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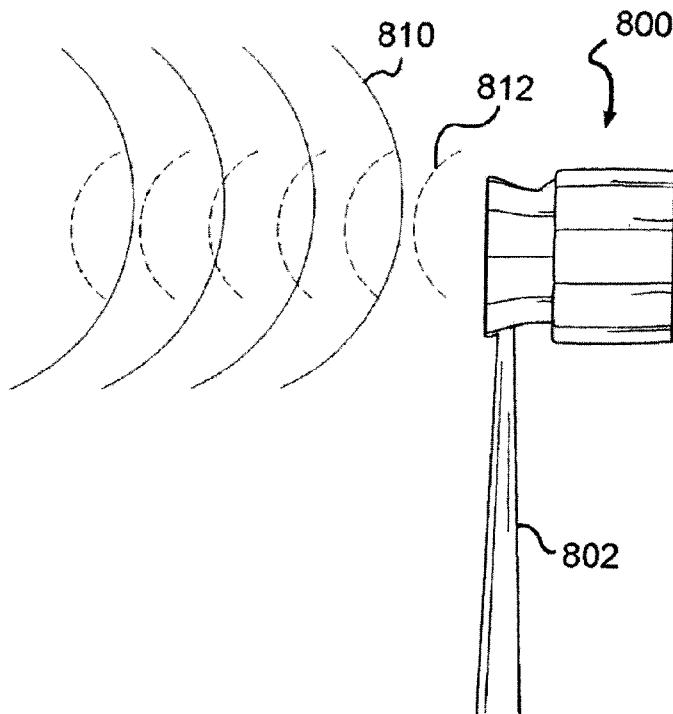
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[Continued on next page]

(54) Title: WIND TURBINE WITH REDUCED RADAR SIGNATURE



(57) **Abstract:** Various components of a shrouded wind turbine are coated with a radar absorbent material. The resulting wind turbine has a reduced radar signature compared to conventional wind turbines.

FIG. 8



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WIND TURBINE WITH REDUCED RADAR SIGNATURE

BACKGROUND

[0001] This application claims priority to U.S. Provisional Patent No. 61/195,307, filed on October 6, 2008. The provisional application is hereby fully incorporated by reference.

[0002] The present disclosure relates to wind turbines. In particular, the wind turbines have a reduced radar signature compared to conventional wind turbines.

[0003] A conventional open propeller blade type wind turbine typically includes blades of up to 150 feet or more in length rotating about an axis, producing a swept area having a diameter of 300 feet and consequently a very large radar cross section. Wind turbines of the existing open blade type have been found to degrade the performance of air traffic control and air defense radar by causing sudden or intermittent appearance of radar contacts at the location of the wind turbine, due to the blade motion or rotation of the turbine into the wind. This degradation in performance is particularly strong if the wind turbine is located within the radar line of sight of the radar antenna, particularly at ranges within five miles of the radar antenna. The motion of the wind turbine blades or the turning of the turbine assembly for wind alignment can be particularly troublesome for Doppler radar systems.

[0004] In addition, the wind turbine may cause direct interference by virtue of high reflectivity reducing the radar sensitivity and may produce false images (ghosting) or shadow areas (dead zones). The motion of the large rotor blades or the turning of the turbine assembly for wind alignment may also create false targets in Doppler radar systems.

[0005] The strength of a reflected radar signal depends not only upon the power level of the radar system, but how large or efficient a reflector of radar energy the reflecting object is. This largeness or size factor is commonly referred to as a Radar Cross Section (RCS). For the same amount of radar energy, objects with a large RCS reflect proportionately a larger amount of radar energy than an object with a lower RCS and are thus easier to detect. RCS is normally expressed in terms of decibel square meters (dBsm), a logarithmic expression of an object's radar reflecting surface area.

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[0006] It would be desirable to provide a wind turbine with a lower radar signature than that of existing open blade wind turbines.

SUMMARY

[0007] The present disclosure describes wind turbines which have a reduced radar cross section. The disclosure also described methods of reducing the radar signature of a wind turbine by applying a surface coating of radar absorbent material to the wind turbine to thereby minimize the reflectivity of a transmitted radar signal. In particular, the radar absorbent coating may comprise a coating containing carbonyl iron ferrite. In another version, the radar absorbent coating may be in the form of relatively thin tiles formed of a synthetic polymer matrix having particles of a ferric compound interspersed therein. The synthetic polymer material may be a neoprene material. The radar absorbent coating may also be applied by spraying.

[0008] Disclosed in embodiments is a wind turbine comprising a fan; a shroud disposed about the fan; and a coating of radar absorbent material. The wind turbine may also be a three bladed horizontal axis wind turbine (HAWT) where the coating is applied to the entire turbine, the turbine blades, or a portion of the blades.

[0009] The radar absorbent coating may comprise a carbonyl iron ferrite material. The radar absorbent coating may be applied by spraying. The coating may also be formed from at least one tile, the tile comprising a synthetic polymer matrix having ferric compound particles interspersed therein. The synthetic polymer matrix may comprise neoprene.

[0010] The radar absorbent coating may be located on a leading edge of the shroud; an exterior of the shroud; at least one blade of either a rotor or a stator; a leading edge of an ejector; and/or an exterior of an ejector. In some embodiments, the radar absorbent coating is located on a leading edge of the shroud, an exterior of the shroud, a leading edge of the ejector, and an exterior of the ejector.

[0011] Disclosed in other embodiments is a ejector shroud wind turbine, comprising: a shroud having a plurality of lobes on a trailing edge thereof; a fan located within the shroud; a ejector shroud having a plurality of lobes on a trailing edge thereof, wherein

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the ejector shroud is located downstream of the shroud; and a coating of radar absorbent material located on the turbine.

[0012] The radar absorbent coating can be located on the shroud and/or the ejector shroud.

[0013] Also disclosed is a method of reducing the radar signature of a wind turbine comprising: providing a wind turbine having a shroud surrounding a fan assembly; and applying a coating of radar absorbent material to the wind turbine.

[0014] The coating can be applied by laminating tiles formed of a synthetic polymer matrix having particles of a ferric compound interspersed therein to a surface of the wind turbine or by spraying the coating onto a surface of the wind turbine.

[0015] Also disclosed in embodiments is a horizontal axis wind turbine comprising a nacelle and blades, and a coating of radar absorbent material located on the turbine. The coating of radar absorbent material may be located on the blades of the turbine, or on the nacelle.

[0016] These and other non-limiting features or characteristics of the present disclosure will be further described below.

BRIEF DESCRIPTION OF THE DRAWINGS

[0017] The following is a brief description of the drawings, which are presented for the purposes of illustrating the disclosure set forth herein and not for the purposes of limiting the same.

[0018] **FIGURE 1** shows a side view and a perspective view of one embodiment of a wind turbine mounted on a mast.

[0019] **FIGURE 2** shows a side view and a perspective view of another embodiment of a wind turbine employing mixer lobes.

[0020] **FIGURE 3** shows a side view and a perspective view of another embodiment of a wind turbine employing mixer lobes and an ejector.

[0021] **FIGURE 4A** is a perspective view of a wind turbine with an ejector having mixer lobes on the downstream edge thereof.

[0022] **FIGURE 4B** is an exploded view of the wind turbine of **FIGURE 4A**.

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[0023] **FIGURE 5** shows a front view and a perspective view of another embodiment of a wind turbine employing a three-bladed impeller.

[0024] **FIGURE 6A** is a front view comparing the radar cross section of a conventional wind turbine having open blades with a shrouded wind turbine of the present disclosure, both turbines having the same generating capacity.

[0025] **FIGURE 6B** is a side view of the conventional wind turbine and the shrouded wind turbine of the present disclosure, as described in **FIGURE 6A**.

[0026] **FIGURE 7** is a side view illustrating radar waves striking and reflecting from an open blade wind turbine.

[0027] **FIGURE 8** is a side view illustrating radar waves striking and reflecting from a shrouded wind turbine of the present disclosure.

[0028] **FIGURE 9** is a cross section of an embodiment of a wind turbine of the present disclosure, with a portion thereof enlarged to show a radar absorbent coating.

[0029] **FIGURE 10** shows the radar cross section for various objects, including a conventional 1.5MW open blade wind turbine.

DETAILED DESCRIPTION

[0030] A more complete understanding of the processes and apparatuses disclosed herein can be obtained by reference to the accompanying drawings. These figures are merely schematic representations based on convenience and the ease of demonstrating the existing art and/or the present development, and are, therefore, not intended to indicate relative size and dimensions of the assemblies or components thereof.

[0031] Although specific terms are used in the following description for the sake of clarity, these terms are intended to refer only to the particular structure of the embodiments selected for illustration in the drawings, and are not intended to define or limit the scope of the disclosure. In the drawings and the following description below, it is to be understood that like numeric designations refer to components of like function.

[0032] Generally, the present disclosure includes a wind turbine that has a reduced radar signature. The reduced radar signature is due to several factors, including

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reduced blade diameter, lack of external moving parts, and the use of a radar energy absorbing surface on the wind turbine.

[0033] Referring to **FIGURE 1**, a first embodiment of a wind turbine **100** is shown in a side view and a perspective view.

[0034] The turbine **100** comprises a fan surrounded by a shroud **102**. The fan may generally be any assembly in which blades are attached to a shaft and able to rotate, allowing for the generation of power or energy from wind rotating the blades. As illustrated here, the fan is a rotor-stator assembly. The stator **106** has multiple blades or vanes **107** and is surrounded by the shroud **102** extending in a downstream direction beyond a multi-bladed rotor (not shown) which is situated downstream of and immediately adjacent the stator **106**. The turbine **100** is supported on a mast **101** at a desired distance above a support base, which may be the surface of a building or structure on a vessel, such as a water craft, or the surface of the earth. As desired, the mast **101** can be configured to allow the turbine **100** to rotate freely about the axis of the mast.

[0035] Referring to **FIGURE 2**, another embodiment of a wind turbine **200** is shown in a side view and a perspective view. The turbine **200** has a multi-vaned stator **204** surrounded by a shroud **202** which has the trailing or downstream edge thereof configured with lobes **208** for effecting mixing of the air exiting the turbine with the air flowing over the exterior of the shroud **202**. A rotor (not shown) is disposed downstream of and immediately adjacent the stator **204**. The turbine assembly **200** is similarly supported on a mast **201**.

[0036] Referring to **FIGURE 3**, another embodiment of a wind turbine **300** is shown in a side view and a perspective view. The turbine **300** has a stator **306** surrounded by a shroud **302** having mixer lobes **308** formed on the downstream edge thereof. A rotor (not shown) is disposed downstream of and immediately adjacent stator **306**. The turbine **300** further includes an ejector **304** surrounding the shroud with lobes **308** for effecting further mixing of additional free stream air through the stator vanes **306** and the rotor. The turbine **300** of **FIGURE 3** is similarly supported on a mast **301** connected to the shroud **302**.

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[0037] **FIGURE 4A** is another embodiment of a wind turbine of the present disclosure, in a form also known as a ejector shroud wind turbine (MEWT). The MEWT is a new type of wind turbine that uses a shrouded impeller, prop, or rotor/stator to improve the efficiency of a wind turbine such that more power may be extracted for a turbine having the same area than other current types of wind turbines. The MEWT accomplishes this by drawing air from a larger area than the most common type of wind turbine, the horizontal-axis wind turbine (HAWT).

[0038] A wind turbine can theoretically capture at most 59.3% of the potential energy of the wind passing through it, a maximum known as the Betz limit. The amount of energy captured by a wind turbine can also be referred to as the efficiency of the turbine. The MEWT may exceed the Betz limit.

[0039] Referring to **FIGURE 4A**, the turbine **400** comprises a fan located at an intake end of a mixer shroud **402**. The fan may generally be any assembly in which blades are attached to a shaft and able to rotate, allowing for the generation of power or energy from wind rotating the blades. As illustrated here, the fan is a rotor-stator assembly. The stator **406** engages the shroud **402**, and the rotor (not shown) engages a motor/generator (not shown). The stator **406** has stationary blades **407** which turn the air before it reaches the rotor. The blades of the rotor then rotate, generating power in the generator. The shroud **402** comprises a ringed airfoil, or in other words is approximately cylindrical and has an airfoil shape, with the airfoil configured to generate relatively lower pressure within the shroud (i.e. the interior of the shroud) and relatively higher pressure outside the shroud (i.e. the exterior of the shroud). The fan and the motor/generator are contained within the shroud. The shroud **402** may also have mixer lobes **408**. The mixer lobes generally cause the exhaust end of the shroud, where air exits, to have a generally peak-and-valley shape about its circumference. Put another way, the lobes **408** are located along the trailing edge of the shroud.

[0040] The turbine **400** also comprises an ejector shroud **404**, which is engaged with the shroud. The ejector shroud comprises a ringed airfoil, or in other words is approximately cylindrical and has an airfoil shape, with the airfoil configured to generate relatively higher pressure within the ejector shroud (i.e. the annular area between the mixer shroud **402** and the ejector shroud **404**) and relatively lower pressure outside the

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ejector **404**. The ejector may also have mixer lobes **410**, in which case the ejector is then referred to as a mixer-ejector shroud. The mixer lobes generally cause the exhaust end of the ejector, where air exits, to have a generally peak-and-valley shape about its circumference. Put another way, the mixer lobes are located along the trailing edge of the ejector **404**.

[0041] The ejector shroud **404** has a larger diameter than the mixer shroud **402**. The shroud **402** engages the ejector shroud **404**. Put another way, the exhaust end of the mixer shroud fits within the intake end of the ejector shroud, or the intake end of the ejector shroud surrounds the exhaust end of the mixer shroud. The mixer shroud **402** and ejector shroud **404** are sized so that air can flow between them. Phrased another way, the ejector shroud **404** is concentrically disposed about the shroud **402** and is downstream of the shroud **402**. The fan, mixer shroud **402**, and ejector shroud **404** all share a common axis.

[0042] The mixer lobes **408, 410** allow for advanced flow mixing and control. The mixer shroud and ejector shroud are different from similar shapes used in the aircraft industry because in the MEWT, the air flow path provides high-energy air into the ejector shroud. The mixer shroud provides low-energy air (after energy has been extracted by the rotor) into the ejector shroud, and the high-energy air outwardly surrounds, pumps, and mixes with the low-energy air.

[0043] The motor/generator may be employed to generate electricity when the wind is driving the rotor. The generator on the turbine may also be used as a motor to drive the fan, and thus draw air into and through the turbine **400**, when the wind is insufficient to drive the rotor.

[0044] Referring to **FIGURE 4B**, the wind turbine **400** is shown in exploded view. The rotor **411** has a plurality of radial blades **413** surrounded by a ring **412** connected to the outer ends of the blades **413**. The mixing lobes **408** of the mixer shroud **402** generally fit within the front end of the ejector shroud **404**, such that an air stream can flow through a space between the mixer shroud **402** and the ejector shroud **404**.

[0045] Referring to **FIGURE 5**, another embodiment of a wind turbine **500** is shown in a front view and a perspective view. The turbine **500** includes an impeller **518** having aerodynamically configured blades for efficient extraction of energy from the free

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stream. The impeller **518** is surrounded by a mixer shroud **502** having downstream mixing lobes **508** provided on the trailing edge thereof. The lobes **508** are surrounded by an ejector shroud **504** having mixing lobes **510** provided about the downstream or trailing periphery thereof. The wind turbine **500** of **FIGURE 5** is supported on a suitable mast **501** which may extend through the shroud **502** to support a motor/generator **520** and the impeller **518**.

[0046] **FIGURE 6A** is a front view comparing the radar cross section of a conventional wind turbine having open blades (left hand side) with a shrouded wind turbine of the present disclosure (right hand side), both turbines having the same power generating capacity. The prior art open blade wind turbine **650** is mounted on a mast **601** and has a swept area of diameter **605** as the blades **620** rotate, resulting in a radar cross section indicated by the dashed outline. In contrast, the wind turbine **600** of the present disclosure has a much smaller swept area of diameter **603**, resulting in a smaller radar cross section.

[0047] **FIGURE 6B** is a side view comparing the radar cross section of a conventional wind turbine having open blades (left hand side) with a shrouded wind turbine of the present disclosure (right hand side), both turbines having the same power generating capacity. Again, the conventional wind turbine **650** with open impeller blades **620** has a radar cross section based on swept area of diameter **605** and drives a generator which is mounted on mast **601** and located within nacelle **612**. The shrouded wind turbine **600** has a smaller swept area of diameter **603**. The stator, mixer shroud **602**, and ejector shroud **604** prevent the blades of the shrouded wind turbine from being “seen” by radar.

[0048] **FIGURE 7** is a side view of a conventional wind turbine **700**, which is mounted on a mast **713** and has open blades **736**. An incoming radar wave **734** is shown in solid line and strikes the blades **736**. The reflected wave **732** is indicated in dashed line. The reflected energy or wave **732** may also cause a second fainter return known as “multi-bounce,” which occurs when incoming wave **734** is reflected by the turbine blade **736**, then the turbine tower **713**, and then again by the blade **736**, before returning to the radar source.

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[0049] **FIGURE 8** is a side view of a shrouded wind turbine **800** of the present disclosure. The turbine **800** is also mounted on a mast **802**. An incoming radar wave **810** is shown in solid line and, upon contacting the turbine **800**, creates reflected wave **812** illustrated in dashed line. The shroud and ejector of the wind turbine eliminate the multi-bounce of the conventional turbine of **FIGURE 7**. In addition, the reflected wave **812** is much smaller because the blades (not shown) of the shrouded wind turbine **800** are smaller, resulting in a reduced radar signature.

[0050] One advantage of a shrouded wind turbine is that they are more efficient than conventional open-bladed wind turbines. In particular, shrouded turbines with a mixer ejector (MEWT) can provide efficiencies in excess of the Betz limit of 59.3%. Thus, a shrouded wind turbine can have a much smaller rotor diameter than an open blade wind turbine, yet extract the same amount of wind energy. Thus, a ejector shroud wind turbine (MEWT) can be mounted on top of a building or closer to the ground because the clearance for a lengthy rotor blade is eliminated.

[0051] **FIGURE 9** is a cross-sectional view of a shrouded wind turbine **1000**. The turbine **1000** has vanes **1008** disposed on stator **1006** and a multi-bladed rotor **1012**. A mixer shroud **1002** surrounds the stator **1006** and rotor **1012**, and has a ring of mixer lobes **1016** disposed about the downstream periphery thereof. The mixer shroud **1002** has disposed thereabout and adjacent thereto on the downstream side an annular streamlined ejector shroud **1004** which also has a plurality of mixer lobes **1018** disposed about the downstream periphery thereof.

[0052] Referring to the encircled portion of the view of **FIGURE 9** as enlarged, a portion of the upstream or leading edge of the ejector shroud **1004** has a coating **1014** of radar absorbent material disposed thereon. The material **1014** is operative to absorb incoming or transmitted radar waves **1010**, which are then dissipated as heat within the material, indicated pictorially as helical arrow **1018** in **FIGURE 9**.

[0053] The radar absorbent coating **1014** may comprise carbonyl iron compounds, such as carbonyl iron ferrite. The coating may be applied as a spray or incorporated into a polymer matrix and then applied as laminated tiles onto the wind turbine. In some embodiments, a laminated tile is formed from a synthetic polymer matrix, such as neoprene, with particles of a ferric compound interspersed therein. The radar absorbent

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coating may be applied to any or all parts of the wind turbine, including, for example, the leading edge and/or the exterior of the shroud, the leading edge and/or the exterior of the ejector, the blades of the stator, the blades of the rotor, and/or the mast. Any desired combination of these parts can be covered with the radar absorbent coating.

[0054] In operation, when a radar wave encounters the coating 1014, it creates a magnetic field within the metallic elements of the coating. This field has alternating polarity and dissipates the energy of the radar signal by converting a significant portion of the radar energy into heat. Although it is not expected that the resulting heat will be significant in light of the cooling effect of wind / air stream produced by the turbine itself, cooling mechanisms are also contemplated within the scope of the present disclosure. For example, the shroud and/or ejector may include spraying mechanisms for dispensing liquids, such as water, upon the radar absorbent coating.

[0055] It should be recognized that conventional wind turbines use large blades, such as about 150 feet in length. Such blades are subject to flexing and bending under wind loads and very high centrifugal forces in the high velocity outer regions of the blade. As a result, maintaining the adhesion of a radar absorbent coating to such blades is difficult. In contrast, the mixer shroud and the ejector shroud of a shrouded wind turbine are smaller and are substantially rigid and stationary objects as well, making the application of such coating much easier. However, a radar absorbent coating may be applied to a HAWT with the proper surface preparation and the proper polymer adhering the carbonyl iron ferrite to the HAWT blade. The coating could be applied to the entire turbine, the nacelle or body of the turbine, the front face of the turbine blades, the leading edge of the turbine blades, the rotor, or any combinations thereof.

[0056] **FIGURE 10** shows the radar cross section of various objects, including a 1.5MW wind turbine.

[0057] The systems and methods of the present disclosure have been described with reference to exemplary embodiments. Obviously, modifications and alterations will occur to others upon reading and understanding the preceding detailed description. It is intended that the exemplary embodiments be construed as including all such

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modifications and alterations insofar as they come within the scope of the appended claims or the equivalents thereof.

CLAIMS:

1. A wind turbine comprising:
 - a fan;
 - a shroud disposed about the fan; and
 - a coating of radar absorbent material.
2. The wind turbine of claim 1, wherein the radar absorbent coating comprises a carbonyl iron ferrite material.
3. The wind turbine of claim 1, wherein the radar absorbent coating is formed from at least one tile, the tile comprising a synthetic polymer matrix having ferric compound particles interspersed therein.
4. The wind turbine of claim 3, wherein the synthetic polymer matrix comprises neoprene.
5. The wind turbine of claim 1, wherein the radar absorbent coating is located on a leading edge of the shroud.
6. The wind turbine of claim 1, wherein the radar absorbent coating is located on an exterior of the shroud.
7. The wind turbine of claim 1, wherein the fan is a rotor-stator assembly, and the radar absorbent coating is located on at least one blade of the stator.
8. The wind turbine of claim 1, wherein the fan is a rotor-stator assembly, and the radar absorbent coating is located on at least one blade of the rotor.

9. The wind turbine of claim 1, further comprising an ejector located downstream of the shroud, wherein the radar absorbent coating is located on a leading edge of the ejector.

10. The wind turbine of claim 1, further comprising an ejector located downstream of the shroud, wherein the radar absorbent coating is located on an exterior of the ejector.

11. The wind turbine of claim 1, further comprising an ejector located downstream of the shroud, wherein the radar absorbent coating is located on a leading edge of the shroud, an exterior of the shroud, a leading edge of the ejector, and an exterior of the ejector.

12. A ejector shroud wind turbine, comprising:
a shroud having a plurality of lobes on a trailing edge thereof;
a fan located within the shroud;
a ejector shroud having a plurality of lobes on a trailing edge thereof, wherein the ejector shroud is located downstream of the shroud; and
a coating of radar absorbent material located on the turbine.

13. The wind turbine of claim 12, wherein the radar absorbent coating comprises a carbonyl iron ferrite material.

14. The wind turbine of claim 12, wherein the radar absorbent coating is formed from at least one tile, the tile comprising a synthetic polymer matrix having ferric compound particles interspersed therein.

15. The wind turbine of claim 12, wherein the radar absorbent coating is located on the shroud.

16. The wind turbine of claim 12, wherein the radar absorbent coating is located on the ejector shroud.

17. The wind turbine of claim 12, wherein the radar absorbent coating is located on the shroud and the ejector shroud.

18. A method of reducing the radar signature of a wind turbine comprising:
providing a wind turbine having a shroud surrounding a fan assembly;
and
applying a coating of radar absorbent material to the wind turbine.

19. The method of claim 18, wherein the step of applying includes laminating tiles formed of a synthetic polymer matrix having particles of a ferric compound interspersed therein to a surface of the wind turbine.

20. The method of claim 18, wherein the step of applying comprises spraying the coating onto a surface of the wind turbine.

21. A horizontal axis wind turbine comprising a nacelle and blades, and a coating of radar absorbent material located on the turbine.

22. The turbine of claim 21, wherein the coating of radar absorbent material is located on the blades of the turbine.

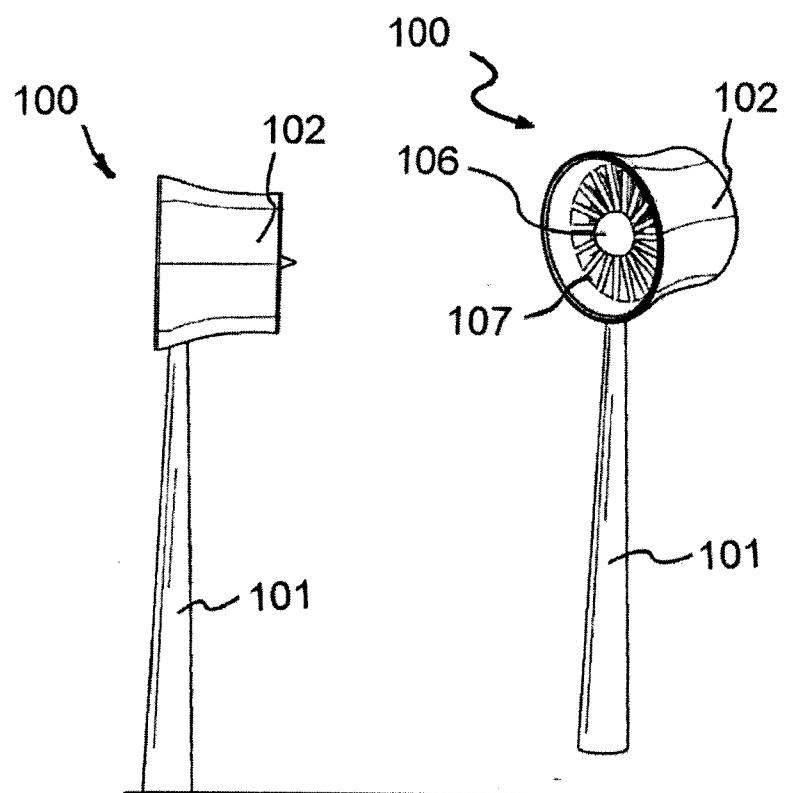


FIG. 1

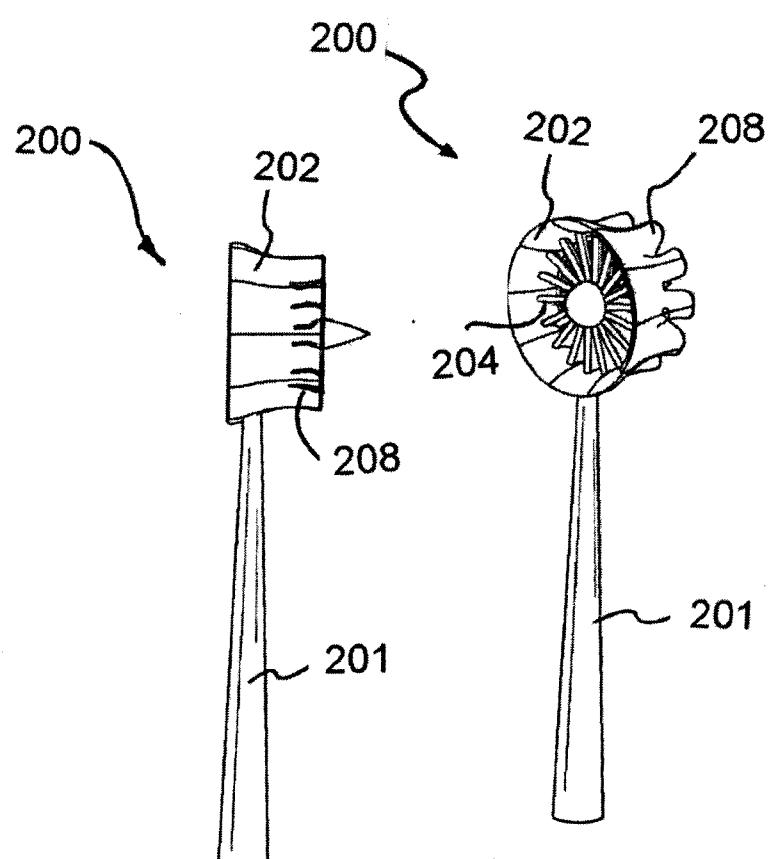


FIG. 2

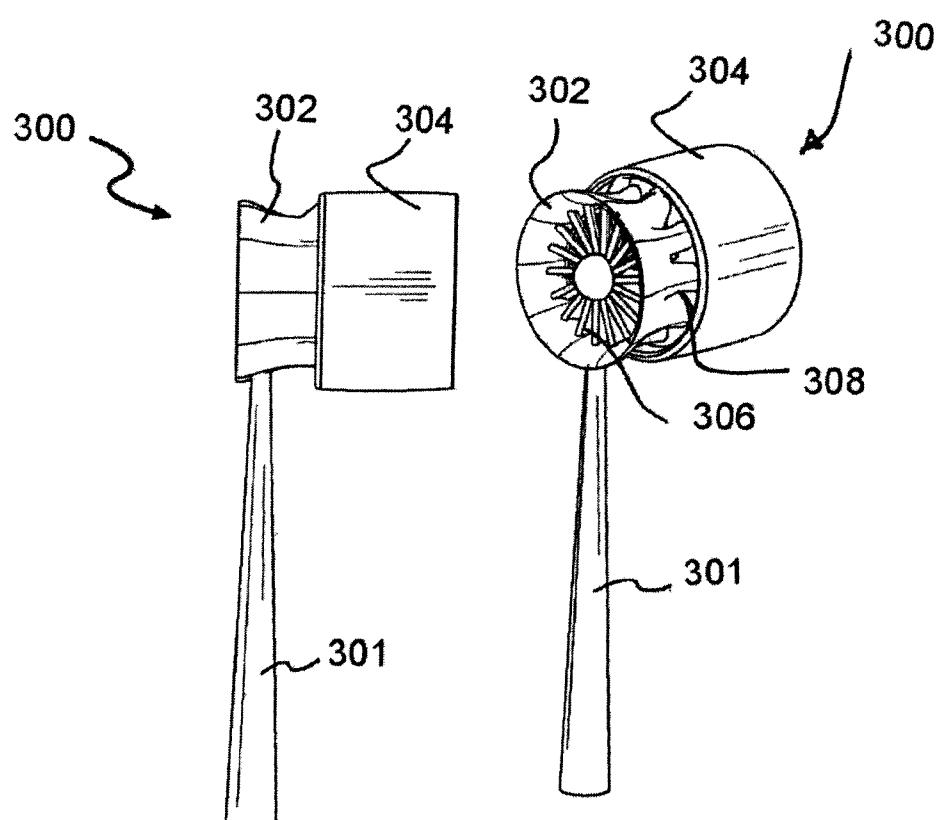
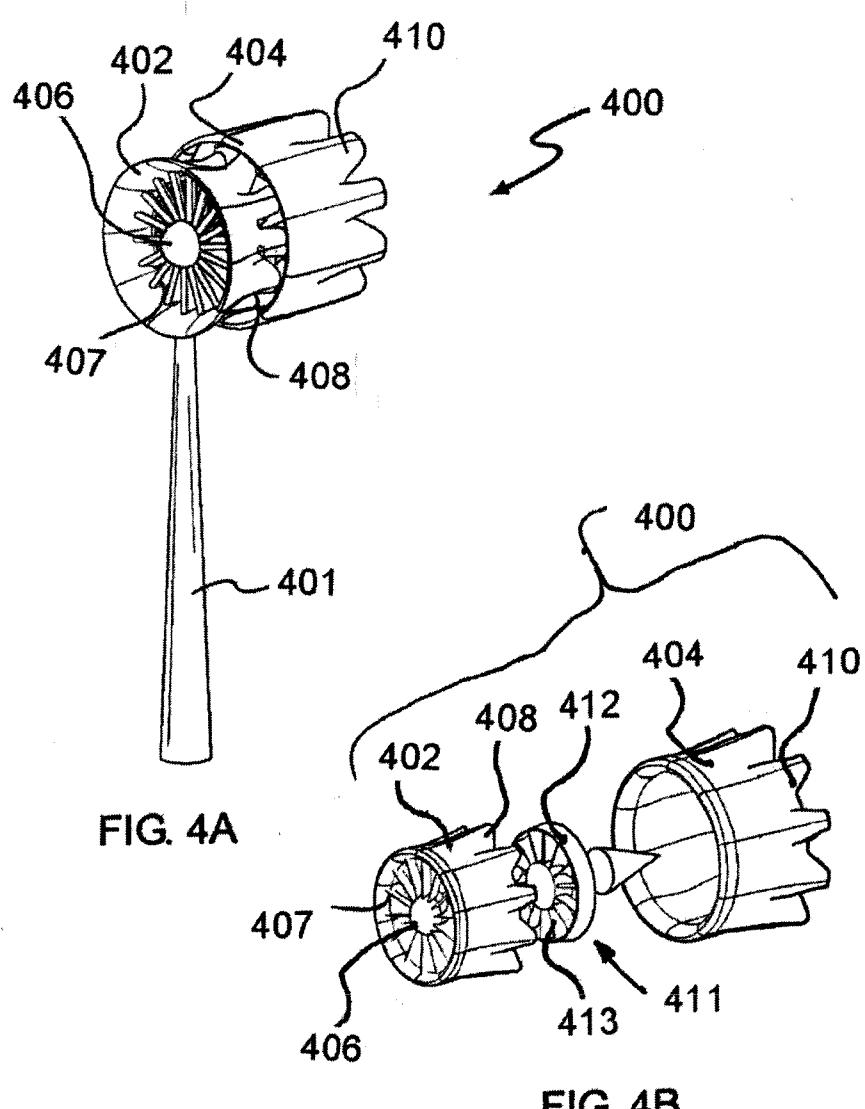
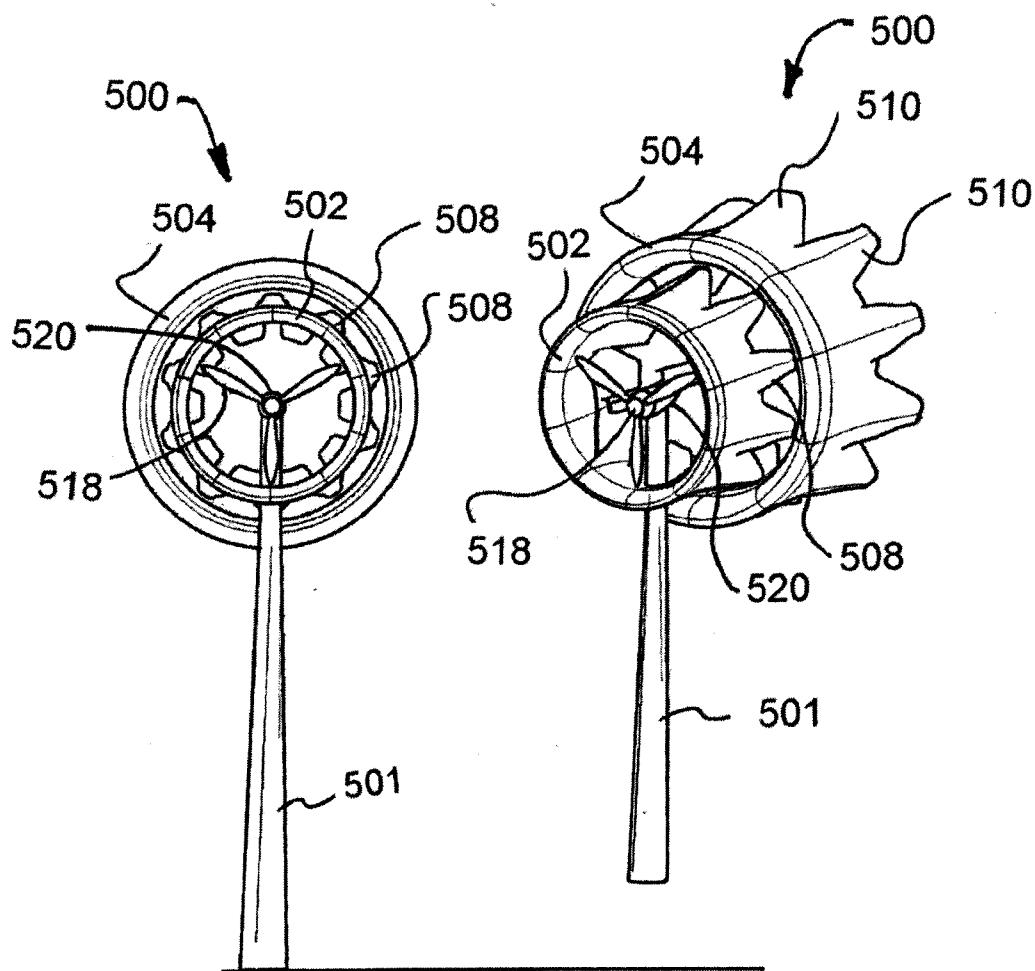


FIG. 3



**FIG. 5**

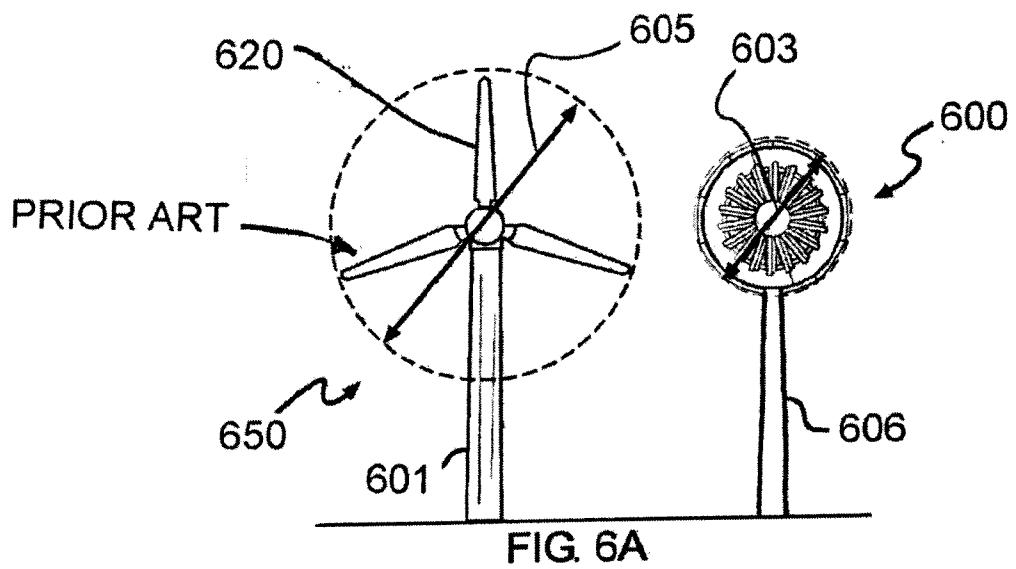


FIG. 6A

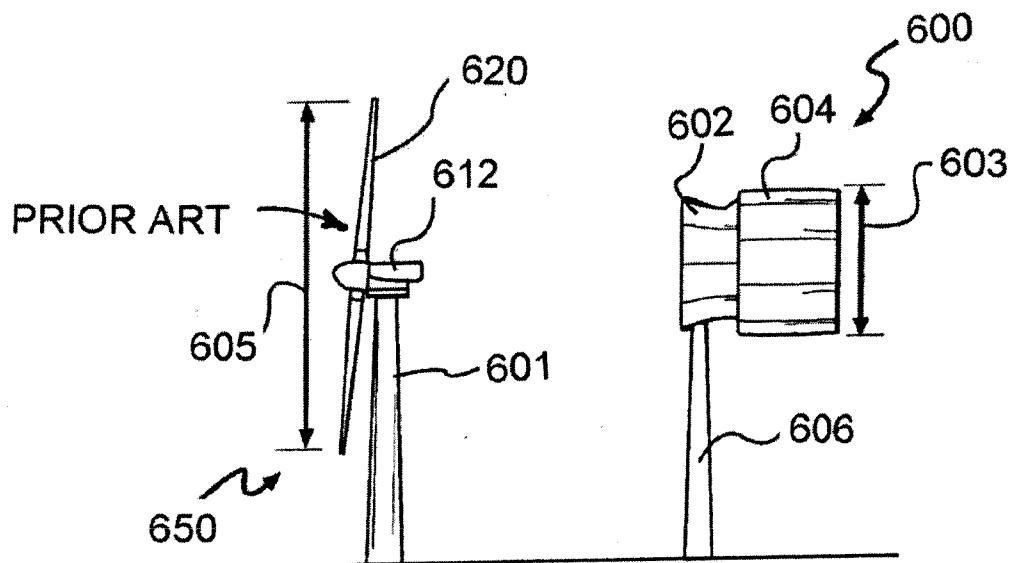


FIG. 6B

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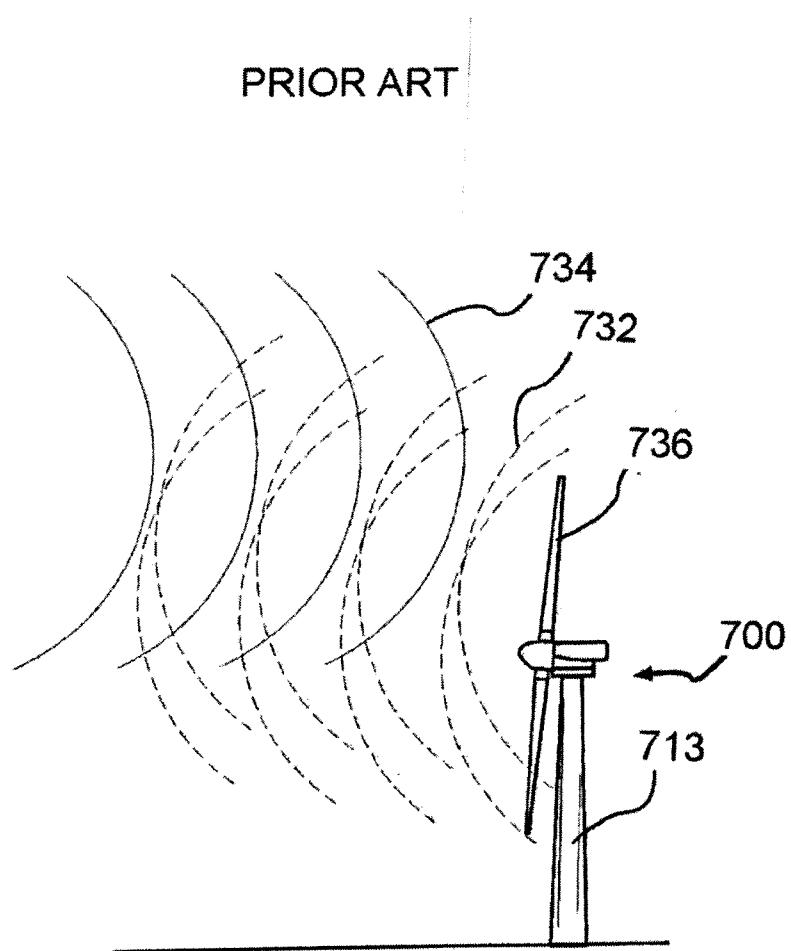


FIG. 7

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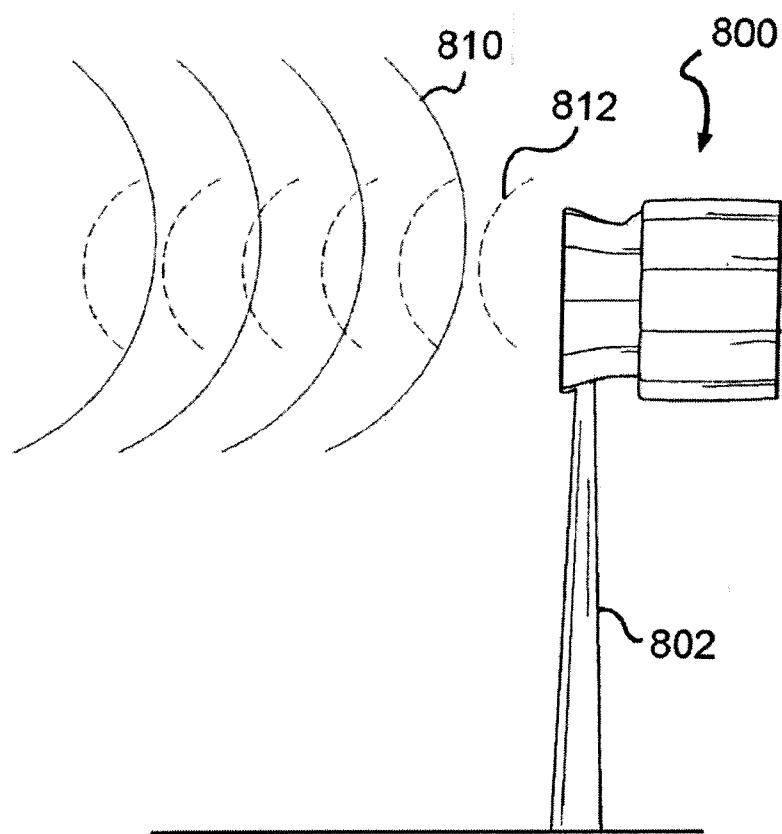


FIG. 8

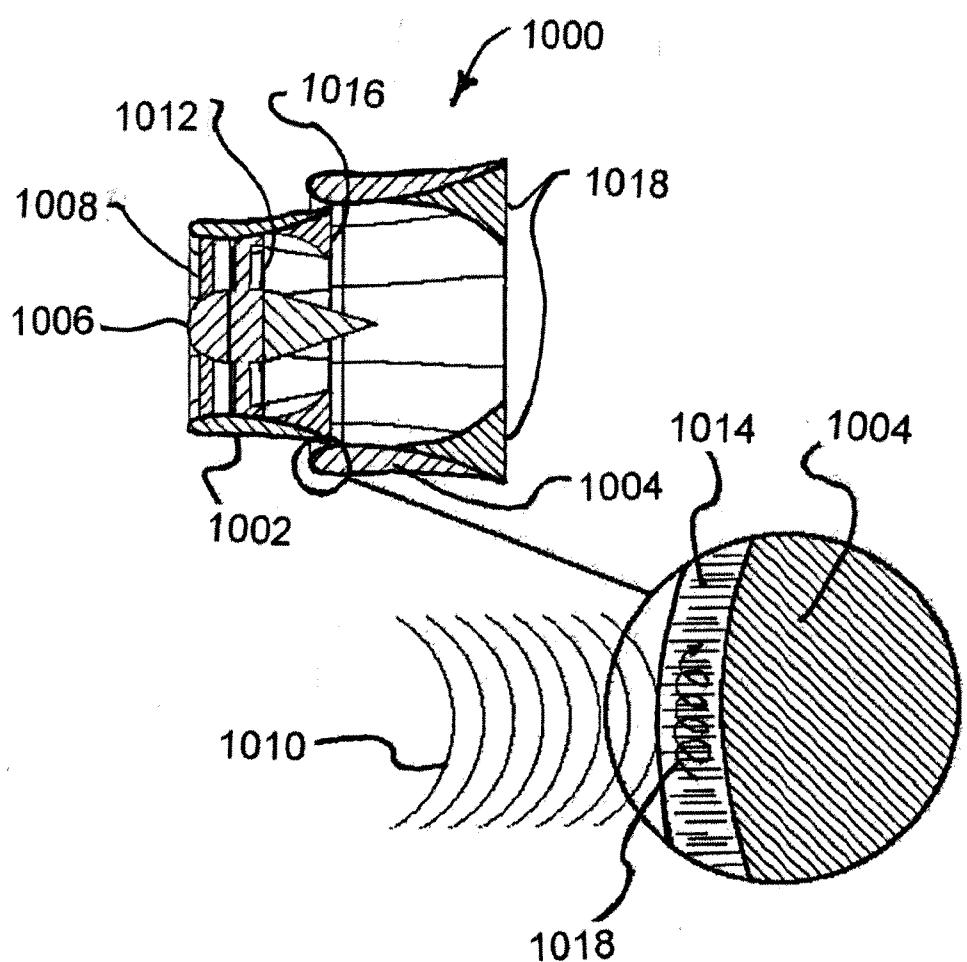
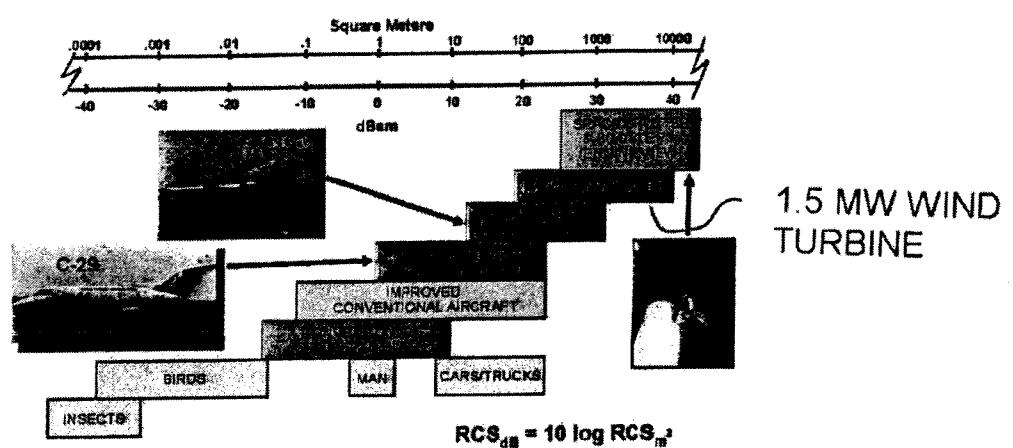


FIG. 9

10/10



PRIOR ART

FIG. 10

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2009/059647

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - F03D 1/04 (2009.01)

USPC - 415/191

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(8) - F03D 1/04 (2009.01)

USPC - 415/191, 220

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

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

PatBase

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2008/0232957 A1 (PRESZ et al) 25 September 2008 (25.09.2008) see entire document	1-22
Y	US 2006/0227056 A1 (BRITTINGHAM et al) 12 October 2006 (12.10.2006) see entire document	1-22
Y	WO 95/28014 A1 (TUSCH) 19 October 1995 (19.10.1995) see entire document	3-4, 14, 19

Further documents are listed in the continuation of Box C.

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Date of the actual completion of the international search 29 November 2009	Date of mailing of the international search report 09 DEC 2009
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