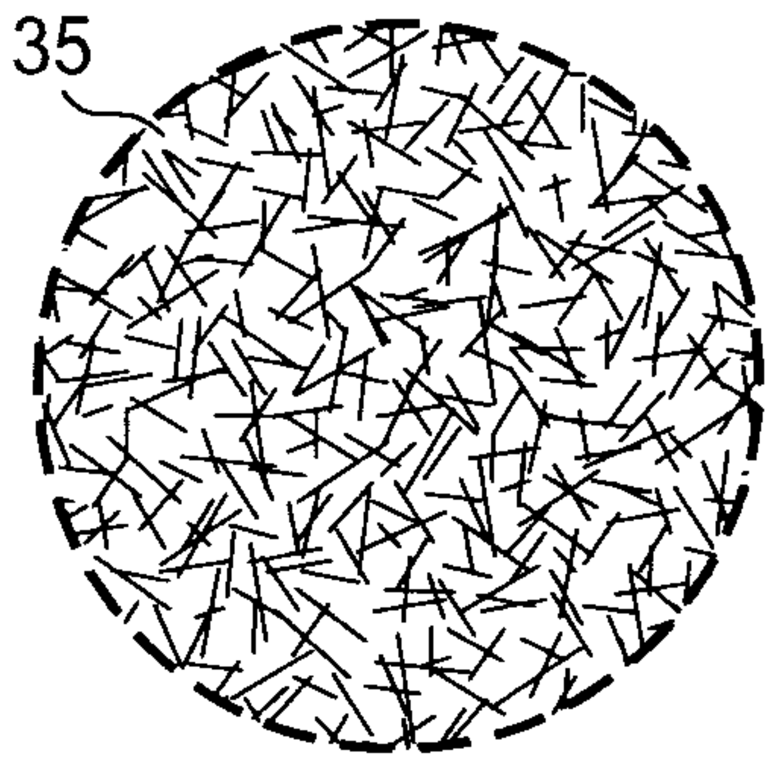



FIG. 5A

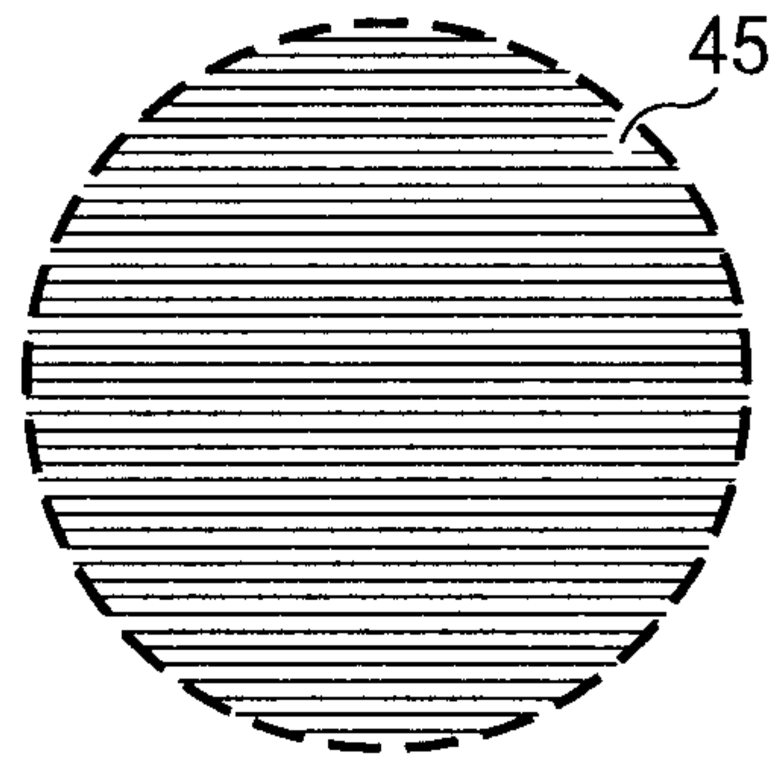



FIG. 5B

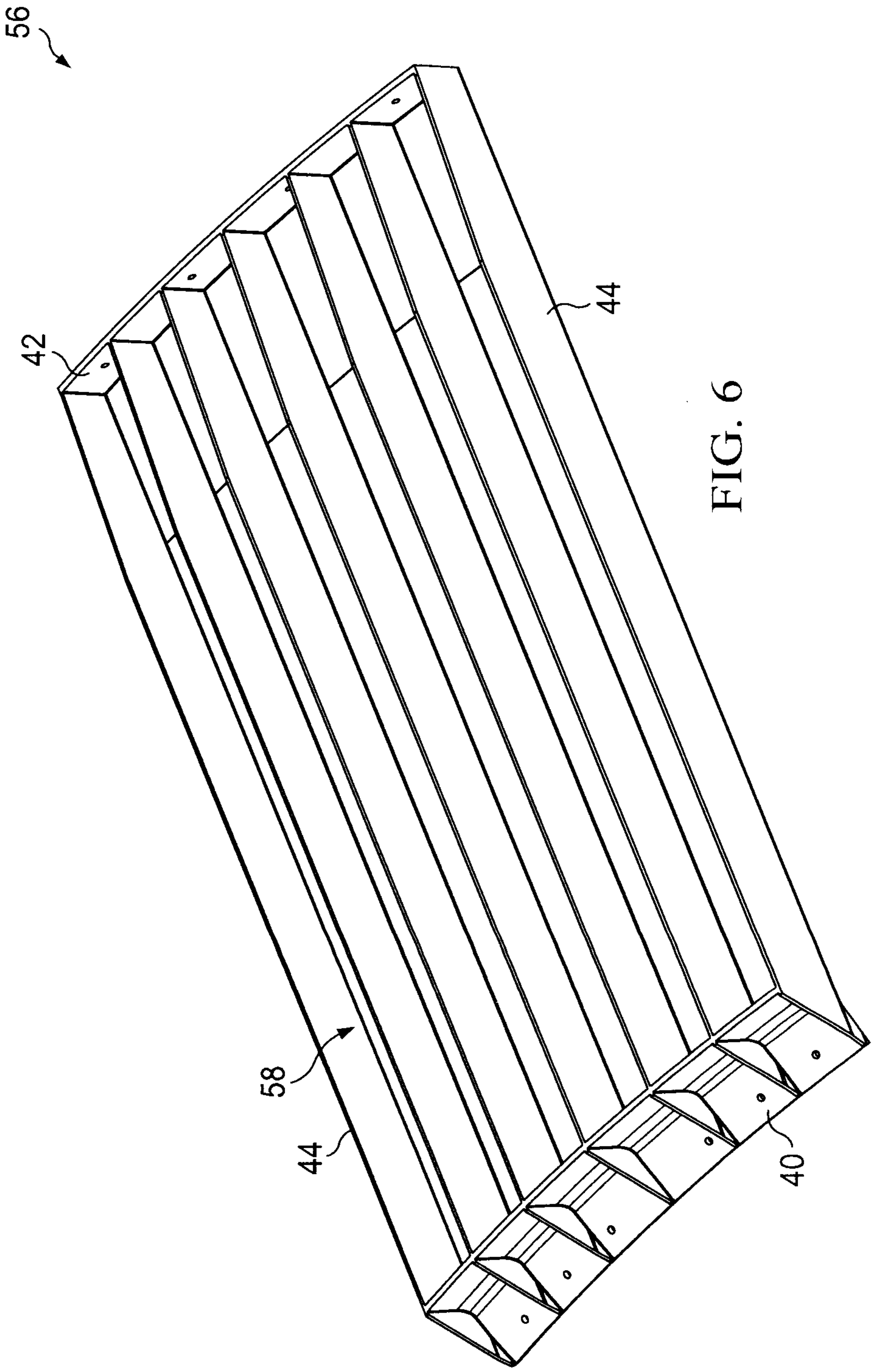



FIG. 6

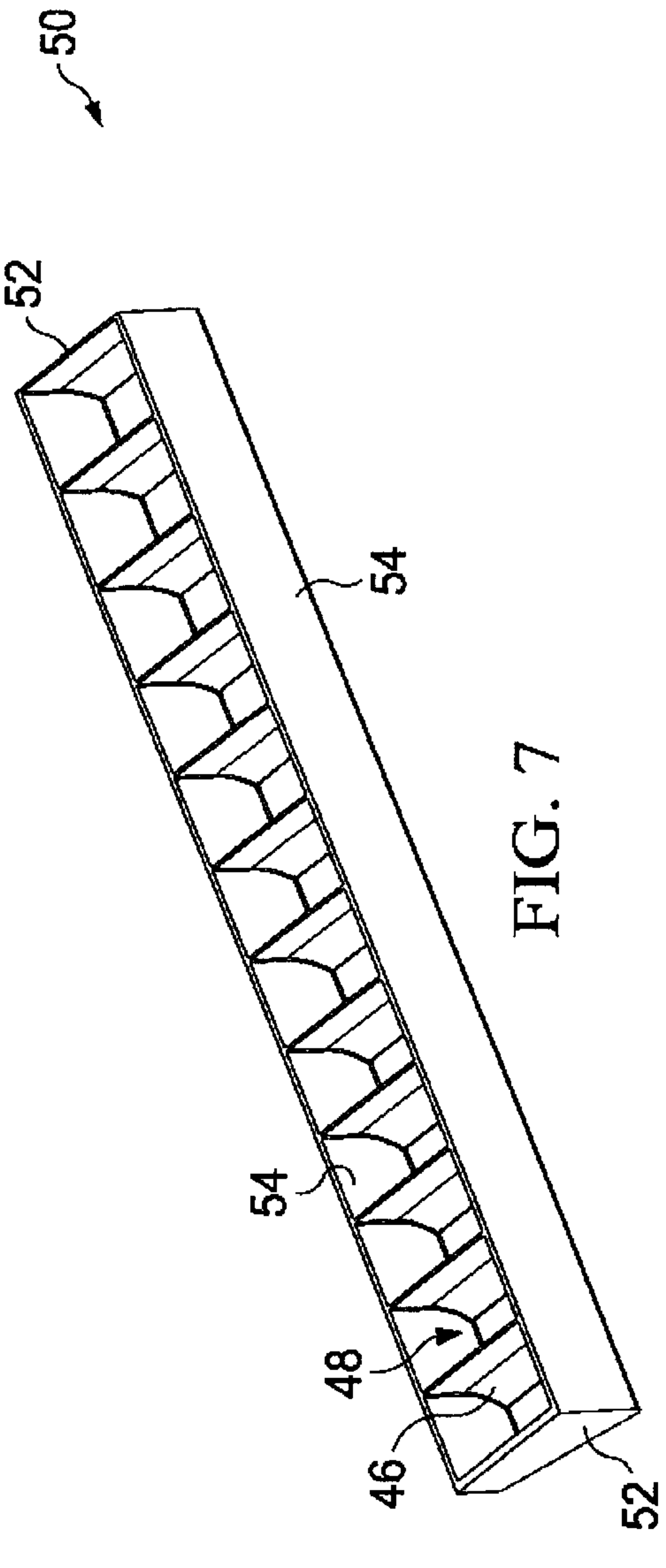



FIG. 7

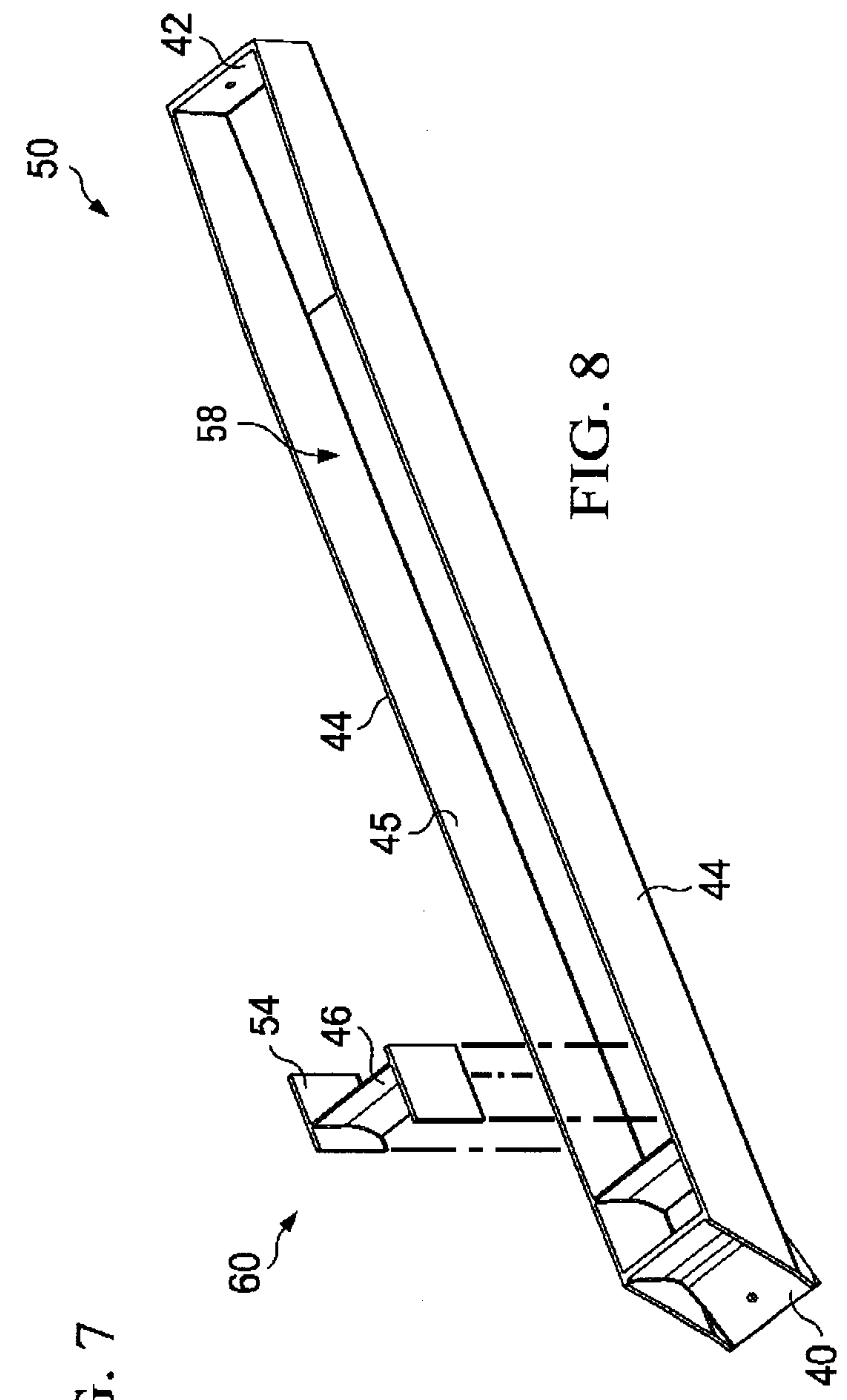



FIG. 8

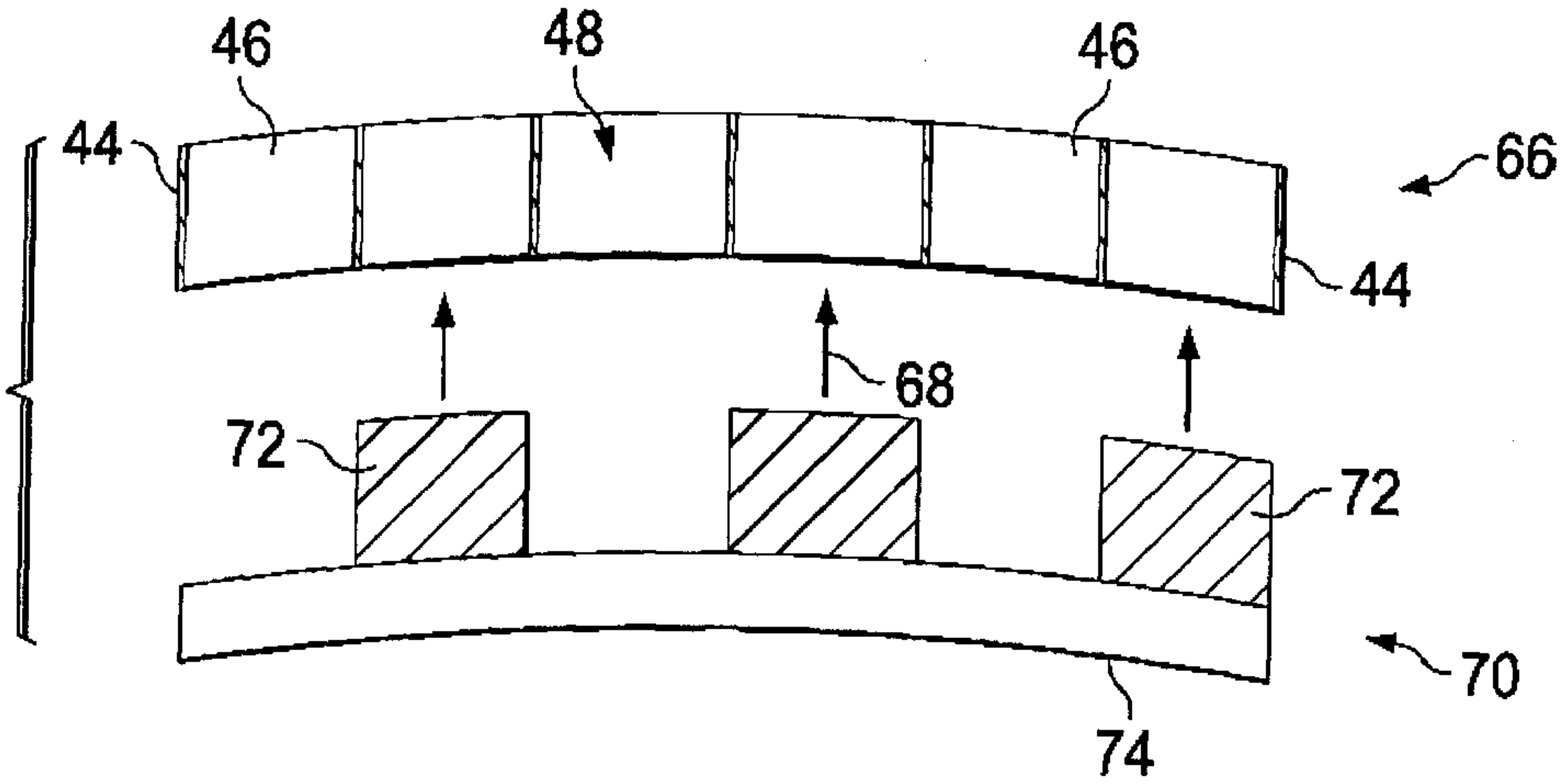
FIG. 9


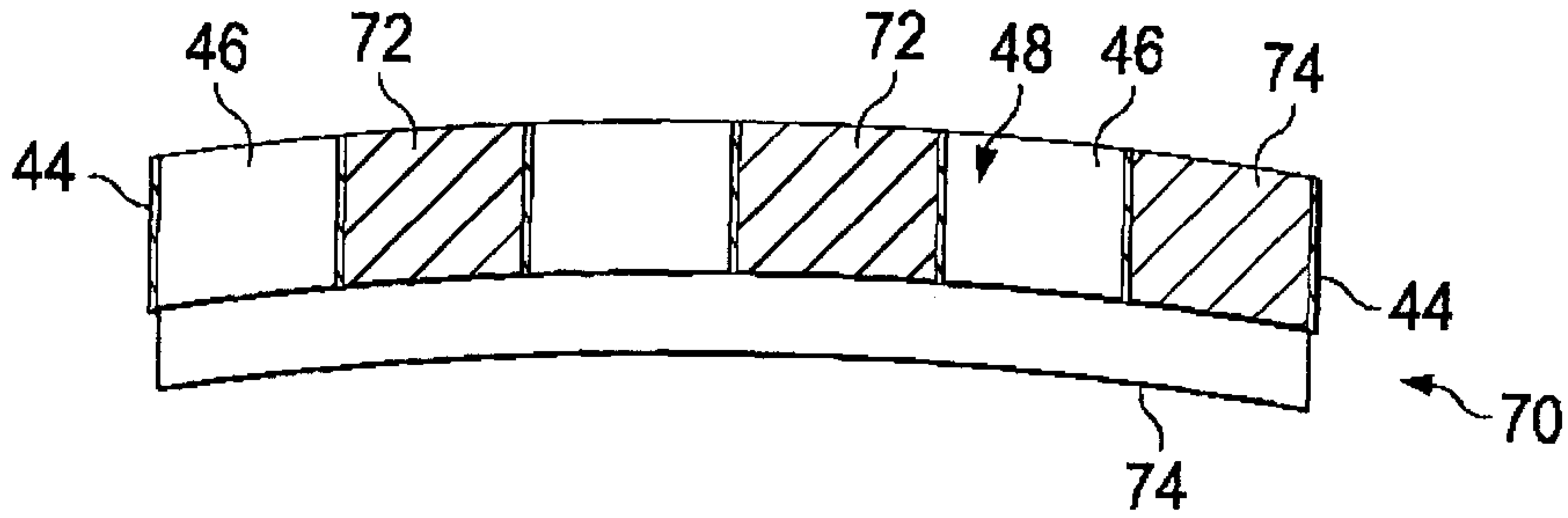

FIG. 10


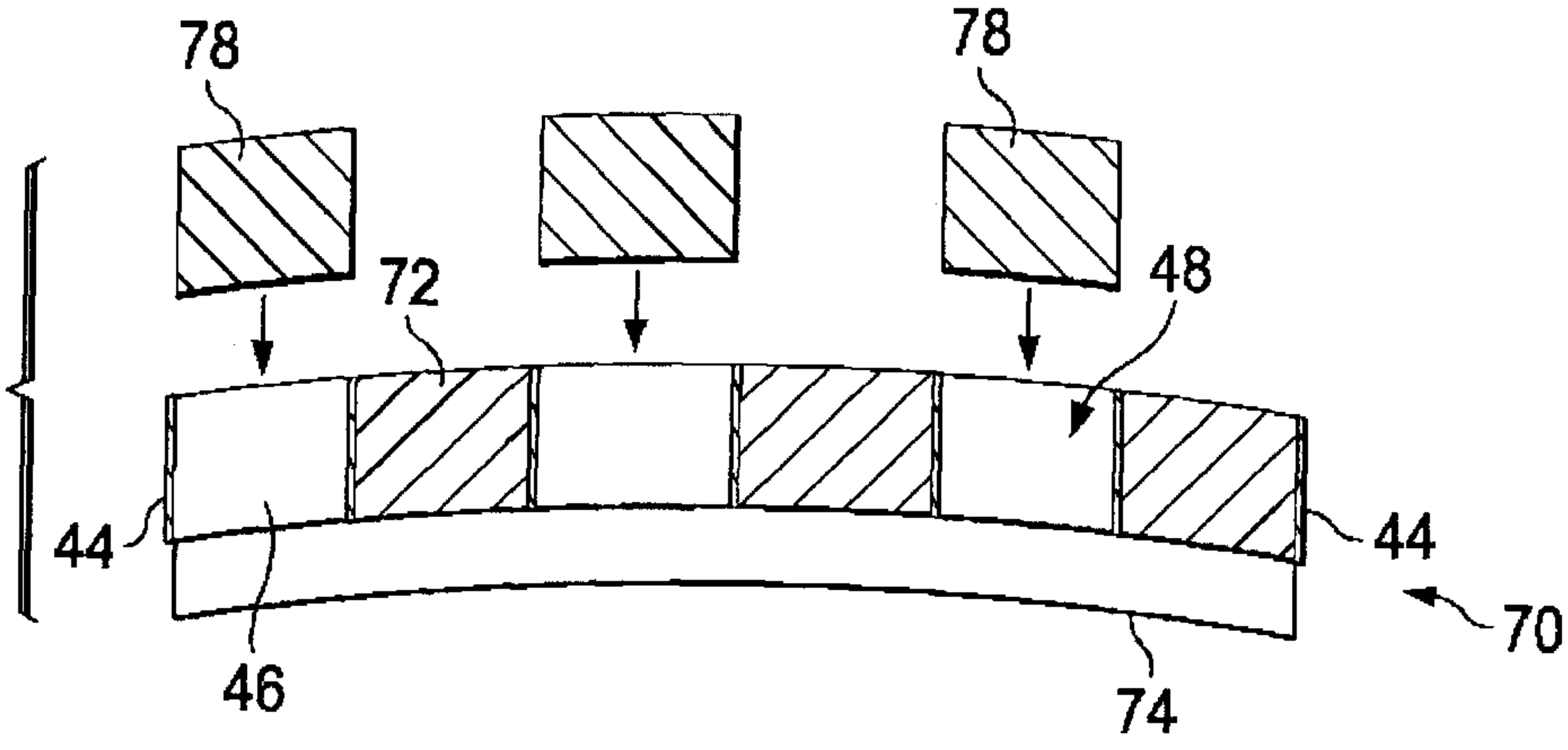
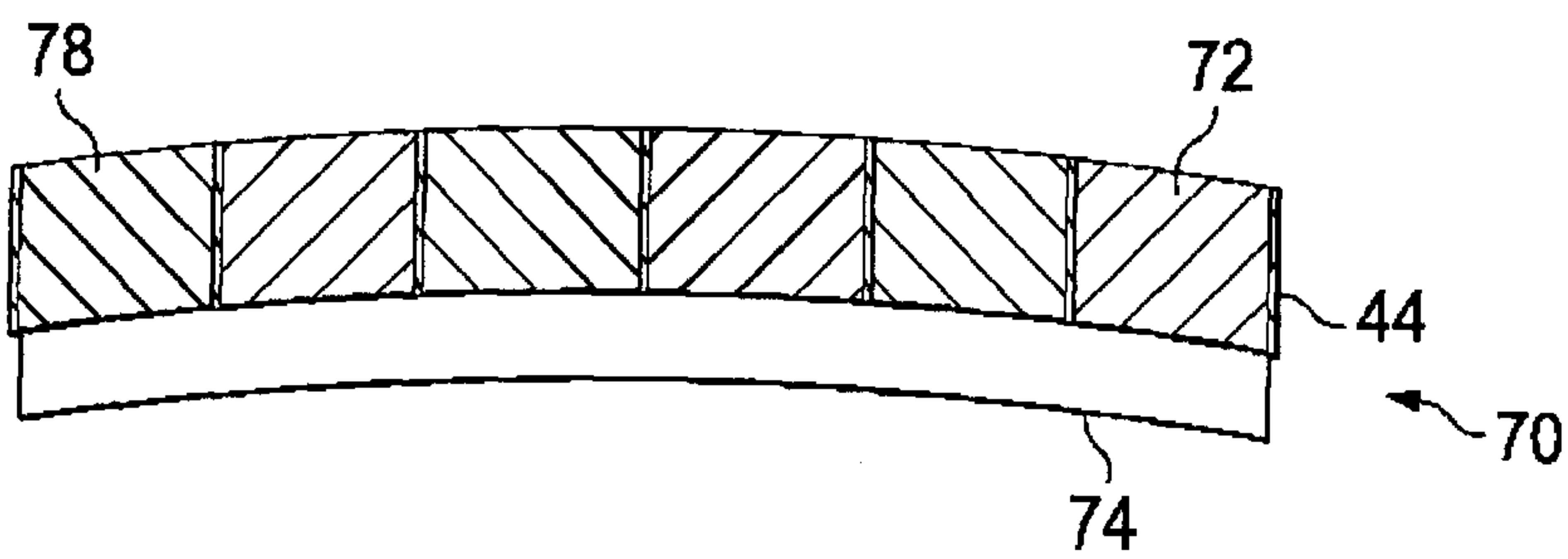

FIG. 11



FIG. 12


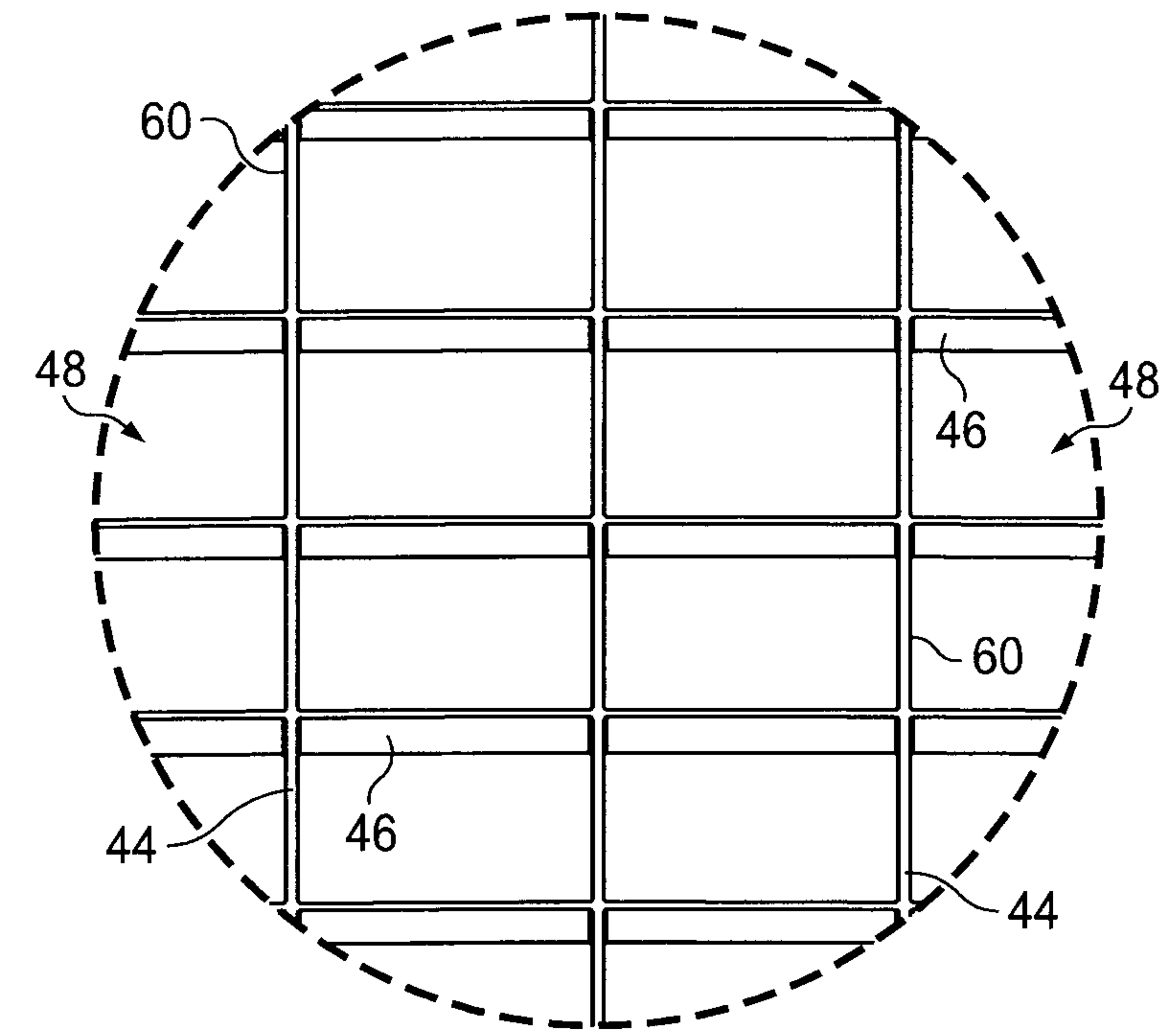



FIG. 13

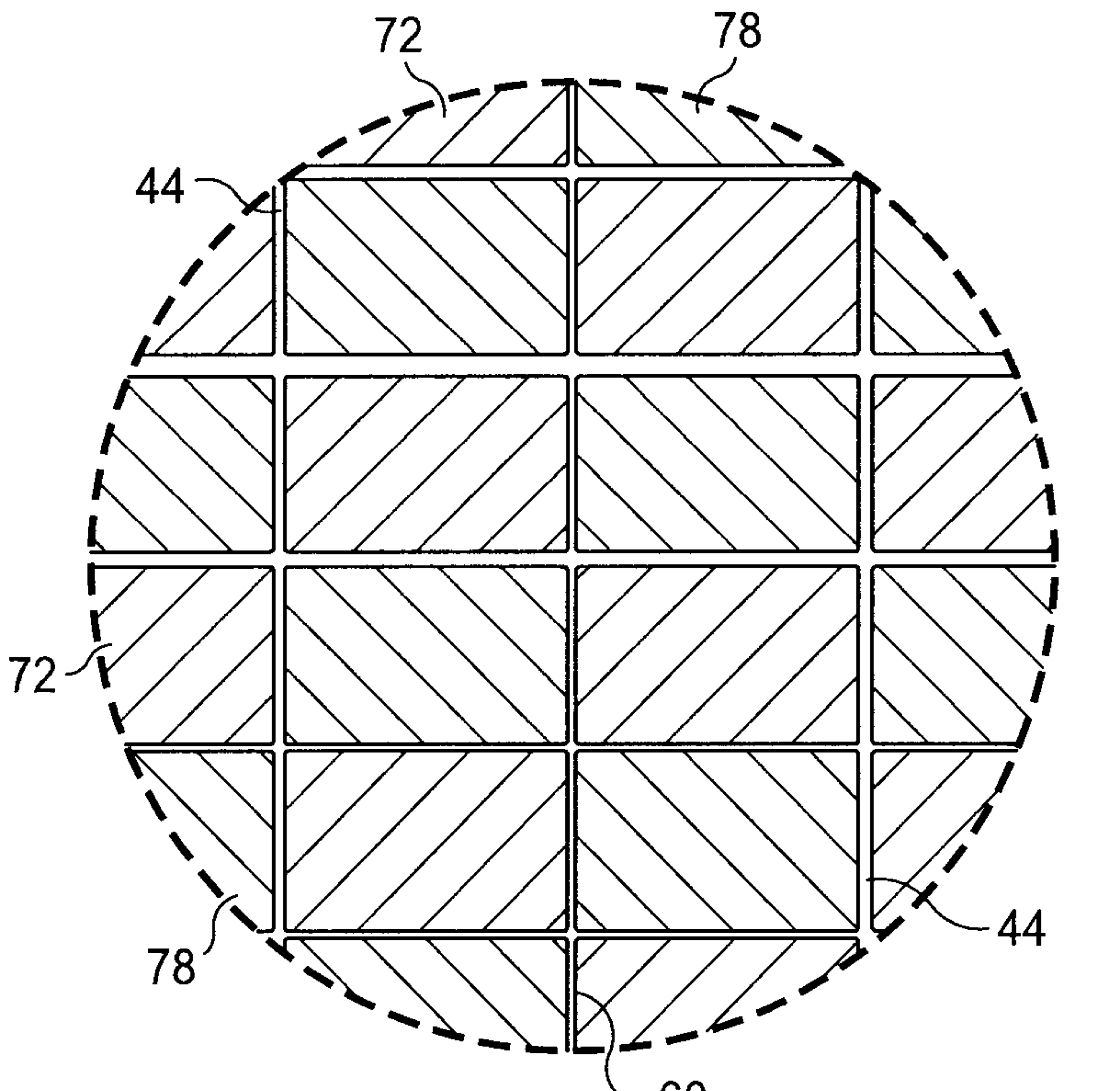



FIG. 14

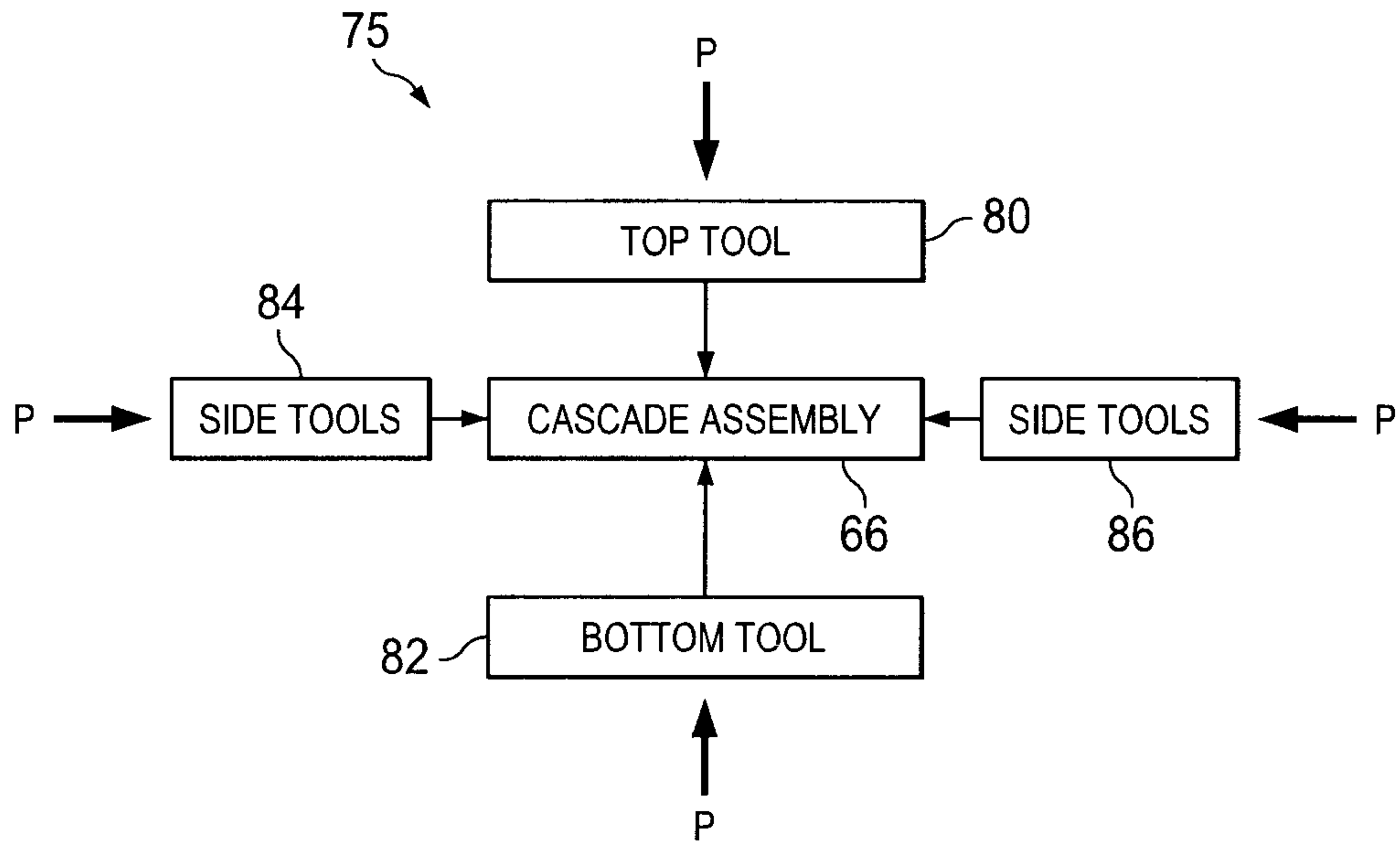

75
P
TOP TOOL
80
84
P
SIDE TOOLS
CASCADE ASSEMBLY
SIDE TOOLS
P
66
86
82
BOTTOM TOOL
P

FIG. 15

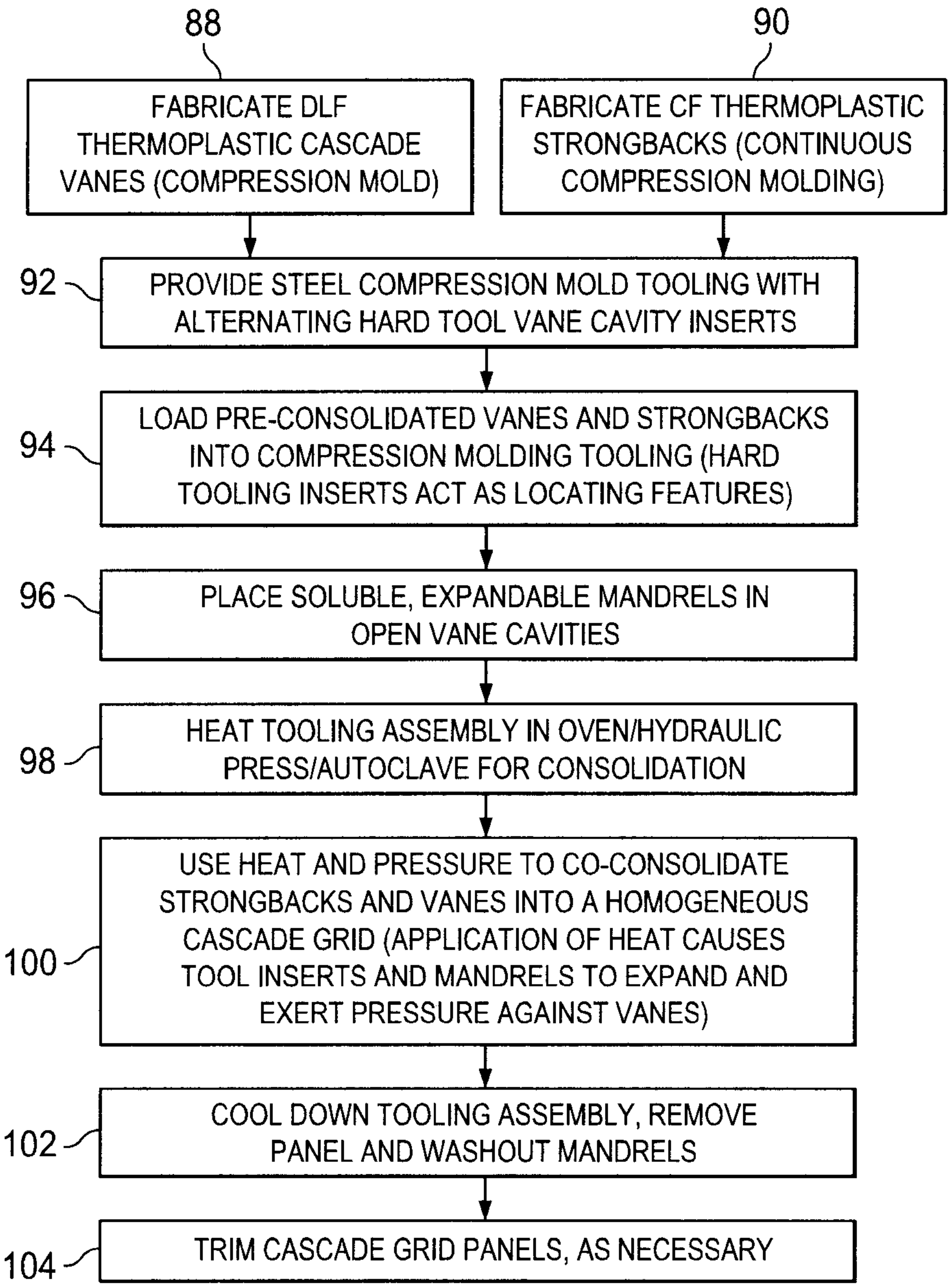

88
FABRICATE DLF THERMOPLASTIC CASCADE VANES (COMPRESSION MOLD)
90
FABRICATE CF THERMOPLASTIC STRONGBACKS (CONTINUOUS COMPRESSION MOLDING)
92
PROVIDE STEEL COMPRESSION MOLD TOOLING WITH ALTERNATING HARD TOOL VANE CAVITY INSERTS
94
LOAD PRE-CONSOLIDATED VANES AND STRONGBACKS INTO COMPRESSION MOLDING TOOLING (HARD TOOLING INSERTS ACT AS LOCATING FEATURES)
96
PLACE SOLUBLE, EXPANDABLE MANDRELS IN OPEN VANE CAVITIES
98
HEAT TOOLING ASSEMBLY IN OVEN/HYDRAULIC PRESS/AUTOCLAVE FOR CONSOLIDATION
100
USE HEAT AND PRESSURE TO CO-CONSOLIDATE STRONGBACKS AND VANES INTO A HOMOGENEOUS CASCADE GRID (APPLICATION OF HEAT CAUSES TOOL INSERTS AND MANDRELS TO EXPAND AND EXERT PRESSURE AGAINST VANES)
102
COOL DOWN TOOLING ASSEMBLY, REMOVE PANEL AND WASHOUT MANDRELS
104
TRIM CASCADE GRID PANELS, AS NECESSARY

FIG. 16

FIG. 17

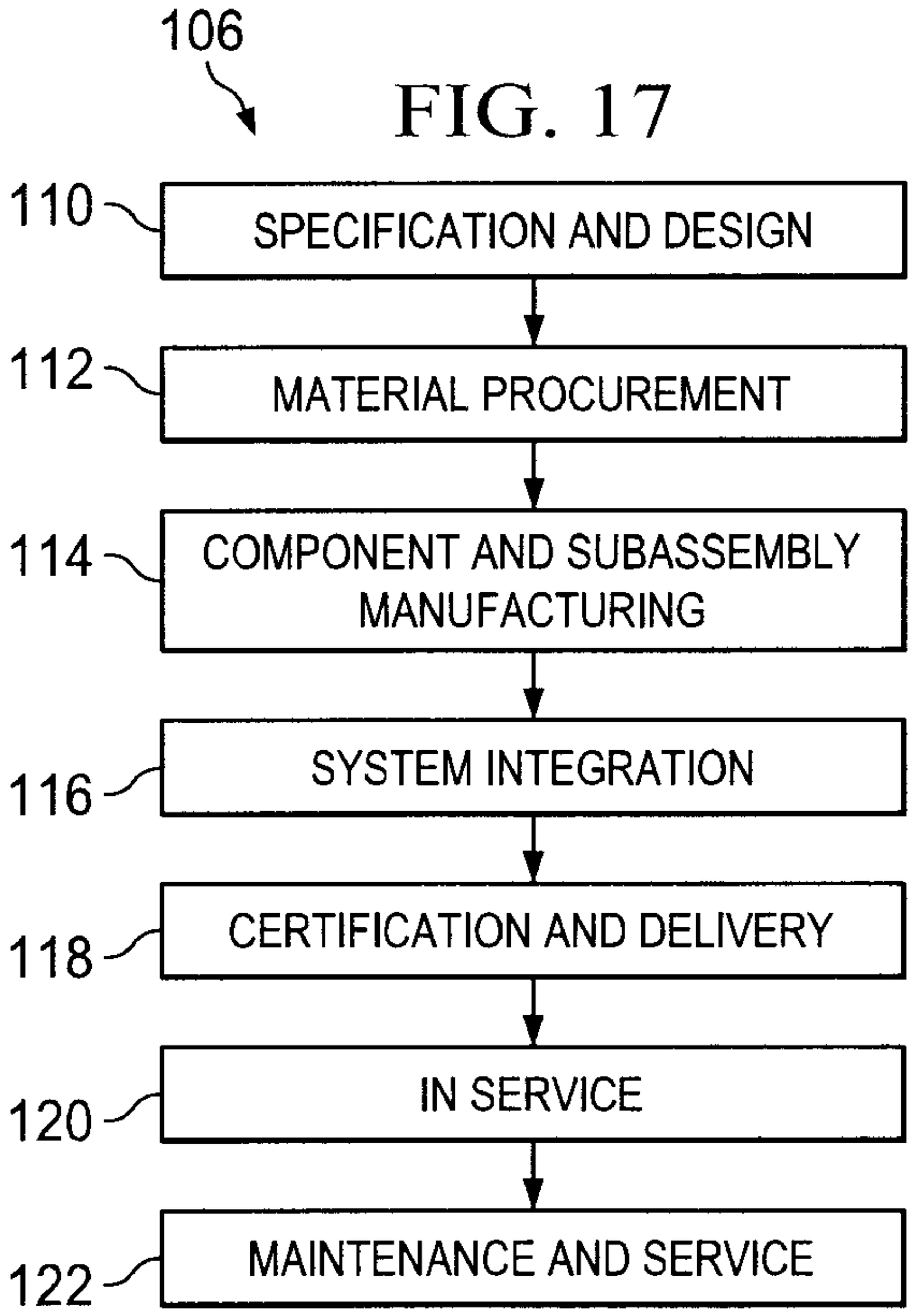
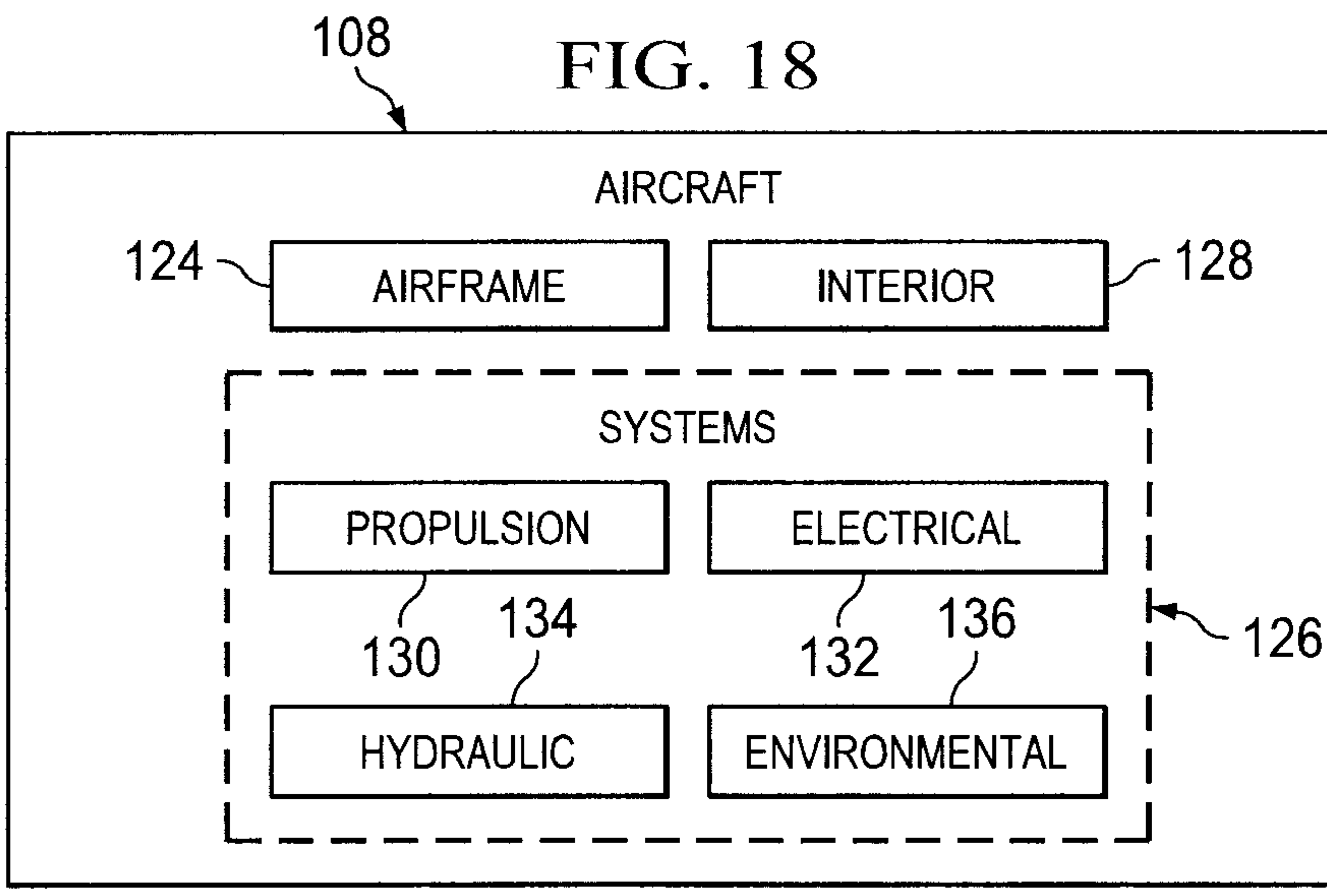
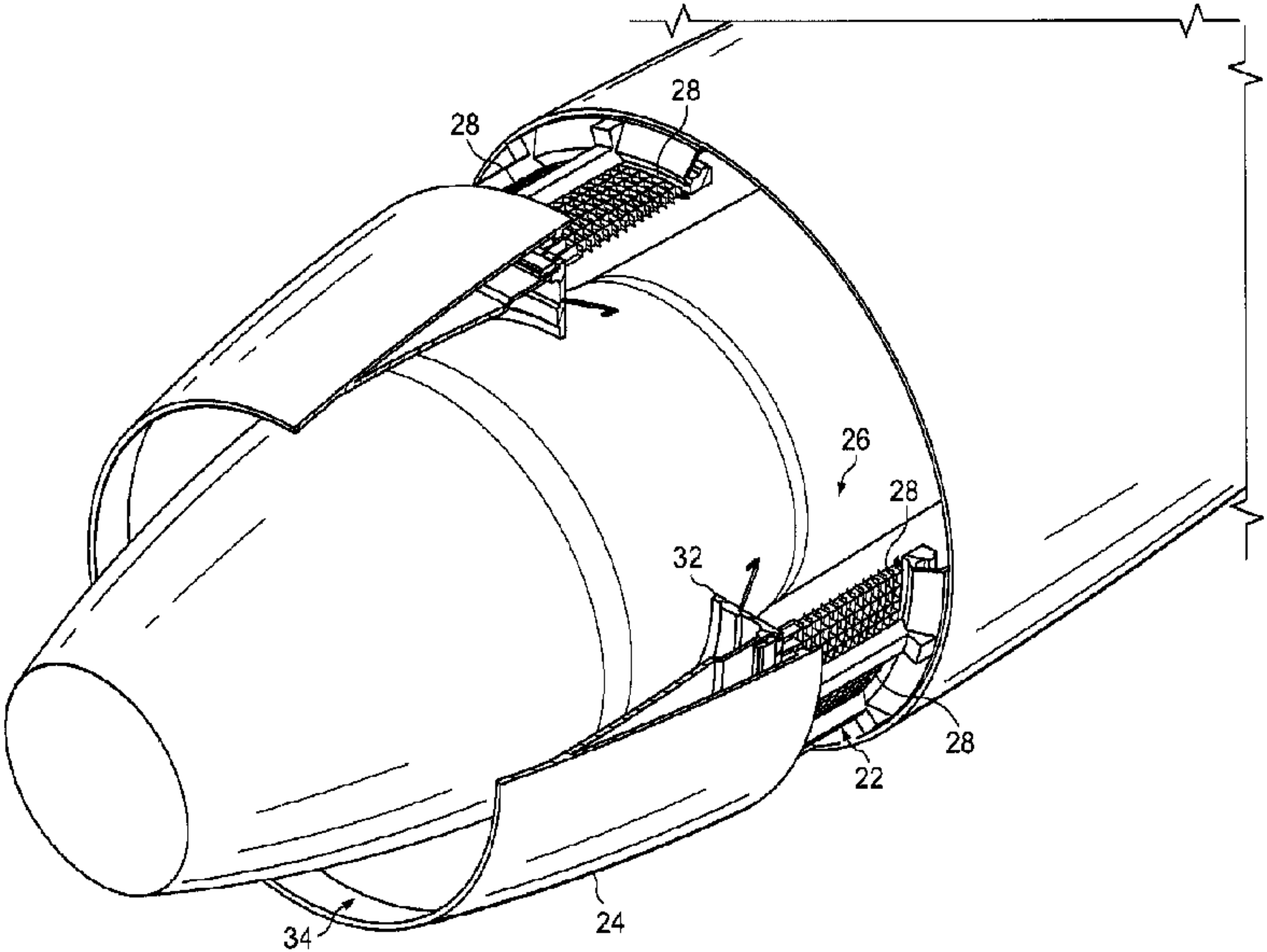

106
110
SPECIFICATION AND DESIGN
112
MATERIAL PROCUREMENT
114
COMPONENT AND SUBASSEMBLY MANUFACTURING
116
SYSTEM INTEGRATION
118
CERTIFICATION AND DELIVERY
120
IN SERVICE
122
MAINTENANCE AND SERVICE

FIG. 18


108
AIRCRAFT
124
AIRFRAME
INTERIOR
128
SYSTEMS
PROPULSION
ELECTRICAL
130
134
132
136
126
HYDRAULIC
ENVIRONMENTAL


28
28
26
28
32
28
22
24
34