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

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
3 June 2010 (03.06.2010)

PCT

(10) International Publication Number
WO 2010/060192 A1

(51) International Patent Classification:
F03D 1/04 (2006.01) *F03B 3/18* (2006.01)
F01D 1/02 (2006.01) *F03D 1/02* (2006.01)
F01D 9/02 (2006.01) *F03D 3/02* (2006.01)
F03B 3/04 (2006.01) *F03D 3/04* (2006.01)

(21) International Application Number:
PCT/CA2009/001649

(22) International Filing Date:
12 November 2009 (12.11.2009)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
2,645,296 27 November 2008 (27.11.2008) CA

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

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:
— *with international search report (Art. 21(3))*

(54) Title: ANNULAR MULTI-ROTOR DOUBLE-WALLED TURBINE

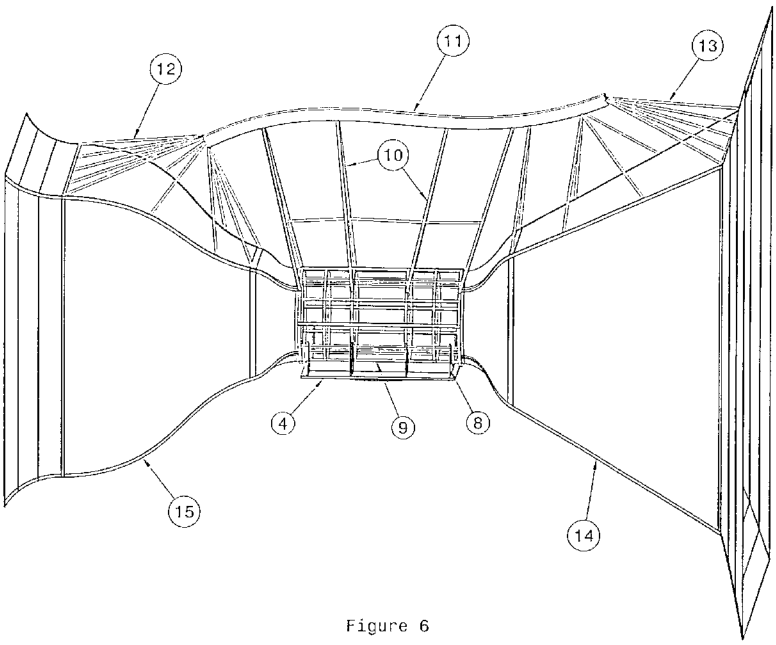

Figure 6

(57) Abstract: An annular single or multi-rotor double-walled turbine. The turbine includes an outer shroud, an inner shroud, and a plurality of driveshafts. The turbine also includes a plurality of rotors coaxially attached to the plurality of driveshafts at spaced intervals. Each of the plurality of rotors comprises a plurality of turbine blades extending between the inner and outer shrouds. Each of the plurality of turbine blades comprises a face. The inner shroud and the outer shroud form a continuous channel for directing a fluid entering the turbine towards the faces of the turbine blades and for directing fluid discharged from a first of the plurality of rotors to the remaining rotors. The channel greatly improves efficiency of power extraction from all augmented and non-augmented fluid streams.

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ANNULAR MULTI-ROTOR DOUBLE-WALLED TURBINE

FIELD OF THE INVENTION

The present invention generally relates to both wind and water turbines. More specifically, the present invention relates to an annular multi-rotor double-walled turbine. The present invention also relates to a single rotor cross-flow turbine. To distinguish the additional complexity of the present invention as compared to a standard windmill, the design of the invention is referred to as a Wind Power Plant (WPP).

BACKGROUND OF THE INVENTION

The present art for modern windmill design is based on Horizontal-Axis Wind Turbines (HAWT) using long, twisted propeller-type blades. In order to increase the generating capacity, the two predominant variables are fluid speed and rotor swept area. The faster the nominal wind speed, the more power is produced and, as the energy produced increases with the cube of the wind speed, the wind conditions of the location is of paramount importance. As such, windmills are placed along coastlines or in areas of wind velocities around 6.0-7.0 m/s and above. The existing HAWT technology cannot produce competitive power unless these two above-mentioned conditions are met.

Windmill diameters have increased substantially with the development of synthetic composite materials such as fiberglass, carbon fiber etc. Large HAWT have blade lengths that now exceed 50 meters in length. This long length reflects the fact that the power produced is dependent on the area swept by the blades. The longer the length of the blades of the rotor, the larger will be its swept area. At this time, there are no ducted commercial-sized windmills in operation. Windmills operate using the velocity pressure or simply the velocity of the wind. Little interest or research has been applied to the addition of devices to increase the total pressure (velocity pressure and static pressure) of the air stream striking the blades.

If the total pressure of the fluid stream has been increased the most appropriate method of applying it to the blades is by simply ducting the turbine. This simple approach has been tried in the past with no commercial successes. The equipment or devices needed to increase the velocity pressure increase the fabrication costs and the increase in energy was insufficient to justify the additional cost and complexity of the equipment required.

One of the major drawbacks of simply ducting the rotor is that much of the air stream with increased total pressure will always take the path of least resistance. Much of the air stream passes through the middle section of the rotor where it develops little or no useful torque. Figure 1 illustrates the fact that a HAWT rotor has a high torque area around the periphery and a low torque area in its center. Even if the air stream total pressure has been increased its preferred path will be through the low torque zone in the center of the rotor where little power is produced.

In order for a double-walled channel to be effective, it must be installed around the outer edges of the rotor(s) and the turbine tunnel must continually rotate into the path of the wind. This requires that all elements be mounted on a common structure and that the structure rotates. If an augmentation device, such as a convergent-divergent nozzle, is used to increase the air stream total pressure, it must also be supported on the same structure and rotate with the WPP.

In the case of axial rotors, the channel is circular. The most efficient and easily built augmentation devices have straight walls. This requires that highly aerodynamic adapters must be installed at the entrance of the channel to convert a straight-walled convergent nozzle to a circular channel. Similarly, the exit from the channel requires an aerodynamic transition from circular to straight-walled nozzle.

The purpose of wind augmentation devices is to increase the total pressure of the air stream. In other words, one or both of the velocity pressure or static pressure are increased. As such, entrance configurations such as curved surfaces designed to minimize entrance and discharge friction losses are not an augmentation device for the simple fact that they do not augment either the velocity pressure or static pressure of the air stream. Similarly, exit configurations designed to minimize exit and discharge friction losses that do not decrease the velocity or static pressure of the fluid stream are not augmentation devices.

A technology that addresses the above difficulties would greatly improve turbine efficiency, improve the electrical stability of the production and decrease the production costs for electricity.

There is thus presently a need for a turbine that can maximize the efficiency of the application of an augmented air stream to a turbine rotor.

There is also a need for an apparatus that can accommodate the operation of several turbine rotors in series rotating at constant velocity.

There is also a need for an adjustable width fluid channel to keep the fluid stream speed constant as the fluid speed varies.

There is also a need for an apparatus with sufficient augmentation and sufficient number of rotors and such performance as to provide cheap competitive electricity at relatively low fluid speeds.

There is also a need for a double-walled channel that applies the augmented fluid stream to the periphery of the rotor where the most torque is produced and eliminates fluid flow to the low torque zone.

There is also a need for an apparatus to enclose the turbine rotors to minimize noise and visual impacts.

There is also a need for an apparatus to remove from the augmented fluid stream all parts of the rotor with the exception of the blades.

There is also a need for an apparatus to distribute as equally as possible the augmented fluid stream into the channel and to the face of the rotor blades.

There is also a need for an apparatus to create a WPP that can integrate, into its operation, various subsystems for improving performance such as a rotor-sectoring system, a fluid stream augmentation apparatus and annular rotors for HAWT applications.

There is also a need for an apparatus to provide an innovative rotating mechanism for large capacity WPP with a long structural carriage supporting a double-walled channel, multiple rotors, generators and a wind augmentation device.

There is also a need for an apparatus that can accommodate a motorized compressor fan on the end of the rotor shaft facing the incoming fluid to increase the fluid flow to the high torque zone of the rotor.

SUMMARY OF THE INVENTION

An object of the present invention is to provide a turbine that satisfies at least one of the above-mentioned needs.

According to the present invention, there is provided an annular multi-rotor double-walled turbine comprising:

-an outer shroud;

-an inner shroud;

-a plurality of driveshafts; and

-a plurality of rotors coaxially attached to the plurality of driveshafts at spaced intervals, each of the plurality of rotors comprising a plurality of turbine blades extending between the inner and outer shrouds, each of the plurality of turbine blades comprising a face,

wherein the inner shroud and the outer shroud form a continuous channel for directing a fluid entering the turbine towards the faces of the turbine blades and for directing fluid discharged from a first of the plurality of rotors to the remaining rotors.

The present invention also provides an adjustable flow channel area, double-walled, cross-flow turbine comprising:

-a vertical or horizontal axis cross-flow rotor comprising a plurality of turbine blades, each of the turbine blades comprising a cylindrical face;

-an outer shroud enclosing side portions, a top portion and a bottom portion of a swept area of the rotor;

-upstream fluid deflectors for adjustably reducing a width or height of the swept area of the rotor;

-upstream fluid deflector actuators for adjusting a projection of the fluid deflectors into a fluid stream entering the turbine;

-adjustable inner walls located within a circumference of the cylindrical faces of the turbine blades; and

-inner wall actuators for positioning the inner walls relative to a width or height of a fluid channel created by the fluid deflectors,

wherein the inner walls and upstream fluid deflectors form a channel for directing the fluid entering the turbine towards the cylindrical faces of the turbine blades and for directing fluid discharged from upstream blades to the cylindrical faces of downstream blades.

The present invention also provides an annular double-walled turbine comprising:

-an outer shroud;

-an inner shroud;

-a driveshaft; and

-a rotor coaxially attached to the driveshaft, the rotor comprising a plurality of turbine blades extending between the inner and outer shrouds, each of the plurality of turbine blades comprising a face,

wherein the inner shroud and the outer shroud form a continuous channel for directing a fluid entering the turbine towards the faces of the turbine blades.

The present invention generally can be applied to wind turbines that are axial and use a circular annular-shaped rotor and to cross-flow type turbines employing vertical axis blades. The turbines may be augmented or non-augmented. The double-walled configuration is applicable for both windmill and water turbine applications. As water flow for energy production is mostly only unidirectional or bi-directional (tidal application), there is typically no need for the carriage or supporting structure to rotate in water turbine applications.

The present invention also provides a WPP that mounts one or multiple turbines in series that share a common, double wall, and ducted wind channel. If an axial flow turbine is used, the ducted channel is round, whereas if a cross-flow turbine is used, the ducted channel is rectangular. The installation of multiple wind turbines on a single tower and the high production capacity of the unit are the justification for calling the invention a WPP. A ducted wind channel greatly improves efficiency of power extraction from all augmented and non-augmented air streams.

This continuous channel allows the wind energy to be augmented and then applied successively to a series of one or more rotors. The width of the air channel is equal to the length of the rotor blades. As the two rings or shrouds that hold the blades in place are located just outside the channel, the blades are the only element of the rotor making contact with the augmented air stream. The air stream is applied strictly to the exterior tips of the blades that in turn convert more of the wind energy into useful torque.

Almost all existing large commercial windmills are of the Horizontal Axis Wind Turbine (HAWT) configuration and use a three-blade twisted propeller. Although the energy of the wind over the entire face of the blades is constant for a HAWT, the percentage of useful energy converted varies from a maximum at the rotor periphery to a minimum near the root of the blades.

In cases of very high wind augmentation, the tip speed of the blades can become supersonic. This apparatus allows several rotors to be installed in series whereby the pressure drop over each series of blades decreases. This permits the use of high augmentation factors that would otherwise generate supersonic blade speeds if only one rotor were used.

Only the bladed section of the rotor is contacting the air stream. This eliminates the parasitic losses that result from the rotor spokes and the low efficiency sections of the blades turning in the air stream. These elements now turn in sheltered compartments where parasitic losses are decreased. As the apparatus also mounts the electrical generator outside of the air stream its wind resistance is also eliminated. As the wind velocity varies, the width of the wind channel is adjusted to maintain a constant velocity to the blades. It is mandatory that wind velocity measurement be taken upstream of the rotor and not downstream of the rotor.

The entire wind turbine can be mounted on one common carriage that is motorized to face the prevailing winds and the carriage sits on one tower. The motorized carriage is replaced by a slew bearing or equivalent device for small wind turbines. To be most effective, the circular air channel is fed and discharged through adapters to straight-walled convergent and divergent nozzles.

The important economic challenge that is met by this invention is the improvement in the performance by integrating several new and innovative techniques. In effect, the performance is improved to the point that winds of lower velocities can now produce competitive electricity. The WPP can be located in urban areas or next to industries where wind velocities are low. As such, the cost for distributing the power and the need for new infrastructure are eliminated.

In the channelled WPP design, the air or fluid stream with its augmented-energy is directed exclusively to the area of the blades in the high torque zone. No wind or fluid is directed to the low torque zone. An axial turbine configuration of a WPP uses a double-walled annular channel to direct the air stream to the peripheral or high torque zone. A vertical axis configuration of a WPP uses a double-walled channel to direct the airflow to the center of the swept area and away from the two outer edge areas.

This double-walled channel provides several important benefits. The fluid stream is directed to the optimum area of the blades to maximize the production of useful torque. The cross-sectional area for the fluid flow can be decreased to further increase the fluid stream velocity once it has left the augmentation device and increased velocity improves power production at the rate of the cube of the increase. The air stream is contained permitting several rotors in series to be used to extract fluid energy. The possible fluid leakage into the low torque zone or back to atmosphere is negligible. It is possible to adjust the width of the fluid channel. This provides an optimization tool whereby as the fluid speed varies, the cross-section is automatically adjusted to hold the fluid stream velocity constant.

In order for the fluid stream arriving from the augmentation device to be properly and evenly distributed over 360 degrees of the channel, a circular deflector is installed directly upstream of the rotor facing the wind. This deflector can be of many shapes including semicircular, conical, parabolic, etc. but it must have an aerodynamic shape to distribute the fluid evenly with minimal friction losses.

An augmentation device takes a fluid of low energy density and increases the energy density. The WPP design can optimize the power extraction from augmented air streams. A WPP uses much smaller turbine rotors and the rotors can be installed in series. The energy produced per area of swept area is now many times that of an existing HAWT or Vertical Axis Wind Turbine (VAWT). The number of towers required for supporting the turbines and the environmental footprint are decreased. The blades of a WPP are enclosed and there are no obstacles in the path of the air stream, before or after it makes contact with the blades. This eliminates the noisy woof created by large propeller-type rotors as they pass in front of the mast. The non-productive parts of the rotor and the electrical generator are now completely isolated from the air stream. Parasitic drag losses are minimized.

BRIEF DESCRIPTION OF DRAWINGS

These and other objects and advantages of the invention will become apparent upon reading the detailed description and upon referring to the drawings in which:

Figure 1 is a schematic view of the zones (sectors) of low and high torques on the swept area of an axial flow turbine.

Figure 2 is a schematic view illustrating zones (sectors) of low and high torques on the swept area of a cross-flow turbine using airfoil blades.

Figures 3A to 3C are side, front and rear views respectively of a turbine installed on a steel or concrete tower according to a preferred embodiment of the present invention.

Figures 4A to 4C are side and detailed views respectively of the turbine shown in Figures 3A to 3C illustrating the rotation of the turbine by a slew bearing.

Figures 5A to 5C are side, front and rear views respectively illustrating the tunnel, the entrance and exit adapters of the turbine shown in Figures 3A to 3C.

Figure 6 is a perspective view illustrating the integrated structure and support for the tunnel, the cross beam of a convergent divergent nozzle and the frame of the convergent divergent nozzle of the turbine shown in Figures 3A to 3C.

Figures 7A to 7E are three perspective, a section and a detailed view respectively illustrating the interior wall, exterior wall, liners and liner actuators of the turbine shown in Figures 3A to 3C.

Figure 8 is a side view illustrating the positioning of three rotors, three generators and a semi-circular deflecting cone within the turbine shown in Figures 3A to 3C.

Figures 9A to 9F are perspective, top, front and three detailed views illustrating the rotation of the carriage structure by motorized wheels of the turbine shown in Figures 3A to 3C.

Figure 10 is a side cut view illustrating an electrical generator driven by a rotor at both ends and a pony motor of the turbine shown in Figures 3A to 3C.

Figure 11 is a perspective view of a single rotor cross-flow or Vertical Axis Wind Turbine and its air stream channel centered on the vertical rotor shaft according to another embodiment of the present invention.

Figure 12 is a graph showing Channelling Ratio (CR) versus Power Output for a HAWT.

Figure 13 is a graph showing Channelling Ratio (CR) versus Power Output for a VAWT.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Although the invention is described in terms of specific embodiments, it is to be understood that the embodiments described herein are by way of example only and that the scope of the invention is not intended to be limited thereby.

As shown in Figures 3 to 10 and as better shown in Figures 7A to 8, according to the present invention, there is provided an annular multi-rotor double-walled turbine 70. The turbine 70 includes an outer shroud 17, an inner shroud 32, and a plurality of driveshafts 80, 82, 84 (shown in Figure 8). The turbine 70 also includes a plurality of rotors 72 coaxially attached to the plurality of driveshafts 80, 82, 84 at spaced intervals. Each of the plurality of rotors 72 comprises a plurality of turbine blades 74 extending between the inner 32 and outer 17 shrouds . Each of the plurality of turbine blades 74 comprises a face. The inner shroud 32 and the outer shroud 17 form a continuous channel for directing a fluid entering the turbine 70 towards the faces of the turbine blades 74 and for directing fluid discharged from a first of the plurality of rotors 76 to the remaining rotors. The channel greatly improves efficiency of power extraction from all augmented and non-augmented fluid streams.

Preferably as better shown in Figures 7D and 7E, the turbine 70 further comprises an adjustable inner shroud liner 20 and an actuating system 22 for displacement of the adjustable inner shroud liner 20 with respect to a face of the inner shroud 32.

Preferably as better shown in Figure 6, the turbine 70 further comprises an inlet and a converging nozzle 15 for directing and accelerating fluid towards the inlet of the turbine.

Preferably, the turbine 70 further comprises an outlet and a diverging nozzle 14 for directing and decelerating fluid discharged from the outlet of the turbine.

Preferably, the turbine further comprises a support structure 10 fixed over the outer shroud 17 and connected to the converging nozzle 15 and the diverging nozzle 14, the support structure partly supporting a weight of the converging nozzle 15 and the diverging nozzle 14.

Preferably as better shown in Figures 4A to 4C, the turbine 70 further comprises a turbine base structure 40 and a turbine rotation system 42 for rotating the turbine base structure to align the driveshafts with an incoming direction of the fluid entering the turbine.

Preferably, the turbine further comprises a fluid velocity measurement system located upstream of the turbine and producing a signal indicative of fluid velocity entering the turbine. The actuating system displaces the adjustable overlapping inner shroud liner 20 with respect to the face of the inner shroud 32 based on the signal indicative of fluid velocity entering the turbine. The expansion of the inner liner shroud is permitted by sliding connections between the inner liner segments 21.

Preferably as better shown in Figures 7A to 7C, the turbine 70 further comprises a directing system 18 mounted upstream of the inner shroud 32 and over the inner shroud 32 for directing fluid entering the turbine towards the plurality of turbine blades 74 of the first of the plurality of rotors 76.

Preferably, the turbine further comprises a compressor fan positioned upstream of the turbine and increasing velocity of the fluid entering the turbine.

Preferably, the fluid is air or water.

In one embodiment of the present invention, the turbine blades are preferably hollow, perforated and connected to a vacuum system for controlling boundary layers in proximity of the turbine blades.

In another embodiment of the present invention, the turbine blades are preferably hollow, perforated and connected to a pressurized fluid supply system for controlling boundary layers in proximity of said turbine blades.

According to the present invention, there is also provided a double wall channelled WPP that easily permits the application of an augmented air stream to the high torque region of rotor(s) for use with at least one or a series of turbine rotors to increase the performance of the turbine rotors, the double-walled channelled WPP comprising:

a) inner and outer channel walls and framing that direct the air stream to the high torque region of the rotor;

b) an actuated inner wall liner that permits the adjustment of the width of the channel with the nominal air speed;

c) a radius of the inner channel wall equal to the radius drawn by the inner rim or shroud that supports one end of the blade, and a radius of the outer channel wall equal to the radius drawn by the outer rim or shroud that supports the outside end of the blades;

d) a measurement device for the upstream wind velocity of the turbine rotors and a programmable controller to adjust the width of the augmented air stream channel;

e) an adapter between the channel entrance and the upstream augmentation device and an adapter between the channel and downstream augmentation device;

f) a carriage structure that is designed to carry the weight of all turbine-related equipment including the augmentation device;

g) a compressor fan to increase the total pressure of the air stream at the entrance to the channel;

h) an aerodynamic deflector mounted on the face of the rotor facing upwind and an aerodynamic deflector mounted on the face of the rotor facing downwind;

i) a steel frame or concrete tower to support the platform that supports the carriage structure; and

j) an augmentation apparatus for converting a nominal wind into an augmented air stream.

Preferably, the width of the channel is equal to the length of the bladed section of the rotor.

Preferably, the WPP can accommodate the installation of one or more turbine rotors in series and one or more rotors per generator.

Preferably, the unit and the augmentation apparatus are supported on a common rotating structure.

Preferably, the WPP isolates the low-torque zone of the rotor and the electrical generator from the wind stream.

Preferably, the width of the channel can be adjusted based on the variation of upstream wind speed.

Preferably, the WPP can accept various configurations of an augmentation apparatus.

Preferably, the WPP creates a measurable increase in air stream augmentation once the area of the deflector over the low-torque zone exceeds 50% of the area swept by the blades.

Preferably, the WPP can produce competitive electricity in areas of low wind velocity by integrating the techniques of wind augmentation, rotor sectoring and using annular rotors.

Preferably, the WPP uses a double wall round channel for HAWT applications and a double wall rectangular channel for VAWT applications.

Preferably, the WPP can use slew bearings for the rotation of small units and an innovative motorized carriage traveling on a platform for large units.

Preferably, the WPP can be used in generating electrical power from both wind and water flows.

The aforesaid and other objectives of the present invention are realized by generally integrating into a WPP a double-walled channel accommodating the use of several turbine rotors in series and several generators into one operating unit. The WPP comprises a double-walled channel, multiple rotors, multiple generators, a carriage rotating apparatus and an air stream distribution mechanism. A wind augmentation apparatus and a sectoring apparatus may be integrated into the wind turbine operation. However the use of the aforementioned is not necessary to obtain the patent objectives or claims.

The double-walled channel consists of an outer wall, an inner wall, an inner liner and a set of actuators to deploy or retract the inner liner. A circular frame supports the outer wall that has a smooth inner face. A second circular frame supports the inner wall that has a smooth outer surface. These frames are supported by the carriage structure. The inner wall supports the liner and the liner actuators that are mounted on the inside face of the inner wall.

The inner liner is not essential to the successful operation. Its intent is to reduce expansion and contraction losses as the air stream progresses from rotor to rotor. An alternative solution would be to install actuated deflector plates upstream and downstream of each rotor. As the wind velocity varied the actuator plates would deploy or retract to keep the airspeed to the blades constant.

The air stream distribution mechanism consisting of a deflector mounted on the shaft of the rotor facing the wind to direct the air stream equally over the area of the channel, a deflector at the exit from the channel to minimize air pressure recovery losses, an adapter upstream to convert from a straight walled convergent to a circular tunnel and an adapter at the exit to convert from a circular tunnel to a straight walled divergent.

The multiple rotor bases and generator bases are mounted on an equipment floor located along the centerline of the axis of the wind channel. One rotor may drive one generator or several rotors may drive one generator. The equipment floor is supported by the rotating carriage structure.

The rotating carriage structure consists of a structure capable of supporting the weight of all equipment and a mechanism able to rotate the structure around a central axis. For small and medium sized units a standard slew bearing device is sufficient to support the weight. For a large WPP, the weight of all the equipment is transferred to a concrete platform that sits atop a tower. The carriage structure sits on motorized wheels and a centrally located bearing. The bearing absorbs the lateral thrust, whereas the motorized wheels rotate the unit.

In a preferred embodiment the double-walled channelled WPP is equipped with an augmentation apparatus to increase the total pressure of the air stream well above the total pressure of the nominal wind. This WPP will work satisfactorily with many configurations of augmentation apparatus using convergent and divergent or only divergent and is not limited to operating with the augmentation apparatus illustrated. Nor is it limited to the use of a HAWT. As will be illustrated, the double wall, channelled WPP may employ cross-flow or vertical turbines.

In another preferred embodiment a compressor fan blade with motorized drive is installed on the end of the shaft of the rotor facing the wind direction. This fan serves to increase the total energy of the air stream as it enters the channel. This embodiment is not essential to the operation or performance of the WPP. Its use will be determined on an application-by-application basis.

In another preferred embodiment a sectoring apparatus is added to the rotor and in another an augmentation device is added. The augmentation device may be simply by divergent or by a combination of convergent and divergent nozzles.

To assess quantitatively the effects of using an annular multi-rotor double-walled turbine on augmented HAWT and VAWT (Vertical Axis Wind Turbine, described in more detail below), two computer programs, which have the capability to calculate the performance (power output) of such wind turbines, have been used. For HAWT analysis the code used was WT Perf, and for VAWT analysis, the CARDAAV code has been used.

The WT Perf code

WT Perf uses blade-element momentum (BEM) theory to predict the performance of HAWT. It was developed at the National Renewable Energy Laboratory (NREL) from the code PROP, originally set up by Oregon State University decades ago. The staff at the National Wind Technology Center from the National Renewable Energy Laboratory, USA, has recently modernized PROP by adding new functionalities developed into the current WT Perf.

The CARDAAV code

CARDAAV is a computer code developed by Ion Paraschivoiu for the prediction of the aerodynamic qualities and the performances of the vertical axis wind turbines.

CARDAAV is based on the Double-Multiple-Streamtube model with variable upwind- and downwind-induced velocities in each streamtube (DMSV). Due to this model and to a quite large number of options regarding the geometrical configuration, the operational conditions and the control of the simulation process, CARDAAV proves to be an efficient software package, appropriate for the needs of VAWT designers. It computes the aerodynamic forces and power output for VAWTs of arbitrary geometry at given operational conditions.

The numerous parameters that are necessary to fully describe the analyzed VAWT provide a rather large freedom in specifying its geometry. Among the most important in this category are: the rotor height and diameter, the number of blades and the type of airfoil defining their cross-section, the diameter of the central column (tower), the size and position of the struts, the size of the spoilers, etc. Virtually any blade shape can be analyzed, including, of course, the straight one. Moreover, the blade can be made of segments having different chord lengths and cross-sections (airfoils). The airfoil data-base of the code includes some of the well known symmetrical NACA shapes (NACA 0012, NACA 0015, NACA 0018, NACA 0021) as well as several of those specially designed for VAWTs at Sandia National Laboratories (SNLA 0015, SNLA 0018, SNLA 0021). If the user wants to perform the analysis with an airfoil that is not among those already available, this can be done quite simply, by including the values of its experimentally determined lift and drag coefficients in the actual airfoil data base. These data must be given for several Reynolds numbers that correspond to those attained on the revolving blades and cover (at each Re) the full 360° range for the angle of incidence ($0° \leq \alpha \leq 360°$).

Among the principal operating parameters that are readily modifiable to meet the needs of a specific analysis one can mention: the wind speed, the rotational speed of the rotor, the local gravity acceleration and the working fluid properties (density, viscosity – usually for air). Either constant rotational speed at different wind speeds or different rotational speeds at a constant wind speed can be considered when performing an analysis. By specifying the adequate value for the atmospheric wind shear exponent, a power law type variation of the wind speed with height will be taken into account during the computations.

In what regards the control parameters, the code requires the number of half cycle (azimuthal) divisions and vertical divisions which define the total number of stream tubes that are going to be considered in the computations as well as the number of integration points over the width of each tube. In the same category, the user has to specify the maximum number of iterations in the computation of the upwind and downwind interference factors along with the convergence criteria (relative error levels that must be satisfied when computing the interference factors and the dynamic stall). The decision on whether to apply or not the aerodynamic corrections related to the blade-tip effects and those due to the occurrence of the dynamic stall must be taken when the control parameters are specified. Four dynamic stall models are available, three derived from Gormont's method and the "indicial" model.

The important number of parameters and options (mentioned above) give CARDAAV a rather large capacity and flexibility in computing the performances of various Darrieus type VAWTs. Depending on the actual values given to these parameters, the code performs the computations on a particular configuration by neglecting or taking into account the effects of the dynamic stall as well as several "secondary effects", such as those due to the rotating central column, the struts and spoilers. The dynamic stall has a significant influence on the aerodynamic loads and the rotor performances at low tip-speed ratios, whereas the "secondary effects" are important at moderate and high tip-speed ratios.

Running under the Microsoft Windows environment, CARDAAV is user-friendly, being provided with a graphical interface so that all the input data that need to be frequently changed for a comprehensive performance analysis (rotor geometry, operational and control parameters) is easily modified. The local induced velocities, Reynolds number and angle of attack, the blade loads and the azimuthal torque and power coefficients are the output data. These results can be directly visualized on the computer's display or stored in ASCII files or in a format compatible with the graphic software TECPLOT (Amtec Engineering Inc.) for further post processing and interpretation.

Numerous validations have demonstrated the capacity of CARDAAV to compute with a fair accuracy the aerodynamic loads and global performances (torque, power) of the usual types of vertical axis wind turbines, including those of Darrieus H–type. The CARDAAV results compare quite well with the experimental ones over a large range of tip speed ratios (TSR).

Figure 1 shows the relative high torque and low torque zones for a HAWT turbine. The closer longer the distance from the rotating axis the higher the torque produced.

Figure 2 shows the high and low torque zones for a VAWT. The two outer edges of the rectangle formed by the swept area produce less torque than the middle section.

Figure 3 shows a WPP installed on a standard pre-cast concrete or fabricated steel tower 1 and uses a standard slew bearing for rotation into the wind. The principal sections of the WPP besides the turbine tunnel 2 include the inlet adapter, the semi-circular sectoring deflector covering the low torque zone of the rotor, the inner and outer walls of the air stream channel, the rotor(s), the electrical generator(s), the exit deflector over the low torque zone facing downwind, the exit adapter, the structure supporting the aforementioned equipment and the rotating device that keeps the sectoring deflector facing the wind.

Figure 4 is an elevation view of a WPP, equipped with an air stream augmentation device, and installed on a tower platform 1 using a slew bearing for rotation. The base of the WPP 4 sits on the slew bearing upper race 3. The motorized gears 5 rotate the WPP. In this example a convergent and divergent are used to increase the total pressure of the air stream to the WPP. The augmentation device is supported from the structure of the WPP and as such both the WPP and augmentation apparatus turn on a common slew bearing.

Figure 5 shows an elevation of the air stream tunnel, the entrance adapter 6 and exit adapter 7.

Figure 6 illustrates the integrated structure for all the components of an augmented WPP. The carriage support structure 8, the air channel horizontal and circular members 9, the cross beam support columns 10, the cross beam 11, convergent tension cables 12, divergent tension cables 13, divergent nozzle 14, convergent nozzle 15.

Figure 7 illustrates the double wall channel consisting of an inner shroud 32, outer shroud 17, interior inner shroud liner 20 and liner actuators 22. The wall liner actuators are mounted on the interior face of the interior channel wall. As such they are not in contact with the air stream and can be serviced from the generator room. The liner actuators deploy and retract the wall liner to adjust the inner radius of the channel.

In order to hold the air stream speed constant the inside radius of the channel increases when the wind speed decreases. A programmable controller and upstream wind velocity measurement control the positioning of the liner actuators. The wind measuring devices are located at the entrance to the convergent. Given the time for the air to reach the blades the wall liner is adjusted before the change in wind velocity reaches the deflector.

By increasing and decreasing the area of the channel, one decreases the area of the rotor receiving air at lower winds and increasing it at higher wind speeds. There will result in a certain loss of power as the swept area decreases. However by adjusting the channel inner radius to maintain the air stream speed high and constant the overall efficiency of the rotor will improve.

This is important as synchronous generators turn at a fixed rpm. When a direct drive is used the generator rpm is also the rpm of the rotor. As the wind speed varies the effect is to change the Tip Speed Ratio (TSR) of the rotor. This is the ratio of the tip of the blade speed to the speed of the wind. If this is not possible, the blades begin operating farther from their optimum TSR and the rotor blades lose efficiency.

The rotor enters into the channel formed by the inside and outside channel walls. Two circular shrouds 19 are installed on the rotor at the same radius as the inside shroud and outside shroud. The inside shroud serves as a barrier to prevent the augmented air stream from discharging into the generator room. Detail A in Figure 7E illustrates the sideways movement of the overlapping liner segments 21 as the actuators extend the liners into the air stream.

Figure 7 also illustrates a semi-circular directing system 18 covering the low torque zone of the rotor. This deflector is important as it acts as an augmentation device. Once the surface area of the deflector exceeds that of the swept area of the rotor it slowly begins to augment the total pressure of the air stream. The effect is provided whether the WPP is augmented or non-augmented.

The enclosure created inside the inner channel wall becomes the generator room. It may be pressurized for air quality considerations and this will also limit leakage from the augmented air stream channel into the generator room.

Figure 8 illustrates a typical generator room layout for one set of rotor-generator. One or more sets of rotor-generator can be installed in series. As shown, two rotors 19 direct-drive one main generator 33.

The role of the entrance and exit adapters is to minimize friction losses as the air enters the WPP and to convert the air stream from a straight walled configuration to a circular configuration. Many different shapes of adapter are applicable; their design is based on limiting the friction losses and the configuration of the augmentation apparatus.

Figure 9 shows an innovative carriage structure 90 with motorized wheels. Very large WPP's contain multiple turbines and generators. The weight and bending moments of the WPP and augmentation apparatus are transferred to the wheels 24 of the carriage. As the loads are distributed around a large circle and due to the considerable wind thrust from the convergent and divergent nozzles, the preferred tower design is multiple columns rather than the standard central steel or concrete tapered cylindrical tower.

Figure 10 shows a synchronous electrical generator and rotor assembly for a double-wall channelled turbine having an annular shroud 1008 and a hub ring 1010. Rotors 1000 attached to both ends drive the generator 1040. In a preferred embodiment a rotor may include several stages of blades 1006. In this event, several sets of spokes protrude from the same rotor hub at different angles to the vertical. Another advantage of the present invention is that the configuration of the turbine allows isolation and separation of the turbine from the fluid stream.

In a preferred embodiment a second much smaller pony generator 1040 is driven by a drive 1042 off one of the shafts of the generator. This drive is connected to a two-speed speed increaser.

This pony generator is set to turn at one design speed that is in relation to the speed of the rotor shaft. However in very low winds the speed of turbine rotor is decreased to approximately 50% of its nominal operating speed. The second speed range of the speed reducer will be engaged to keep the pony generator at its rated speed. At the low wind speeds the field will be removed from the main synchronous generator and only the pony generator will operate. At very high wind speeds the main generator will exceed its maximum power. At this point the pony generator will again become operational using the second speed ratio and now operates in parallel with the main generator. The contribution of the pony motor at high wind speeds is to increase the maximum peak power produced.

Many different forms and configurations of augmentation device can be used with the WPP. The role of the augmentation device is to maximize the total pressure of the air stream travelling through the turbine blades. One role of the WPP is to use double wall channels to apply the air stream to the sector of the rotor(s) that will generate the most electrical power. The WPP also provides a common structure and rotating mechanism for all components and a possible augmentation device.

Figure 11 shows the principle of a WPP for a non-augmented vertical axis or cross-flow turbine 1100. If an augmentation apparatus using a convergent nozzle 1108 was installed, it would connect to the entrance adapter. If an augmentation apparatus using a divergent nozzle 1109 was installed, it would connect to the exit adapter.

Consequently, the present invention also provides an adjustable flow channel area, double-walled, cross-flow turbine. The turbine comprises a vertical or horizontal axis cross-flow rotor comprising a plurality of turbine blades, each of the turbine blades comprising a cylindrical face. The turbine also comprises an outer shroud enclosing side portions, a top portion and a bottom portion of a swept area of the rotor, upstream fluid deflectors for adjustably reducing a width or height of the swept area of the rotor, upstream fluid deflector actuators for adjusting a projection of the fluid deflectors into a fluid stream entering the turbine, adjustable inner walls located within a circumference of the cylindrical faces of the turbine blades and inner wall actuators for positioning the inner walls relative to a width or height of a fluid channel created by the fluid deflectors. The inner walls and upstream fluid deflectors form a channel for directing the fluid entering the turbine towards the cylindrical faces of the turbine blades and for directing fluid discharged from upstream blades to the cylindrical faces of downstream blades.

Preferably, the turbine further comprises downstream fluid deflectors and downstream fluid deflector actuators for providing a less turbulent transition for the fluid leaving the channel created by the inner or double walls and expanding towards the fixed outer walls.

As shown in Figure 11, the vertical axis WPP unit consists of an entrance and exit adapter, the outer wall 1110 and the adjustable inner wall 1103, the inner wall actuators 1107, the upstream fluid deflectors 1104, the upstream fluid deflector actuators 1106, the downwind fluid deflectors 1105, the downwind fluid deflector actuators, the rotor assembly 1101, the rotor blades 1102, the upstream fluid speed measurement, the frame used to hold all the components in place, a slew bearing rotating mechanism and a steel framed tower.

Although a double wall principle is being applied in the case of a VAWT, the flow is in a canal rather than a channel. The second or inner wall serves to reduce the width of the canal. The height remains constant as the top and bottom walls have a standard continuous surface.

Example 1

A single non-augmented HAWT rotor was equipped with a double wall channelling mechanism by computer simulation. Wind velocities were varied and the results compared with an identical HAWT operating without double wall channelling.

Although only one rotor was used for the simulation any number of rotors could be aligned in series within the channel and the improvement in the power output would be the same for subsequent rotors.

A computer-simulated experiment was performed to compare the performance of the WPP concept using a double-walled channel and a standard HAWT rotor. The Channelling Ratio (CR) or the ratio of the area of the flow channel to the swept area of the rotor blades was varied from 1.0 to .25 at three different wind speeds in a shrouded, non-augmented HAWT turbine. A Channelling Ratio of 1.0

implies the flow channel area equals the swept area of the rotor blades. A Channelling Ratio of 0.25 implies only the outer 25% of the swept area is receiving wind. At the three wind velocities the increase in performance is illustrated in Table 1 and illustrated as a continuous curve in Figure 12.

Table 1

Channelling Ratio (CR) versus Power Output for a HAWT

Channel Ratio	**Power Output (kW)**		
	4 m/s	**7m/s**	**12 m/s**
1.0	10	70	180
0.80	11	80	250
0.60	12	100	400
0.40	15	175	775
0.25	50	300	1500

Example 2

A single non-augmented VAWT rotor was equipped with a double wall channelling mechanism by computer simulation. Wind velocities were varied and the results compared with an identical VAWT operating without double wall channelling.

Although only one rotor was installed in the channel for the simulation any number of rotors could be aligned in series and the improvement in the power output would be the same for subsequent rotors. The channel is ducted on all sides meaning that the volume of air striking the first rotor will remain constant for all rotors in the series.

A computer-simulated experiment was performed to compare the WPP concept using a double walled channel and a standard VAWT rotor. The Channelling Ratio (CR) or the ratio of the area of the flow channel to the swept area of the rotor blades was varied from 1.0 to 0.67 at three different wind speeds in a shrouded, non-augmented VAWT turbine. A Channelling Ratio (CR) of 1.0 implies the flow channel area equals the swept area of the rotor blades. A channelling ratio of 0.67 implies only the inner 67% of the swept area is receiving wind. At the three wind velocities the increase in performance is illustrated in Table 2 and illustrated as a continuous curve in Figure 13.

Table 2

Channelling Ratio (CR) versus Power Output for a VAWT

Channel Ratio	**Power Output (kW)**		
	4 m/s	**7m/s**	**12 m/s**
1.0	4	50	220
0.90	6	75	280
0.80	10	85	380
0.70	20	105	550
0.67	25	110	620

As a person skilled in the art would understand a plurality of types of axial flow or horizontal axis turbines may be used with the device of the present invention. Also for each wind turbine different combinations of speeds, frequencies and type of electrical generators may be used for example with a different number and/or configuration of blades, different wind conditions, and different sizes of the convergent and divergent.

As a person skilled in the art would understand the parameters of the double-wall channelled wind turbine may differ from the examples shown in this document. Similarly the mechanism for adjusting the inner lining, the configuration of the deflector over the low torque area, the philosophy of control may differ based on the fluids, operating conditions and turbine apparatus.

While illustrative and presently preferred embodiments of the invention have been described in detail hereinabove, it is to be understood that the inventive concepts may be otherwise variously embodied and employed and that the appended claims are intended to be construed to include such variations except insofar as limited by the prior art.

CLAIMS

1. An annular multi-rotor double-walled turbine comprising:
-an outer shroud;
-an inner shroud;
-a plurality of driveshafts; and
-a plurality of rotors coaxially attached to said plurality of driveshafts at spaced intervals, each of said plurality of rotors comprising a plurality of turbine blades extending between said inner and outer shrouds, each of said plurality of turbine blades comprising a face,
wherein the inner shroud and the outer shroud form a continuous channel for directing a fluid entering the turbine towards the faces of the turbine blades and for directing fluid discharged from a first of the plurality of rotors to the remaining rotors.

2. The turbine as claimed in claim 1, wherein the turbine further comprises an adjustable inner shroud liner with an actuating system for displacement of adjustable inner shroud liner overlapping segments with respect to a face of the inner shroud.

3. The turbine as claimed in any one of claims 1 or 2, further comprising:
-an inlet; and
-a converging nozzle for directing and accelerating fluid towards the inlet of the turbine.

4. The turbine as claimed in claim 3, further comprising:
-an outlet; and
-a diverging nozzle for directing and decelerating fluid discharged from the outlet of the turbine.

5. The turbine as claimed in claim 4, further comprising a support structure fixed over the outer shroud and connected to the converging nozzle and the

diverging nozzle, said support structure partly supporting a weight of the converging nozzle and the diverging nozzle.

6. The turbine as claimed in any one of claims 1 to 5, further comprising:

-a turbine base structure; and

-a turbine rotation system for rotating the turbine base structure to align the driveshaft with an incoming direction of the fluid entering the turbine.

7. The turbine as claimed in claim 2, further comprising a fluid velocity measurement system located upstream of the turbine and producing a signal indicative of fluid velocity entering the turbine, and wherein the actuating system displaces the adjustable inner shroud liner with respect to the face of the inner shroud based on the signal indicative of fluid velocity entering the turbine.

8. The turbine as claimed in any one of claims 1 to 7, further comprising a directing system mounted upstream of the inner shroud and over the inner shroud for directing fluid entering the turbine towards the plurality of turbine blades of the first of the plurality of rotors.

9 The turbine as claimed in any one of claims 1 to 8, further comprising a compressor fan positioned upstream of the turbine and increasing velocity of the fluid entering the turbine.

10. The turbine as claimed in any one of claims 1 to 9, wherein the fluid is air.

11. The turbine as claimed in any one of claims 1 to 10, wherein the fluid is water.

12. The turbine as claimed in any one of claims 1 to 11, wherein the turbine blades are hollow, perforated and connected to a vacuum system for controlling boundary layers in proximity of said turbine blades.

13. The turbine as claimed in any one of claims 1 to 11, wherein the turbine blades are hollow, perforated and connected to a pressurized fluid supply system for controlling boundary layers in proximity of said turbine blades.

14. An adjustable flow channel area, double-walled, cross-flow turbine comprising:

-a vertical axis cross-flow rotor comprising a plurality of turbine blades, each of said turbine blades comprising a cylindrical face;

-an outer shroud enclosing side portions, a top portion and a bottom portion of a swept area of the rotor;

-upstream fluid deflectors for adjustably reducing a width of the swept area of the rotor;

-upstream fluid deflector actuators for adjusting a projection of the fluid deflectors into a fluid stream entering the turbine;

-adjustable inner walls located within a circumference of the cylindrical faces of the turbine blades; and

-inner wall actuators for positioning the inner walls relative to a width of a fluid channel created by the fluid deflectors,

wherein the inner walls and upstream fluid deflectors form a channel for directing the fluid entering the turbine towards the cylindrical faces of the turbine blades and for directing fluid discharged from upstream blades to the cylindrical faces of downstream blades.

15. An adjustable flow channel area, double-walled, cross-flow turbine comprising:

-a horizontal axis cross-flow rotor comprising a plurality of turbine blades, each of said turbine blades comprising a cylindrical face;

-an outer shroud enclosing side portions, a top portion and a bottom portion of a swept area of the rotor;

-upstream fluid deflectors for adjustably reducing a height of the swept area of the rotor;

-upstream fluid deflector actuators for adjusting a projection of the fluid deflectors into a fluid stream entering the turbine;

-adjustable inner walls located within a circumference of the cylindrical faces of the turbine blades; and

-inner wall actuators for positioning the inner walls relative to a height of a fluid channel created by the fluid deflectors,

wherein the inner walls and upstream fluid deflectors form a channel for directing the fluid entering the turbine towards the cylindrical faces of the turbine blades and for directing fluid discharged from upstream blades to the cylindrical faces of downstream blades.

16. The turbine as claimed in either one of claims 14 or 15, further comprising downstream fluid deflectors and downstream fluid deflector actuators positioned downstream of the rotor.

17. The turbine as claimed in any one of claims 14 to 16, further comprising:

-an inlet; and

-a converging nozzle for directing and accelerating the fluid towards the inlet of the turbine.

18. The turbine as claimed in any one of claims 14 to 17, further comprising:

-an outlet; and

-a diverging nozzle for directing and decelerating fluid discharged from the outlet of the turbine.

19. The turbine as claimed in any one of claims 14 to 18, further comprising:

-a turbine base structure; and

-a turbine rotation system for rotating the turbine base structure to align the turbine with an incoming direction of the fluid entering the turbine.

20. The turbine as claimed in either one of claims 14 or 15, further comprising a fluid velocity measurement system located upstream of the turbine and

producing a signal indicative of fluid velocity entering the turbine, and wherein the inner wall actuators displace the inner walls with respect to the outer shroud based on the signal indicative of fluid velocity entering the turbine.

21 The turbine as claimed in any one of claims 14 to 20, further comprising a compressor fan positioned upstream of the turbine and increasing velocity of the fluid entering the turbine.

22. The turbine as claimed in any one of claims 14 to 21, wherein the fluid is air.

23. The turbine as claimed in any one of claims 14 to 22, wherein the fluid is water.

24. The turbine as claimed in any one of claims 14 to 23, wherein the turbine blades are hollow, perforated and connected to a vacuum system for controlling boundary layers in proximity of said turbine blades.

25. The turbine as claimed in any one of claims 14 to 24, wherein the turbine blades are hollow, perforated and connected to a pressurized fluid supply system for controlling boundary layers in proximity of said turbine blades.

26. An annular double-walled turbine comprising:

-an outer shroud;

-an inner shroud;

-a driveshaft; and

-a rotor coaxially attached to said driveshaft, the rotor comprising a plurality of turbine blades extending between said inner and outer shrouds, each of said plurality of turbine blades comprising a face,

wherein the inner shroud and the outer shroud form a continuous channel for directing a fluid entering the turbine towards the faces of the turbine blades.

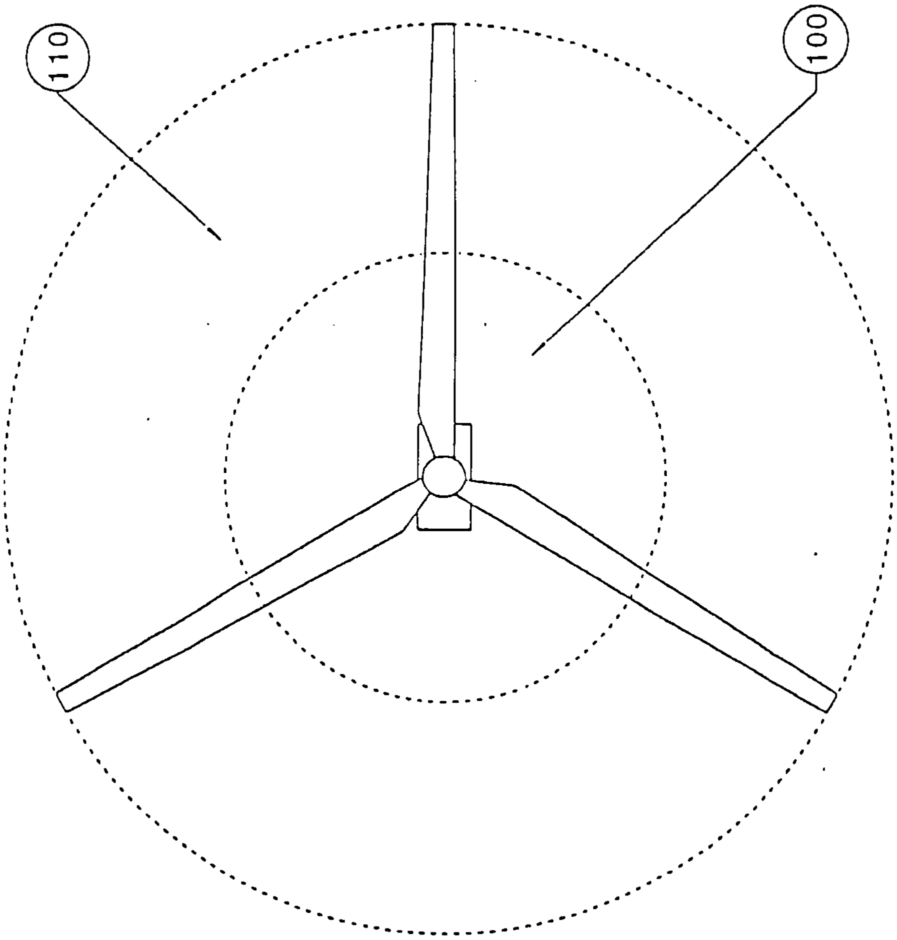


Figure 1
(PRIOR ART)

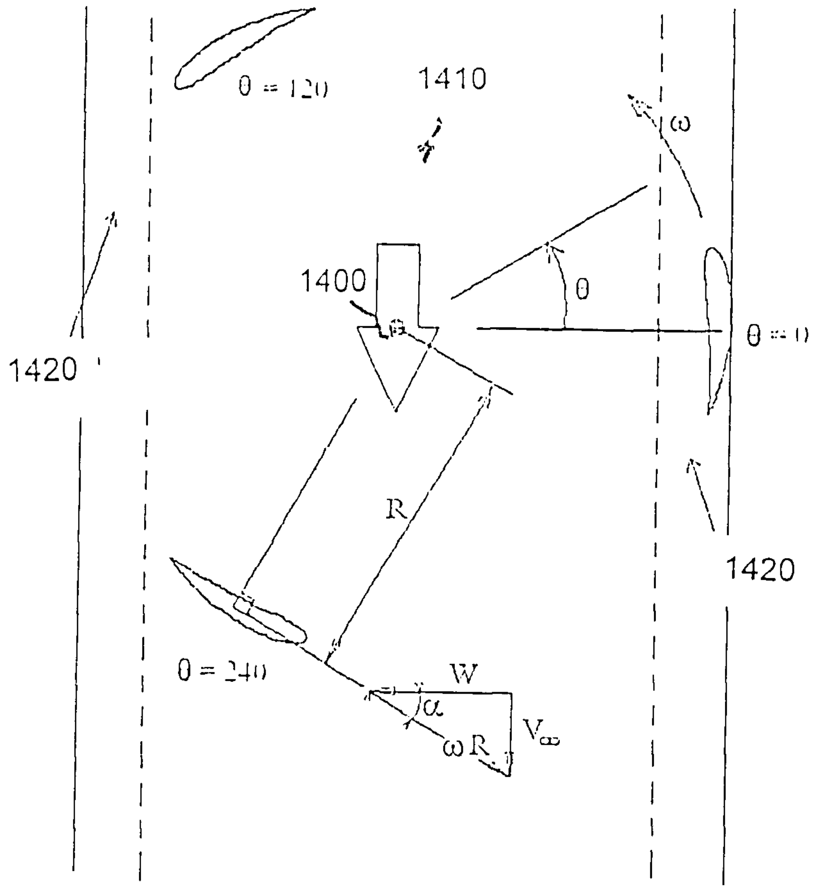


Figure 2

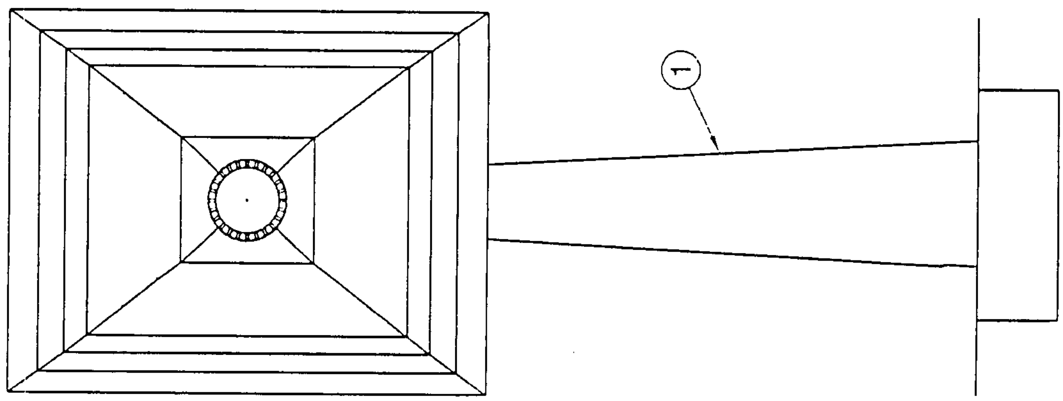


Figure 3C

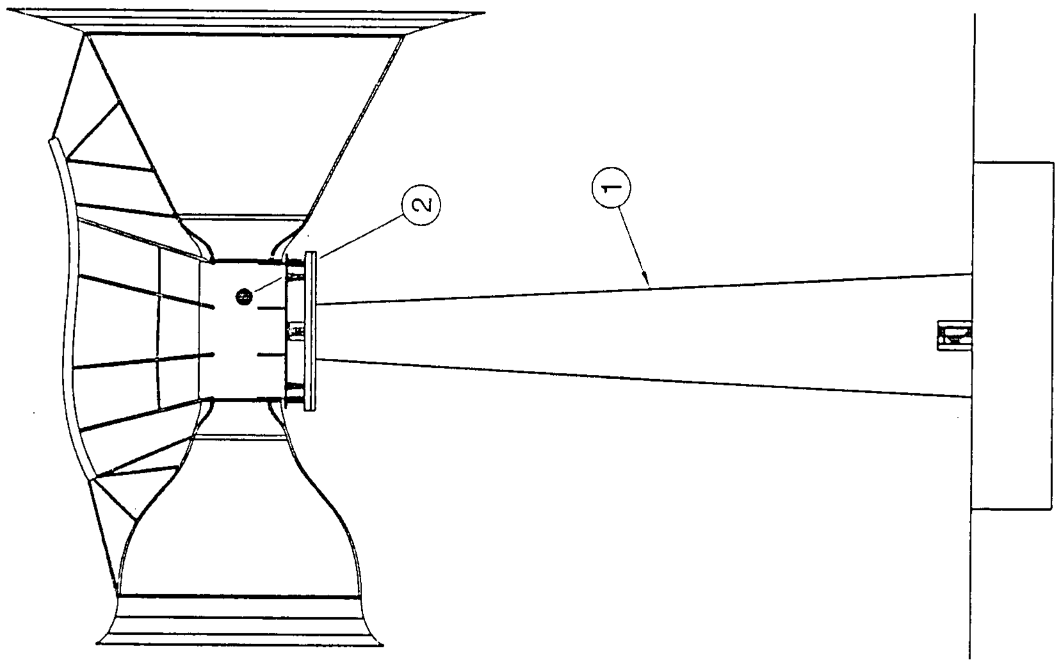


Figure 3A

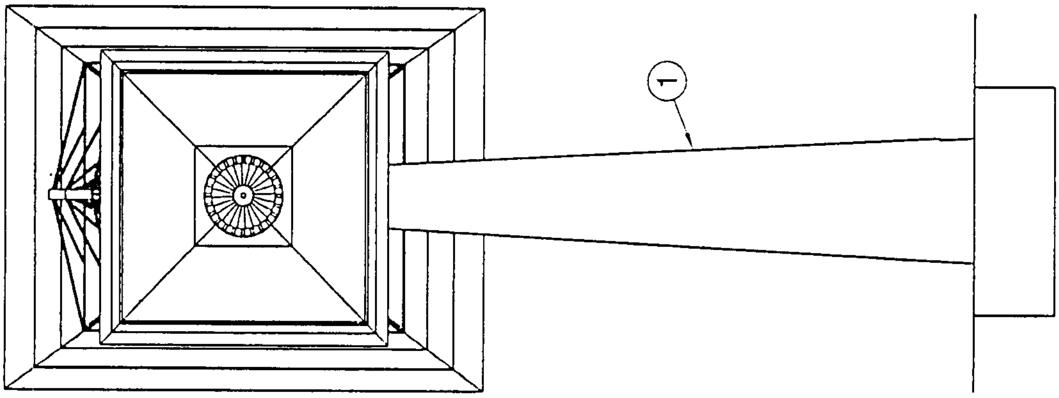
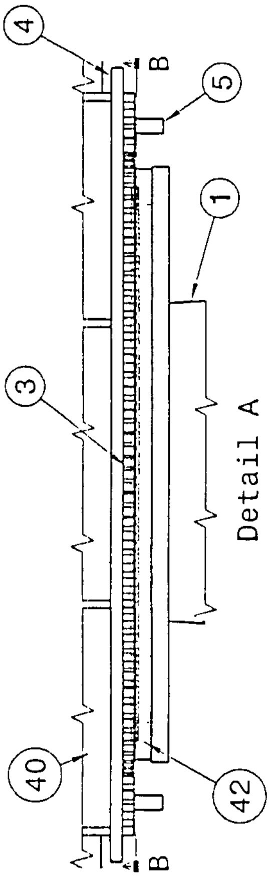
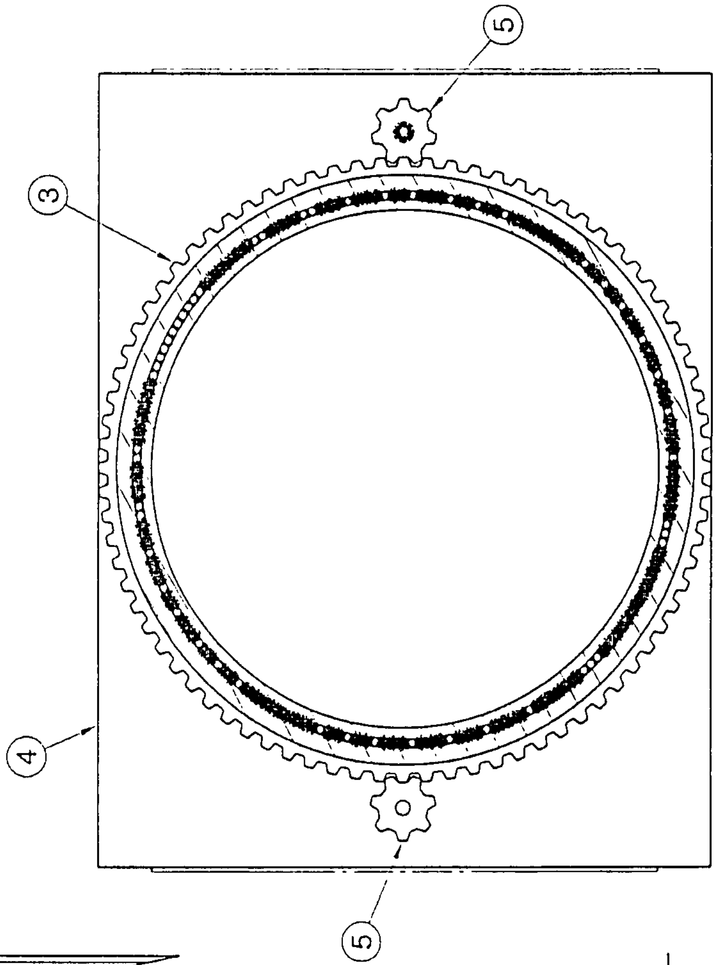


Figure 3B



Detail A
Figure 4B



Section view B-B
Figure 4C

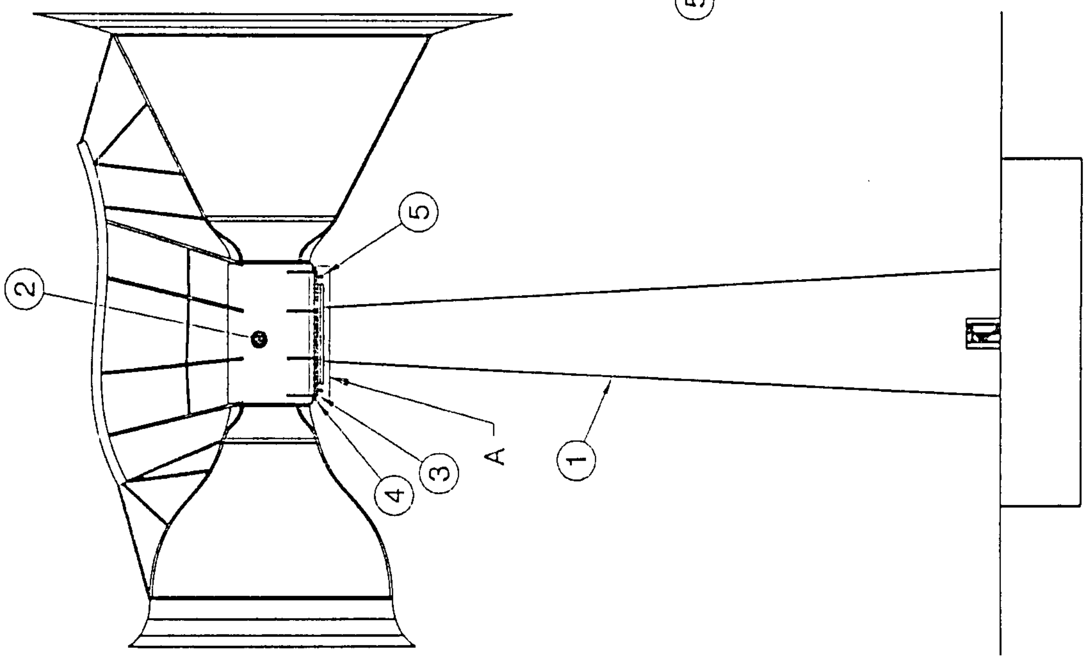


Figure 4A

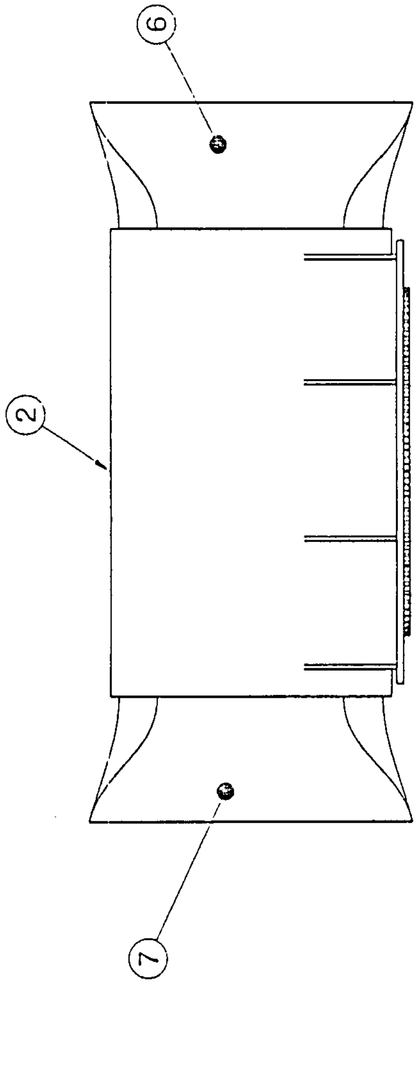
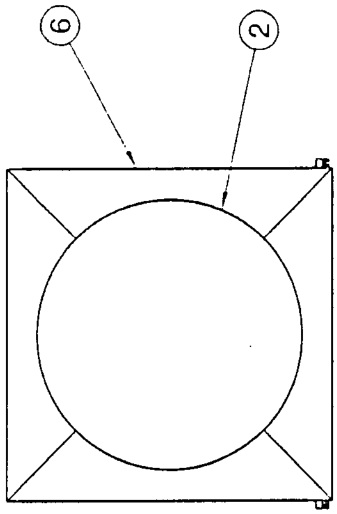
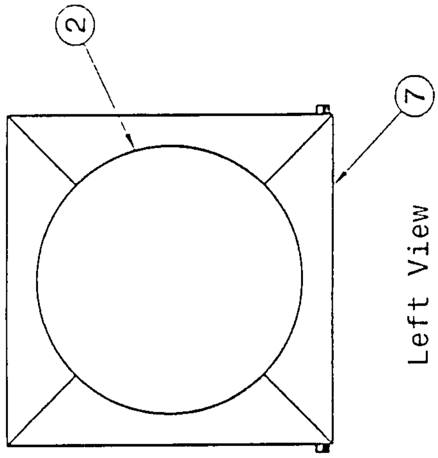


Figure 5A



Right View
Figure 5C



Left View
Figure 5B

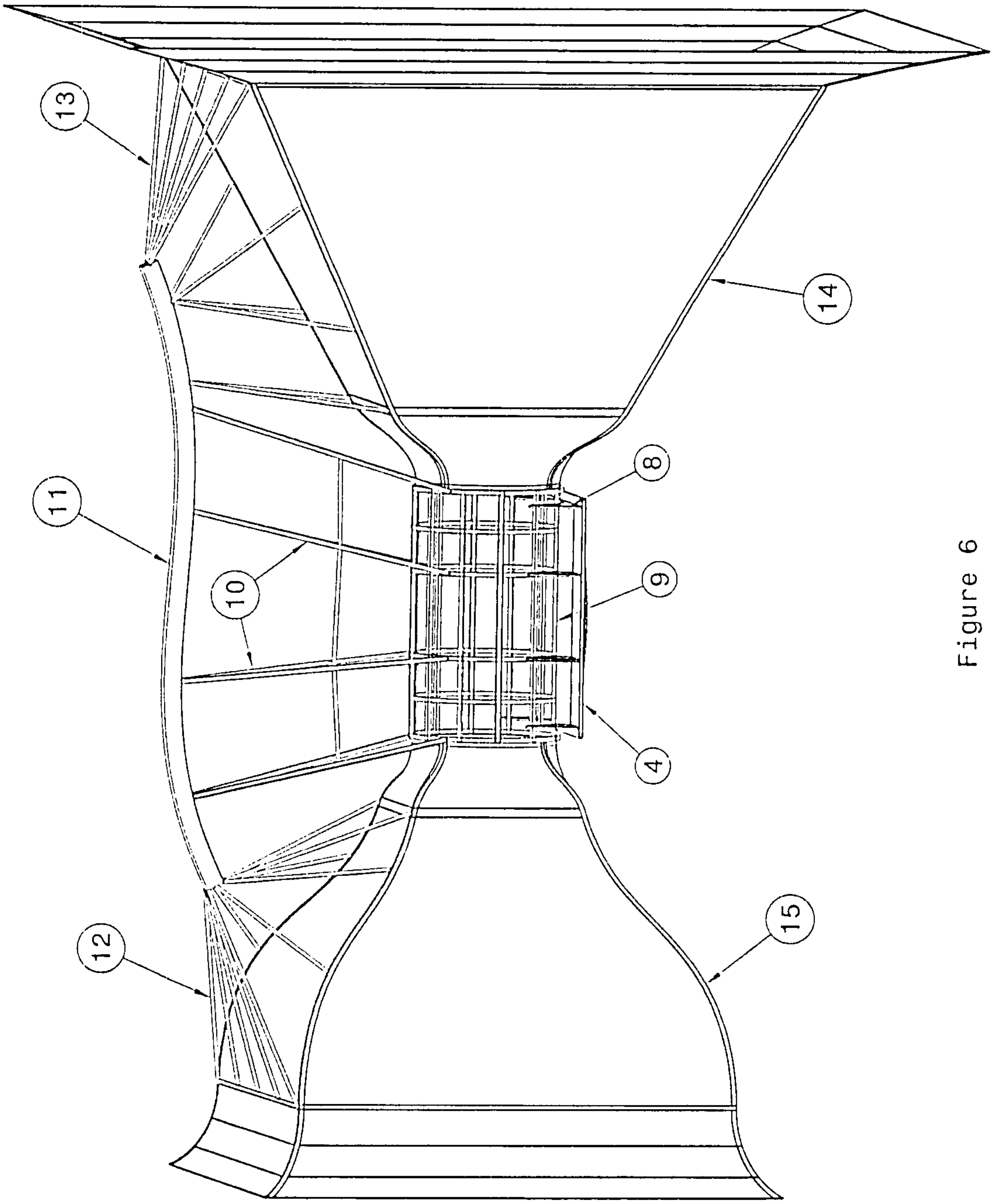


Figure 6

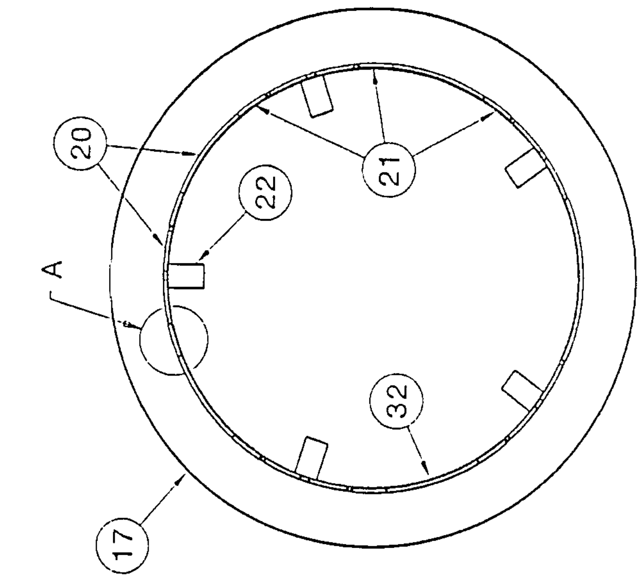
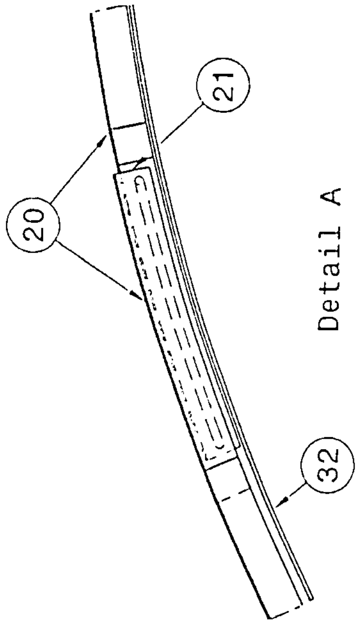


Figure 7D



Detail A
Figure 7E

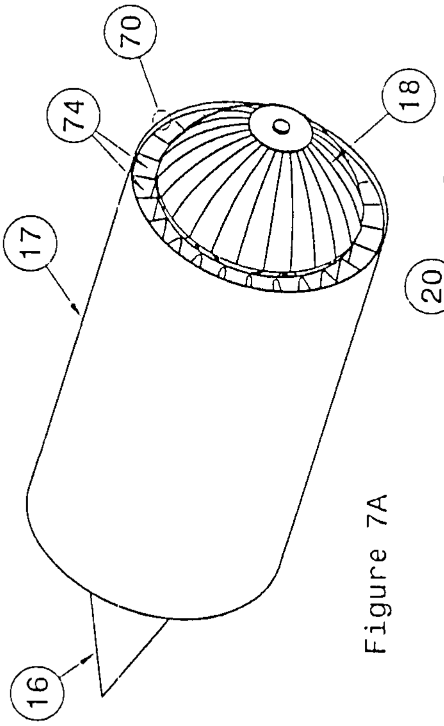


Figure 7A

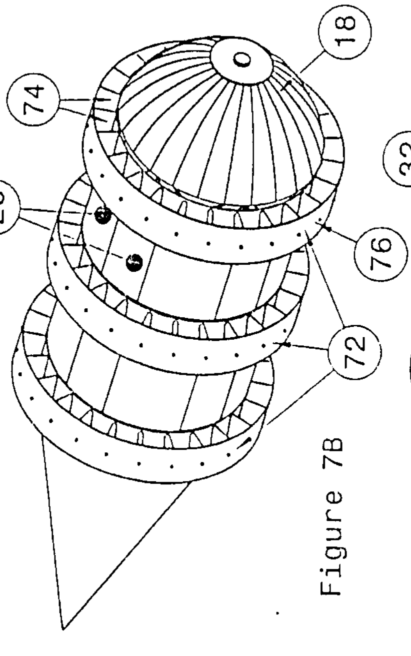


Figure 7B

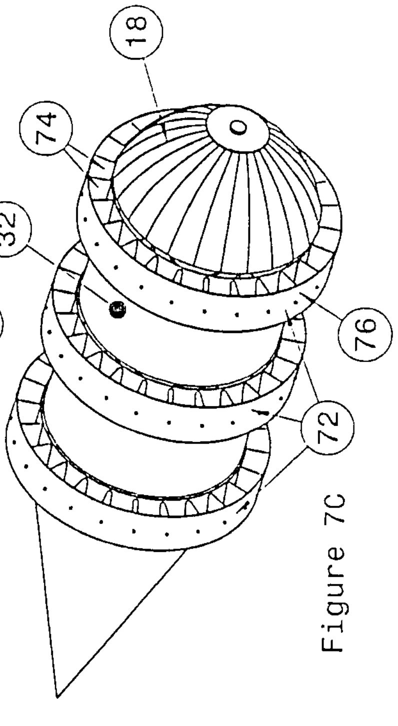


Figure 7C

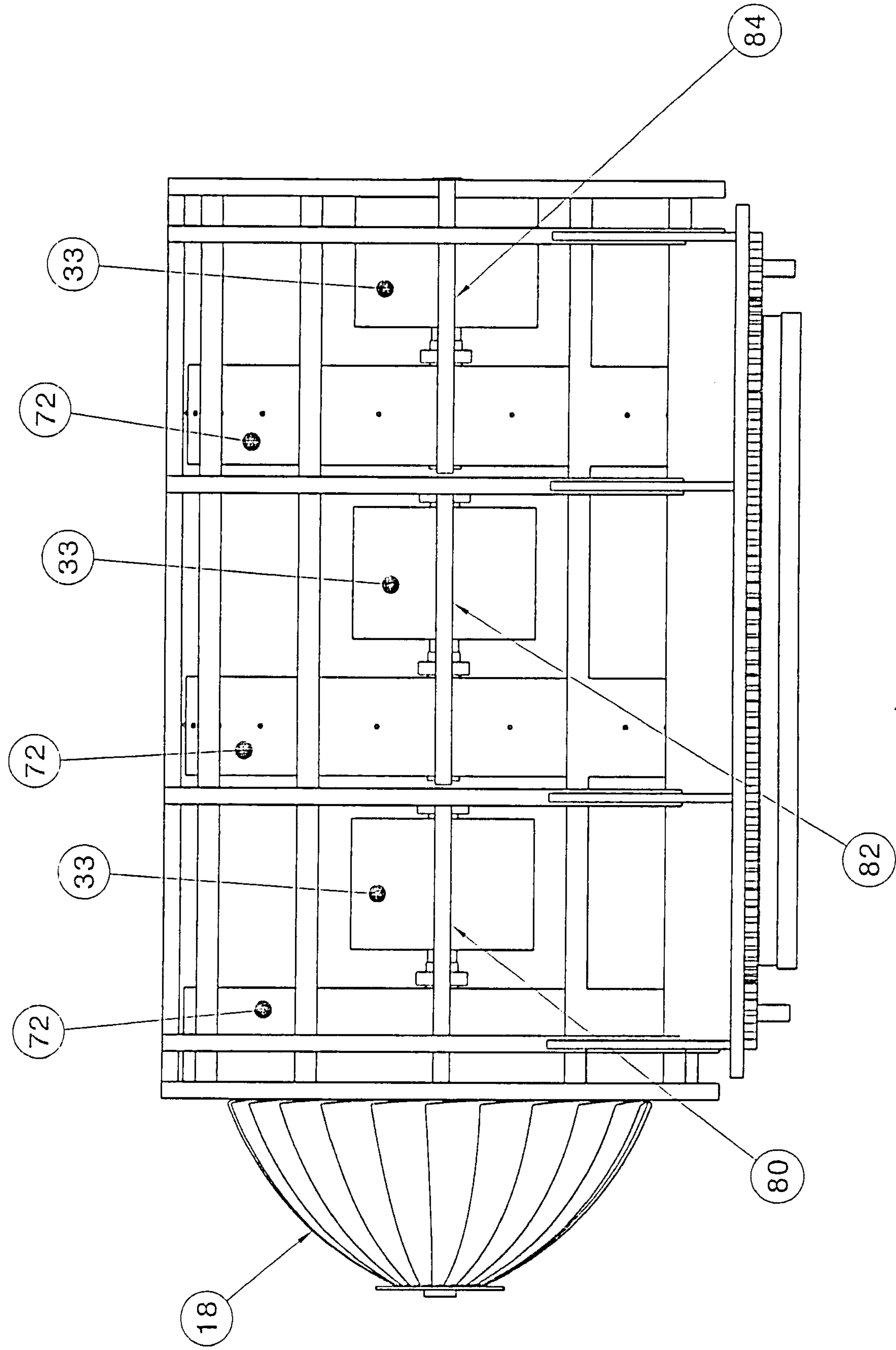
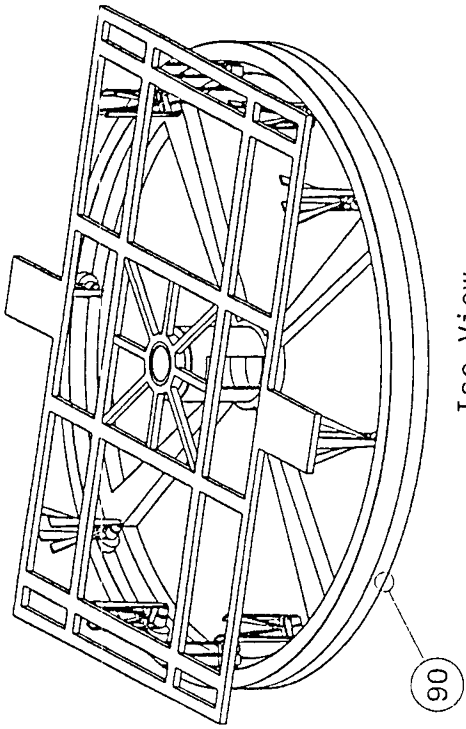
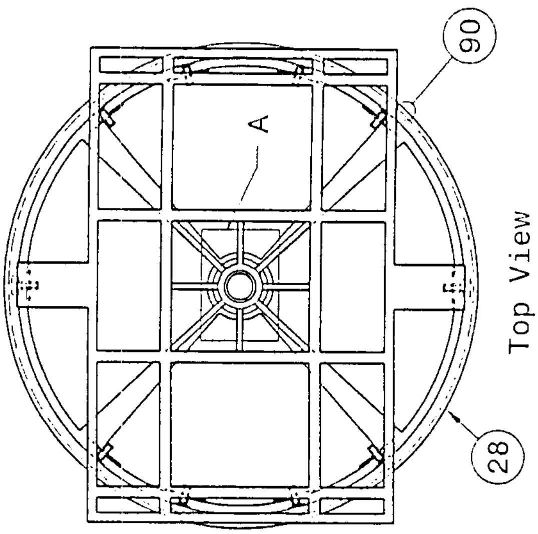


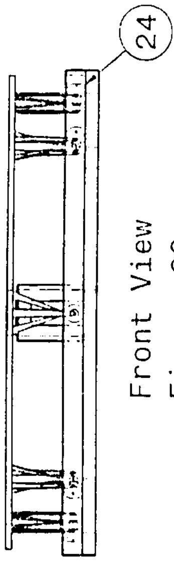
Figure 8



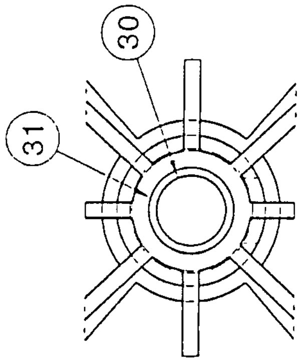
Iso View
Figure 9A



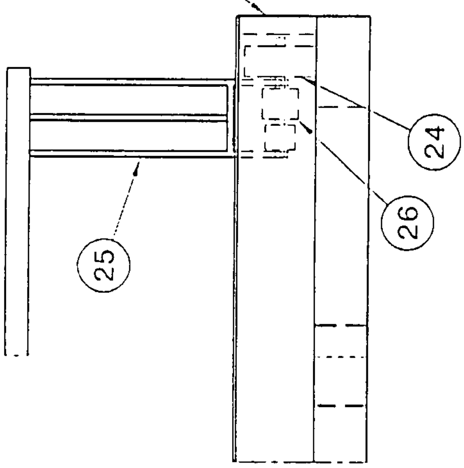
Top View
Figure 9B



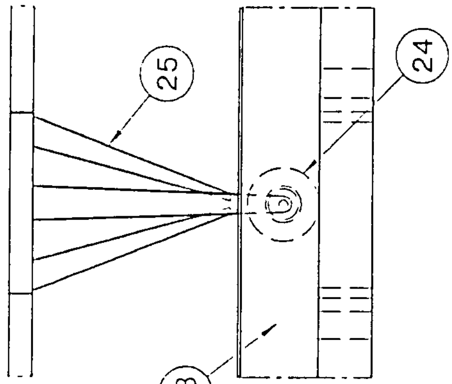
Front View
Figure 9C



Detail A
Figure 9D



Front View
Figure 9E



Right View
Figure 9F

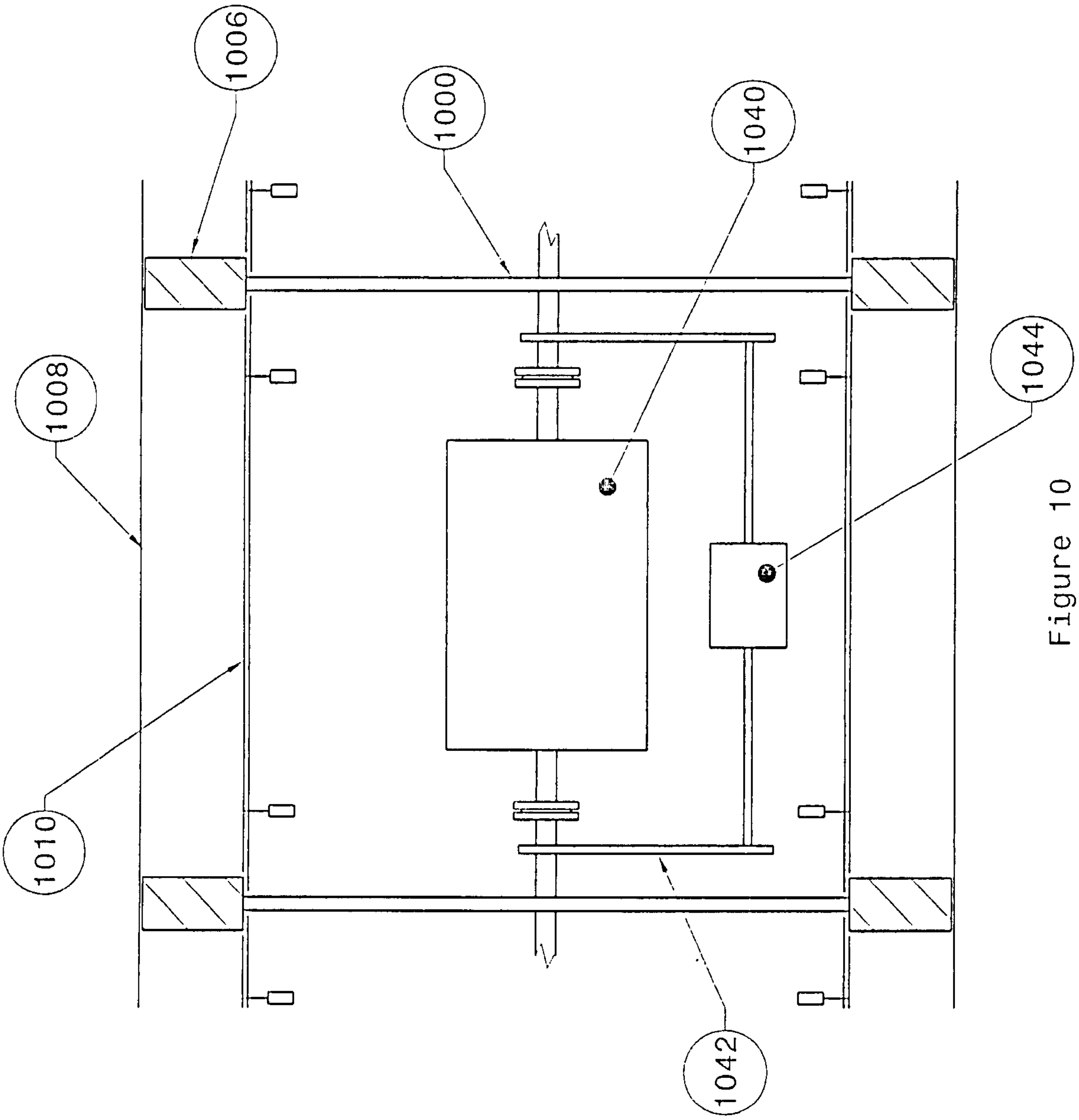


Figure 10

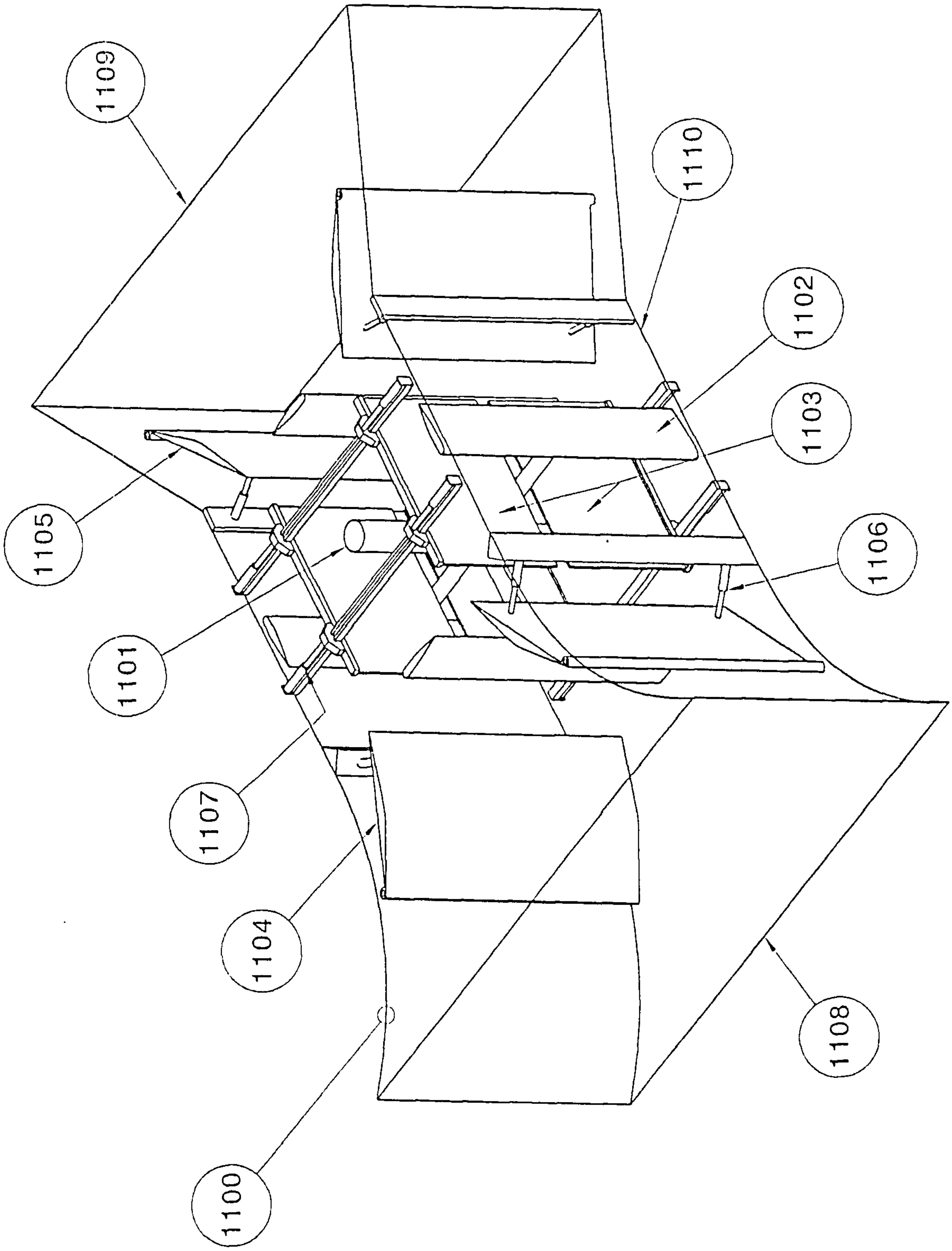
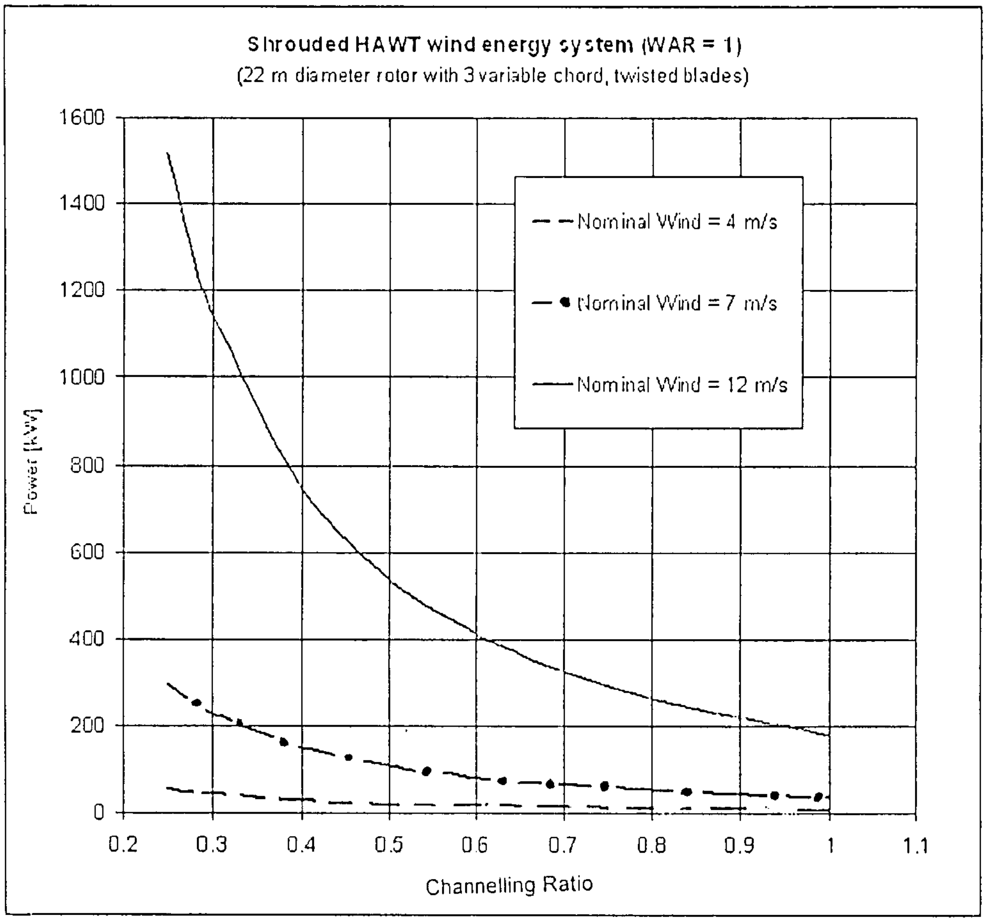


Figure 11



Shrouded HAWT wind energy system (WAR = 1)
(22 m diameter rotor with 3 variable chord, twisted blades)
1600
1400
1200
1000
800
600
400
200
0
Power [kW]
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1.1
Channelling Ratio
Nominal Wind = 4 m/s
Nominal Wind = 7 m/s
Nominal Wind = 12 m/s

Figure 12

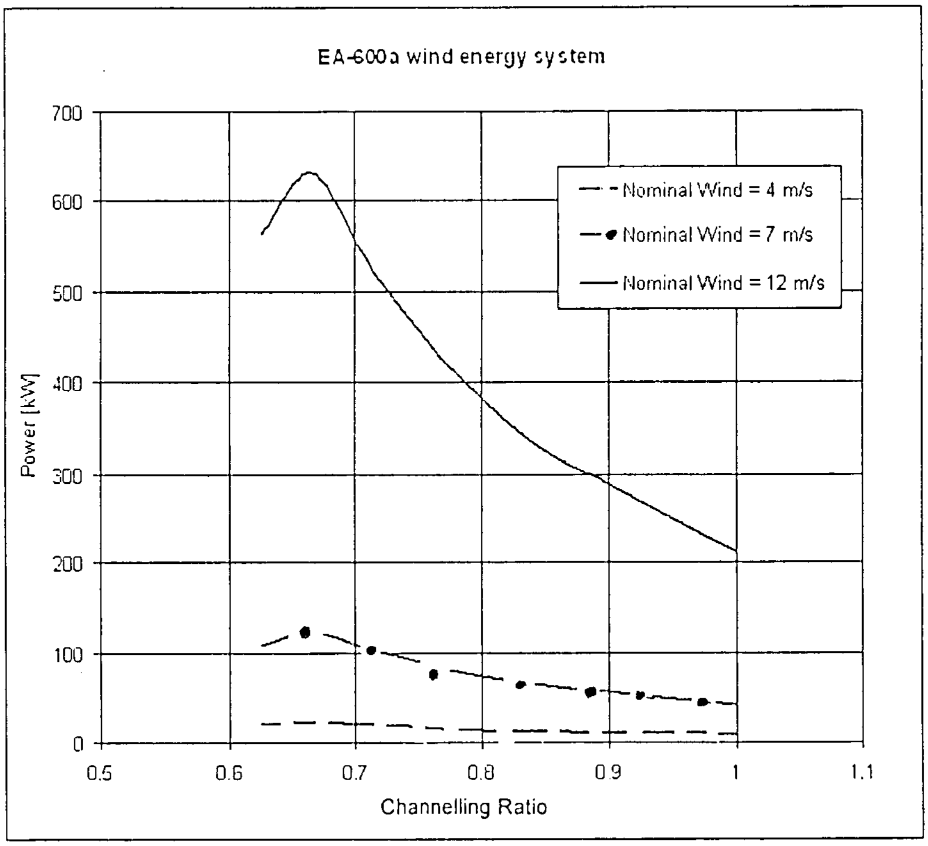

EA-600a wind energy system
Power [kW]
700
600
500
400
300
200
100
0
0.5
0.6
0.7
0.8
0.9
1
1.1
Channelling Ratio
Nominal Wind = 4 m/s
Nominal Wind = 7 m/s
Nominal Wind = 12 m/s

Figure 13

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CA2009/001649

A. CLASSIFICATION OF SUBJECT MATTER
IPC: ***F03D 1/04*** (2006.01) , ***F01D 1/02*** (2006.01) , ***F01D 9/02*** (2006.01) , ***F03B 3/04*** (2006.01) , ***F03B 3/18*** (2006.01) , ***F03D 1/02*** (2006.01) (more IPCs on the last page)
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC (2006.01): F03D, F01D, F03B USCL: 415, 416, 290 CPC: 170, 138

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

Electronic database(s) consulted during the international search (name of database(s) and, where practicable, search terms used)
EPOQUE (X-Full, EPODOC, WPI), Canadian Patent Database
key words: wind, turbine, axial, horizontal, shroud, coaxial+, liner, carenage, eolienne, fan, hollow

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	GB 2036193 A (KLING, A.) 25 June 1980 (25-06-1980) * Abstract; Fig. 1,2 *	26
X	US 7323792 B2 (SOHN, C.) 29 January 2008 (29-01-2008) * Col. 7, line 58 - Col. 8, line 27; Fig. 12, 13,14 *	26
X	US 4147472 A (KLING, A.) 3 April 1979 (03-04-1979) * Col. 4, lines 11-35; Col. 5, lines 5-22; Abstract; Fig. 1,2 *	26
Y	WO 2006/054290 A2 (HIRSHBERG, I.) 26 May 2006 (26-05-2006) * Par. 0141; Abstract; Fig. 18, 19, 21 *	1,3,4,5,6,8,9,10,11,12,13
Y	WO 2007/027765 A2 (SELSAM, D.) 8 March 2007 (08-03-2007) * Paragraph [0213]; Fig. 31,32 *	1,3,4,5,6,8,9,10,11,12,13
A	US 4641799 A (QUAST, A. et al.) 10 February 1987 (10-02-1987) * Col. 3, line 47 - Col. 4, line 3; Abstract; Fig. 1,2 *	1-13,26

[X] Further documents are listed in the continuation of Box C. [X] See patent family annex.

* Special categories of cited documents :
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
2 March 2010 (02-03-2010)	9 March 2010 (09-03-2010)

Name and mailing address of the ISA/CA
Canadian Intellectual Property Office
Place du Portage I, C114 - 1st Floor, Box PCT
50 Victoria Street
Gatineau, Quebec K1A 0C9
Facsimile No.: 001-819-953-2476

Authorized officer
Gilbert Plouffe (819) 997-9811

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

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

1. [ ] Claim Nos. :
because they relate to subject matter not required to be searched by this Authority, namely :

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

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

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

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

See further sheet

1. [X] As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

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

3. [ ] As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claim Nos. :

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

Remark on Protest [ ] The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

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

[ ] No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CA2009/001649

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2005/093435 A1 (PEDERSEN, T.) 6 October 2005 (06-10-2005) * Abstract; Fig. 1,2	1-13,26
A	US 6126385 A (LAMONT, J.) 3 October 2000 (03-10-2000) * Col. 7, lines 30-43; Abstract; Fig. 1,7, 8, 9, 10 *	1-13,26
A	US 2006/0002786 A1 (RICHTER, D.) 5 January 2006 (05-01-2006) * Abstract; Fig. 3,4 *	1-13,26
A	EP 2053240 A1 (CAMPE, R. et al.) 29 April 2009 (29-04-2009) * Abstract; Fig. 11-16 *	1-13,26
A	US 4164382 A (MYSELS, K.) 14 August 1979 (14-08-1979) * Fig. 6 *	1-13,26
A	US 2006/0006658 A1 (MCCOIN, D.) 12 January 2006 (12-01-2006) * Abstract; Fig. 3 *	1-13,26
A	WO 81/00286 A1 (BARRACHO, J.) 5 February 1981 (05-02-1981) * Fig. 1,2 *	1-13,26
A	WO 03/025385 A2 (DAVIS, B. et al.) 27 March 2003 (27-03-2003) * Whole document *	1-13,26
A	EP 2006535 A2 (PLANA QUEROL, J.) 24 December 2008 (24-12-2008) * Whole document *	1-13,26
A	US 5332354 A (LAMONT, J.) 26 July 1994 (26-07-1994) * Abstract; Fig. 2,3 *	14-25
A	US 2006/0026954 A1 (TRUONG, M.-H. et al.) 9 February 2006 (09-02-2006) * Fig.3,10 *	14-25
A	US 2007/0138797 A1 (REIDY, M. et al.) 21 June 2007 (21-06-2007) * Fig. 7,8 *	14-25
A	US 2009/0169354 A1 (KELAIDITIS, K. et al.) 2 July 2009 (02-07-2009) * Abstract; Fig. 1-3,23,24 *	14-25
A	US 2006/0232076 A1 (PLATT, M.) 19 October 2006 (19-10-2006) * Abstract; Fig. 3 *	14-25
A	US 2003/0122380 A1 (HARBISON, C.) 3 July 2003 (03-07-2003) * Paragraph 0023; Fig.2,6 *	14-25
A	WO 2006/054290 A2 (HIRSHBERG, I.) 26 May 2006 (26-05-2006) * Fig. 7,19 *	14-25

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Continuation of Box No. III

Group A:

Claims 1-13 and 26 are directed to an annular double-walled turbine comprising inner and outer shrouds forming a continuous channel for directing fluid entering the turbine towards the faces of the turbines blades extending between the shrouds.

Group B:

Claims 14-25 are directed to an adjustable flow channel area double-walled turbine having a rotor comprising an outer shroud enclosing side, top and bottom portions of the rotor, upstream fluid deflectors and actuators to reduce the width of the swept area and adjustable inner walls and actuators to position the inner walls relative to the width of a channel to direct fluid entering the turbine towards the faces of the turbines blades.

The examiner considers that the subject matter of independent claims 1, 14, 15 and 26 of Groups A-B are distinct alleged inventions and do not form a single inventive concept.

The claims must be limited to one inventive concept as set out in **Rule 13 of the PCT**. Indeed, it cannot be reasonably inferred from the language of the independent claims a single common inventive wind turbine of any one Group.

F03D 3/02 (2006.01) , ***F03D 3/04*** (2006.01)