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Design and Analysis of Cutting Blade for Rotary Lawn Mowers

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***Abstract*- Lawn mowers are machines used to level grass in lawns for maintaining the aesthetic beauty and for recreational purposes. The design of various parts of a rotary lawn mower has been covered in a previous journal entitled "Design and Analysis of Rotary Lawn Mower", but the cutting blade being one of the most important part of the rotary lawn mower hasn't been covered in it. Here we are trying to design a cutting blade for the same mower design mentioned earlier. The existing blade designs were studied and analyzed. Improvements were made for the existing design, FLUENT and Static Structural analysis were carried out with the help of ANSYS Workbench in order to develop a new design.**

Keywords- Rotary Lawn Mower, Cutting Blade Design, CFD, Static Structural Analysis, Mower Blade

I. INTRODUCTION

Reel Mowers and Rotary Lawn Mowers are two types of mowers used for mowing grass. But researches has showed that the rotary lawn mowers are more effective than the reel mowers because of its clean mowing and provision for collecting grass. The most important part of the rotary mower is the cutting blade and cutter deck housing. The speed of cutting blade, angle and sail are some of the factors influencing the quality of cut.

The design of a rotary lawn mower has been told in the journal "Design and Analysis of Rotary Lawn Mower" by various authors[1]. The design of elements like bevel gear, v belt drive, ball bearing, mower frame and wheel mount has been done in the aforementioned. A cost effective design was achieved with a simple mechanism for height adjustment and grass collection. The design of the cutting blade for such a lawn mower was not covered in it.

According to Basil Okafor[2], For smooth grass cutting, a motor power of not less than 628.3W (0.84hp) having a rotational speed of 2,000-3,000 rev/min and producing a shear force of about 10.5 N is recommended.

Studies by O'Dogherty[3] have shown that blades used in forage chopping should have a blade cutting angle in the range 30 - 40°. The ideal radius of the cutting edge is about 0.05 mm. A rotary mower has shown minimum power requirements at blade angles between 25° and 30°. Studies indicated that a high impact velocity is required, in both laboratory experiments on single stems and field experiments on mowers. Typical speeds employed by disc and rotary mowers are in the range of 71 - 84 m/s.

According to Anonymous[4], Cutting clip is the most important factor deciding the cutting action of the rotary lawn mower. Cutting clip is defined as the forward distance travelled by the cutting unit during one revolution of the blade. This distance is divided by the number of blade tips to arrive at the clip dimension. Although the blade cutting edge may be 3"-4" long the very tip is the primary contact point with the grass blades on each pass. The remaining portion of the cutting edge will tend to cut off the stragglers from the previous blade pass. The blade tips are normally lower than the rest of the blade to avoid any drag on the turf absorbing rotating horsepower and damaging the grass.

II. DESIGN OF CUTTING BLADE

In order to design an effective cutting blade. We decided to analyze an already existing simple design of cutting blade using ANSYS Workbench 14. The length of the cutting blade was taken as 20inch (508mm) and width 2inch (50mm). A 30^0 cutting angle was taken as recommended by O'Dogherty[2]. The speed of rotation was taken as 3000rpm as recommended by Basil Okafor[1], which produces and angular velocity of 80m/s for a blade of 20inches length. A sail portion is important for the cutting blade inorder to channel the grass after cutting to the upper stream of air for proper collection of grass. So there has to be minimum turbulence inside the cutter deck. Also the

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parameters like downforce and drag must be considered to decrease the load on engine and thus increasing efficiency.

A. Blade in Test Domain – FLUENT Analysis

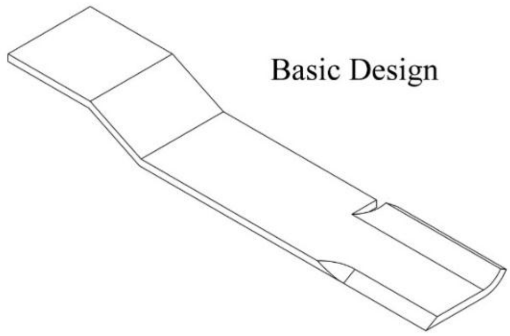

Fig 1: Basic blade design

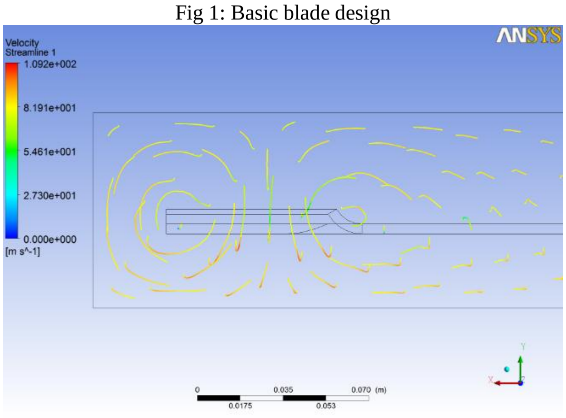

Fig 2: Basic blade vortex

In order to study the aerodynamics of the blade, a fluid domain of 30x50x100mm was created for test purpose. The stream of air on the trailing edge of the blade causes a rotating effect so called the vortex effect. This increases the turbulence on the rear side of the blade which in turn reduces the effectiveness of transferring the grass to the discharge window of the lawn mower. In order to prevent the grass from scattering away and to increase the efficiency of grass transfer into the collecting bag, turbulence has to be reduced. Several designs were put forward by us to reduce this, of which two were found to be most effective. They are show below.

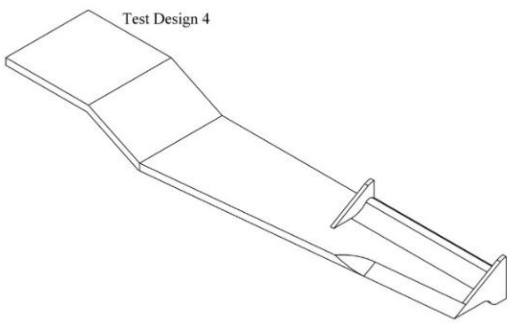

Fig 3: Blade D4

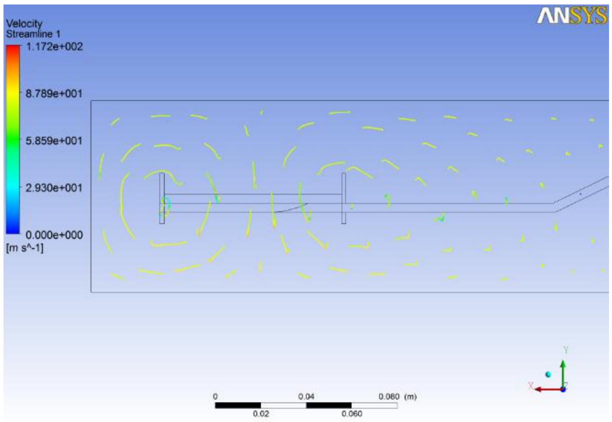

Fig 4: Blade D4 vortex

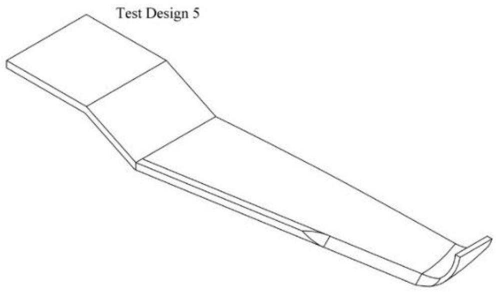

Fig 5: Blade D5

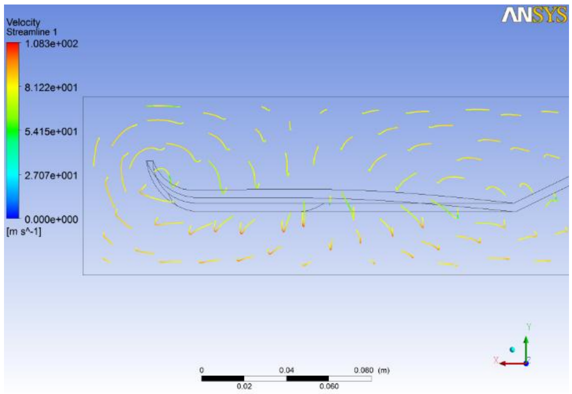

Fig 6: Blade D5 vortex

Test design 4 was preceded by several other designs which went through the analysis in ANSYS. Test design 4 was the one which gave us satisfactory results. The tapered profile was given to reduce the downforce on the blade, since the area of the wing is directly proportional to the downforce produced. For a blade of this profile it is almost impossible to reduce the vortex effect induced on the trailing edge completely, just like the standard design of wings for all airliners produces a vortex effect. We can only decrease this effect by design changes. One of the design considerations to reduce the vortex effect is the use of winglets. The triangular shaped member at the tip of Test design 4 and the bend tip of Test design 5 are types of winglet. The vortex formed nearer to the trailing edge of the blade has greater effect on the aerodynamics than the one

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farther from it. So in order to displace the vortex effect away from the blade, usage of winglets is an effective way. Data from ANSYS Fluent analysis, showed a 23% reduction in drag force in a blade using the triangular winglet at the tip compared to the one without the winglet. The downforce also decreased by an amount of 65%. In Test design 4 two winglets were used which helped in streamlining the flow, which was necessary for grass collection. Though it did not have much effect in drag and downforce compared to the design using a single winglet. In Test design 5, we focused on separating the vortices so as to decrease its effect in the cutting edge of the blade. The sail portion was widened and a curved winglet was provided at the tip to reduce the vortex effect. But in order to find the effects it produced inside the cutter deck. The fluid domain was changed according to the actual dimensions of the cutter deck that we have designed.

B. Blade in Actual Domain – FLUENT Analysis

The cutter deck analysis of both the blades were done. Test design 5, due to its increased sail width pushed most of the air to the upper stream which increased the downforce giving us a value of 0.262N on one half of the balde. It also increased the turbulence inside the cutter deck by spreading the air stream to a wider area which resulted in less efficient transfer of air through the discharge window. The drag force generated in this case was 9.298N. Test design 4 on the other hand produced satisfactory results. The flow was almost streamlined with most of the air stream channeling through the discharge window properly. Also there was significant decrease in drag and downforce. The drag force decreased by 28% giving a value of 6.638N and the downforce decreased by 56% giving a value of 0.113N compared to Test design 5.

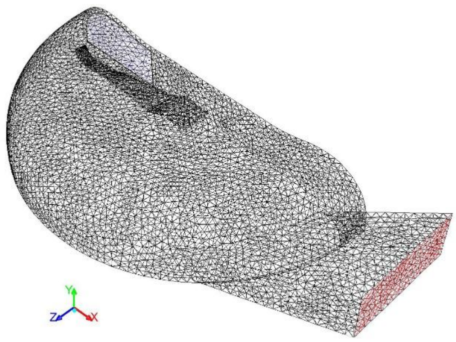

Fig 7: Blade D5 MESH

The above image shows the meshed domain of the cutter deck with blade design 5 setup. Fine meshing was used for the whole setup using ANSYS Workbench 14. Element sizing were set to the default values. Total nodes formed is 16940 and elements 84700. The blue face portion on the left-top end is the inlet and the red face portion on the bottom-right end is the outlet. The inlet velocity was set to 80m/s.

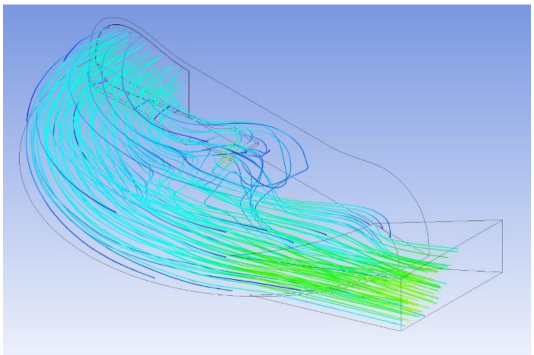

Fig 7: Blade D5 flow

The above image shows the velocity streamline of the blade design 5 inside the cutter deck, showing a lot of undesirable turbulence as mentioned before.

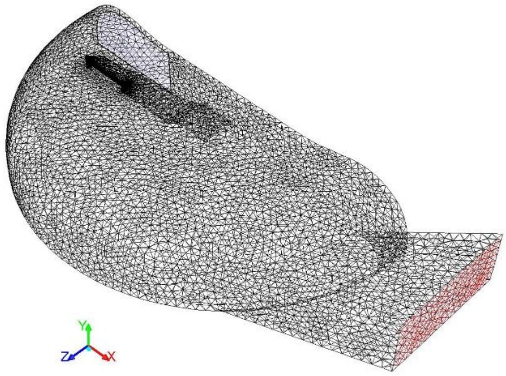

Fig 8: Blade D4 MESH

The above image shows the meshed domain of the cutter deck with blade 4 setup. As in the former case, fine meshing was used for the whole setup using ANSYS Workbench 14. Element sizing were set to the default values. Total nodes formed is 26571 and elements 136154. The inlet velocity was set to 80m/s.

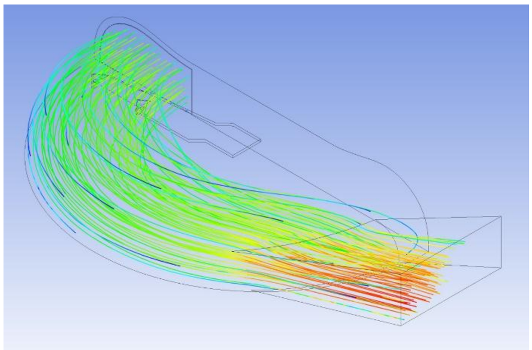

Fig 9: Blade D4 flow

The above image shows the velocity streamline of the blade design 4 inside the cutter deck. Here there is minimum turbulence inside the cutter deck and almost all the air from the inlet is channeled to the outlet. Also velocity of flow increases towards the outlet due to decreased pressure. So we can say the results obtained from this design is satisfactory.

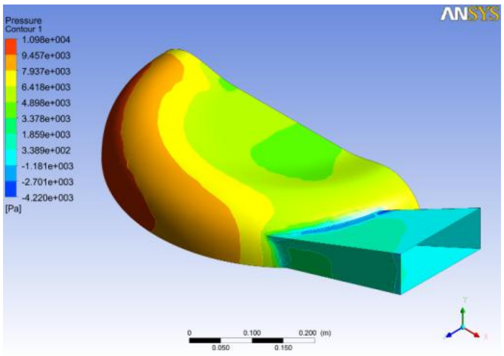

Fig 10: Blade D4 pressure contour (view1)

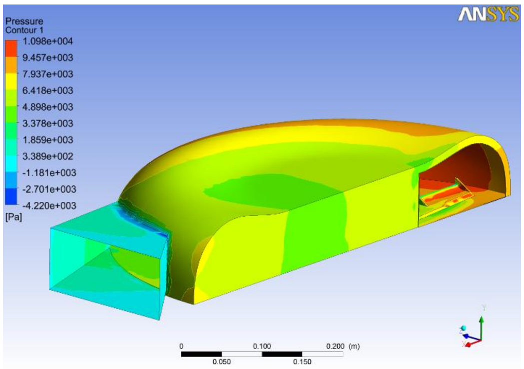

Fig 11: Blade D4 pressure contour (view2)

The above figures shows the pressure distribution of the cutter deck as a result of flow through it. The red color on the front portion indicates the increased pressure when the blade is 90^0 position. The pressure decreases as the flow nears the outlet. Also note the increased pressure on the top surface of the blade shown by the red contours and the light green color below it, which indicates that the blade tends to deflect downwards.

C. Blade D4 - Static Structural Analysis

Due to the forces acting on the blade while rotating. The blade has to be analyzed statically for various stresses created on it as a result of drag and downforce. Static structural analysis was carried out on this blade design in ANSYS Workbench 14. The drag and downforces were taken as pressure forces, in which drag will be acting on the Y-Z planes and downforce on X-Z planes. The pressure force was calculated by dividing the forces obtained from Fluent analysis with the combined area of surfaces on the blade in which these forces are acting.

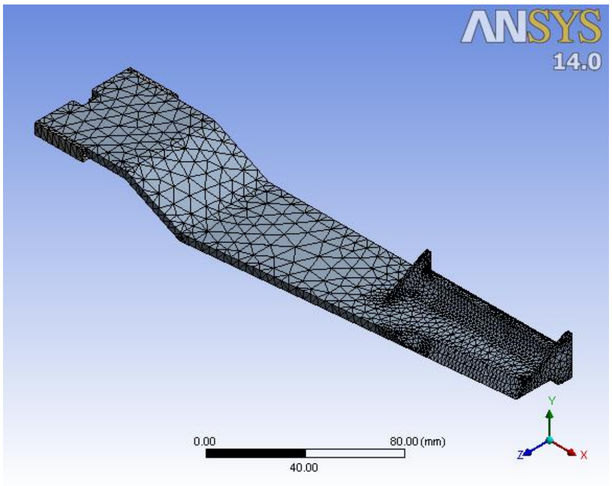

Fig 12: Blade D4 MESH

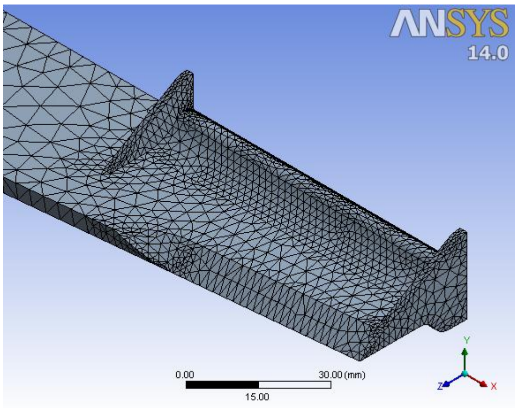

Fig 13: Blade D4 MESH (enlarged)

The above images shows the mesh generated in Static structural analysis of ANSYS Workbench 14. The blade was fine meshed with refinement provided to the cutting edge and sail portions for accurate results. Total number of nodes formed is 18241 and elements 9124. The mount bracket which is used to mount the blade on the shaft can also be seen here. An 8mm bolt will be used to mount the blade to the shaft, so the bracket was considered as the fixed support. The results after the analysis are shown below.

Table 1: Cutting Blade Static Analysis

Parameter	Value
Maximum Deflection	0.680mm
Maximum Normal Stress	39.076MPa
Maximum Principal Stress	95.050MPa
Maximum Shear Stress	38.292MPa
Maximum Principal Strain	$3.833*10^{-4}$
Maximum Strain Energy	38.08J

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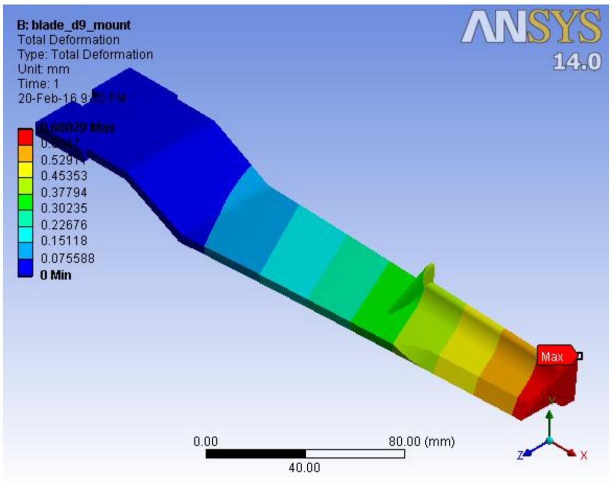

Fig 14: Blade D4 deflection

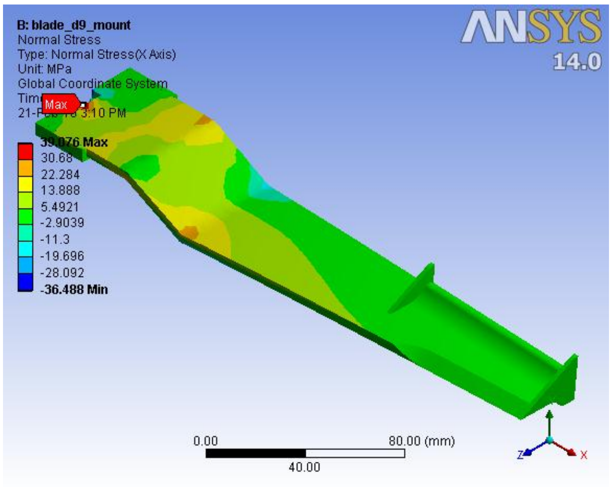

Fig 15: Blade D4 N-Stress

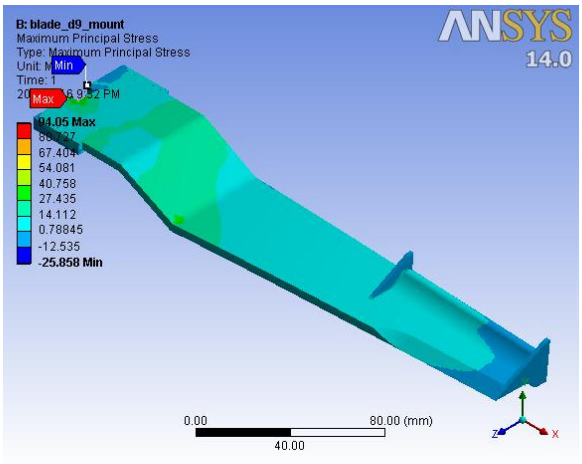

Fig 16: Blade D4 P-Stress

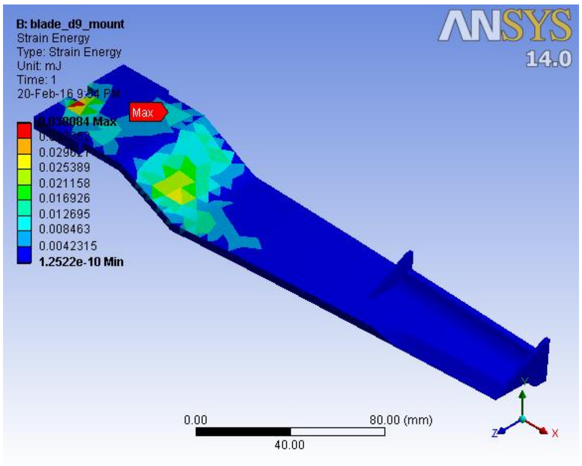

Fig 17: Blade D4 S-Energy

Fig.14 shows the deflection of the blade as a combined effect of the forces acting on it. The deflection is more towards the tip portion reading 0.6802mm. Fig.15 shows the Normal stress distribution, the maximum value of normal stress was 39.076MPa located near the shaft mount portion. Fig.16 shows the Principal stress distribution with a maximum reading of 95.05MPa located at the same position of maximum Normal stress. Both of which is less than the yield strength of Structural Steel which is 250MPa, so we can say the design is safe. Fig.17 represents Strain energy distribution with a maximum value of 38.08J located a few distance away from the mount on the bottom surface of the blade.

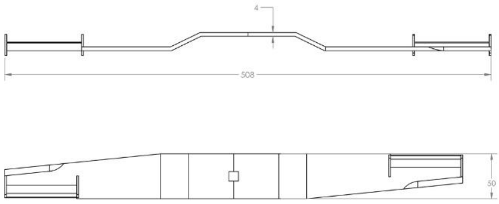

Fig 18: Blade D4, Sketch

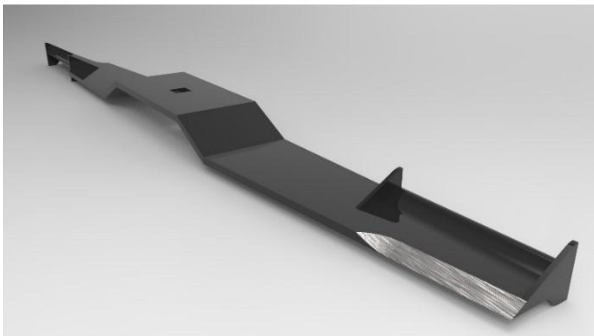

Fig 19: Blade D4, 3D Rendered

III. FINAL ASSEMBLY

Fig 20: Blade D4 in cutter deck

Fig 21: Front view of mower

Fig 22: Isometric view of mower

IV. CONCLUSION

An effective design of cutting blade for rotary lawn mower has been achieved. FLUENT analysis of the existing basic blade design produced a lot of undesirable turbulence resulting in poor channeling of grass to the collecting bag. These limitations was eliminated to a great extend in our final design. Design of the blade was perfected through fluent analysis which showed satisfactory results. The blade was also found to be safe under various forces acting on it while rotating. The design shows potential for improvement by research and testing.

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