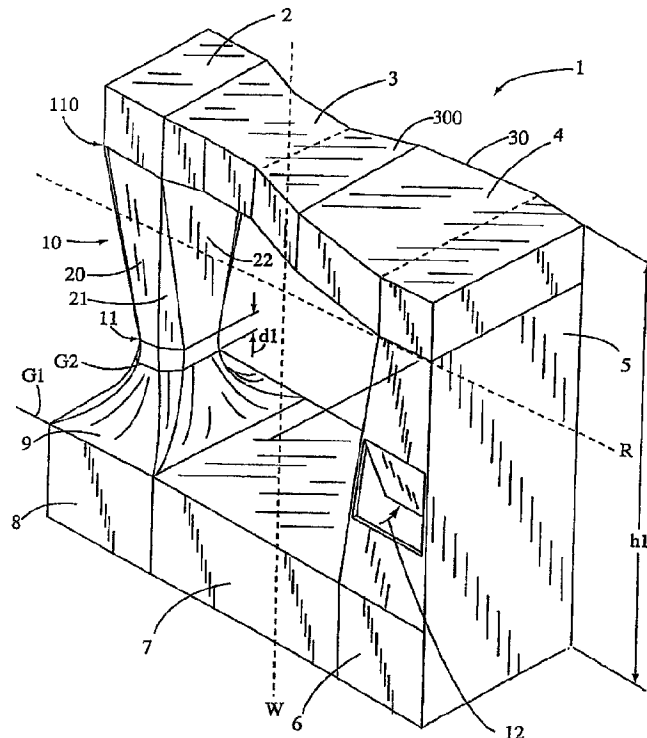




(22) **Date de dépôt/Filing Date:** 2005/08/01  
(41) **Mise à la disp. pub./Open to Public Insp.:** 2006/02/02  
(45) **Date de délivrance/Issue Date:** 2019/03/05  
(62) **Demande originale/Original Application:** 2 865 999  
(30) **Priorités/Priorities:** 2004/07/30 (US10/909,088);  
2005/07/19 (US11/184,940)

(51) **Cl.Int./Int.Cl.** *B64D 23/00* (2006.01),  
*A63G 31/00* (2006.01), *F24F 7/10* (2006.01),  
*G01M 9/02* (2006.01), *G09B 9/00* (2006.01)  
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(54) **Titre : SIMULATEUR DE PARACHUTISME SPORTIF A SOUFFLERIE VERTICALE DE RECIRCULATION ET CABLE DE HALAGE REDUIT UTILISE DANS LES SOUFFLERIES VERTICALES ET AUTRES EMPLACEMENTS**  
(54) **Title: RECIRCULATING VERTICAL WIND TUNNEL SKYDIVING SIMULATOR AND REDUCED DRAG CABLE FOR USE IN WIND TUNNELS AND OTHER LOCATIONS**



(57) **Abrégé/Abstract:**

A vertical wind tunnel flight simulator comprising a flight chamber wherein a flier may experience a freefall simulation. A staging area having openings to the flight chamber is adjacent to the flight chamber. Airflow to support the flier is induced by a plurality of fans, connected to the flight chamber, in one or two return air ducts used to return air from the fans outlet to the fans inlet, the airflow passing through the fans into fan exit ducts which transition from roughly round to roughly square or rectangular.

## ABSTRACT

A vertical wind tunnel flight simulator comprising a flight chamber wherein a flier may experience a freefall simulation. A staging area having openings to the flight chamber is adjacent to the flight chamber. Airflow to support the flier is induced by a plurality of fans, connected to the flight chamber, in one or two return air ducts used to return air from the fans outlet to the fans inlet, the airflow passing through the fans into fan exit ducts which transition from roughly round to roughly square or rectangular.

**TITLE**

Recirculating Vertical Wind Tunnel Skydiving Simulator and Reduced Drag Cable for Use in  
Wind Tunnels and Other Locations

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**FIELD OF THE INVENTION**

10           The present invention relates to the field of vertical wind tunnels, more particularly, to  
temperature controlled return flow vertical wind tunnels used as skydiving simulators and  
amusement devices.

**BACKGROUND OF THE INVENTION**

15           Wind tunnels are well known in the art. Wind tunnels are available in many types and  
styles depending upon the needs of the user. These include subsonic wind tunnels with and  
without return flow, transonic wind tunnels with and without return flow, vertical subsonic  
wind tunnels with and without return flow, supersonic and hypersonic wind tunnels with and  
without return flow, and compressible flow wind tunnels.

20           The majority of the wind tunnels are used for research and testing purposes. These  
include testing of conventional aircraft, helicopters, parachutes and other aerodynamic devices,  
wing surfaces, control surfaces, submarines, rockets and other launch vehicles, ground  
vehicles, buildings and other basic flow investigations.

          Horizontal wind tunnels (those in which the air in the full speed section of the tunnel  
25 flow generally horizontally) are used for aerodynamic research and testing and are generally  
owned by major defense oriented corporations, the Federal government, or educational  
institutions and universities. Some of these have been converted or adapted for vertical  
operation (in which the air in the full speed section of the tunnel flows generally vertically) but  
most or all perform poorly in that role.

30           Design constraints that apply to vertical wind tunnels used for freefall simulation differ  
from those of horizontal testing tunnels. In a vertical wind tunnel / freefall simulator, it is  
important that the objects in the full speed section of the wind tunnel (in this case the human  
beings in flight) be able to move about inside that section to experience or practice human body

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flight. In a horizontal wind tunnel, the objects placed in the tunnel are usually static objects observed or measured by others. For this reason, this fastest part of a horizontal wind tunnel is called a "test section". In a vertical wind tunnel, this same area is instead referred to as the "flight chamber".

5 In a vertical wind tunnel, it is important that people flying inside the tunnel be allowed to rotate in and out of the flight chamber without stopping the airflow. In contrast, there is little need to move the static objects in the test section of a horizontal wind tunnel during its operation. Furthermore, since fliers in a vertical wind tunnel are free to move about inside flight chamber, it is necessary to constrain their movement to appropriate parts of the system.

10 While it is possible to put a safety net on both the upstream and downstream ends of the flight chamber, these produce an enormous amount of drag which creates noise and increases the power required to attain any given speed. In fact, such a pair of nets can consume as much as 30% to 50% of the total power required to operate such a wind tunnel.

15 It is also helpful to have a woven grid of cables at the bottom or upstream end of the flight chamber for use as a standing platform when the occupants are not flying. This "cable floor" provides a convenient work platform for the safety officers or instructors in the flight chamber.

20 Therefore, for the above safety and usability reasons, it is desirable to have a cable floor / safety net made from cables with the lowest amount of aerodynamic drag possible for a given strength and diameter. In addition to wind tunnels, there are any number of applications employing cables moving through the air or air flowing over cables in which a simple and inexpensive reduced drag cable could provide substantial benefits.

25 Low drag cables with flat or airfoil shaped cross sections are known in the art and are used frequently in the aircraft industry. However, these are not useful in a woven cable floor for a vertical wind tunnel because it is difficult to keep such cables oriented properly in relation to the airflow. Furthermore, the downstream end of such a flat or airfoil type cable is pointed. Since it is the downstream end that a person falling onto the cable floor / safety net will land on, this type of cable is not safe for this type of application. The prior art airfoil type of cables cannot be used in some other types of applications where low drag cables would be desirable, 30 for similar reasons of orientation, stability, cost or injury potential.

It is also important to prevent occupants from flying laterally outside of the air column and falling unsupported to the floor below. For this reason, the most advanced vertical wind

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tunnels are designed such that the air column extends completely from one wall of the flight chamber to the other. This is not necessary in horizontal wind tunnels.

Vertical wind tunnels used for freefall simulation often have to operate in noise sensitive environments such as amusement parks and shopping malls. Horizontal testing tunnels can be located away from the crowds where they are free to make as much noise as is necessary.

As amusement devices, freefall simulators must compete with other amusements on the basis of price and can often be operated on a near continual basis. These two factors make energy efficiency critical to successful commercial operation of a freefall simulator. Energy efficiency is much less important for horizontal testing tunnels in which one often takes hours or days to set up an experiment and then only runs the tunnel for a few minutes to collect the necessary data.

Height is a major constraint of freefall simulators which stand upright and often must be sited in high-density entertainment venues that have severe height limitations. This is not true of horizontal testing tunnels which sit on their side and can be successfully located far away from any crowds.

Finally no known prior art has focused on designing these systems to optimize visibility to public spectators in a high density entertainment venue.

To make a commercially viable vertical wind tunnel for skydiving simulation, one must (1) move enough air and do so smoothly enough to adequately simulate freefall for one or more persons in the flight chamber; (2) with a device that is short enough and quiet enough to be located where large numbers of potential customers tend to be; and, (3) at power consumption levels low enough to make the price of the experience acceptable to the public.

The inventive challenge of satisfying these competing requirements is met by the present device. High airspeeds are required at the flight chamber to float one or more human beings. However, moving air through ductwork at high speeds creates an enormous amount of sound and heat and requires a huge amount of power. Consequently, most modern wind tunnels expand and slow the air just downstream of the flight chamber to decrease power consumption, noise output and heat generation. Doing so can reduce power consumption by more than 60%, and only by doing so will vertical wind tunnels become commercially viable as entertainment devices or skydiving simulators.

However, if one expands the airflow in any section of a wind tunnel too rapidly, the flow will "separate" and become turbulent rather than laminar. This will make the entire

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system performance poor, increasing power consumption and decreasing flow quality to the point  
that the device will not adequately simulate true freefall. The threshold at which this flow  
separation occurs in an expanding duct is fairly well defined in the literature; in simple terms,  
the walls of such an expansion cone cannot diverge away from one another at greater than 9 –  
5 12 degrees. For that reason, increasing the length of horizontal test tunnels or the height of  
vertical wind tunnels tends to improve efficiency.

Unfortunately, while this is easily done for a horizontal system, doing so in a vertical  
system dramatically increases the construction and operation cost and reduces the number of  
places at which one can gain governmental approval to build. Consequently, minimizing  
10 height while maximizing the expansion and deceleration of the airflow downstream of the  
flight chamber is the key to making a vertical wind tunnel commercially successful. Similarly,  
constraining the occupants to the safe areas of the wind tunnel without increasing drag and  
power consumption is essential.

The prior art wind tunnels do not offer a design that is quiet and short enough to be  
15 built in high density shopping and entertainment venues while remaining efficient enough to  
allow commercially viable operation.

The foregoing example of the related art and limitations related therewith are intended  
to be illustrative and not exclusive. Other limitations of the related art will become apparent to  
those of skill in the art upon a reading of the specification and a study of the drawings.

20

#### SUMMARY OF THE INVENTION

An aspect of the present invention is to provide a vertical wind tunnel amusement  
device having a flight chamber situated on the inlet side of a plurality of fans which are in turn  
connected to a plurality of expanding return air ducts, thereby maximizing efficiency while  
25 minimizing the height of the amusement device.

Another aspect of the present invention is to provide a vertical wind tunnel having a  
flight chamber on the inlet side of the fans for improved airflow speed and quality, at lower  
power consumption and higher safety for the fliers.

Another aspect of the present invention is to provide a vertical wind tunnel having a  
30 plurality of smaller fans angled in a non-parallel alignment rather than a single, more expensive  
and difficult to maintain fan.

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Another aspect of the present invention is to provide a vertical wind tunnel having one or more return air ducts to conserve heat, reduce energy consumption, reduce noise and allow all-weather operation.

Another aspect of the present invention is to provide a vertical wind tunnel having only one or two return ducts even though it may have a greater number of fans than return ducts.

Another aspect of the present invention is to provide a vertical wind tunnel having fans housed in low profile, diffusing casings that allow them to be mounted as closely together as possible so that more than one fan can be connected to each return air duct without the need for long transition ducts that would increase the height or width of the entire system.

Another aspect of the present invention is to provide a vertical wind tunnel having a passive air exchange system with adjustable inlet/outlet doors that mechanically ejects heated air from the system and draw in cooler ambient air in order to most efficiently control the temperature inside the wind tunnel with minimal extra work by the fans.

Another aspect of the present invention is to provide a vertical wind tunnel in which the adjustable inlet/outlet doors are arranged such that they also form a "nozzle" or flow contraction thereby creating a favorable pressure gradient between the inside and outside of the tunnel and encouraging the air exchange in order to efficiently control the temperature inside the wind tunnel with minimal extra work by the fans and without the use of other more costly air cooling technologies .

Another aspect of the present invention is to provide a vertical wind tunnel having a mesh "floor" made of specially designed cables (preferably steel) that produce less drag and, therefore, less noise than conventional cables.

Another aspect of the present invention is to provide a vertical wind tunnel having one or more zero-drag electronic upper barriers instead of a physical net designed to prevent fliers from moving too high in the flight chamber and capable of quickly modulating the speed of the air to bring fliers back down to and hold them at a safe level.

Another aspect of the present invention is to provide a vertical wind tunnel having the lowest possible total height for any given efficiency in order to reduce construction costs and meet common governmental constraints on building height.

Another aspect of the present invention is to provide a vertical wind tunnel optimized for height by having not just the primary diffuser just downstream of the flight chamber but also most or all of the components downstream of the flight chamber expand the air as rapidly as possible without creating flow separation.

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Another aspect of the present invention is to provide a vertical wind tunnel optimized for height by expanding the air as much as possible without creating separation as it passes through the flight chamber. This diffusing flight chamber could also be thought of as a zero-height flight chamber or zero-length test section.

5 Another aspect of the present invention is to provide a zero height flight chamber wherein the fliers fly in an expanding diffuser chamber with a reduced air velocity the higher they fly, thereby forming a self-catching flow in the chamber to slow the flier as he or she descends.

10 An aspect of the present device is to provide a cable with reduced drag and noise in moving air.

Other aspects of this invention will appear from the following description and appended claims, reference being made to the accompanying drawings forming a part of this specification wherein like reference characters designate corresponding parts in the several views.

15 To reduce the risk of occupants falling out of the air column and injuring themselves, the air column extends completely from one wall of the flight chamber to the other. This "wall to wall" airflow also reduces drag at the edges of the air column and increases efficiency of the entire system. The airflow passes through a "cable floor" into the flight chamber. The cable floor provides support for the users when the airflow through the flight chamber is not sufficient to support them. The cable floor is made from reduced drag cables comprised of a  
20 collection of round strands in a particular orientation and of particular sizes. These cables can also be used in any application where a reduced drag in air would be advantageous.

At or near the upper (or downstream) end of the flight chamber, a "virtual net" comprised of one or more electronic (preferably optic) sensors, monitors the position of the occupant(s) within the flight chamber. In the disclosed embodiment, the control system will  
25 automatically lower the speed if the occupant(s) fly too high in the flight chamber.

The flight chamber can be round, oval or polygonal and can range from a bit less than 75 square feet to over 160 square feet in area. The flight chamber may accommodate up to six users at a time. The airflow velocity in the flight chamber can reach as high as 160+ mph, which will fully support as many as six users. In the preferred embodiment, one or more of the  
30 walls of the flight chamber include or comprise flat or curved windows constructed of transparent Plexiglas®, acrylic plastic, glass or similar high strength transparent material. When present, the windows into the flight chamber allow an unrestricted view of the activities taking place within the therein.



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Adjacent to the flight chamber is a staging area. The flight chamber has an entry opening and exit opening to the staging area through which a user or multiple users may enter and exit the flight chamber. In certain embodiments in which rotations of occupants in and out of the flight chamber might be less frequent, these opening may be fitted with doors which slide, roll or otherwise move to close one or both of these openings. Users wait in the staging area for their turn in the flight chamber. The staging area has transparent windows so that an observer may view the flight of any person(s) within the flight chamber without entering the staging area. The staging area has a single or multiple doors that open periodically to allow people to exit the entire system. The staging area may also be fit with an optional "piggyback" or secondary staging area. This creates an airlock that allows groups to rotate in and out of the staging area from outside the system without requiring the airflow to stop.

The area above (downstream of) each doorway in upper section of the flight chamber may include perforated panel which provides an alternate airflow path when users are entering and exiting the flight chamber. In the preferred embodiment, a small flow deflector will also be located below (upstream of) the cable floor just below each opening between the flight chamber and staging area to minimize the amount of air moving between them and reduce the amount of balancing necessary.

The fans and other controls can be operated from inside the staging area, inside the flight chamber or from an attached or remote control room. The fans are controlled to achieve the optimum airflow velocity through the flight chamber.

Next above the perforated section is the primary divergent diffuser. The primary diffuser diverges at approximately 3.5 to 5 degrees from the major axis providing a "equivalent cone angle" of 7 to 10 degrees. The increasing cross-sectional area reduces the velocity of the airflow from the flight chamber to the fans. Above (or downstream of) the primary diffuser is the upper plenum which may include the first set of high efficiency turning vanes. In a single return system these turning vanes (or simply the plenum if no vanes are used) redirect the airflow from substantially vertical to substantially horizontal. In a multiple return system; these vanes (or simply the plenum if no vanes are used) split the air into to basically equal flows and turn each flow from substantially vertical to substantially horizontal.

The airflow then passes through the inlet ducts and into the fans. The fan inlet duct transitions the flow from roughly square or rectangular to roughly round. In the preferred embodiment, the fan inlet ducts act as diffusers expanding the flow area as much as possible without creating flow separation. The fans are preferably high-efficiency axial flow fans,

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although any fan adapted for use in a wind tunnel is acceptable. In the preferred embodiment, the fans contain a bullet-shaped nosecone and a teardrop-shaped tailcone. In the preferred embodiment, the fan casings act as diffusers and are sized such that, after taking into account the area in the center of the fan obscured by the nosecone, fan centerbody and tailcone, the net flow area through the fans increases as much as possible without creating flow separation. The velocity of the airflow through the invention is controlled by either changing the pitch of the fans or by changing the rotational speed of the fans.

The airflow passes through the fans and into the exit ducts which also transition from roughly round to roughly square or rectangular. In the preferred embodiment, the exit ducts act as diffusers expanding the airflow as much as possible without creating flow separation. The airflow travels through a set of exit ducts to the second set of high-efficiency turning vanes (if used) which turn the air from substantially horizontal to substantially vertical.

The airflow then enters the return air ducts. In the preferred embodiment, these return air ducts are also shaped as divergent diffusers expanding the airflow as much as possible without creating flow separation. In the preferred embodiment, each return air duct has an air exchange mechanism comprised of an even number of louvers located on opposing faces of the return air duct. These are situated and sized so that they together create a nozzle or sudden contraction in the flow area at the point of the louvers. This nozzle [increases] decreases the [dynamic] static pressure at that point of the system and assists in the expulsion of heated air from the wind tunnel through the exhaust louver. This lowers the pressure in the system and assists the inlet louvers as they draw in cooler ambient air from outside of the system. This arrangement allows heated air in the system to be replaced with cooler ambient air, thereby allowing a user to adjust the temperature in the flight chamber for flyer comfort without the need for expensive alternatives such as air conditioning or evaporative cooling.

At the bottom (or downstream) end of the return air towers, the air again passes through a set of turning vanes (or simply a duct with a 90 degree turn if no vanes are used) that redirects the air from a substantially vertical to a substantially horizontal path. The air then enters the bottom plenum which may also act as a divergent diffuser expanding the air as much as possible without causing flow separation. At the end or the (or downstream) end of the bottom plenum, the air again passes through a set of turning vanes (or simply a duct with a 90 degree turn if no vanes are used) that redirects the air from a substantially horizontal to a substantially vertical path. In a multiple return system, the flows will be re-joined at this point.

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The air then passes into the inlet contractor. This trumpet-shaped or bell-shaped device quickly reduces the flow area and accelerates the air to its maximum speed just ahead of the flight chamber. Here again aerodynamic laws govern how quickly one can reduce this flow area without degrading the quality of that flow.

5

### BRIEF DESCRIPTION OF THE DRAWINGS

- FIG. 1 is a top perspective view of a single return simulator.
- FIG. 2 is a cutaway view of the FIG. 1 embodiment.
- FIG. 3 is a top perspective view of the flight chamber of FIG. 1.
- 10 FIG. 4 is a top plan view of an oval outlet, rectangular inlet airflow contractor.
- FIG. 5 is a schematic view of an oval/polygon shaped outlet of an airflow contractor.
- FIG. 6 is a schematic view of an oval outlet airflow contractor.
- FIG. 7 is a schematic view of an oval viewing area.
- FIG. 8 is a top perspective view of a double airlock staging area.
- 15 FIG. 9 is a schematic view of a temperature regulator.
- FIG. 10 is a side, cutaway view of the temperature regulator of FIG. 9.
- FIG. 11 is a top perspective view of deflectors on flight chamber entrance doors.
- FIG. 12 is a close up view of a deflector.
- FIG. 13 is a side cutaway view of a fan and housing.
- 20 FIG. 14 is a side cutaway view of two fans and housings mounted divergent from a centerline therebetween.
- FIG. 15 is a top perspective view of a two return simulator.
- FIG. 16 is a cutaway view of the FIG. 15 embodiment.
- FIG. 17 is a schematic view of a V footprint two return simulator.
- 25 FIG. 18 is a schematic view of a V footprint two return simulator in a mall.
- FIG. 19 is a schematic view of a multi-simulator configuration in a building.
- FIG. 20 is a side perspective view of a mall type viewing area for a simulator.
- FIG. 21 is a schematic view of a dual contractor (one underground and horizontal) system.
- FIG. 21A is a sectional view taken along lines 21A-21A of FIG. 21.
- 30 FIG. 22 is a top perspective view of a cable floor.
- FIG. 23 is a schematic view of a floor sensor/shutoff system.
- FIG. 24 is a top perspective view of a rounded diffuser.
- FIG. 25 is a schematic view of a cruise ship having a water-cooled simulator.

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FIG. 26 is a side perspective view of an anti-drag cable, first embodiment.

FIG. 27 is a view of a second embodiment cable.

FIG. 28 is view of a third embodiment cable.

FIG. 29 is a cross sectional, schematic view of a cable with a single outer strand a different size  
5 from the other outer strands.

FIG. 30 is a cross sectional, schematic view of another embodiment of a reduced drag cable.

FIG. 31 is a cross sectional, schematic view of another embodiment of a reduced drag cable  
with a single larger wire.

FIG. 32 is a cross sectional, schematic view of another embodiment of a reduced drag cable  
10 with two smaller wires.

FIG. 33 is a perspective view of a cable with a large strand.

FIG. 34 is a perspective view of a cable with two smaller strands.

FIG. 35 is a graph showing the reduction in drag of some of the disclosed cables.

Before explaining the disclosed embodiment of the present invention in detail, it is to  
15 be understood that the invention is not limited in its application to the details of the particular  
arrangements shown, since the invention is capable of other embodiments. Also, the  
terminology used herein is for the purpose of description and not of limitation.

### DETAILED DESCRIPTION OF THE DRAWINGS

20 Referring first to FIG. 1 a single return simulator 1 is shown, wherein height  $L_1$   
is preferably in the range of about 50-120 feet. Some installations may bury all components  
below a ground level of either  $G_1$  or  $G_2$ . The flight chamber 10 may be made entirely or  
partially with transparent panels. If ground level is at  $G_2$ , then an opaque pedestal-type image  
formed in area  $d_1$  which may be about seven feet high. This embodiment in a mall creates an  
25 eye-catching, live action human flight studio in the flight chamber 10. This design attracts new  
“fliers” who pay to experience simulated skydiving in flight chamber 10. Dotted line R  
represents a roof, wherein components above R can be roof-mounted to reduce noise. Dotted  
line W represents a wall, wherein components beyond the wall W away from the flight  
chamber 10 could be isolated from the flight chamber to reduce noise near the flight chamber  
30 10.

Most prior art flight chambers provide for parallel walls in the flight chamber so that  
experienced fliers can practice maneuvers at a constant wind velocity perhaps at around 140  
miles per hour. Simulator 1 has a “zero height” flight chamber along elevation 11. Elevation

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11 is the line which joins the airflow contractor 9 to the airflow diffuser 10, wherein the diffuser 10 has diverging walls 20, 21, 22, etc., and the diffuser 10 also serves as the flight chamber 10.

Nominally the air speed at line 11 is at about 140 mph, the maximum speed in the simulator. As the flier goes higher in the flight chamber 10 to the top of the flight chamber 10 to junction 110, the air speed drops, perhaps to about 120 mph. Fliers can change their drag profiles from a maximum spread eagle position to a minimum human ball position. Thus, if a flier ascends to the top of the flight chamber 10 and then changes his drag to a human ball shape, he will fall downward. The diffuser shape of the flight chamber 10 will provide a self-braking system due to the increasing airspeed with each incremental descent down into the flight chamber 10. A safety net is provided a line 11.

The diverter 2 meets the diffuser 10 at junction 110. The air is diverted from a vertical path to a horizontal path in the diverter 2. All the diverters 2, 4, 6, 8 change the air direction by about 90 degrees.

The fan assembly 3 accelerates the air, perhaps with two side-by-side fans. The basic dynamics in a return air simulator involve compromises in energy efficiency, noise and size. In the simplest design, one would attempt to keep the airflow close to full speed for the entire loop through the simulator. However, the height would have to rise, the noise would be enormous, and the heat from friction in the plenums would be enormous. Therefore, for more efficient operation, it is necessary to slow the air down during its travel through the simulator loop by enlarging the cross-sectional areas of the plenum to attain commercially acceptable levels of height  $h_1$  as well as noise, and simultaneously attempt to use the least horsepower possible for the fans.

The diverters 2, 4, 6, 8 generally do not have diverging walls due to cost construction considerations. The fan housing segment 300 and the fan section 3 have diverging walls. The top plenum 30 has diverging walls. The vertical return plenum 5 has diverging walls. The bottom plenum 7 does not have diverging walls due to tradeoffs in cost construction considerations. Bottom plenum 7 could have diverging walls.

The airflow contractor 9 has converging walls functioning to narrow the cross-sectional plenum area, thereby accelerating the air to about 140 mph for flight simulation. The air inlet 12 brings in ambient air to cool the simulator air.

Referring next to FIG. 2 a schematic representation of the internal workings of the simulator 1 is shown. Airflow is shown by the arrows F. Diverting vanes 200, 201, 202, 203

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each change the air direction by 90 degrees. Two fans 40, 41 are schematically shown mounted horizontally side by side in their housing 3 (refer to FIG. 13 for a perspective view) wherein right after the fans a plenum diffuser 300 expands and slows the airflow. The diffusing continues in top plenum 30, and then in vertical return plenum 5, and finally through  
 5 the flight chamber 10.

A passive temperature regulation system is provided by having air inlet 12 louver 120 face downstream. Additionally the air outlet 26 has a louver 260 that faces upstream. By mounting the inlet 12 about opposite outlet 26, a reducing nozzle is formed by louvers 120, 260, thereby creating a decreased static pressure zone V downstream from the inlet 12.  
 10 Therefore, ambient air is [forced passively] drawn into the simulator 1 without the use of an additional fan.

Referring next to FIG. 3 the diffuser/flight chamber 10 is in the shape of a polygon (octagon) as seen by the base B. Base B is covered by a safety net. The walls 20, 21, 22 etc. diverge at an optimal aerodynamic angle in the range of about 7-12 degrees from each other.  
 15 The top of the flight chamber 10 is seen as a rectangle at arrow 110. All or some of the walls 20, 21, 22 etc. may be transparent.

Referring next to FIG. 4 an airflow contractor 400 has the preferred design of a rectangular inlet 401 and an oval outlet 402. Transition walls 403 contract the airflow from the inlet 401 to the outlet 402. Preferably the height  $h_2$ , FIG. 2, which is sometimes buried  
 20 underground, equals length  $d_4$ . This combination of shape and dimensions form a cost-effective balance for a relatively low height, and commercially viable simulator 1.

Referring next to FIGS. 5, 6, 7 the term "oval outlet" airflow contractor covers any oval-like shape such as polygon oval outlet 500 and perfectly oval outlet 600. The oval-like shape provides for a larger viewing area 700 compared to a round outlet having the same cross-  
 25 sectional area. Area 701 includes a staging and entry area. The flight chamber bottom B1 could be in a mall with expensive retail space, wherein the larger viewing area 700 has considerable commercial value.

Referring next to FIG. 8 a two-stage staging chamber 800 consists of a flight chamber bottom B2 with a flight chamber wall 809 having windows 810 and flier entrances 806, 807.  
 30 Entrances 806, 807 can be doorless or with hinged doors or with sliding doors. So long as doors 801, 805 are closed the fans do not have to be shut down to allow fliers to enter/leave the flight chamber 10. Ambient pressure is shown as A. Doors 801, 805 open from ambient A to first staging room 802 and second staging room 804. Door 803 separates the staging rooms

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802, 804. In operation, a group of fliers could enter room 804 while door 803 is closed, then door 805 is closed. Then the fliers would enter room 802 with doors 801, 805 closed. Flier entrances 806, 807 are used.

Referring next to FIGS. 9, 10 the temperature regulating system 1000 consists of a plenum 5 having an airflow F. The outlet 26 is located opposite the inlet 12, but slightly upstream at a distance  $d_{11}$  chosen by design parameters. Preferably louvers 120, 260 are controllable from a control room to vary the air exchange from ambient A to the plenum 5. Inlet air volume I must approximate outlet air volume O. The decrease in internal static pressure V is formed by contracting and accelerating the air at nozzle N.

The air exchange system used for closed-circuit wind tunnels disclosed herein consists of two large louvers in each return leg of the tunnels: an exhaust louver and an intake louver. The exhaust and intake louvers are located and oriented so that there is favorable interaction between them. This location is part of what is novel about this system.

The leading edge of the exhaust louver deflects into the tunnel and scoops out the air from inside the tunnel. The intake louver is located on the opposite tunnel wall from the exhaust louver. Its hinge line is designed to line up with the leading edge of the exhaust louver at the design setting. The trailing edge of the intake louver is deflected into the tunnel. It is deflected to a greater extent than the exhaust louver to cause the internal airflow velocity to increase by creating nozzle N. This is the key. That increase in velocity causes a decrease in the internal static pressure (Bernoulli's law). The lower internal static pressure (below atmospheric) actually sucks air into the inlet. As a minimum, the intake louver has the same chord or length as the exhaust louver. In some wind tunnel configurations it is desirable that the intake louver have a greater length or chord than the exhaust louver to reduce the deflection required.

Traditional wind tunnel air exchangers either have the exhaust and intake in separate sections of the wind tunnel, or if they are in the same part of the wind tunnel there is not favorable interaction between the two louvers to cause this desired drop in the internal static pressure. Other designs have employed a screen or some other drag-producing device downstream of the exhaust and upstream of the intake to achieve a drop in internal static pressure in order to cause the outside air to enter the tunnel. While this works, it is very inefficient. This results in unnecessary loss in total pressure and the attendant loss in tunnel performance. Often there is additional ducting required to control the internal static pressure

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 which increases the construction cost. The present invention avoids these problems and achieves the desired air exchange with the lowest power loss.

Referring next to FIGS. 11, 12 a deflector 1100 is placed along the bottom edge of a flier entrance 1101, 1102 in order to reduce airflow from the flight chamber into the room 802 and thereby minimize cavity resonance in room 802. The deflector 1100 has an angled leading edge 1103. The leading edge 1103 inclines into the flight chamber 10 in a downstream direction. The flight chamber 10 could be round instead of a polygon as shown. Optionally a deflector 1196 could be mounted at the top of the door, wherein it bends inward into the staging area from the flight chamber.

Referring next to FIGS. 13, 14 the fans 40, 41 of FIG. 2 are shown in their preferred design. They are oriented slightly away from each other relative to a centerline as shown. The fan planes P41, P42 are canted downstream forming acute angle P43. The fan cowling (fan can) 1300 has diverging walls 1302 after the segment next to the blade 1301. Nominally W1 may be 2.62 meters (103 inches), and W2 may be 3.10 meters (122 inches). A staggering of the fans can help place the two fan cans 1300 closer together such as by moving the front of fan 41 to dotted line 1499. This reduces the distance between the two columns of air from the fans which reduces the length of the return plenum and the height. Blade 1301 could be forward.

Referring next to FIGS. 15, 16 a dual return simulator 1500 is shown. Functional equivalent components to the single return simulator 1 are given like numbers, wherein no further description is needed.

In this particular embodiment, the flight chamber 1503 has parallel walls rather than diverging walls in order to provide a relatively constant airflow therein. Above the flight chamber 1503 is a diffuser 1504 which connects to a double diverter 1505. Double diverter 1505 has two diverting vanes 1507, 1508. Fan ductwork 1521 supports the fans 40, 41. Top diffusers 1520 connect to the diverters 2, 4 as shown. A left and a right vertical return plenum 5 each has a temperature regulator system 1000.

The bottom plenums 7 each connect to a double diverter 1501. Double diverter 1501 has two diverting vanes 1505, 1506. An airflow contractor 1502 accelerates the airflow into the flight chamber 1503. A larger flight chamber 1503 can be supported with the four fans shown as compared to the two-fan embodiment of FIG. 2.

Referring next to FIG. 17 a dual return simulator 1700 has a flight chamber 1701 with flier 1704 therein. The air return components 1702, 1703 are shown with this top plan view to



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form a V configuration (angle 1705 is an acute angle) extending from the flight chamber 1701.

One use for this simulator 1700 is in a public pedestrian walkway PW as shown, a viewing area VA juts into the pedestrian walkway PW, while the components 1702, 1703 are soundproofed and hidden by wall W. As noted above, the fans and related ductwork may be mounted on the  
5 roof.

Referring next to FIG. 18 another V shaped simulator 1800 is set in a different mall environment. The pedestrian walkway PW has expensive retail store space along area 1805. Less expensive mall space 1899 may have storage areas and could house return air components 1801, 1802. An outside wall WOUT locates the return air components 1803, 1804 outside as  
10 shown.

Referring next to FIG. 19 a wall W creates an enclosed area designated as PUBLIC. Possible configurations of simulators 1 and 1500 are shown. Flying humans 1704 could create an exciting indoor amusement area designated as PUBLIC.

Referring next to FIG. 20 an artist's rendering of the simulator 1 of FIG. 1 is shown,  
15 wherein a mall 2000 has a pedestrian walkway PW. The term "mall" herein includes a high-people density entertainment venue including amusement parks, theatre complexes, family entertainment centers, and college campuses. Ground level  $G_2$  forms pedestal area  $d_1$  so that the public looks up into the transparent flight chamber 10. A ticketing area 2001 could blend in with other retail store fronts. Walls W and the ground  $G_2$  screen components 5, 6, 7, 8 are  
20 shown in dots.

Referring next to FIGS. 21 and 21A, a two-stage airflow contractor is shown. A first stage contractor 2111 is horizontal and feeds diverter 8. The second stage contractor 2112 is vertical and feeds the flight chamber 10. The simulator 2110 could bury the first stage contractor 2111 underground. The result is less noise and less height for the second stage  
25 contractor 2112. This invention can provide a lower overall height for the simulator 2110.

Referring next to FIG. 22 a staging area 2200 has a flight chamber 2202 with a bottom B consisting of a mesh net 2201.

One embodiment of the mesh net forming the floor of the flight chamber is a 3/32-17-strand stainless steel aircraft cable woven into a 2'x2' (60 cm x 60 cm) grid. One or both ends  
30 of the cable are run through a compression spring, depending on the conditions of the particular application. One hundred-twenty two (122) cables make up the tunnel floor depicted. The number of cables will depend on the shape and size of the flight chamber 2202, the maximum number of fliers planned for the flight chamber and other design considerations.

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The compression of the springs is adjusted to give the proper "bounce" to the floor providing increased safety should a flyer become unstable and fall to the cable floor.

#### Tunnel Viewing Walls

There are 11 large 1-1/4" (31 mm) acrylic panels which allow the controller, flyers and spectators in the staging/viewing area to see the activity in the flight chamber and flight deck in the depicted embodiment. The number of panels would depend on the installation. There is a large acrylic panel that allows spectators to see inside the control room.

Referring next to FIG. 23 a flight chamber 10 has a flier sensor 2600 that uses energy waves 2601 (light, radio, sound, UV, etc.) to detect a flier moving too high into the flight chamber 10. A controller 2602 may consist of simple on/off output logic, or current modulator or the like to temporarily reduce the airflow to drop the flier lower into the flight chamber. An emergency ambient door 2604 could also be opened by the controller 2602. A mesh net 2605 may also be used to prevent fliers from traveling too high.

Referring next to FIG. 24 another diffuser 2700 might also serve as a flight chamber. The walls 2701 could be three-inch acrylic panels. The oval outlet 2702 has curved edges.

Referring next to FIG. 25 a ship 2850 has a simulator 2801 with a seawater cooling system 2800. A seawater inlet 2851 feeds a heat exchanger 2853 in the simulator via a flow controller 2852. An air temperature sensor 2854 communicates to a temperature controller 2802 to keep the air temperature at a set point by controlling the flow controller 2852.

FIGS. 26, 27, 28 offer individual cable designs which could form mesh net. Basic aerodynamics teaches that a wing-type profile reduces drag as opposed to a blunt or flat profile. Cable 2300 has a standard twisted element core 2301 with an external helical wrap 2302 shown in Fig. 26.

Cable 2400 has a modified twisted element core 2401 with a single helical element 2402 missing as shown in FIG. 27.

Cable 2500 has a modified twisted core 2501 with double helical elements 2502 missing as shown in FIG. 28.

Referring next to FIG. 29 the depicted embodiment of cable 2900 has eighteen strands. Strands 2901 form an outer cable perimeter and have approximately equal diameters  $d_1$ .  $D_1$  is about .4826 mm (.019 inch) in the depicted embodiment. Strand L19 completes the outer cable perimeter and has a diameter of  $d_2$ , which is different from  $d_1$ . In the depicted embodiment of FIG. 29, strand L19, shown in the solid line, has a larger diameter of about .7112 mm (.028 inch). The strand L19a, shown in dotted lines, has a smaller diameter than strands 2901.

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~~$D_2$  should be at least 10% different from  $d_1$ , more commonly  $D_2$  will be 25% or more different from  $d_1$ . In those embodiments where  $d_2$  is larger than  $d_1$ ,  $d_2$  can be as much as 250% the size of  $d_1$ . Other amounts of size variation would work in a similar fashion. When  $d_2$  is smaller, the minimum size of  $d_2$  will be determined by structural considerations. Strand L19a~~

5 must be of sufficient size to not break in use and to hold the two adjacent strands 2901 apart at least minimally. The number of strands will depend on the application the cable will be used in. In principle, cables with 6 or more strands could be made according to the present disclosure and function accordingly.

The inner strands 2902, 2903 can have different diameter from strands 2901 and form

10 the core of the cable 2900. Center strand 2903 can have a different diameter from strands 2902. It is irrelevant what the diameter of inner strands 2902 and 2903 is in relation to the diameter  $d_2$  L19.

In the depicted embodiment of 2900 with L19 the ratio of  $D_2/D_1$  is about 1.47, wherein the diameter  $d_3$  is about 10% larger than a uniform strand diameter  $d_4$ . The cable 2900 is a

15 twisted strand type with strand L19 forming a helical ridge shown in FIG. 9.

Referring next to FIG. 30 cable 3000 has a larger outer perimeter strand solid line L30 with a diameter of  $d_5$ . In the depicted embodiment  $d_5$  is .8636mm (.034").  $D_1$  is the same as in FIG. 5. The ratio  $D_5/D_1$  is about 1.79. Length  $d_6$  is about .5055 mm (.0199 inch) above the perimeter surface extent S in the depicted embodiment.

20 Also shown in FIG. 30, strands L30a are shown in dotted lines with a diameter  $d_5$  of less than 50% of  $D_1$ . In this embodiment, two or more strands L30a will be used to hold open gap G. Cable 300 with two strands L30a is shown in a perspective view with gap G forming a helical groove in FIG. 34.

In FIG. 32, another embodiment of the cable 3010 is shown. The outer strands 3011,

25 the inner strands 3012 and 3013 form the main structure of the cable 3010. Strands L301a have a diameter of less than 50% of the diameter of 3011. Instead of both strands L301a being in a single gap G, as in FIG. 6, strands L301a are placed on either side of strand 3010, forming two helical grooves.

Referring next to FIG. 339 the helical ridge of L19 is seen in perspective.

30 In operation of the wind tunnel, air over 20 MPH passes at about a 90° angle to the cable which forms a cable floor / safety net shown in FIGS. 22 (2202). In all of the disclosed wires the direction the air flow comes from is not critical for the functioning of the device.

Other than airflow going directly down the length of the cable, all other directions of air flow over the cable are believed to result in at least some reduction of drag.

FIG. 31 shows a cable 3300 with 15 strands. Strands 3301 form the outer premier with L31. Strands 3302 and 3303 form the inner core of cable 3300. L31 could be smaller in diameter than strand L31 (not shown).

The cables disclosed can be used in any wind tunnel or other environment where it is desirable to employ a cable that suffers less than the normal drag when it passes through the air or when air passes over the cable, not just in re-circulating wind tunnels.

FIG. 35 is a graph showing the drag coefficient of different cables as a function of the dynamic pressure. In all of the test cables, all most of the strands in the cable were approximately 0.019 inch in diameter. Line 3401 shows a standard twisted wire cable. Lines 3403 and 3405 show cables 2300 with helical strand 2302 wrapped around the perimeter. Line 3402 shows a strand as in FIG. 30 with a  $d_3$  of .035 inches. Line 3404 shows a strand as in FIG. 29 with a  $d_2$  of 0.025.

The disclosed cables generally do not cost any appreciable amount more to manufacture than a standard cable of the same size. Therefore, any reduction in drag and noise and any corresponding savings in energy consumption that results from the use of this low drag cable will result in a direct cost savings.

Although the present device has been described with reference to depicted embodiments, numerous modifications and variations can be made and still the result will come within the scope of the invention.

The scope of the claims will not be limited by any preferred embodiment or example set forth herein, but should be given the broadest interpretation consistent with the description as a whole.

## CLAIMS:

1. A vertical wind tunnel freefall simulator comprising:
  - a recirculating airflow plenum having a generally rectangular configuration;
  - 5 a vertical flight chamber (10, 1503, 2202) capable of floating at least one human housed within a first vertical member of the airflow plenum;
  - one or two return ducts of the generally rectangular configuration, each return duct comprising a top horizontal member (30), a second vertical member (5), and a bottom horizontal member (7);
  - 10 the simulator comprises a plurality of fans (40, 41) in each return duct, the airflow passing through the fans (40, 41) into fan exit ducts, which transition from roughly round to roughly square or rectangular;
  - whereby the flight chamber is located on the inlet side of the plurality of fans; and
  - 15 whereby a portion of the airflow plenum further comprises divergent walls to expand and slow the airflow.
  
2. Simulator according to claim 1, the simulator having one return duct comprising the top horizontal member (30), the second vertical member (5) and the bottom horizontal member (7), the first vertical member being a first vertical side member and the second vertical member being a second vertical side member of the generally rectangular configuration further comprising the top horizontal member and the bottom horizontal member.
- 25
  
3. Simulator according to claim 1, the simulator having two return ducts; the generally rectangular configuration comprising the top members, the second vertical side members, and the bottom members of the two return ducts, the first vertical member of the airflow plenum being a central vertical member of the generally rectangular configuration.
- 30

4. Simulator according to any one of claims 1 to 3, wherein the simulator has a greater number of fans (40, 41) than return ducts.
5. Simulator according to any one of claims 1 to 4, wherein the plurality of fans (40, 41) is mounted in a side-by-side arrangement.
6. Simulator according to any one of claims 1 to 5, wherein the exit ducts act as diffusers expanding the airflow.
10. 7. Simulator according to any one of claims 1 to 6, wherein an airflow contractor (400) is trumpet-shaped or bell-shaped accelerating the air to its maximum speed just ahead of the flight chamber (10, 1503, 2202).
15. 8. Simulator according to any one of claims 1 to 7, wherein the airflow contractor (400) has a rectangular inlet (401) and an oval outlet (402).
9. Simulator according to any one of claims 1 to 8, wherein the airflow plenum comprises four diverters (2, 4, 6, 8), all of which change the airflow direction by about 90 degrees.
20. 10. Simulator according to any one of claims 1 to 9, wherein the diverters (2, 4, 6, 8) do not have diverging walls.
25. 11. Simulator according to any one of claims 1 to 10, wherein diverting vanes (200, 201, 202, 203) each change the airflow direction by 90 degrees.
30. 12. Simulator according to claim 3 or any one of claims 4 to 11 in their dependency to claim 3, wherein a double diverter (1505) has two diverting vanes (1507, 1508).

13. Simulator according to any one of claims 1 to 12 wherein the fans (40, 41) are oriented slightly away from each other relative to a centerline.
14. Simulator according to claim 13, wherein the fan planes (P41, P42) of the fans (40, 41) are canted downstream forming an acute angle (P43) with the centerline.
15. Simulator according to any one of claims 1 to 14, the simulator having fan inlet ducts, which transition from roughly square or rectangular to roughly round.
16. Simulator according to any one of claims 1 to 15, wherein the fan inlet ducts act as diffusers expanding the flow area.
17. Simulator according to any one of claims 1 to 16, wherein the bottom horizontal member does not have diverging walls.

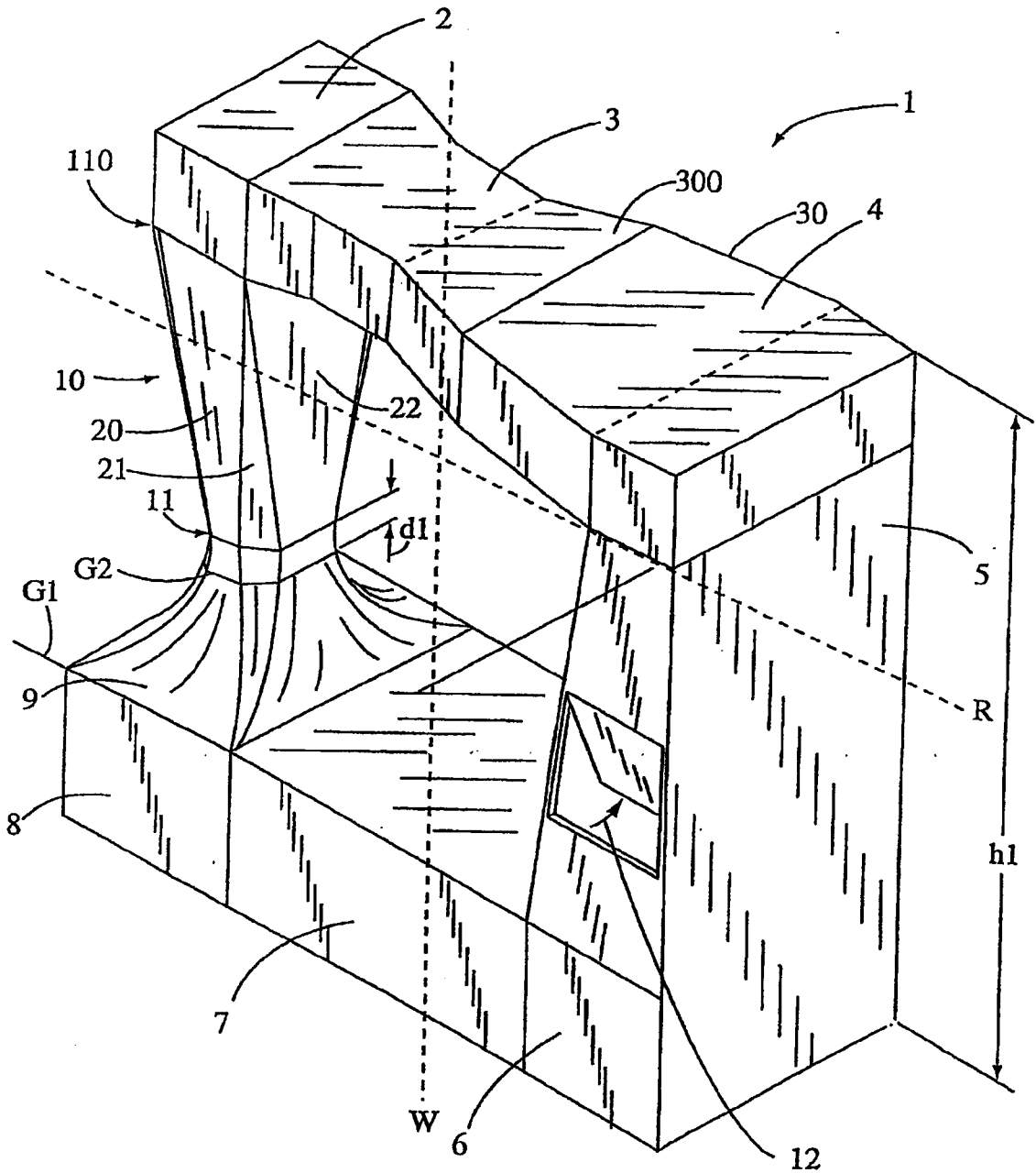


Fig. 1



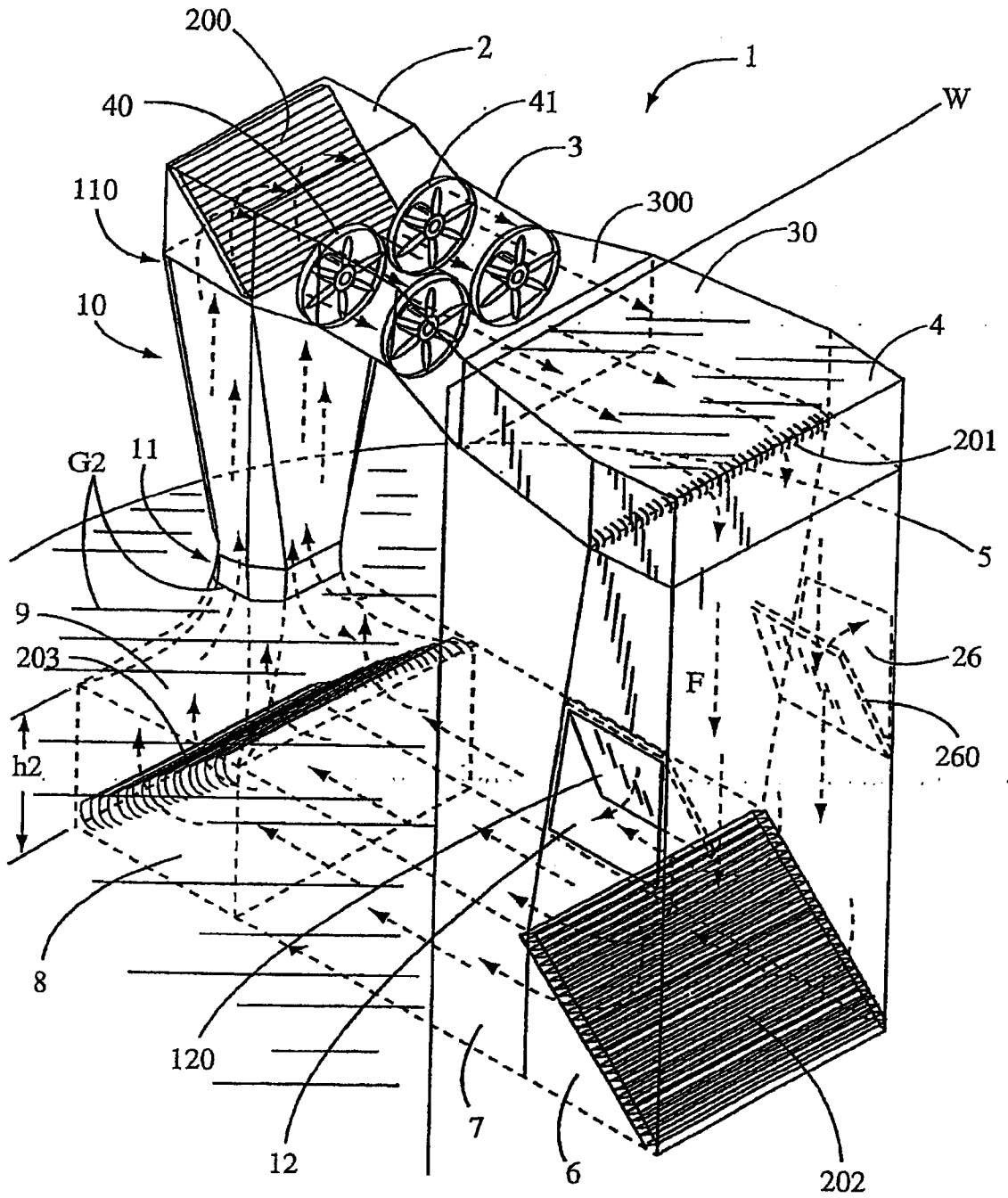


Fig. 2

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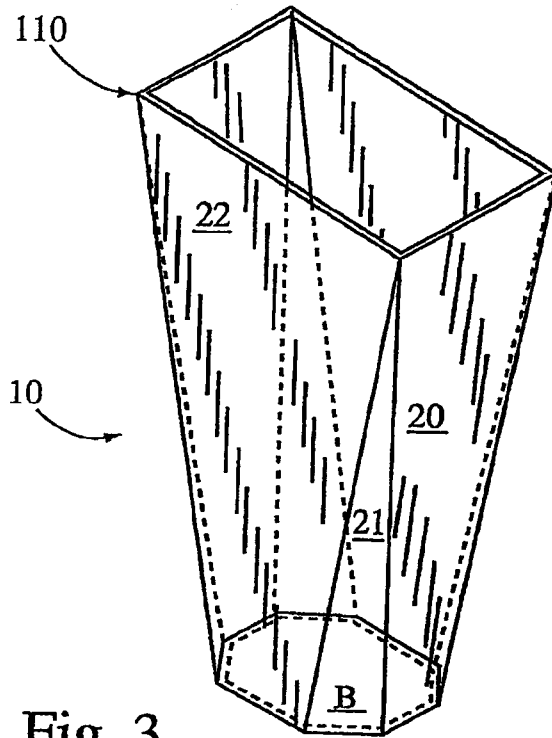


Fig. 3

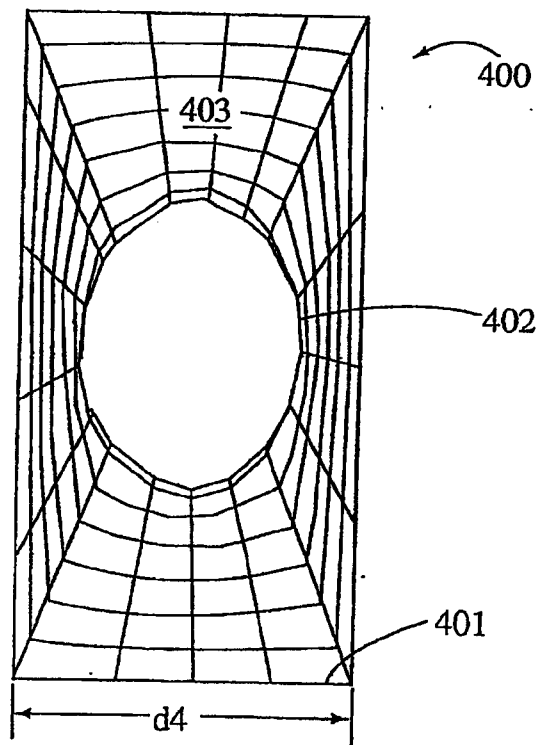


Fig. 4

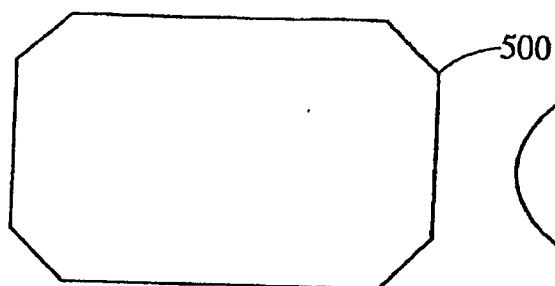


Fig. 5

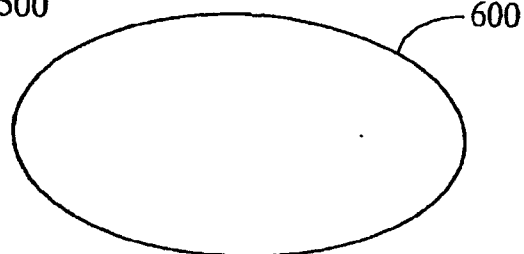


Fig. 6

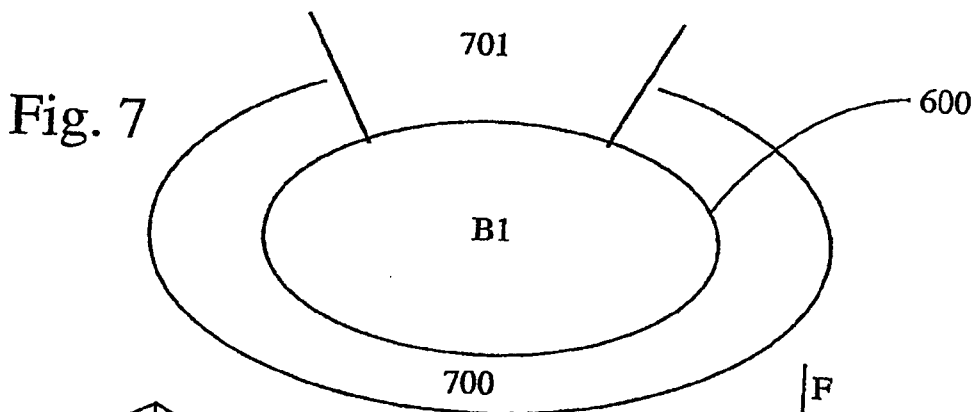


Fig. 7

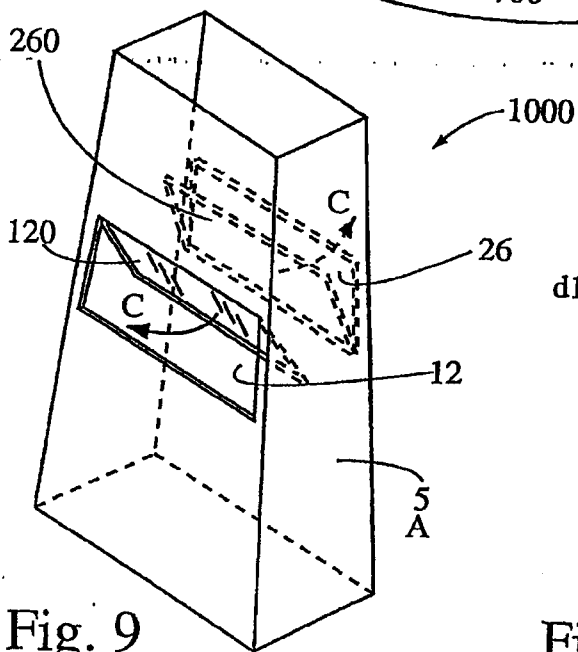


Fig. 9

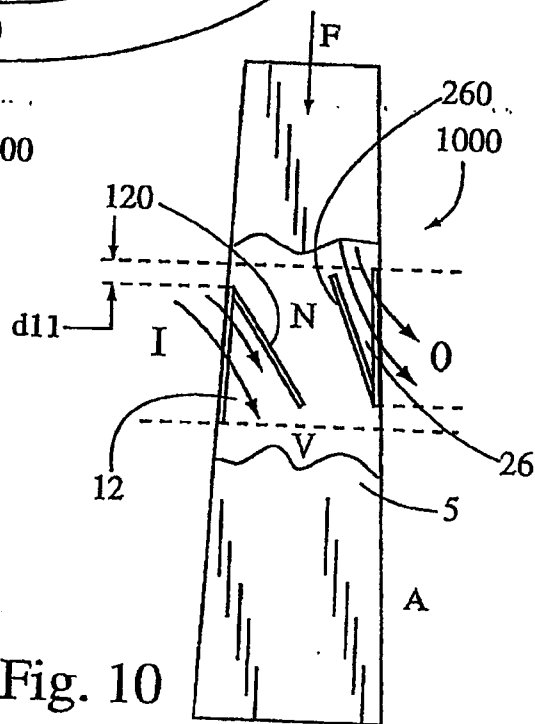
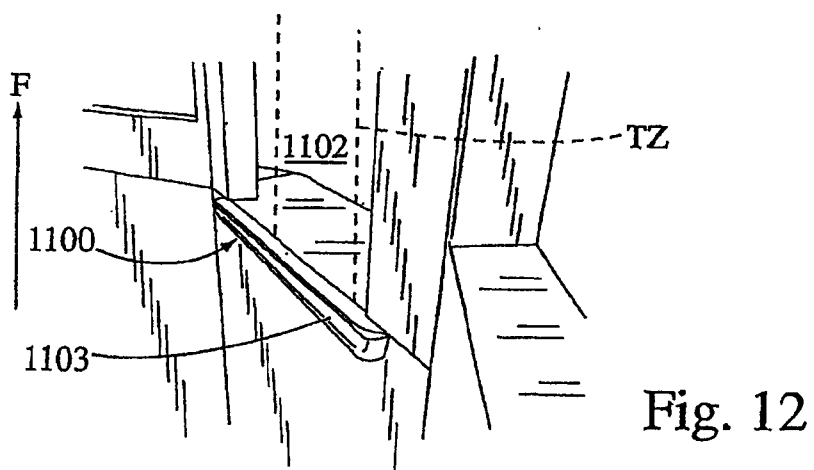
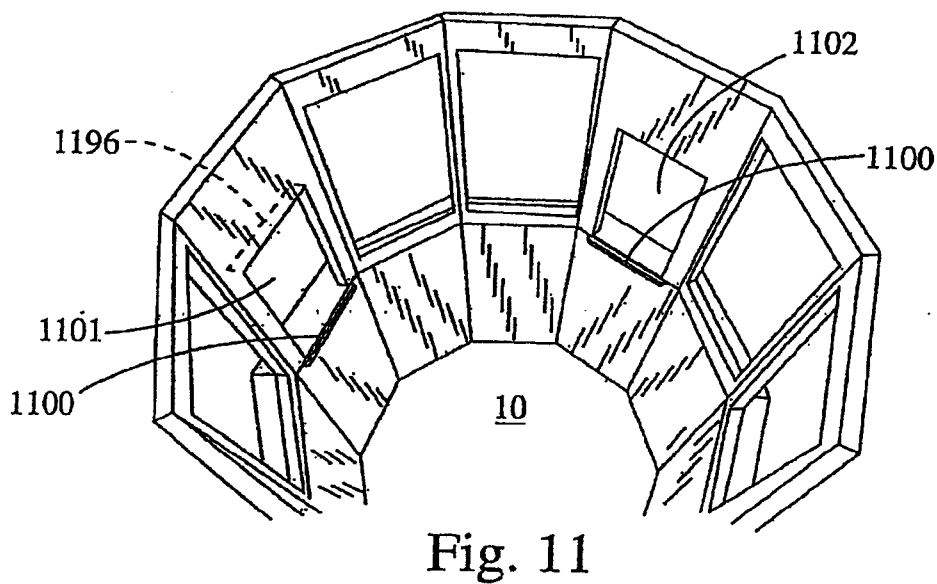
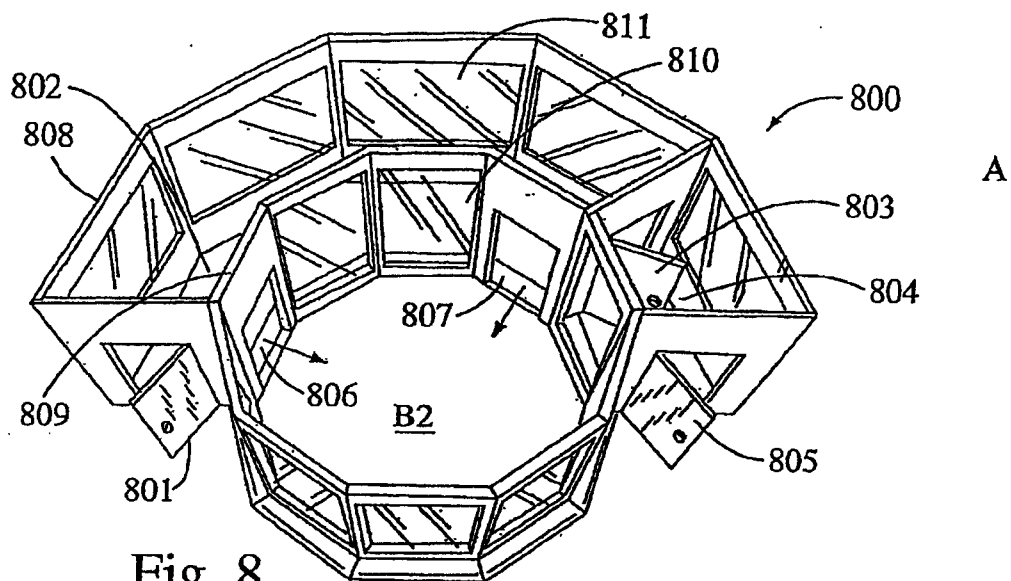


Fig. 10



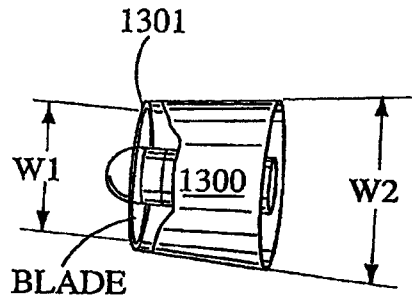


Fig. 13

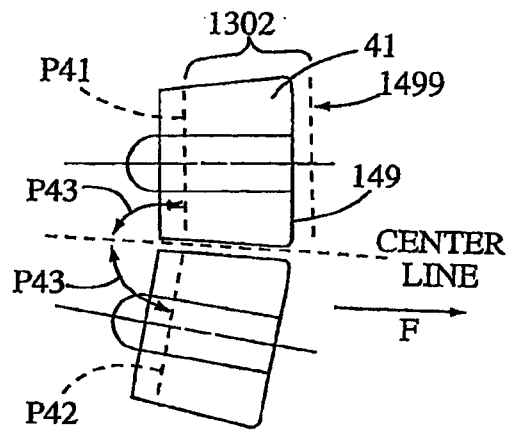


Fig. 14

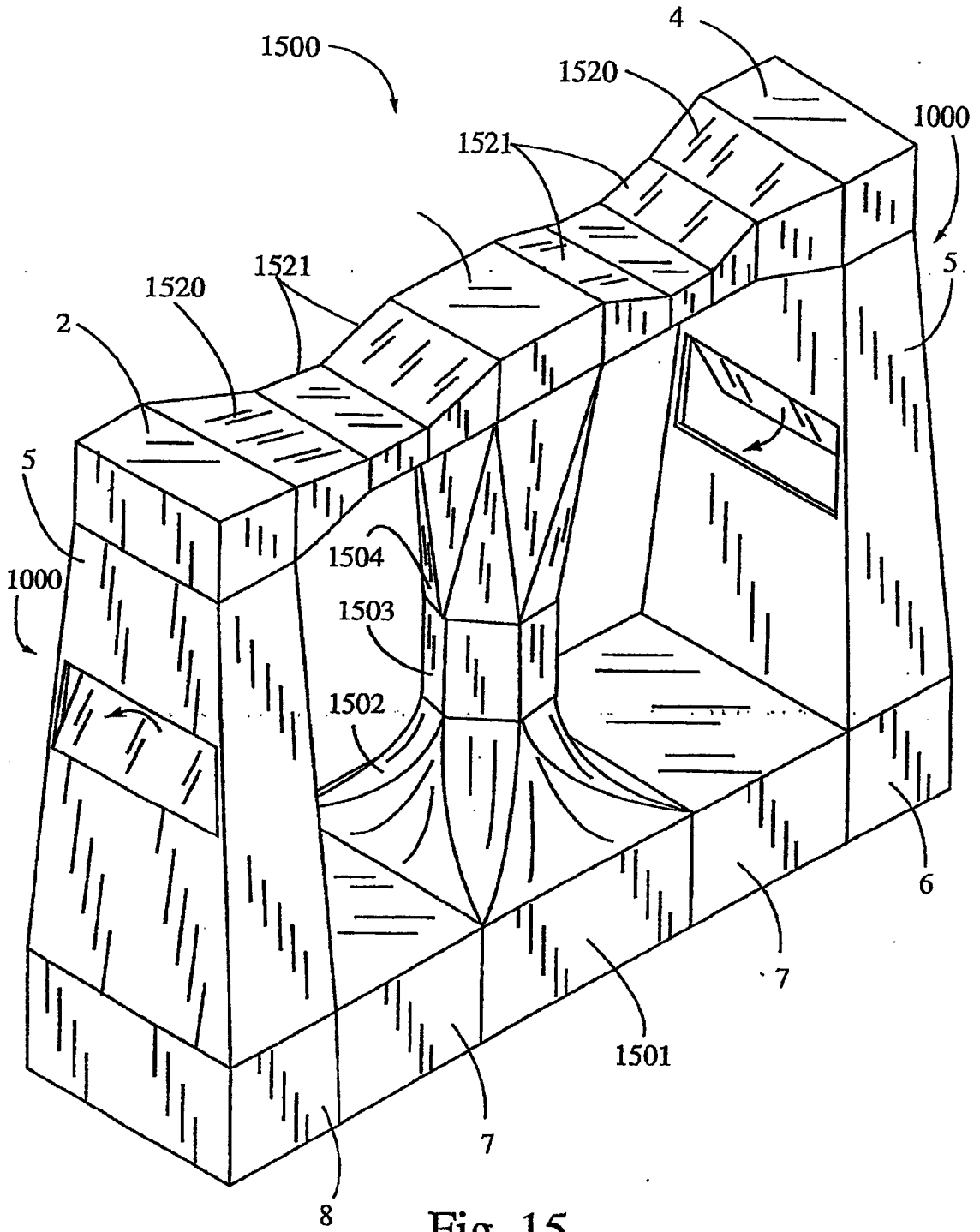
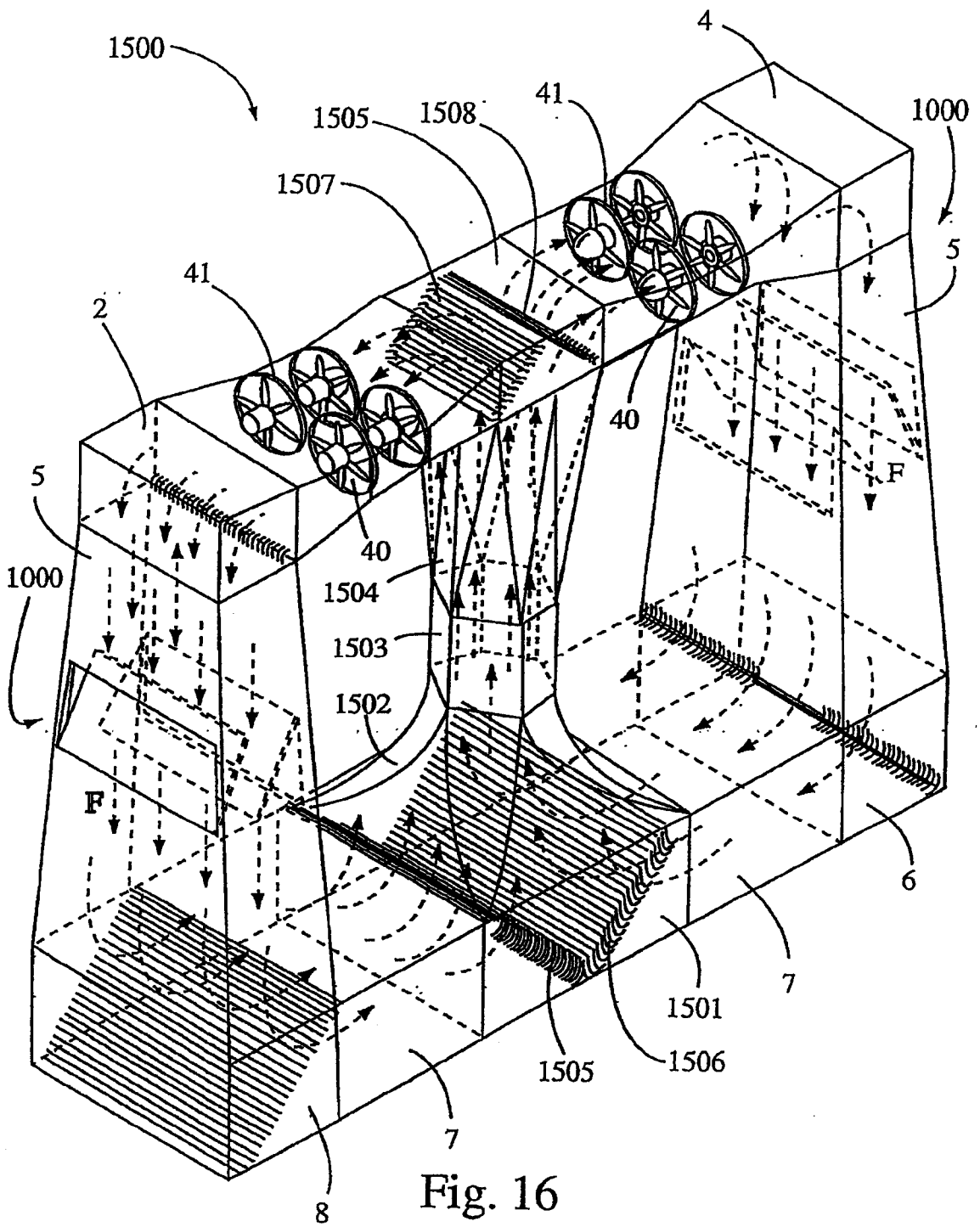
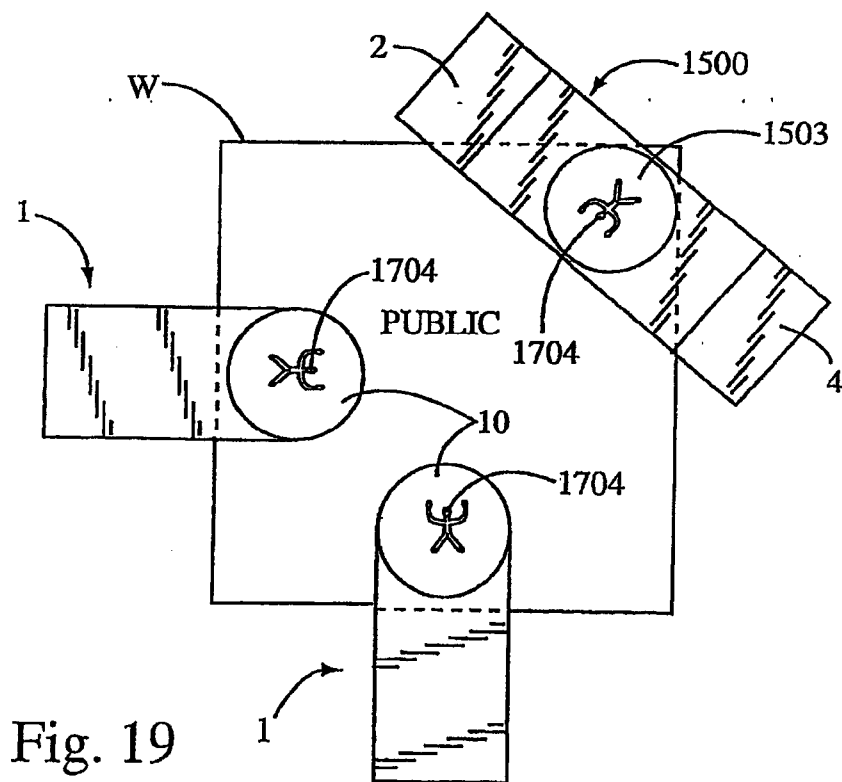
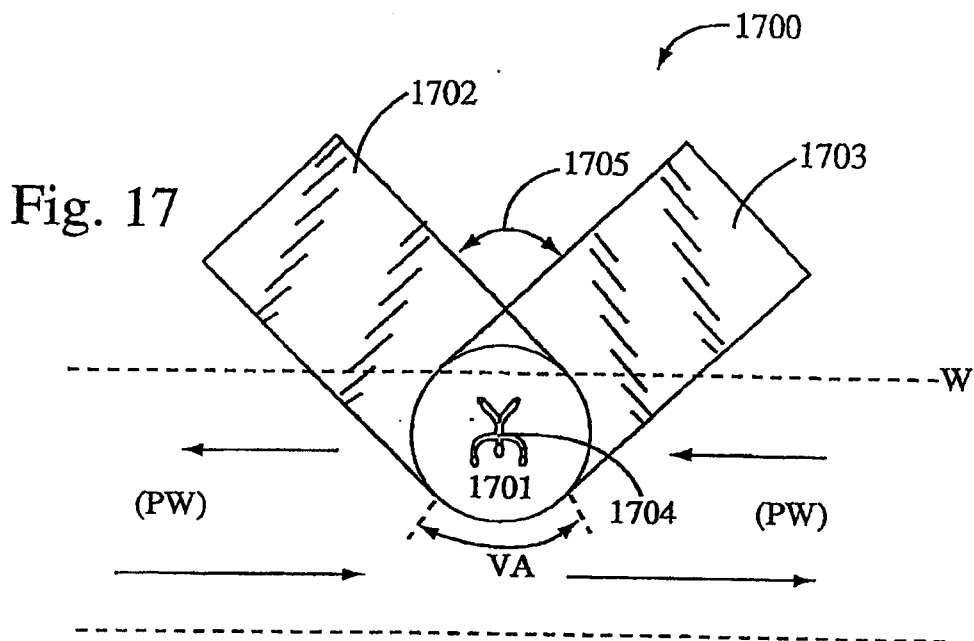
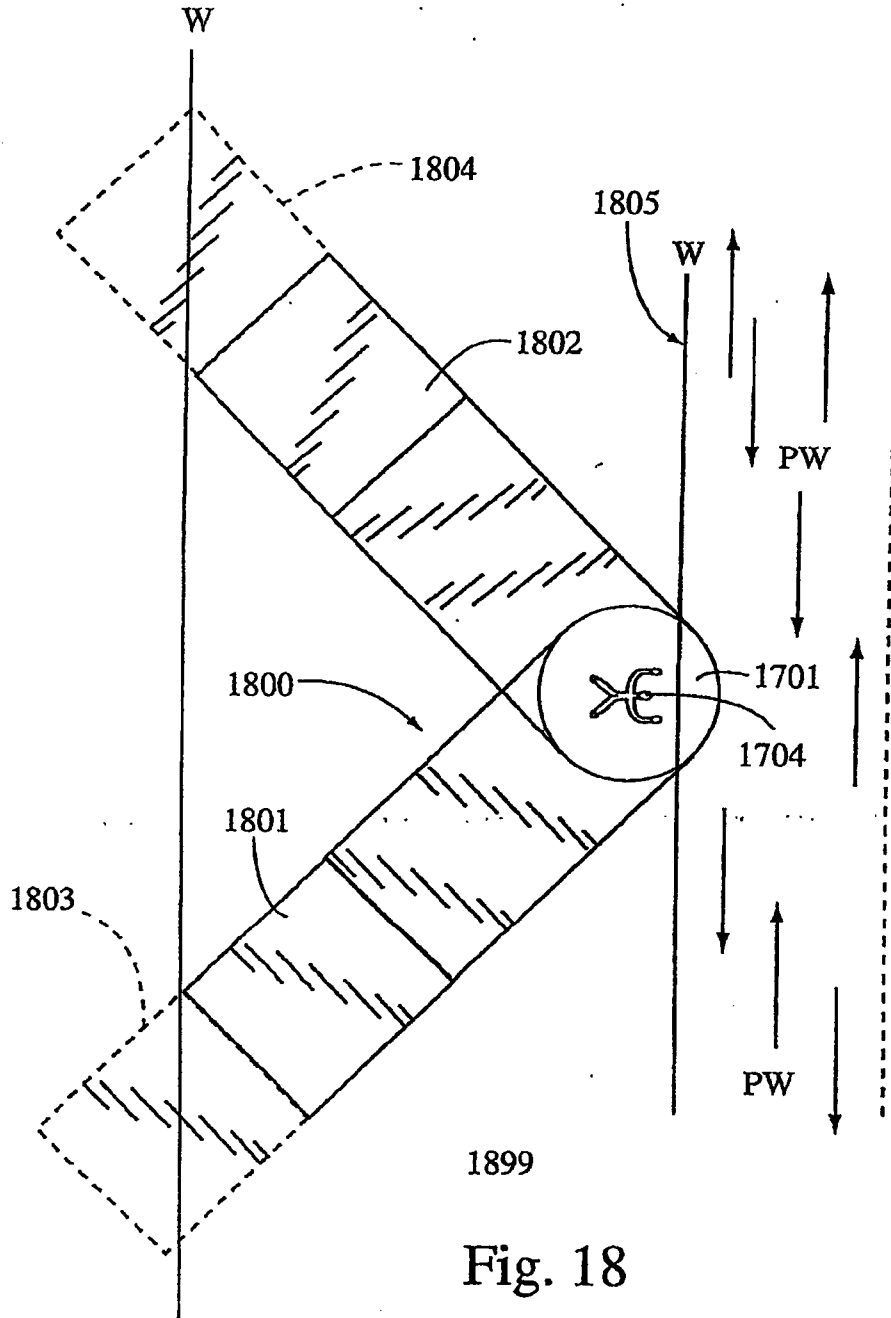


Fig. 15









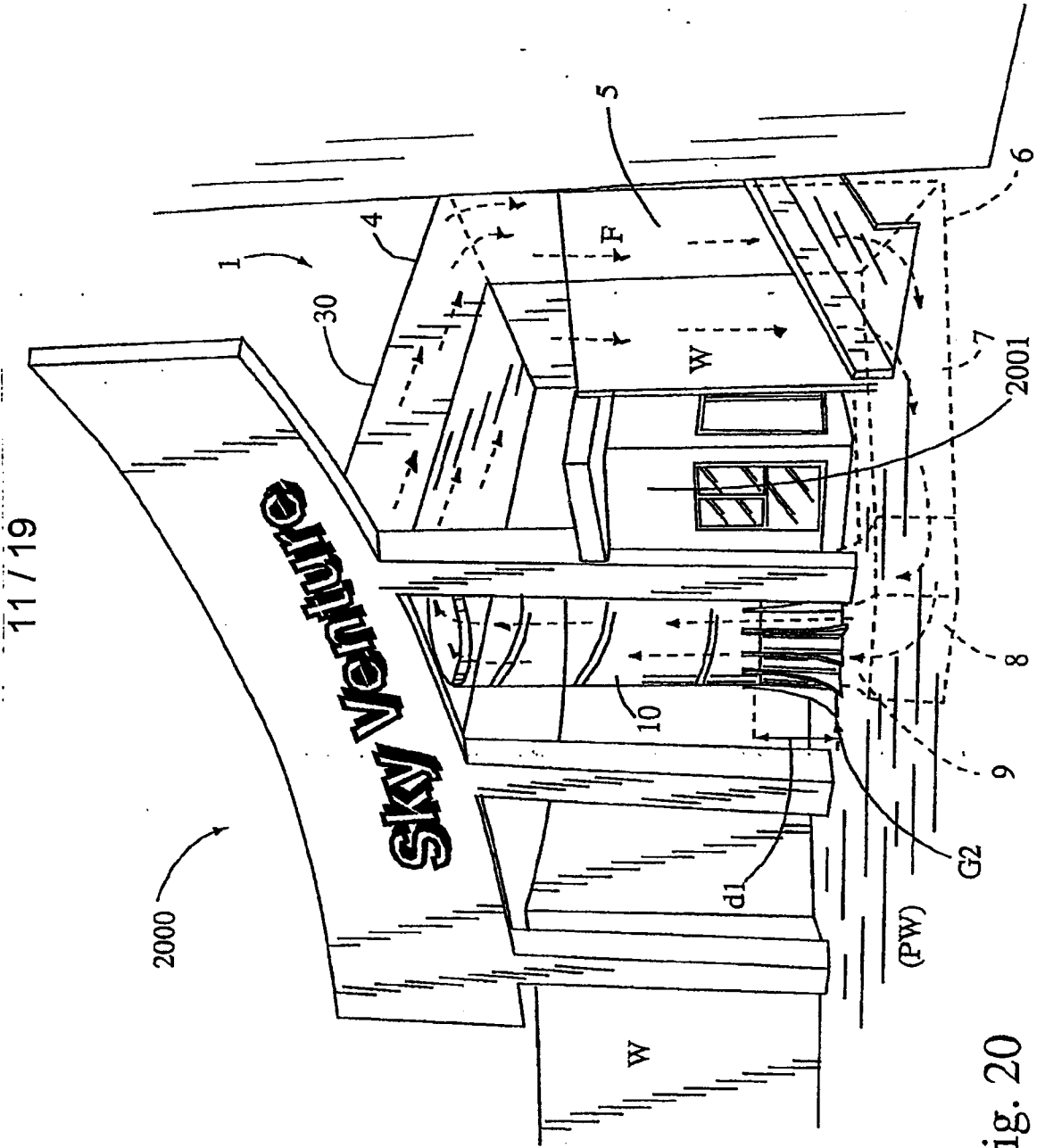


Fig. 20

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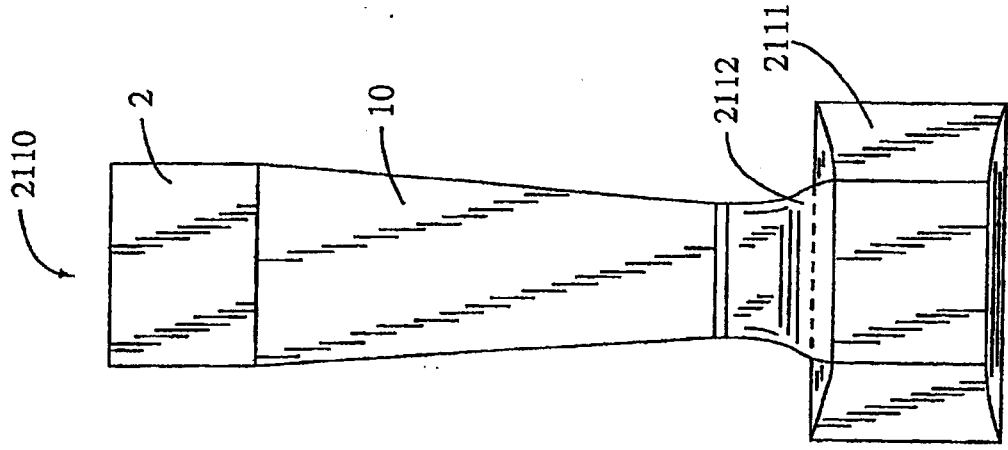


Fig. 21A

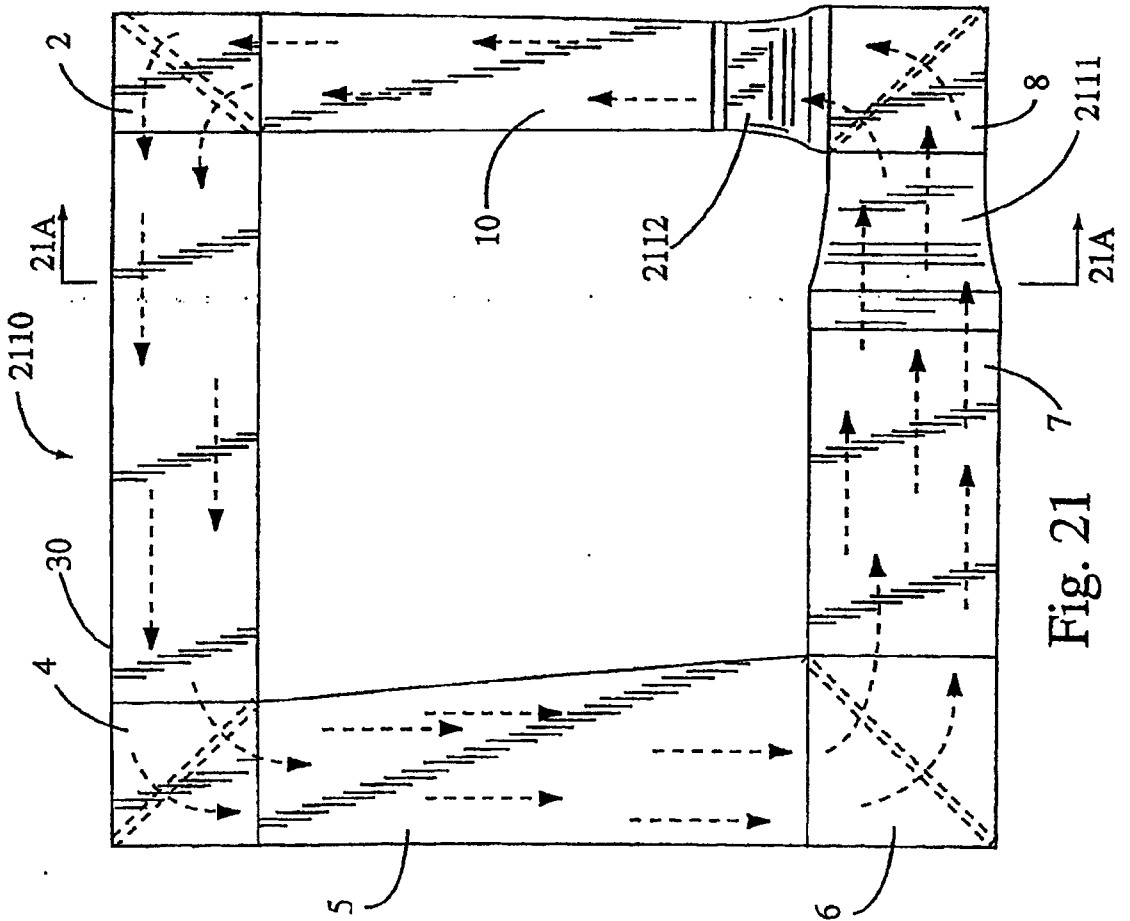


Fig. 21

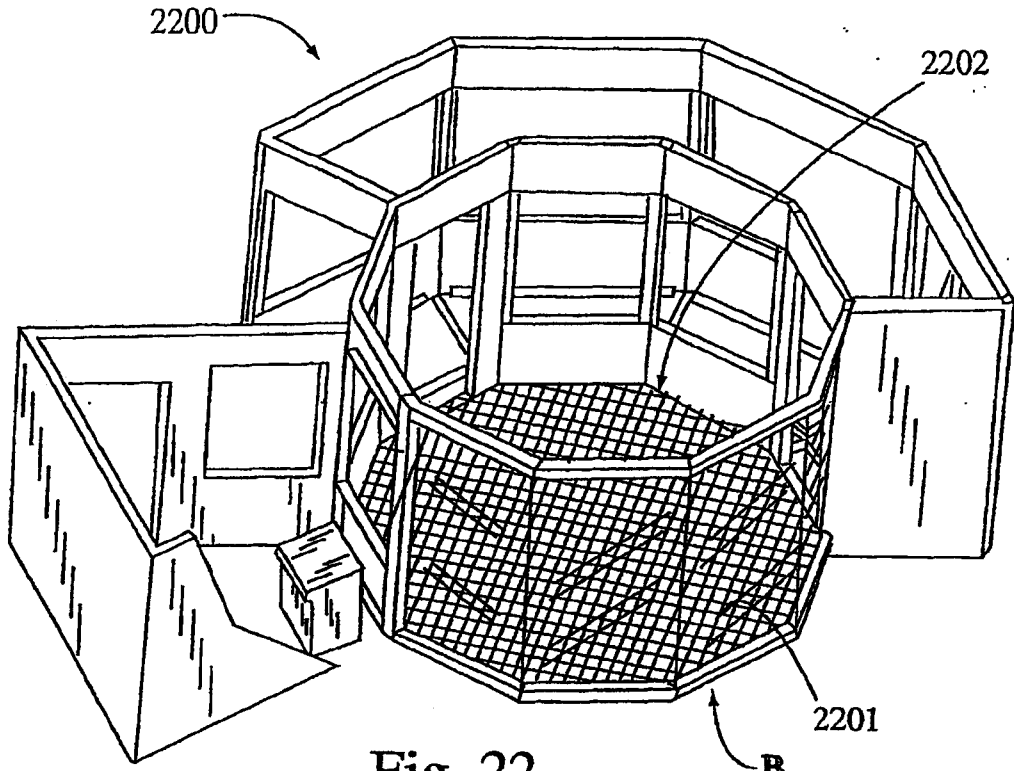


Fig. 22

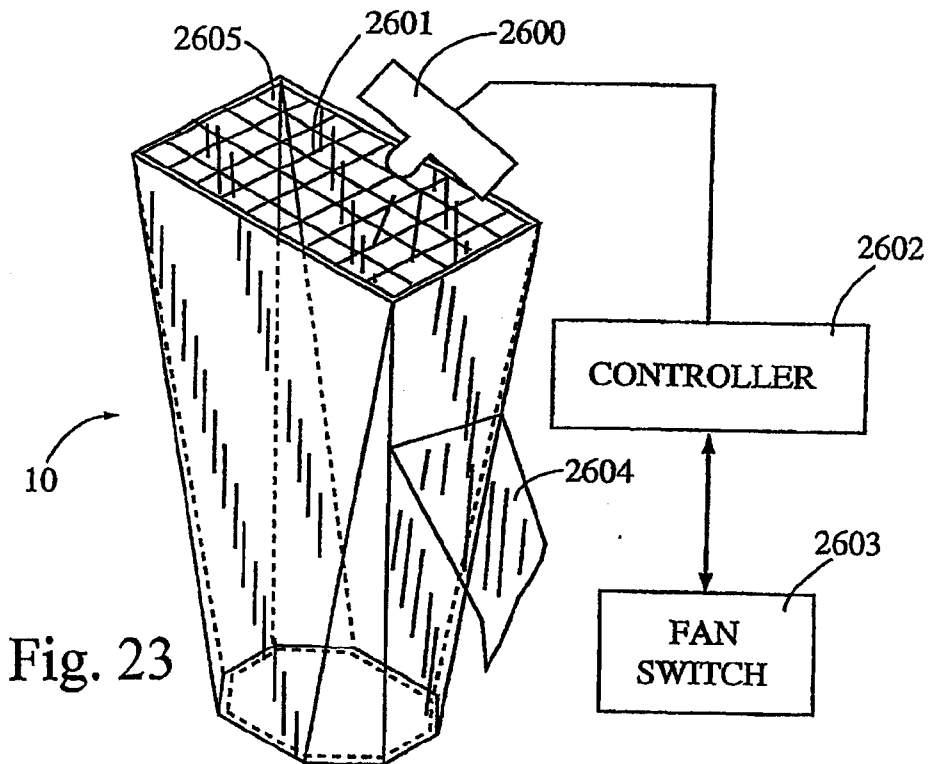
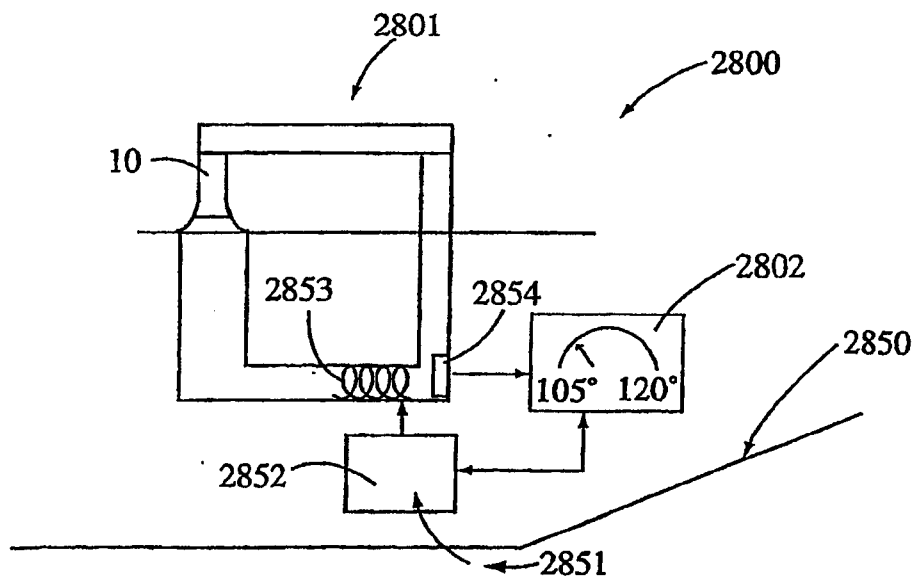
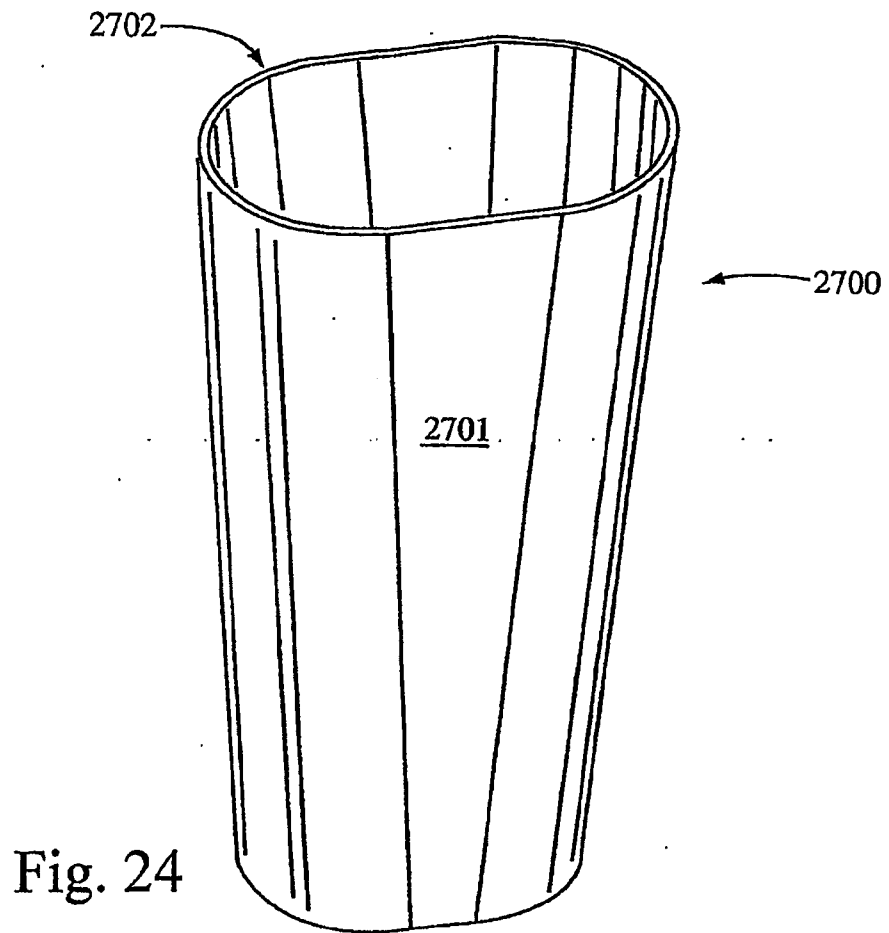


Fig. 23

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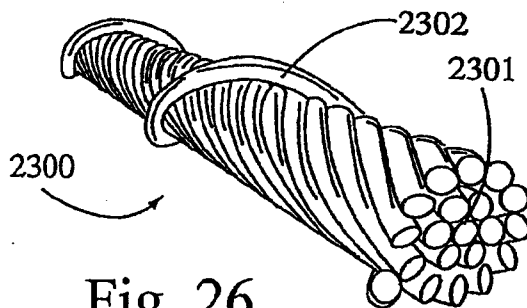


Fig. 26

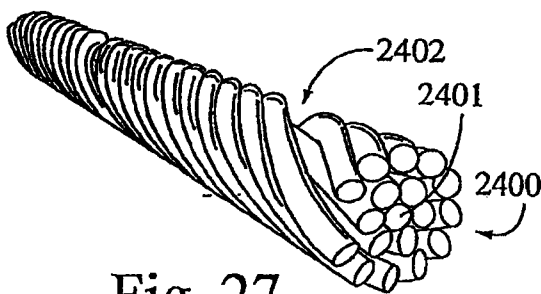


Fig. 27

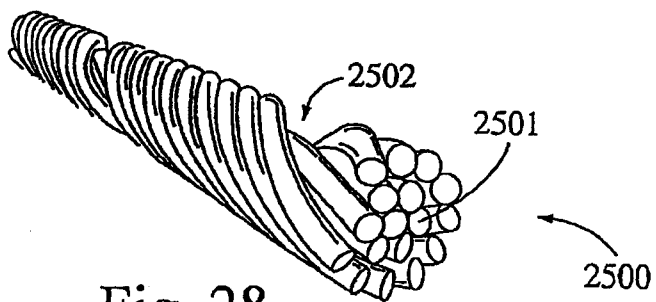


Fig. 28

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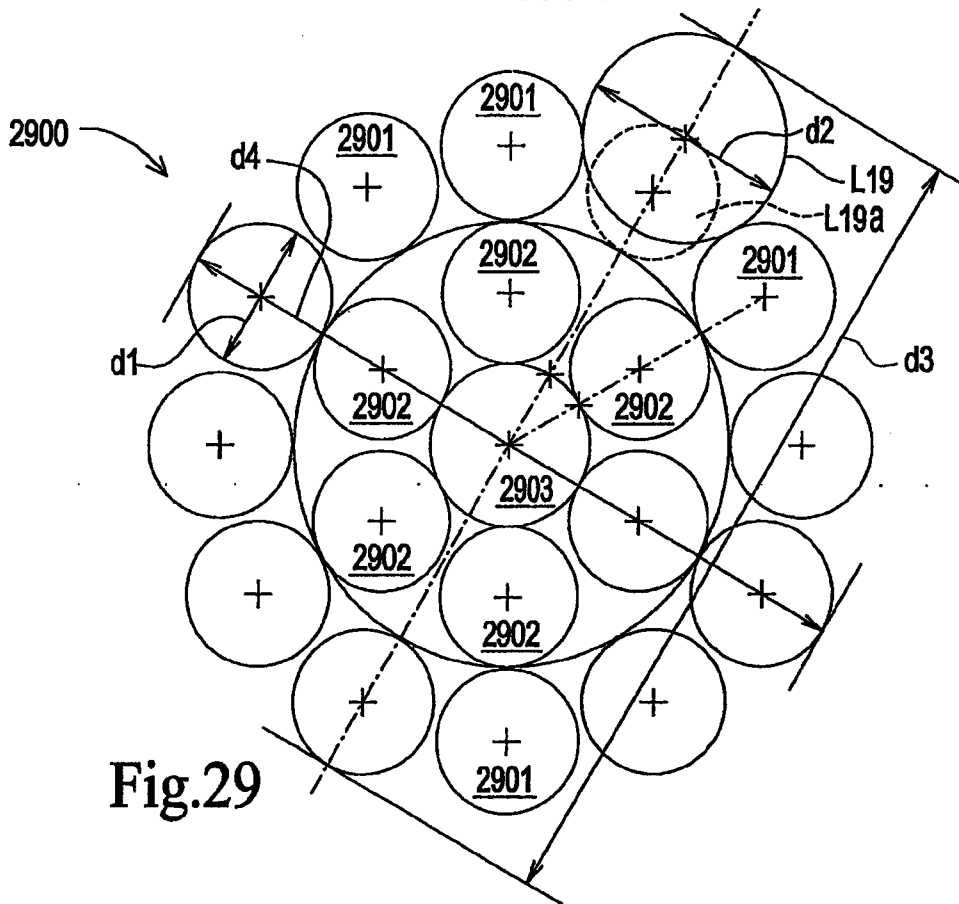


Fig.29

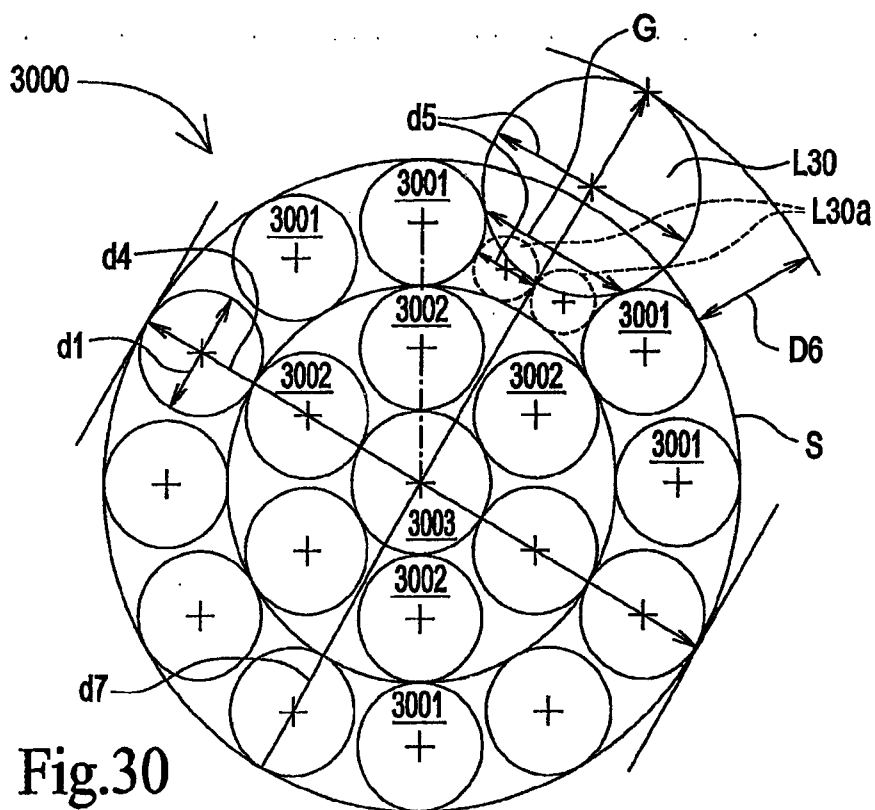


Fig.30

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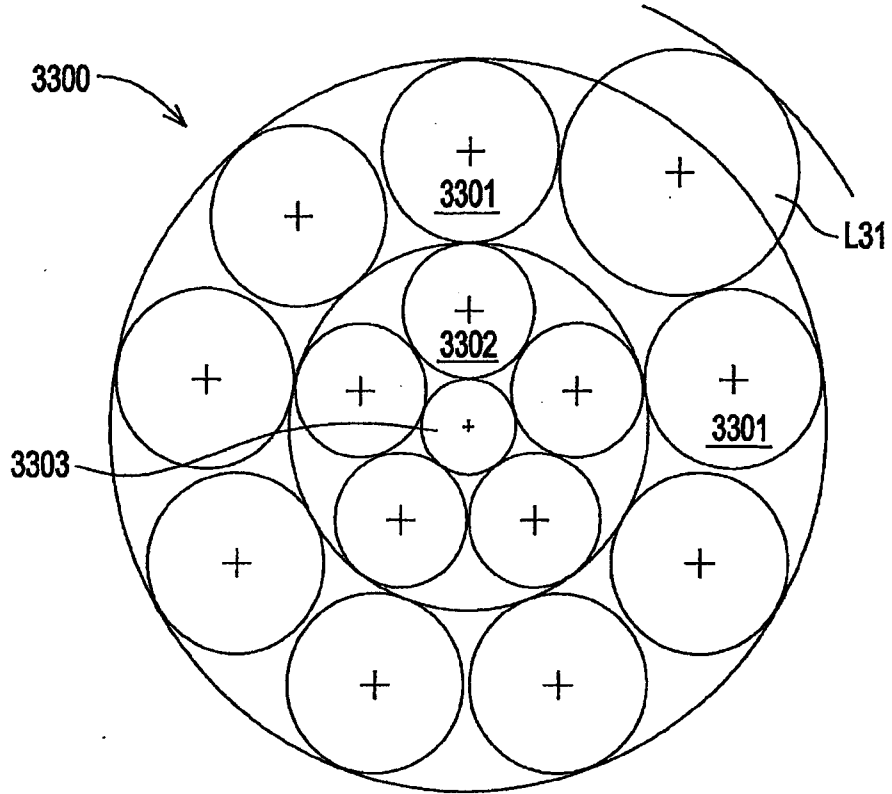


Fig.31

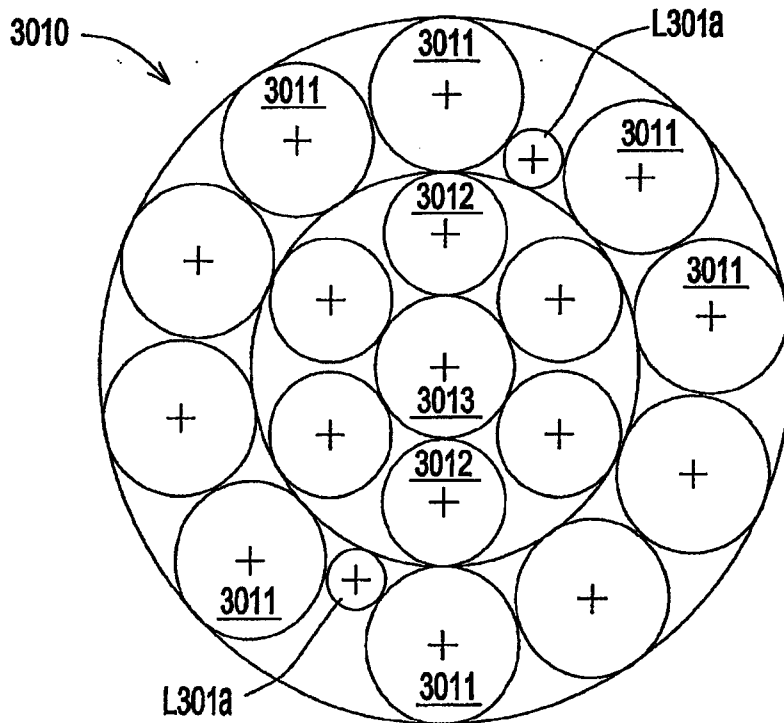


Fig.32



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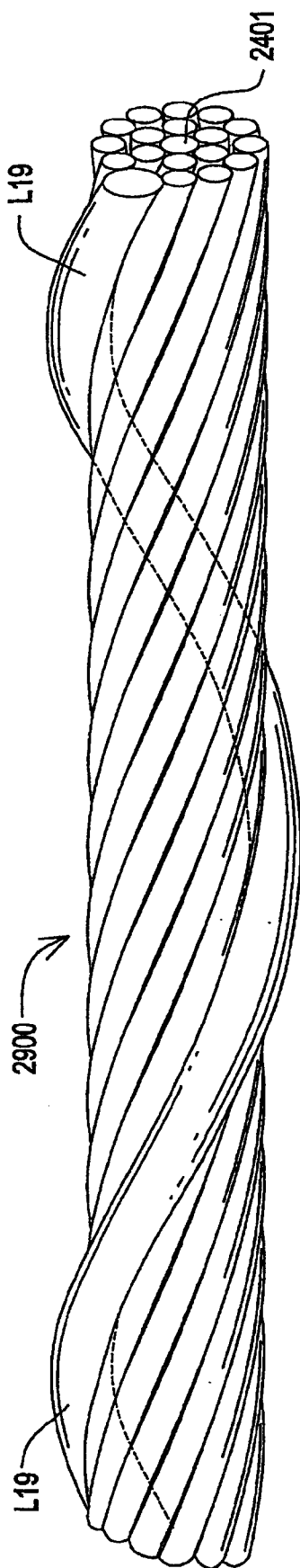


Fig.33

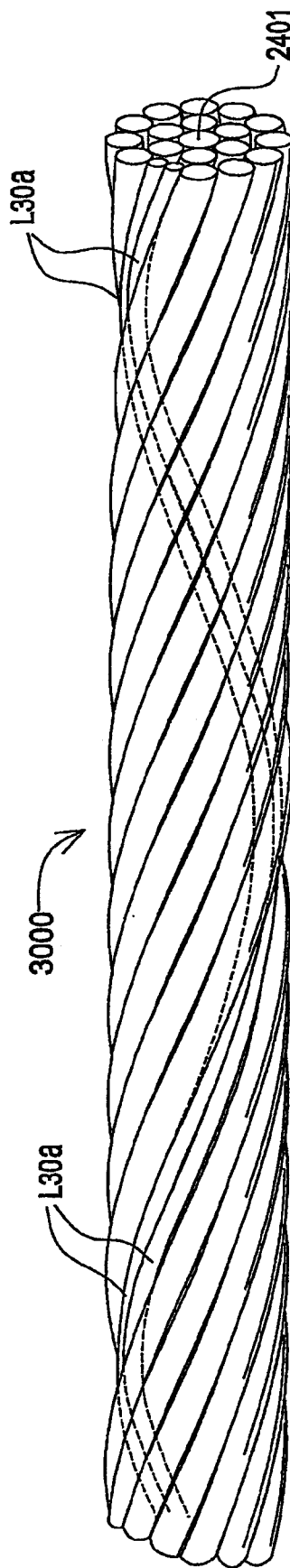


Fig.34

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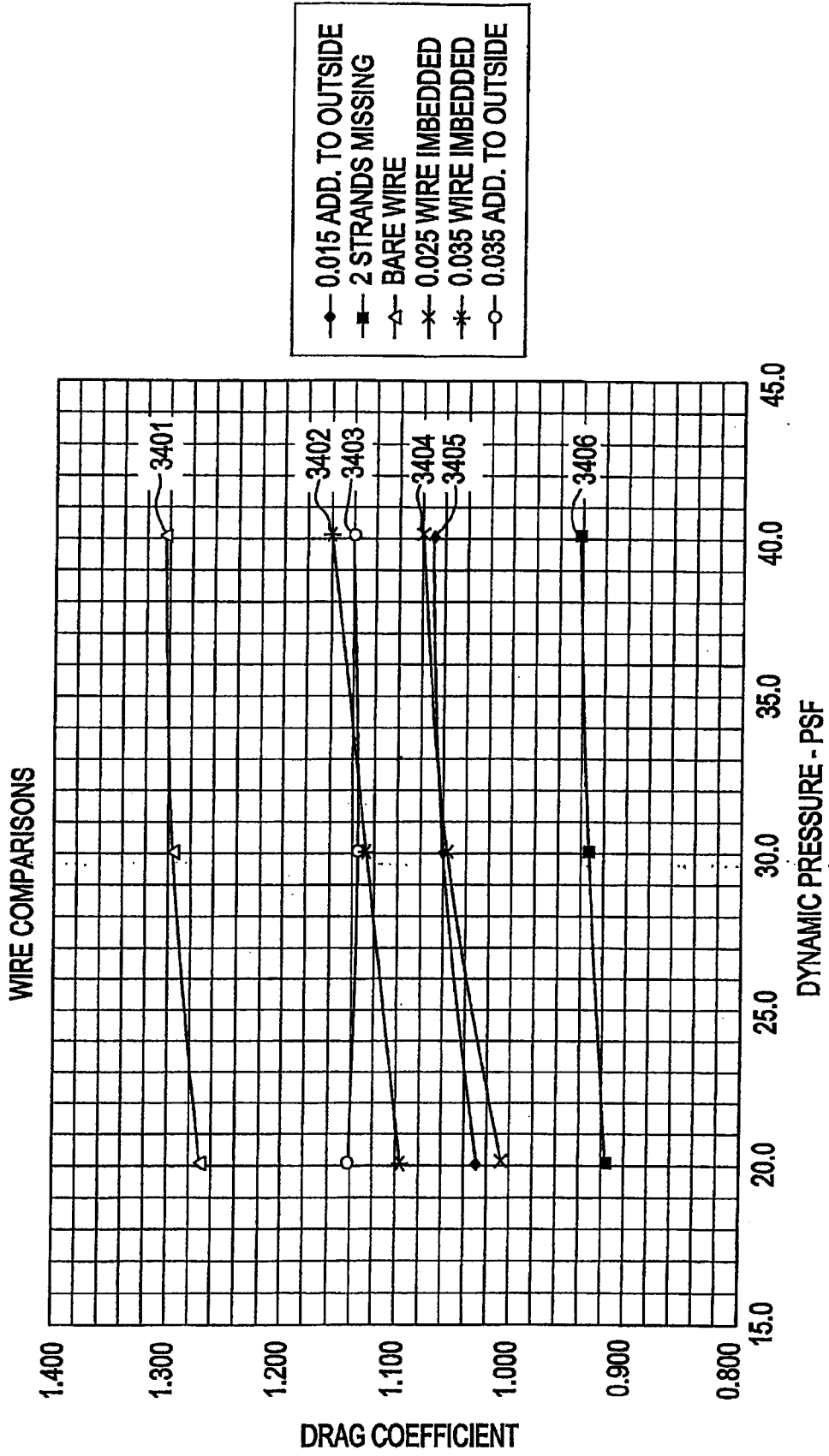


Fig.35

