FLODESIGN WIND TURBINE
Avian Safety Validation Project and Study
Proposal Outline
July 2011

EXECUTIVE SUMMARY

FloDesign Wind Turbine (FloDesign) is a Massachusetts-based developer of high-performance, next-generation wind turbine technology to help meet the world's growing need for clean, renewable energy. The company's shrouded, mixer/ejector wind turbine ("MEWT") design uses proven technology, long used in aeronautical applications, to achieve major performance improvements compared to conventional horizontal-axis wind turbine ("HAWT") technology. These improvements include: much higher output per unit of swept area; lower cut-in speeds; and improved off-axis performance.

FloDesign also believes that, beyond these performance improvements, MEWTs will reduce many of the environmental impacts that have impeded acceptance of wind generation. Specifically, FloDesign believes that MEWTs will be more avian-friendly than conventional, open-blade HAWTs. This working hypothesis is based on inherent design features including the smaller size, lower height and shrouded construction of MEWTs, and rests on a combination of intuitive logic and a literature review on wind-avian impacts.

With MEWT technology now poised for commercial introduction, it is timely and necessary to test this hypothesis. The performance advantages of MEWTs have been validated through wind tunnel and pilot testing. By contrast, claims regarding avian safety and other environmental impacts, if they are to gain acceptance by users, government, NGOs and the public at large, must be ascertained through in-field commercial-scale demonstrations.

This paper outlines a plan to achieve this goal. It includes a description of FloDesign's technology; sets forth the basis for the company's hypothesis regarding the avian friendliness of its turbine design; and outlines a two-pronged plan aimed at validating or refuting its thinking on the topic. The first prong entails construction and installation of a demonstration project, comprising ten 100kW turbines, at a site within the Altamont Pass Wind Resource Area (APWRA) in Alameda County, California, beginning before the end of 2012. The second prong entails a rigorous, independently-managed and peer-reviewed study of the avian impacts of these experimental turbines, compared to a control group of twenty similarly-rated, similarly-sited conventional turbines. The entire group of thirty turbines would be intensively monitored for a period of at least one year.

FloDesign seeks reaction and input to this plan from interested parties, including academic experts, government agencies and environmental NGOs concerned with avian issues. The company's hope is to finalize the plan during summer 2011, so that the first experimental turbines may be installed during 2012 and scientifically rigorous conclusions about the avian impacts of MEWTs can begin to be drawn in 2013.

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1. FLODESIGN BACKGROUND AND OVERVIEW

FloDesign Wind Turbine (FloDesign or FDWT) is a developer of high-performance, next-generation wind turbine technology that is headquartered in Waltham, Massachusetts with operations in Denmark and China. Founded in 2007, FDWT is a spinoff from FloDesign Inc. (FDI), a contract engineering firm headquartered in Wilbraham, Massachusetts. For several decades, FDI has been using fundamental principles of aeronautical engineering to develop novel applications in a variety of fields including jet aircraft engine design, advanced weaponry, noise and IR suppression. More information about FDI may be found at www.flodesign.org. This paper focuses exclusively on wind power applications of FDI's technology, to which FDWT holds exclusive rights. For convenience, and unless otherwise noted, the term "FloDesign" refers to FDWT throughout this paper.

2. MIXER-EJECTOR WIND TURBINE (MEWT) TECHNOLOGY OVERVIEW


Figures 1-2. The Mixer-Ejector Wind Turbine (MEWT) (left) is based on aerodynamic principles first developed for applications in military and commercial aircraft (right).

The distinguishing feature of FloDesign's innovative, high-performance shrouded wind turbine is the use of a lobed, mixer-ejector shroud (Figure 1). Although new to wind power applications, this design innovation actually has a long heritage. Mixer-ejectors were first developed for applications in the aerospace industry in the 1970s and 1980s, as a means of increasing jet engine thrust performance and reducing engine noise (Figure 2). The concept of the mixer-ejector originated in the late 1960s, and the FDI aerospace engineers who cofounded FloDesign were awarded the first of several key patents covering the technology in 1983. Today, mixer-ejectors are in widespread use in military, commercial and private jet aircraft around the world.

In recent years, FDI has developed a series of new applications derived from the same core aerodynamic principles that led to these first commercial applications in jet propulsion. In the mid-2000s, FDI principals began to consider how to translate these principles into wind turbine designs to meet the growing need for clean, renewable energy, and founded FloDesign Wind Turbine in 2007.

The distinctive feature of FloDesign's mixer-ejector wind turbine (MEWT) is the incorporation of a system of two concentric shrouds surrounding the turbine face, comprising a lobed mixer shroud and a flanged ejector shroud. As explained more fully below, this system draws more air into the turbine face, raising energy output per unit of swept area beyond the limits that bind conventional turbines. Mixer-ejector shroud design continues to evolve as FloDesign seeks to optimize power production and total system economics (Figure 3).

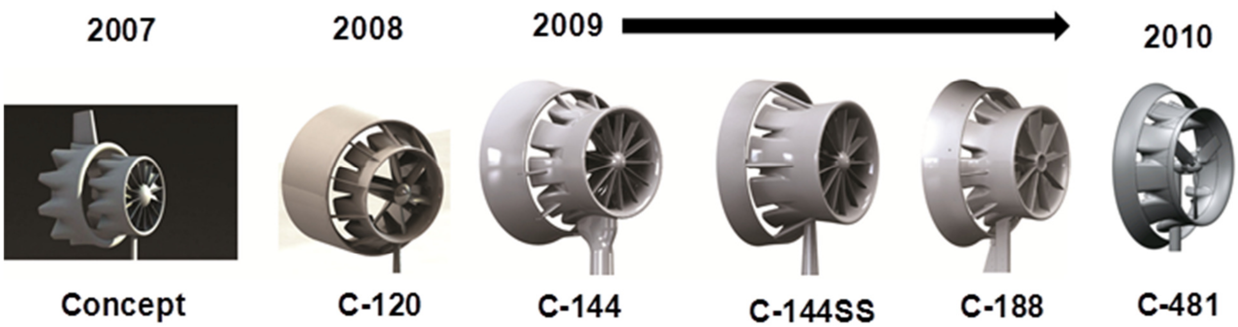
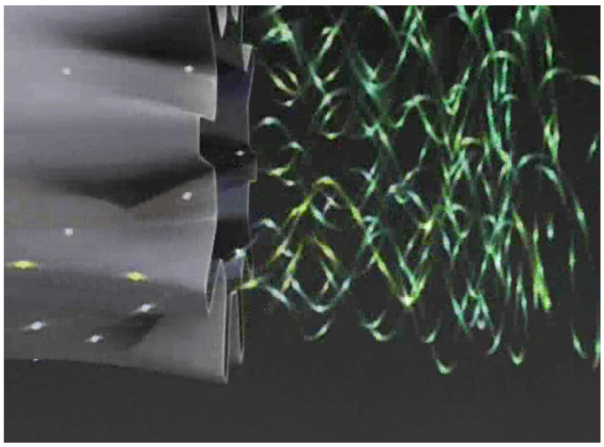
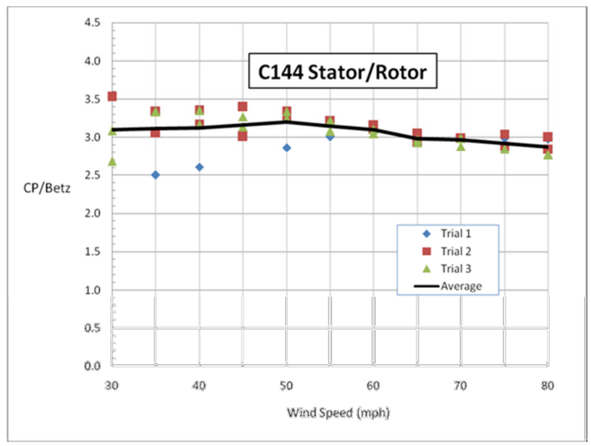


Figure 3. MEWT design continues to undergo rapid evolution.

<u>MEWT vs. HAWT technology comparison</u>. The chief value of the MEWT design is that it enables turbines to surpass the Betz Limit that constrains the performance of conventional, open propeller-type horizontal-axis wind turbines (HAWTs). This limitation, also known as Betz' Law, is named for the German physicist Albert Betz who concluded, in 1919, that no open-blade wind turbine can convert more than 16/27 (59.3%) of the kinetic energy of the wind into mechanical energy turning a rotor. This limit has nothing to do with inefficiencies in the generator, but is based instead on fluid dynamic analyses using conservation principles associated with the flow through an open bladed wind turbine. The potential energy in wind flowing into a conventional HAWT is a cube function of the wind speed, multiplied by the swept area of the turbine. Due to the Betz Limit, however, a minimum of 40.7% of this potential energy is unrecoverable. Moreover, in actual practice, modern turbines can recover only about 70-80% of the available net energy, or about 50% of the theoretical potential energy contained in the mass flow approaching the turbine face. The remaining energy is either used to keep the turbine spinning, or is diverted around the turbine and produces wake turbulence, rather than electricity.

The MEWT can exceed the performance limitation dictated by Betz' Law because its patented design alters the pattern of air flow through and around the turbine. A portion of the airflow approaching the turbine face is drawn into the gap region between the lobed mixer and the ejector shroud. Part of this flow passes through the lobes in the corrugated mixer, and flows behind the rotating turbine blades in a vortical, corkscrew-type pattern; the remainder is diffused away from the rear of the turbine. The effect of the rapid mixing of air flow directly behind the turbine is a reduction in back pressure on the turbine. As a result, more air is pulled through the turbine, boosting electrical output. A further important effect of this mixing is a rapid mitigation of wake turbulence in the region downwind from the turbine. As a result, it is possible to reduce the spacing between MEWTs without compromising their performance.





Figures 4-5. Vortical flow behind MEWT (left) results in rapid mitigation of wake turbulence; wind tunnel tests (right) indicate MEWTs consistently produce ≈3x the Betz limit.

<u>Performance advantages of MEWTs</u>. Wind tunnel tests have shown that MEWTs can achieve up to roughly 3x more output than HAWTs of equal blade radius across a wide range of wind speeds (Figure 5), an output gain that is expected to form the cornerstone of the value proposition for this new design. In addition, MEWTs are expected to offer several other performance advantages including: improved off-axis performance; reduced susceptibility to wind shear due to the shorter distance from top to bottom of the rotor; lower cut-in speeds due to their reduced weight and inertia; and higher cut-out speeds due to the reduced tip speeds of their significantly shorter turbine blades. Apart from the performance gains in the turbine itself, the closer spacing enabled by the reduced wake turbulence of MEWTs could translate into major gains in land use efficiency. For example, a targeted level of output could be achieved within a smaller physical footprint; the shorter height of MEWTs may also enable them to be sited in areas where taller conventional turbines cannot be placed because of setback requirements.

3. MEWT TECHNOLOGY: BASIS FOR ENVIRONMENTAL / AVIAN ADVANTAGES

FloDesign believes that MEWTs may offer important environmental and safety advantages compared to current technology. These advantages are less quantifiable and monetizable than the performance gains discussed above, but could help to ease siting objections to wind generation projects. In the absence of in-field experience at commercial scale, these benefits are asserted as working hypotheses rather than firm claims; they are based on extensive literature review, internal analysis, intuitive reasoning and expert interviews. Examples of these potential advantages include: reduced risk to avian species; lower and less noticeable noise levels; and a reduced radar signal. This paper's specific focus is on the hypothesis that MEWTs will be more bird-friendly than conventional open-blade turbines. This assertion rests on three inherent design features:

- <u>Size</u>. The rotor swept area of a MEWT, the region that poses a direct threat of striking and killing birds, will be approximately 70% smaller than that of a comparably-rated HAWT.
- <u>Shrouding</u>. The likelihood of accidental entry into this region will be greatly reduced or eliminated by the presence of a system of shrouds forming both a physical and a visual barrier. This shrouding will prevent birds from inadvertently entering this smaller kill-area from the sides, above or below. The more solid overall aspect of the turbine should deter direct frontal entry as well.
- <u>Height</u>. The overall height of MEWTs will be lower than HAWTs of equal hub height. Their smaller diameter will afford a degree of freedom to place turbine hubs at heights that captures optimal wind flows, while avoiding avian flight paths.

In addition to the reduced likelihood of direct collisions arising from these inherent design features, MEWTs promise reduced impacts that are indirect but important to bird populations. Because the lower wake turbulence of MEWTs will enable closer turbine spacing, this technology could enable new strategies to reduce overall habitat impacts. Wind farms comprising MEWTs could be configured as dense turbine arrays covering comparatively small areas, reducing the "energy sprawl" effects of wide turbine dispersion across the landscape and allowing more habitat areas to be preserved intact. While the effects of such groupings cannot be known in advance of a field demonstration, some published papers on avian-wind impacts surmise that denser turbine fields could present a visual barrier to birds that would deter entry.

In the course of expert interviews regarding its avian safety hypothesis, FloDesign has encountered two other avian safety concerns about MEWTs that would need to be evaluated in a commercial-scale field demonstration. These include the following:

- <u>Rotor speed</u>. Turbine blade speed is a critical factor in determining avian risks, and is a function of both blade length and rotational speed. Large, modern conventional turbines have slow rotational rates (typically below 20 rpm) compared to the MEWT which will operate at a top speed of 120-150 rpm. All other factors being equal, this difference in rotational speed would indicate that birds entering the rotor disk of a MEWT would be at greater risk. However, it is also important to note that the long blade lengths of conventional HAWTs (approaching or exceeding 50m with the largest models) implies blade tip speeds of nearly 200 mph, moving through a much larger rotor disk. By contrast, despite higher rotational speeds, the much shorter blade length of MEWTs in the 100kW class (expected to be 5.5m) implies comparable or even somewhat lower absolute blade tip speeds (reaching, at maximum, the range of 150-190 mph). Moreover, of course, MEWT blades moving at this speed will (a) sweep a much smaller area and (b) be shielded by the presence of a shrouded structure. Thus, the actual change in the probability that a bird will (a) enter a MEWT's rotor disk and (b) be struck by a rotating blade involves a complex balancing of probabilities. There is no empirical basis at present to evaluate the tradeoffs among these various probabilities. In the company's view, only a field demonstration can provide information to determine the net effects of these different turbine types and sizes on avian safety.

- Air flow into the "pump region." There is a non-negligible probability of birds flying through the "pump" region, or gap between the mixer and ejector shrouds. It is reasonable to expect that a bird entering this region would experience some degree of pressure drop. However, the bird would not be struck by turbine blades. It has been established that bats can experience barotrauma when passing through a turbine from a high-pressure to a low-pressure region. FloDesign believes that field testing will be required to evaluate the probability and physical effects of passage through this gap, both for birds and for bats.

4. A PROPOSED FRAMEWORK FOR TESTING FLODESIGN'S HYPOTHESIS

Over the past several months, FloDesign has consulted with a cross-section of avian safety experts and stakeholders including representatives of the wind industry, academic experts, state and federal government officials, and environmental NGOs. The company has sought to share and refine its thinking on avian safety issues, and to gain input on how to structure a robust and methodologically rigorous test of its thinking. As a result, FloDesign puts forth the following proposal for a collaborative research effort to gain real-world experience that would either validate or refute the hypotheses put forth above. The proposal is for a two-pronged effort entailing an avian safety validation project ("Project") accompanied by a rigorous scientific study ("Study"), as follows.

Avian Safety Project. The proposed Project would be undertaken at a site to be determined within the Altamont Pass Wind Resource Area ("APWRA" or "Altamont"). Several potential host sites have been identified in discussions with stakeholders, and FloDesign now seeks to advance this effort to definitive site selection through direct discussions with turbine field owners. The parameters of the test Project would be determined as follows:

- Qualified experts (e.g., members of the Altamont Scientific Review Committee or SRC) would be asked to identify a group of thirty existing turbines in the 100kW class within the host site that are objectively determined to be highly hazardous (e.g., in accordance with the SRC's Hazardous Rating Scale).
- These thirty turbines would be grouped into ten groups of three sets, matched as closely as possible on the basis of a small number of the most salient micro-siting characteristics deemed relevant by the study administrator (e.g., terrain features,

paired turbines, turbine position relative to a string, and other factors deemed relevant for purposes of this study).

- The Project would entail the replacement and repowering of ten of these conventional turbines with MEWTs (i.e., one out of each group of three similarly-situated turbines).
- The sample size of MEWTs to be studied will be constrained by limited turbine availability, at least in the near term. Given this reality, it will be necessary to avoid introducing too many potentially confounding variables into this study. For this reason, FloDesign proposes that control (conventional) turbine and replacement (MEWT) turbine sites should be selected to represent a reasonably narrow, yet typical, range of operating conditions.
- These new MEWTs would be constructed and installed by FloDesign, at the company's expense, as they become available over the first 12 months of product availability (currently anticipated before the end of CY 2012). As they are installed and commissioned, their electrical output may be sold onto the grid under the terms of existing power purchase agreements.
- The first experimental FloDesign turbines are expected to be available to support this project and study by the end of CY 2012, depending on the timeline for finalizing overall project and study design. FloDesign would expect to complete installation of all ten MEWTs by mid-2013.
- Final disposition of turbines is to be discussed. If the turbines prove successful at reducing avian mortality, they may be left in place with the host site owner, either by themselves or as part of a larger repowering project. However, if the new turbines cause an increase in, or do not cause a significant decrease in, bird mortality, FloDesign would agree to remove and relocate them, if authorized, at the company's own expense.

<u>Avian Safety Study</u>. The proposed Study would begin with the identification of thirty turbines found to score high on the SRC's Hazardous Rating Scale.

- Phase I of the Study, which can begin before actual construction, would entail the collection and evaluation of historical information regarding the thirty selected turbine sites at the host field. This phase of the study would provide a consistent and commonly-agreed baseline of information on the study sites to which future observations are to be compared.
- In Phase II of the Study, all thirty turbine sites would be monitored intensively through frequent (e.g., twice-weekly) visits at regular intervals by trained researchers, who would survey the area around each turbine in accordance with standard, agreed protocols.
- FloDesign proposes that Phase II would conclude one year after the commissioning of the tenth and final MEWT (i.e., if the final turbines are installed by July 2013, then the Phase II period would end as of July 2014).
- Following completion of Phase II, all monitoring data would be reviewed, evaluated and presented simultaneously to FloDesign, its host partner and other project participants.

- A third phase of the study period may be contemplated if circumstances warrant, for example, if the information derived from Phase II is inconclusive; supplemental funding sources for such an extended effort would need to be identified.

The parameters of the proposed Project and Study reflect a balancing of several considerations. Based on a review of criticisms of past avian safety monitoring projects, it appears that in order for results to be accepted as reliable, the study will need to be based upon (a) an appropriate site, (b) an adequate sample size of new turbines, (c) an adequate sample size of control turbines, (d) a monitoring period of appropriate duration, and (e) monitoring of appropriate frequency. With regard to these considerations, the company offers the following rationale:

- <u>Site selection</u>: FloDesign favors the Altamont region as the Project site because of the longstanding presence of avian safety concerns there; a study undertaken in an area without such issues simply would not yield useful information. The existence of an enormous amount of baseline information on wind-avian impacts in the Altamont region, FloDesign believes, should enable the overall study period to be reduced and avoid the incurrence of unnecessary costs. Moreover, the use of an existing site ensures adequate transmission infrastructure, presence of PPAs, and simplification of permitting issues.
- <u>Size of the project</u>: The proposed size of the Project (entailing installation of ten new MEWTs and close monitoring of a total of thirty turbines) is designed to be large and diverse enough to yield meaningful and statistically valid information, without being so large as to cause excessive project cost or delay in undertaking the entire effort.
- <u>Study duration and monitoring frequency</u>: In contrast to site selection and the number of turbine installations, other elements of the study proposal (specifically, study duration and monitoring frequency) may be varied readily and at moderate cost. FloDesign's intent in advancing this proposal is to avoid either prolonging the duration of the study period longer than necessary, or increasing its cost unduly. However, the company recognizes that the study must encompass an adequate number of turbine-years in order for its results to be accepted as reliable. To strike a balance among these considerations, it is also possible that the findings of Phase II of the study would be designated as provisional in nature, and subject to further confirmation in a subsequent "Phase III" monitoring period, whose duration and monitoring frequency would be subject to future determination.

Other issues such as study administration, governance and funding will require further clarification before the effort can get underway, and FloDesign intends to seek input from academic experts, government agencies and other stakeholders on these issues as the project moves toward greater definition. At a general level, the company is prepared to commit the funds required to construct a Project comprising up to ten MEWTs, and intends to retain ownership of these turbine assets. The company is also prepared to provide a contribution toward the Study of up to $250,000 over the life of the effort. FloDesign is well aware of the criticism that research efforts that are purely privately-funded are often perceived to lack independence and rigor. For this reason, the company is open to a joint funding arrangement for the Study, and would be prepared to join with other participants to pursue federal and state funding opportunities. In either case, FloDesign would expect the Study to be administered by an independent third party under the direction of a broadly representative board of advisors. While the company is fully prepared to cede control over the Study, it would insist on adequate protection of its own IP and competitively sensitive information, and recognizes that other issues (e.g., rights of access) must be negotiated with a host partner before site selection for the Project and Study can be finalized.

5. NEXT STEPS AND CONCLUSION

Over the next few months (i.e., through summer 2012), FloDesign plans to solicit input and reaction to this plan from a broad cross section of avian safety experts, and to enter discussions with potential hosts aimed at final site selection, so that the outlines for the proposed Project and Study may be finalized and plans made to install the first experimental MEWTs before the end of CY 2012.

Finally, in advancing this proposal, FloDesign does not seek to put undue emphasis on avian safety issues in the overall value proposition for MEWTs. This proposal if offered with full awareness of major recent improvements in reducing wind-avian impacts of conventional turbines through improved siting practices, and in the belief that conventional turbines offer an appropriate, safe and economically efficient solution for a large number of wind farm sites. Moreover, FloDesign concurs with other wind advocates that undue focus should not be placed on wind energy as a cause of bird mortality relative to factors that cause much greater aggregate losses such as collisions with buildings, windows and vehicles; housecats; habitat loss and degradation; and industrial air pollution. Nevertheless, whether justified or not, avian safety concerns have undeniably contributed to a negative perception of wind energy within some communities that threatens the nation's ability to achieve ambitious clean energy production targets. Ironically, by extending our dependence on other energy sources, this perception could lead to even greater levels of avian mortality, albeit through more indirect mechanisms (e.g., through air pollution or habitat loss and degradation). Moreover, many otherwise-prime sites for wind power development have been ruled out due to avian safety concerns, and other sites with real potential have simply never received consideration. Finally and specifically, there remain real and acute avian safety concerns at APWRA and a small number of other wind energy sites, chiefly those developed in the earliest era of the modern wind industry.

Meeting our nation's energy needs in an increasingly carbon- and supply-constrained environment is one of our society's most profound challenges. Across the political spectrum there is agreement on the urgent need to develop and commercialize new, scalable and economic sources of clean energy. Truly sustainable solutions must be based on reducing or eliminating problems such as avian collisions and habitat loss, rather than managing around such concerns, for example, either by forgoing development or explaining away avian impacts as unavoidable. This proposal is put forth in the interest of finding an objective and scientific way to test the avian impacts of one promising new technology to address this need. Objective validation of FloDesign's hypotheses regarding MEWTs could create a new solution to repower existing wind power sites in the near term. In the longer term, it could open up new opportunities to site clean, low-carbon wind generation in areas that would be considered off limits for conventional technologies.

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