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Performance Evaluation of Ceiling Fan Considering Bubble/ Dimple Shape Fan Blade

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Abstract - This study explores ceiling fan performance based on blade geometry, spinning speed, and the effect of the blade surface interacting with the airflow. In particular, this study describes the design-based assessment of Dimple Wing, which represents a surface modification that can be attached to compatible ceiling fan blades. The study analyzes CAD models and other materials describing the design of the proposed surface modification in order to establish a basis for future performance assessment of the Dimple Wing surface modification. The reference configuration described in the project involves three-blade ceiling fan having diameter equal to 1200 mm. An inspection of the available mesh produces a geometric characterization of the Dimple Wing attachment part. However, more details such as physical scale, exact parameters of the dimples, and their exact placement must be verified. Possible aerodynamic consequences of the Dimple Wing attachment are discussed, in particular with regard to boundary layer dynamics, flow separation, and pressure drag. However, in the absence of validated CFD modeling results and relevant experiments, this study makes no claim about any positive changes in the efficiency, power consumption, airflow or noise reduction. Comparison with an unmodified configuration may be used as a subject of future research.

Key Words **:** Ceiling fan, dimpled surface, Dimple Wing, blade modification, aerodynamic assessment, CAD.

1. INTRODUCTION

Ceiling fans are widely used for air movement inside the rooms because of their simplicity of construction, easy installation, and low electricity consumption during the operation. The functionality of these devices comes from the combination of many factors including the blade design, blade rotation speed, blade orientation, and the aerodynamic effect created by rotating blades and ambient air. In particular, during the operation, the blades transfer their momentum to air, creating air circulation in the room. Hence, the modification of blade shape and surface may influence airflow and affect the performance of the fan.

The classical blades of ceiling fans have smooth surfaces which were selected to facilitate the process of the air movement while keeping adequate values of power consumption, noise, and safety. However, the flow around the blade is not uniform. The local conditions depend on the radial distance from the rotation axis of the fan, blade shape and geometry, and operating conditions. Thus, the analysis of the modified blade surface becomes a complex design problem which should be supported by proper experiments and/or numerical computations.

The modification of the blade shape which was studied in fluid mechanics includes the creation of dimples. These local depressions may influence the flow field around the blade, boundary-layer behavior, pressure distribution, etc. Many investigations into this issue resulted in divergent conclusions about the effect of dimpled surfaces [1] – [3]. The simple existence of such depressions does not ensure the positive effect. Furthermore, the results of stationary experiments may not be extrapolated to the case of the rotating blade of a ceiling fan because of differences in geometry, flow conditions, and performance evaluation criteria.

This project analyzes the design of Dimple Wing – the surface modification that is to be installed on conventional ceiling-fan blades. The project documentation includes a reference fan, images of the dimpled attachment, and CAD / STL models. The project is focused on the documenting of available design, assessment of preliminary geometry, analysis of the relevant aerodynamics, and preparation of the basis for comparison of modified and conventional fan.

The performance evaluation criteria for future testing of the fan are suggested to include input electrical power, rotation speed, air velocity, airflow, and noise (if measurement devices are available). The direct comparison of fan performance requires the similar conditions of operation and consistent measurement techniques. The listed manufacturer data may provide useful information for reference only; it cannot be considered as a proof of performance of the specific configuration.

Currently, CFD and experimental data that may serve as the basis for performance evaluation are not included into project documentation. Hence, it is impossible to state the increase of airflow, reduction of input power, noise level, etc. due to the addition of the Dimple Wing. This paper contains design

evaluation and highlights the criteria which should be used for objective performance estimation.

The aims of the paper are the documentation of the available design, identification of the relevant aerodynamics and its limitations in this project, and presentation of methodology for performance evaluation of this fan configuration.

2. LITERATURE REVIEW

A. Aerodynamic Performance of Ceiling-Fan Blade

There are many parameters which govern the aerodynamics of a ceiling fan including blade shape, fan rotation speed, blade pitch angle, and distribution of air flow as a result. The blade shape of a ceiling fan influences the pressure difference on the surfaces of the blade and the momentum of the air surrounding the blade. Changes in the blade shape may affect the air flow, power consumed by the fan and the resulting flow field created by the fan.

Adeeb et al. [1] have studied the parametric design and optimization of ceiling fan blades with respect to their aerodynamic performance indicating the significance of the blade shape in evaluating the performance of fans. Also, Chen et al. [2] studied the indoor air motion generated by a ceiling fan using experiments and simulations highlighting the significance of the air flow distribution while evaluating the performance of a ceiling fan. In all, the above two references indicate that performance of a ceiling fan must be evaluated based on the blade properties and air flow field created as a result.

In the current study, the above discussion provides the background information required for the study of the aerodynamic effects of Dimple Wing attachment on a ceiling fan blade. It is not necessary that the conclusions drawn with respect to changes in blade shape will be applicable for this attachment. The aerodynamic implications of the attachment require its specific evaluation.

B. Boundary - Layer Behaviour And Flow Seperation

The motion of airstreams relative to a solid surface leads to the formation of a boundary layer through viscous forces. This involves a transition from a zero velocity right at the surface to the same value as the external flow. There is a relationship between the properties of the boundary layer and the nature of surface geometry, Reynolds number, and the pressure gradient on the surface [7]. Under an adverse pressure gradient, there may be a tendency for the boundary layer to shed momentum and become separated from the wall, thus affecting the nature of the flow and pressure distributions downstream.

Some surface geometry can affect the local flow in the vicinity of the surface. Such geometry can influence flow mixing, near-surface momentum transport, separation, wake formation, etc. The effect of these surface features is neither necessarily good nor bad: an alteration in surface can affect the local flow in such a way as to minimize one particular form of drag but increase another.

The problem with the rotating ceiling fan blade is that the flow situation over it is far more complicated than in the case of a static flat plate. The rotation of the blade means that the flow characteristics over it change depending on the radius and operation parameters. Hence, there is no way to predict the effects of the dimpled attachment based on surface alone.

C. Research On Dimpled Surfaces

Surfaces with dimples have been studied as a possible way to manipulate near-wall flow in order to decrease skin-friction drag in certain applications. Nevertheless, there is no proof in the literature that drag reduction can be achieved universally. Results depend on dimple geometry, placement, regime of flow, as well as on the methodology of measuring drag.

Gattere et al. [3] considered the state and future perspectives of drag reduction by means of dimples and discussed difficulties arising due to interpretation of results obtained for various setups. The authors suggest that care should be taken as the existence of dimples itself does not mean the aerodynamic advantage.

Van Nesselrooij et al. [4] have studied drag reduction by means of dimpled surfaces in turbulent boundary layer flows. Their results show that drag reduction can be achieved under certain experimental conditions. On the contrary, van Campenhout et al. [5] have found out that the drag depends on configuration and some configurations lead to drag increase. This contradiction shows why generalizations from one dimple setup to another may be misleading.

İlter et al. [6] experimentally studied the influence of dimpled plates in fully turbulent channel flow and obtained significant drag reduction for certain configurations. However, the setup used in the mentioned study differs significantly from ceiling fan application since it was channel-flow setup and its performance criteria are different from those of the ceiling fan blades. Therefore, the results obtained in it can be regarded as the proof neither of better air delivery nor of less power consumption and energy-efficiency.

Conclusively, these works form the base for further research in dimpled surfaces area; however, their main feature is the dependency of the effects on application. For Dimple Wing, the main question of interest is the reduction of drag on the ceiling-fan blade after dimple attachment.

D. Performance Evaluation Of Ceiling Fans

A thorough assessment of the performance of a ceiling fan modification requires the use of quantitative performance metrics along with a well-defined reference design. The air delivery or distribution of airflow may be used as a performance metric of the induced airflow by the fan, while the electrical input power may be used as a metric of the energy consumption during the operation. The rotational speed may also be measured since it may affect both the airflow and electrical power consumption. Measurements of the noise level may be performed using appropriate instrumentation, if available.

These metrics should be measured under controlled and comparable operating conditions. A comparison of the unmodified and modified designs should be done using the same fan, the same operating conditions, the same measurement locations, appropriate instrumentation, and multiple repetitions if possible. Uncertainties of the instrumentation and environmental conditions should be documented. Without such controls, any difference observed may result from the change of operating conditions, not the dimpled attachment itself.

The project documentation shows the presence of a DIGISMART Storm BLDC ceiling fan with the listed sweep of 1200 mm, 3 blades, power of 28 W, and the listed air delivery of 225 CMM. This is a manufacturer- or vendor-provided information and not an experimental data obtained in this project. It should not be used as baseline measured values or as proof that Dimple Wing affects fan performance.

As of now, there are no validated measurements of the electrical input power, rotational speed, airflow, and noise of the unmodified and modified configurations. Thus, quantitative performance claims cannot be made from the available data.

E. Research Gap

The current literature covers two fields, which are related to each other. These two fields are: (a) aerodynamic efficiency of ceiling-fan blades and (b) impact of dimples on flow around selected surfaces. However, the evidence of the two fields does not provide any verification for the efficiency of the attachable dimpled surface on a regular ceiling-fan blade.

In addition, there are certain limitations even in the project-specific evidence of the concept of Dimple Wing. It should be noted that though there is evidence in terms of CAD/STL files, photos, etc., there is no verification of such important features of this device as dimensions, size of the model, material of the model, the way of attachment, and geometry of dimples. There is no verified smooth model and CFD and experimental verification of aerodynamic properties of this concept yet.

Hence, it can be concluded that the research gap is the lack of documentation of the design-oriented assessment of this project. This article fills this research gap as it provides assessment of the currently known information about the project and explanation of aerodynamics behind the project.

As a result, the main contribution of the article is the provided design-oriented assessment and proposed framework for validation of the concept. It does not claim that Dimple Wing will reduce drag, improve air delivery rate, reduce power consumption of ceiling fan, or increase its efficiency.

3. DESIGN AND METHODOLOGY

A. Research Approach

For this research, the design-based approach methodology has been used to record and assess Dimple Wing, which is the attachable modification of the surface that can be integrated with regular ceiling fan blades. The methodology is focused on CAD models, STL models, project documentation, and photographs of the physical prototype and its mounted model.

The research is divided into four parts: analysis of the available design files, preliminary geometrical assessment, aerodynamic assessment based on the existing literature and the development of the framework for future performance assessment. Such structure allows the proposed modification to be recorded without the need to consider unproven design parameters and expected aerodynamic effects as proven results.

At this stage, no experimental comparisons or CFD analysis have been done yet. Thus, no invented experimental or simulation performance figures have been used in this methodology.

B. Reference Fan And Dimple Wing Configuration

The reference fan in the project documentation is the DIGISMART Storm BLDC ceiling fan. This particular ceiling fan has a nominal sweep of 1200 mm and three blades. The manufacturer's rated power of the fan is 28 W, and the air delivery rate is 225 CMM. All these specifications are provided by the manufacturer or supplier and are used only to identify the reference fan without any measurements.

The Dimple Wing is suggested as an additional surface component that would be mounted on a compatible fan blade and not as dimples cut into the blade itself. There are some project photos that show the fan, the dimpled component, and how the component is mounted on the blade. However, the exact mounting method, the material of the component, the number of mounted components, and the geometrical dimensions of the component were not yet confirmed.

Therefore, the main proof of the concept is the design files and photos.

Table - 1 : Reference Ceiling-Fan Specifications

PARAMETER	SPECIFICATION
Reference fan	DIGISMART Storm BLDC
Nominal sweep diameter	1200 mm
Number of blades	3
Rated electrical power	28 W
Listed air delivery	225 CMM
Listed noise level	57 dB

C. CAD and STL Model Assessment

The provided STL files serve as the digital models of the project geometry. A first inspection of the mesh provides some basic properties of the model, such as the number of faces and vertices of the mesh and the size of the model along its coordinate axes.

In the preliminary inspection, the mesh contains 39,692 faces and 19,842 vertices, as stated in the project appendix. The observed model extents are around 600.0, 122.2, and 16.8

model units along the three coordinate axes. However, the physical scale and the unit system of the model have not been checked yet. Therefore, these values should be considered as preliminary mesh descriptors rather than the confirmed physical dimensions.

Mesh statistics define the digital model but do not prove the dimensional accuracy, surface quality, manufacturability, and aerodynamic performance of the model by itself. Prior to using the model for manufacturing or quantitative flow analysis, verification of the physical scale, coordinate system, surface quality, and correspondence of the STL model and the prototype are necessary.

D. Preliminary Aerodynamic Assessment

Aerodynamics involves the theory of the development of boundary layer, flow disturbance due to the surface, flow separation, and formation of wake. These theories will enable us to understand the effect of dimpling on the flow pattern of the air around the rotating fan blades.

The effects of dimpling depend on the geometry, configuration, depth, spacing, position, and flow condition. With the above parameters, a dimpled surface will affect the momentum transfer and the pressure distribution near the wall. The direction and value of the performance change cannot be predicted using the given CAD models and images.

Therefore, in this study, we will use the published studies to give context to the idea, and not to predict any numerical improvement on Dimple Wing. Studies from stationary plates and turbulent channel flows are not considered as proof of performance improvement on the rotating ceiling-fan blade.

E. Proposed Comparative Performance Evaluation

The upcoming experimental study is to examine the standard unaltered fan in comparison with the exact same fan fitted with the Dimple Wing, in a controlled environment. Parameters such as electrical input power, fan's speed, and amount of airflow are expected to vary and need to be measured and quantified.

Proposed experimental procedure :

1. Identify and record the exact condition of the standard unaltered fan.
2. Obtain values for rotational speed, electrical input power, and airflow using proper instruments at specific measuring points.
3. Turn off the fan and make sure that it is completely safe before making alterations.
4. Make sure that the attachment is secured, clearances are correct, and balancing is achieved.
5. Re-test using the attachment and record the values under equivalent conditions.
6. Repeat if feasible; record the uncertainties, and then compare the results before coming to any conclusions.

All testing is to be done under safety standards required for electrical work, as well as working on rotating equipment. An attachment is not to be tested until proven to be securely attached, structurally sound, having clearance, and balanced.

If accurate measurements can be taken, the percent change can be calculated as :

$$\% \text{ Change} = \frac{X_{mod} - X_{base}}{X_{base}} \times 100$$

in which X_{mod} stands for the value of the parameter in question when the Dimple Wing is added to the fan, and X_{base} represents the same parameter value for the original fan. This formula can only be used when the baseline number is not equal to zero and both numbers describe the parameter under the same conditions. Negative change in power means, for example, less energy consumed, whereas positive change in airflow means more airflow.

F. Methodological Limitations

This evaluation is limited by the lack of proven physical dimensions, attachment requirements, a proven smooth reference model, performance data comparisons, and validated CFD data. Specifications provided by the manufacturer cannot be used in place of measurements taken in the test conditions of this project.

As such, this method defines an initial design evaluation and validation process. Quantitative findings on drag reduction, air flow, power usage, noise, and efficiency are not covered by the data that are presently available.

4. DESIGN AND MODEL ANALYSIS

A. Overview of the Dimple Wing Design

The Dimple Wing is a surface modification that can be attached to compatible conventional ceiling fan blades. The idea is to attach a dimpled surface by means of an additional part rather than etching the dimples directly onto the original ceiling fan blades.

Documentation available for the project includes STL files, CAD model views, pictures of the dimpled part, and pictures of the fan with the dimpled part attached. This provides initial visuals and geometries of the design. However, exact physical dimensions, type of material used, method of attaching the part, and the number of parts attached to the fan have not been completely confirmed.

Therefore, in the current analysis, the focus will be placed on geometry and design idea. There is no confirmation that this attachment will produce better air flow, reduced drag, or lower power consumption.

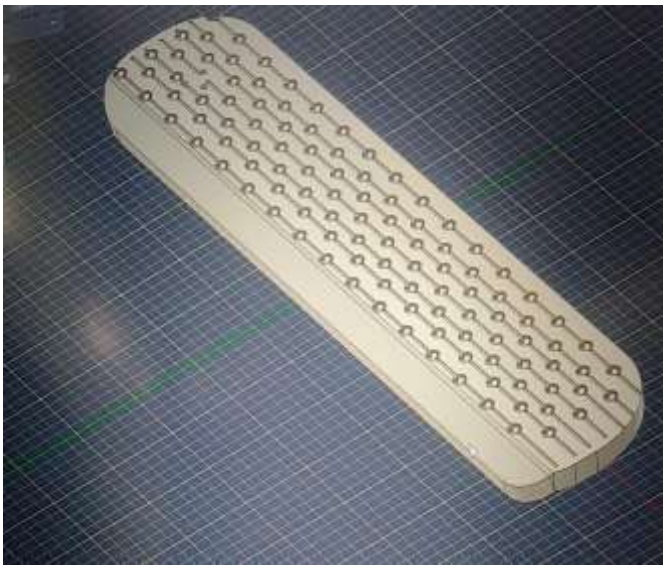


Figure - 1 : CAD Model of the Dimple Wing Attachment.

B. Reference Ceiling Fan

The reference fan used for the experiment is DIGISMART Storm BLDC ceiling fan. From the project data, the number of blades is three and the nominal sweep is 1200 mm.

These specifications define the reference part and should not be confused with the experimental findings of the Dimple Wing project. For instance, the nominal sweep is the diameter of the circle formed by the rotating blades, not the length of a blade.

The reference fan establishes the intended usage scenario for the attachment. Prior to the quantification of geometric differences, it is necessary to verify the provided model against the real fan blade.

C. Available CAD and STL Models

The project involves several STL files of the geometries associated with the fan. The STL file is a description of the surface using triangular facets and is typically used for geometry transfer and 3D printing. Unlike a parametric model native to the CAD software, an STL file may not retain all the features or parameters that were used to create the geometry.

Upon preliminary analysis of the mesh presented, a blade-like element with multiple dimple-like surface indentations was identified. The most recent thesis mentions the following geometric information :

Table - 2 : Preliminary Geometric Information Of The Supplied Stl Model

GEOMETRIC PARAMETER	PRELIMINARY VALUE	INTERPRETATION
File format	STL	Confirmed file format
X-axis extent	600.0 model units	Physical scale unverified
Y-axis extent	122.2 model units	Physical units unverified
Z-axis extent	16.8 model units	Physical units unverified
Triangular mesh faces	39,692	Mesh statistic
Mesh vertices	19,842	Mesh statistic
Dimple diameter and depth	Not established	Further measurement required
Dimple spacing and curvature	Not established	Further geometric analysis required

Bounds of the meshes are provided in model units, since there is no indication in the STL files on what unit system is supposed to be used. Although approximate values in millimeters are given in the thesis for some calculations, they cannot be considered actual physical values until the scale and orientation of the model have been established.



Figure - 2 : Triangular Surface Mesh Representation of the Supplied Dimple Wing STL Model.

In the same way, the number of faces and vertices in the mesh shows how complicated the digital model is and nothing more.

D. Surface Geometry and Dimple Characteristics

A distinctive feature of the Dimple Wing is the presence of several depressions on the component's surface. Such geometrical peculiarities may affect local flows, however, their effects depend on particular geometry and operating conditions.

Several parameters need to be defined from the model before performing any quantitative analysis :

1. Dimple diameter: a characteristic width of each depression on the component's surface.
2. Dimple depth: a depth relative to the surrounding surface.
3. Dimple spacing: the distance between adjacent dimples.
4. Dimple distribution: the distribution and density of dimples on the component.
5. Surface curvature: the local curvature of the blade and dimple profiles.
6. Component thickness: a verified thickness of the attachment and its variation along the geometry.
7. Attachment geometry: the geometry features for mounting the component on the blade.

Such parameters have not yet been verified using available project documentation. Therefore, numerical values should be provided only after extraction from STL/CAD models or measurements of the fabricated component.

It cannot be concluded whether the surface will increase or decrease aerodynamic resistance based on mere visualization of dimples. The geometry needs to be described to make a comparison with similar dimpled surfaces.

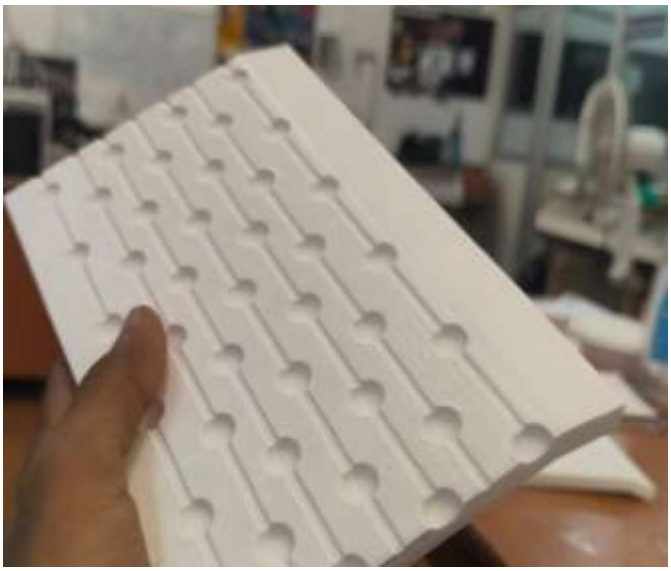


Figure - 3 : Close-Up View of the Dimpled Surface of the Dimple Wing Prototype.

E. Physical Prototype and Mounted Configuration

From the photographs attached with the project, one can see a physically constructed dimple wing component and its physically mounted structure on the ceiling fan. Therefore, it proves that the Dimple Wing is a design concept that exists physically rather than theoretically.

However, the material composition, exact measurements, fastening, mass, and rotation balance of the component cannot be defined from the images presented. From the documentation of the project, there is evidence of an intended or said manufacturing process of 3D printing of the component, but this has to be verified in order to state this as factual.

There is no confirmation of the way in which it is attached. Hence it will be inappropriate to mention it being attached through any specific mode such as glue-mounting, clip-fastened, screwed, etc., till the actual assembly is seen.

Preceding the powered testing, the assembly has to be tested for proper fastening, enough clearance, and balancing. This is a necessity because the attachment on the spinning blade experiences both the centrifugal and aerodynamic forces.



Figure - 4 : Fabricated Physical Prototype of the Dimple Wing Attachment.



Figure - 5 : Dimple Wing Mounted on the Reference Ceiling-Fan Blade.

F. Design Limitations and Further Geometric Verification

There are a number of shortcomings to the current design assessment. Firstly, there has not yet been confirmation of the scale of the stereolithography (STL) model. Secondly, there has been no confirmation of the shape of individual dimples and their spatial distribution. Thirdly, there has been insufficient information about the material used, the way of attaching the part, the mass of the component, and the configuration of the final assembly.

In addition, there are no validated reference smooth geometry models provided in files that could be used in order to directly compare geometries. The current project also does not have a completed CFD investigation or experimental dataset to estimate the influence of the attachment on the aerodynamics.

In light of this, the following measures should be taken before carrying out a performance evaluation :

1. Confirm the unit system, scale, and orientation of the STL model.
2. Compare digital geometry with the produced part.
3. Measure the size, spacing, and distribution of dimples.
4. Confirm the material, mass, way of attachment, and number of attachments attached.
5. Check for correct mounting, clearance, and balance.
6. Produce the geometrically comparable reference configuration for future investigations.

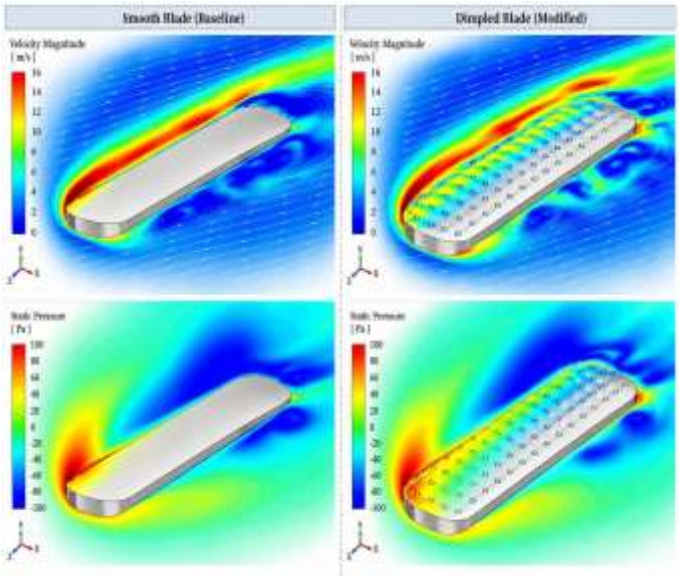


Figure - 6 : Comparative Velocity-Magnitude and Static-Pressure Contours for the Baseline and Dimpled Configurations.

G. Summary of the Design Assessment

Evidences from the current project show that a dimpled ceiling fan mount design exists, with its respective STL file geometry and pictures of the mounted fan setup. Inspection of the mesh also gives preliminary data regarding the range of the 3D model and its mesh size.

However, there are design features and aerodynamic performance benefits that need to be verified. The value of the present section will be to highlight the design details, identify the deficiencies of the current geometric data, and provide guidelines for further verification.

This geometric study will act as an introduction for future validation efforts, but it will not replace any measured or numerically validated data.

5. RESULTS AND DISCUSSION

A. Outcome of the Design Development

The current study reports on the development of Dimple Wing, an attachable dimple structure to suit compatible conventional ceiling fan blades. The available STL designs and photos show that a digital design and mounted design of the attachment have been achieved.

The result at the design stage is the provision of a starting point to assess the geometry of the attachment and possible implementation onto a ceiling fan. But the available data does not prove that the attachment would achieve any aerodynamic benefits. Hence, the current result can only be viewed as an initial design assessment.

B. Preliminary Geometric Assessment

The supplied STL geometry has been reviewed to determine the general shape of the component and to identify surface indentations indicative of dimples. According to the latest project documentation, there are about 39,692 mesh faces and 19,842 mesh vertices. The registered mesh extents are 600.0, 122.2, and 16.8 model units along the X, Y, and Z axes, respectively.

These findings provide a general description of the digital model available. However, it remains unclear what unit system and the physical scale are meant. There is no information about the size parameters of individual dimples, such as their diameter, depth, distance between dimples, and curvature.

In this way, the geometrical analysis is useful in identifying the information that is needed for further design improvements. Nonetheless, it is not enough to define the aerodynamics of the attachment.

C. Discussion of the Potential Aerodynamic Influence

Dimpled surfaces affect the local flow regime through changes in wall momentum transfer, pressure field, and flow separation. The results found in literature depend on the specifics of the surface geometry and the flow field. Although this information provides theoretical background for the evaluation of the performance of the Dimple Wing, it is insufficient to predict the performance of the specific attachment on the ceiling-fan blade.

A reaction of the blade to the attachment can be affected by the geometry, position, orientation, surface configuration, and the interaction with the surface beneath. Furthermore, an improvement in one of the drag components does not mean the increase in efficiency of the air delivery from the blade or the energy efficiency of the whole fan.

In this project, these aerodynamic effects are still potential results to be investigated. There are neither proven CFD results nor experimental data to support the prediction of the change in the performance.

D. Assessment of Available Performance Evidence

The reference fan used for this project can be described in the project documents as DIGISMART Storm BLDC ceiling fan, having a stated sweep diameter of 1200 mm, three blades, an electrical power of 28 W, and an air delivery of 225 CMM. These parameters are used to provide the context in relation to the application of the fan.

Nevertheless, these parameters cannot be considered measurements of the unmodified fan under the test conditions for this project. There is no dataset for the unmodified and the Dimple Wing designs of the fan.

The status of the main parameters is outlined below :

Table - 3 : Available Project Evidence And Validation Status

ASSESSMENT ITEM	CURRENT STATUS
CAD/STL design files	Available
Physical prototype	Photographic evidence available
Mounted configuration	Photographic evidence available
Verified attachment dimensions	Not established
Baseline electrical power	Not measured
Modified electrical power	Not measured
Baseline and modified airflow	Not measured
Comparative noise measurements	Not measured
Validated CFD results	Not available

This absence does not allow for the assessment of the influence of the attachment on the work of the fan quantitatively. It should be noted that the value of the rated power and the air delivery of the reference unit cannot be used for measuring this improvement.

E. Engineering Significance of Current Findings

The first engineering deliverable is the description of the design idea and the definition of the information necessary for its evaluation.

The first assessment shows that digital geometry is present for further analysis, while pictures of the project describe the attachment concept in physical terms.

Further development will require the following: the scale of the model, the geometry of the dimples, the material and mounting method of the attachment, and the baseline configuration.

This is important because proper aerodynamic evaluation depends on correct geometry and proper conditions of operation. Without these, it would not be possible to attribute any difference in performance to the dimpled surface modification.

F. Limitations of the Present Study

The results need to be considered taking into account the following limitations :

1. The scale and units of the given STL model have not been confirmed.
2. The exact dimensions and distribution of dimples have not been measured.
3. The characteristics of the attaching material, its weight, the attaching method, and the final installation are unknown and need to be confirmed.
4. A smooth reference model has not been confirmed.
5. Comparative experimental research has not been done.
6. No CFD analysis has been done.
7. It is impossible to make any conclusions about drag reduction, air delivery, power consumption, noise, or efficiency.

The above-mentioned limitations define the scope of the present study and determine the required evidence for further research.

G. Future Validation Requirements

Further research would begin with geometric validation of the STL model and the attachment device. The size and placement of the dimples would need to be determined, as well as the material, weight, stability, and balancing of the attachment device.

Once it is ensured that the system can be safely operated, a controlled comparison will be made between the unaltered fan and the fan with the Dimple Wing attachment. Measurable data to compare will include electrical input power, speed, and airflow.

If appropriate geometry and boundary conditions are found, computational fluid dynamics (CFD) could potentially be used as well. However, any numerical simulations performed would need to be validated by experimental data first.

H. Overall Discussion

These results provide the foundation for the design documentation and geometric analysis of the Dimple Wing. The provided models and photos help in recognizing the design concept, whereas the mesh analyses give only some information about the digital geometry that is available.

This research does not prove that the attachment improves the aerodynamic or energy performance of the wing. The importance of this work consists in documenting the concept,

setting up the limitations of the current data, and defining the actions to take in order to evaluate it systematically.

Thus, the Dimple Wing should be considered as a design concept, which needs to be verified geometrically and evaluated in terms of performance.

6. CONCLUSION AND FUTURE SCOPE

A. Conclusion

In this study, a preliminary design of Dimple Wing is presented along with a brief geometric evaluation of the attachment as a dimpled-surface modification suitable for conventional ceiling-fan blades.

In this analysis, the focus is placed on describing the design, evaluating the CAD and STL files, analyzing the physical prototype, and exploring the possible aerodynamic consequences associated with installation of a dimpled-surface on a rotating fan blade.

The preliminary evaluation sets the ground for further research as it is focused on design-related issues. Nonetheless, it should be noted that there are some uncertainties concerning scale and dimensions of the geometry, as well as details of the attachment and material. These aspects play an important role in determining whether the design is suitable for installation on a ceiling fan blade.

It has been shown that dimpled surfaces may affect the flow properties under certain conditions. Nonetheless, since the effects associated with the dimpled surfaces depend on geometry, flow regime, and operating parameters, results of studies on dimpled surfaces cannot be taken as an evidence of improved performance of ceiling fans.

Unfortunately, no validated CFD simulations and no experimental measurements have been conducted. As a result, the effect of Dimple Wing on airflow delivery, electric power consumption, rotational speed, noise, and efficiency remains unknown.

B. Contributions of the Study

Conclusions and Contributions of the Study

The main contributions made by this study are enumerated below :

1. **Design documentations :** Creation of a design documentation for the proposed Dimple Wing concept as an add-on that will give the blades of the ceiling fan a surface of dimples.

2. **Preliminary geometrical assessment :** Examination of the available models and establishment of the need for verifying their geometric details.

3. **Aerodynamic assessment through literature :** Discussion of the possible influence of a dimpled surface on the air flow pattern, being careful not to generalize from the other studies.

4. **Establishing validation requirement :** Discussion of the requirements for validation of any claims made regarding the efficiency of the modification in question.

5. **Base for future work :** Formation of a foundation for future improvements, safety evaluations, and tests.

C. Limitations of the Study

The present study has several limitations. First, the physical dimensions and unit scale of the available STL geometry have not been conclusively verified. Second, complete information regarding the attachment mechanism, material, and detailed dimple geometry is unavailable. Third, the study does not include measured baseline and modified fan performance under controlled operating conditions. Finally, no validated CFD analysis has been completed.

These limitations prevent quantitative conclusions regarding aerodynamic improvement, energy savings, airflow enhancement, or noise reduction. The findings are therefore restricted to design documentation, preliminary geometric inspection, and a discussion of potential aerodynamic effects based on existing literature.

D. Future Scope

Further research should begin with verification of the scale, dimensions, geometry of dimples, properties of materials used, and attachment configuration of the digital model. Then a proper assessment of structural strength, balancing, and attachment integrity needs to be performed before using the design for a rotating ceiling fan. Any physical tests should follow the laboratory safety guidelines.

The next step would be carrying out an experiment comparing the performance of the same fan without and with Dimple Wing modification. Applicable measurements would be of the power consumption, revolutions per minute (RPM), air flow and delivery performance. Noise measurements may be conducted as well, if possible. A certain number of repetitions should be used to increase the validity of results obtained.

If the geometry, operating conditions and boundary conditions are successfully established, computational fluid dynamics can be applied in further investigations. The numerical calculations can be compared to actual measurements whenever possible. Various configurations for different sizes and shapes of dimples and surface patterns should be analyzed to see if there is a significant difference in performance for any particular arrangement.

Finally, more research is needed to check if Dingle Wing can bring some advantages to the ceiling fan.

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