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Main Rotor Blade Air Flow Characteristics & Behaviour of a Remote Controlled Sub-scale Helicopter: A Case Study

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Abstract

The airflow through the main rotor blade system of a helicopter is still not exceedingly well understood owing to its obscurity in aerodynamics. It is prognosticated that helicopter wakes can be significantly greater than those formed by a fixed wing aircraft of the same weight. Nuisance incidents such as brownout & noises are engendered from rotor wake. Study through flow visualization plays a key role in understanding the airflow distinctiveness and vortex interaction of a helicopter rotor blade. Inspecting and scrutinizing the effects of wake vortices during operation is a great challenge and imperative in designing effective rotor system. This study aimed at finding a suitable method to visualize the main rotor airflow pattern of a remote controlled subscale helicopter and seek for the vortex flow at the blade tip. The experimental qualitative data is correlated with quantitative data to perform meticulous study on the airflow behaviour & characteristics along with its distinctiveness generated by the main rotor in various flight conditions. Simulation is also performed in similar conditions to bequeath with comparability between the flow visualization results. Several dissimilar flow patterns were identified throughout the blade span. At the centre of the main rotor hub, the presence of turbulent flow was perceived. This is because of the low energy of air pooled in this region. Conversely, an apparent straight streamline pattern in the middle portion of the rotor blade was noticed as the air in this section encompassed high kinetic energy.

Keywords: Main rotor blade; Hover; Rotor wake; Induced velocity; Dynamic pressure.

1. Introduction

Man's reverie to fly commenced with the work of Leonardo da Vinci and took off through the work of the Wright brothers. Since then throughout the century, the aviation industry burgeoned with new designs, superior ideas and ground-breaking materials. Structural strength is a vital element in designing sustainable and burly aircrafts. With the significance of unambiguous materials, from wood to advanced aluminium, steel and composites, dexterous design plays a key role in performance as well. In the field of aeronautics the significance of an airfoil cannot be illustrated using vocabulary. Reduced drag, increased lift and a smooth flight with better control and manoeuvrability can be achieved with a smart and efficient airfoil design according to the precise criteria.

Consequently, a comprehensive knowledge of airfoil flow field plays a key role in achieving better performance. For helicopter performance and behaviour, an adept airfoil design is vital as well. According to Bangalore and Sankar (1996), rotorcraft airfoil sections, designed by Dadone (1976), Noonan (1980) and others achieved high maximum lift coefficient (C_{1max}) and low zero lift drag coefficient (C_{do}).

A pure helicopter is an aircraft that uses rotating wing, which provides lift, propulsion and control forces that enables it to hover relative to the ground without forward flight. Aerodynamic forces are generated by the relative motion of a wing's surface with respect to the air. The helicopter has the ability to take-off and land vertically. Moreover, the helicopter has the ability to climb, fly forward, cruise at a speed, descend and hover. In most cases, the rotor system of a helicopter is categorized as fully articulated, semi-rigid and rigid (*Rotorcraft Flying Hand Book*, 2000). Rotorcraft optimization is basically the design process of the main rotor system. It necessitates amalgamation of several disciplines which includes aerodynamics, dynamics, structures, and acoustics. When handling qualities are considered into the design, broader integration may perhaps be required (Celi, 1999), (Guglieri, 2012).

Aerodynamics plays a vital role in understanding the helicopter behaviour with respect to the airflow. On the contrary, the aerodynamics of helicopter is greatly concealed. Decoding the airflow around a helicopter is a challenge because of the aerodynamic ambience is very much diverse unlike the flow environment around an airplane's wing. Performing wind tunnel tests on small-scaled prototype is one of the most pertinent looms to obtain the aerodynamic characteristics of a helicopter. Though it requires quite a great investment of time, money and resources; still it is the most apt means to visualize the airflow. This study looks into the air flow behaviour of a controllable helicopter where various flow patterns acquired through visualization process are briefly described.

2. Methodology

This study opted for the smoke flow visualization technique to envisage the air flow pattern over the main rotor blade system of Hirobo-Falcon 505, a remote-controlled subscale helicopter. Table 1 portrays some of the imperative stricture of the main rotor blade. The rotor radius for the main rotor blade of the Hirobo-Falcon 505 helicopter is 0.670m with a chord length of 0.05m which uses NACA0014 airfoil. Based on a conceptual design, Figure 1 lays bare the final assembly prior to experimentation. An electric motor is fixed on the test rig where the helicopter is then mounted on it. A drive shaft gets connected to the gear system of the main rotor head, establishing connection with the motor which is powered by the central battery of RotorWay Exec 162F helicopter. In order to visualize the air flow of the rotor blades, Aerotech smoke generator is used for providing white smoke. An indispensable point to be noticed here is that the background is painted in black color; the underlying principle behind doing this is to provide better flow visualization. The disparity between the colors of white smoke and black background would irrefutably offer better sight of the air flow-field. Design software named SolidWorks-2012 is used to carry out simulation in corresponding circumstances for result comparison.

Table 1: Main rotor-head specifications of Hirobo-Falcon 505 controllable helicopter

Rotor System :	Rigid with stabilizing bar
Number of Blades :	2
Rotor Radius:	0.670m
Airfoil Section:	NACA0014
Chord Length:	0.05m

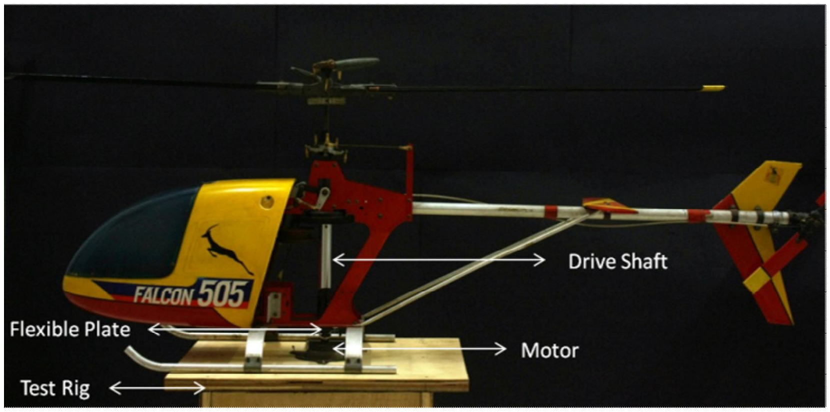

Figure 1: Final assembly prior to experimentation.

3. Result and discussion

3.1 Pressure distribution along the blade span

As the helicopter operated at 450 rpm, the pressure distribution along the blade span was appraised using a measuring probe which moved parallel along the blade span. Pressure distribution data was taken at a distance of 0.15m below the rotor plane. At different blade pitch angles, the probe measured the dynamic pressure along the blade span. Using the obtained data, the graph of Cp versus Rotor Radius was plotted; which is demonstrated in Figure 2. From the graph of Cp versus Rotor Radius, it can be noticed that at about 50 percent of the blade span there is a sudden boost in the dynamic pressure; the main patron to this effect is the stabilizer bar of the rotor system. The stabilizer bar operates as the control surface of the helicopter which consists of an airfoil strip at each end. These airfoil strips unswervingly engenders downward airflow followed by the increment in dynamic pressure during hover. Consequent to this hasty rise of pressure, the lingering fraction of the blades demonstrate an invariable pressure gradient. In this situation, the slope ascended doggedly round about 85 percent of the blade span with impulsive staged alteration afterwards. The graph personifies the jagged pressure reduction to negative values approximately from 550mm to 680mm of the rotor radius, which however has repulsive correspondence with slower airflow. Subsequently, the average values of the dynamic pressure data at different pitch angles (α) throughout the blade span is then used to calculate pressure coefficient C_p. Figure 3 exhibits the graph of C_p versus α. This graph assists in determining the maximum pressure coefficient (C_p), the pitch angle which generates the maximum lift and the stall angle. From the graph, it is prominent that the maximum C_p occurs at around 11 degrees of pitch angle where the stall angle is apparently round about 12 degrees for the main rotor pitch.

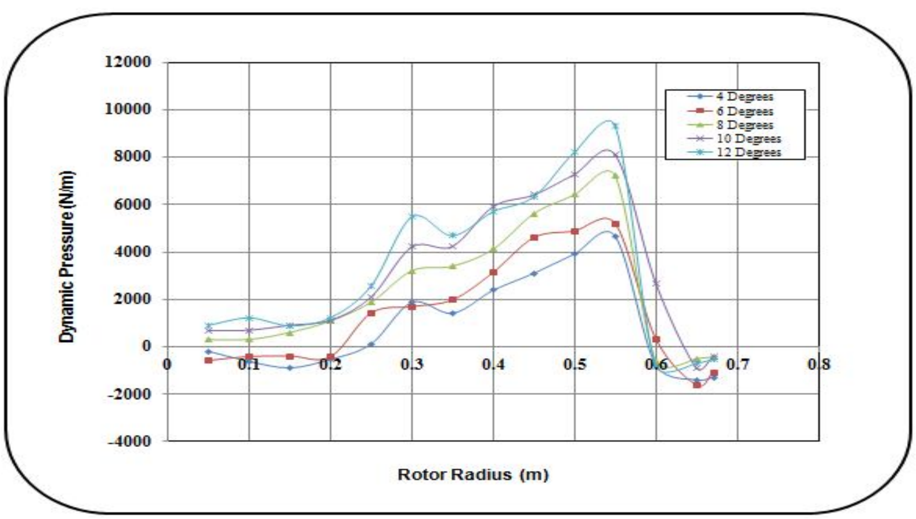

Figure 2: Graph of Cp vs. Rotor Radius.

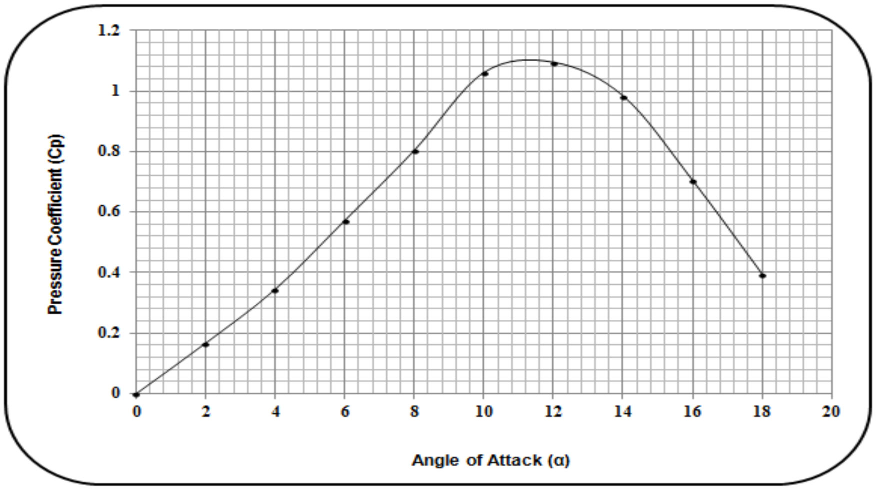

Figure 3: Graph of Pressure Coefficient, C_p vs. Pitch angle, α (^{o}).

3.2 Flow visualization at different blade sections during flight condition

Using the smoke flow visualization technique, Figure 4 (a) exhibits the embodied image of airflow pattern for the main rotor blade in hovering provision. As the smoke was released from outer part just above the blade tip, it gradually moved inward in the form of a curved line. The airflow passed through the rotor plane at ¾ of the rotor radius as the smoke followed the streamline. Slip stream or otherwise known as 'far wake' is produced as the airflow rambled down the rotor. The smoke stream appeared to be moving away from the blade as the blade angle was pitched at about 10 degrees. As the smoke moved inward where it was released just about on the middle segment of the blade span; from Figure 4(b) it is understood that the airflow emerged to be more straighten whilst passing through the main rotor blades. The middle part of the blade plays an imperative role in enabling a helicopter to execute its functions as it generates effective lift and thrust. In this section, the airflow is uninterrupted, as it's has adequate detachment from the blade tip. The blade tip is the vortex subjugated area. As fundamental rule, it is known that for a wing if there is high velocity present at one side and low on the other, the low velocity side will have higher pressure compared to another.

Around the rotor hub, the airflow was figuratively in serene state at the root of the blade. From Figure 4(c), it can be perceived that the smoke is released directly on top of the rotor hub. As the smoke moved through the rotor disc, the flow arched outward. The flow held in reserve its outward curvature pattern furthermore as it passed the helicopter before becoming straight. At about ¼ of the blade radius, low velocity air inhabits in the region just below the rotor hub. Here, as this air does not possess high kinetic energy, the smoke bungled to have explicit directional flow and just pursued the shape of the helicopter. It is also projected that the flow is very emaciated in terms of energy as this region didn't reveal unequivocal streamline of flow. As a corollary, it can be asserted that the hub of the rotor system is ineffectual in lift generation.

(a) Smoke released on the superficial portion of the main rotor blade during hover**.**

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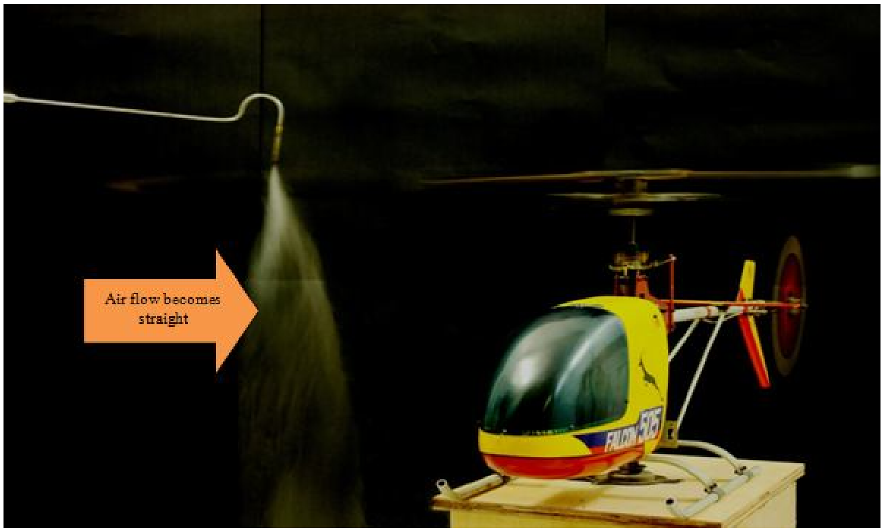
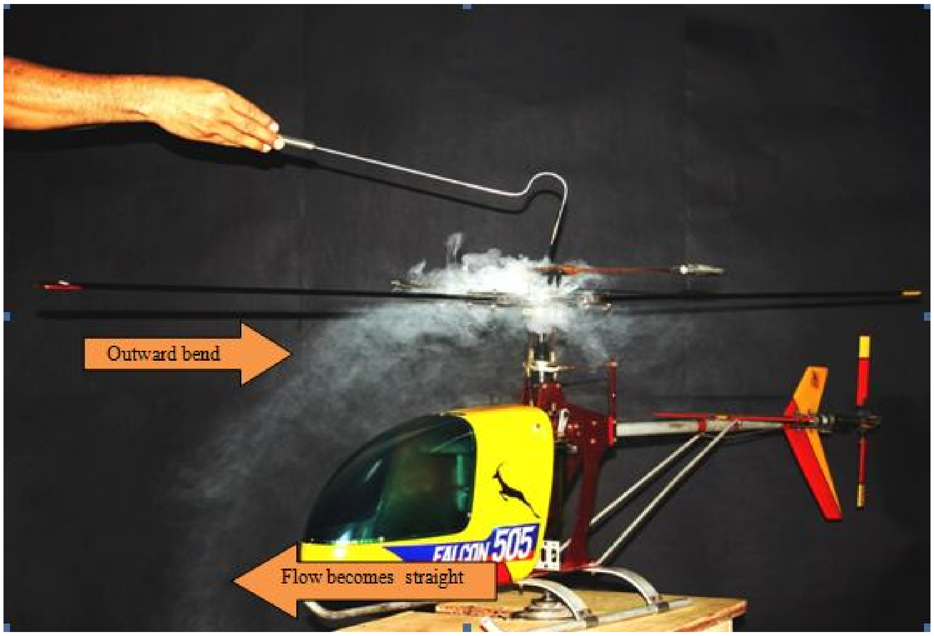


(b) Smoke released on the middle portion of the blade



(c) Smoke released just above the rotor center hub.

Figure 4: Air flow visualization throughout the blade span.

3.3 Rotor wake formation during hover

Figure 5, demonstrates rotor wake formation during hovering condition. From this representation, it can be noticed that a concentrated vortex has trailed from the blade tip. Generally, the inboard turbulent wake is referred as a vortex sheet. The blade tip vortex is set apart by exceedingly distinct dark seed void. This in fact is a consequence of the centrifugal forces generated by high swirl velocity surrounding the vortex core. The local velocity is required to be raised enough to cause centrifugal forces on the seed particles to move spirally outward. The particles attain equilibrium as soon as the centrifugal force and pressure force are in balance.

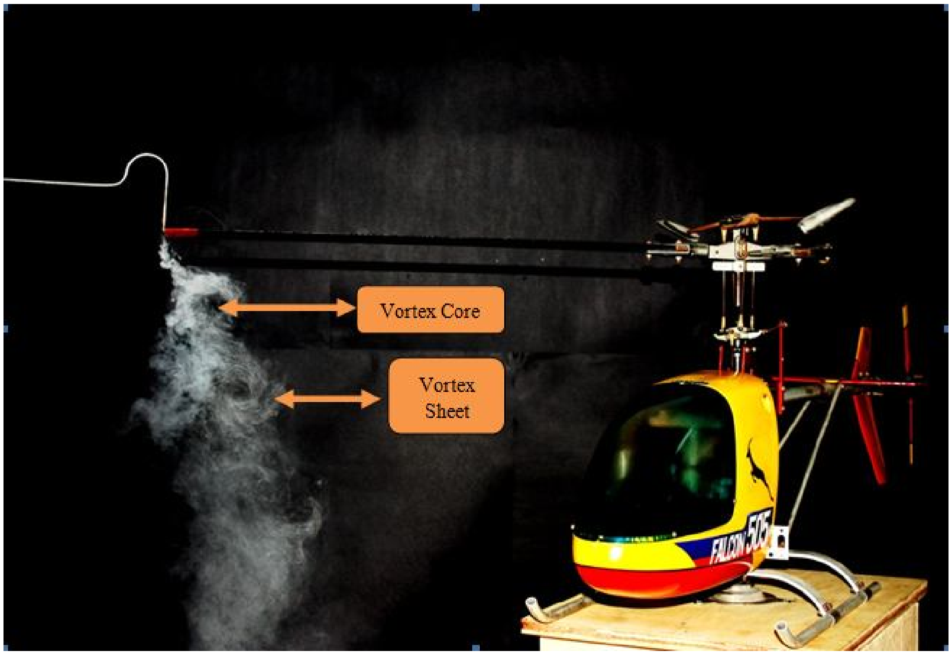
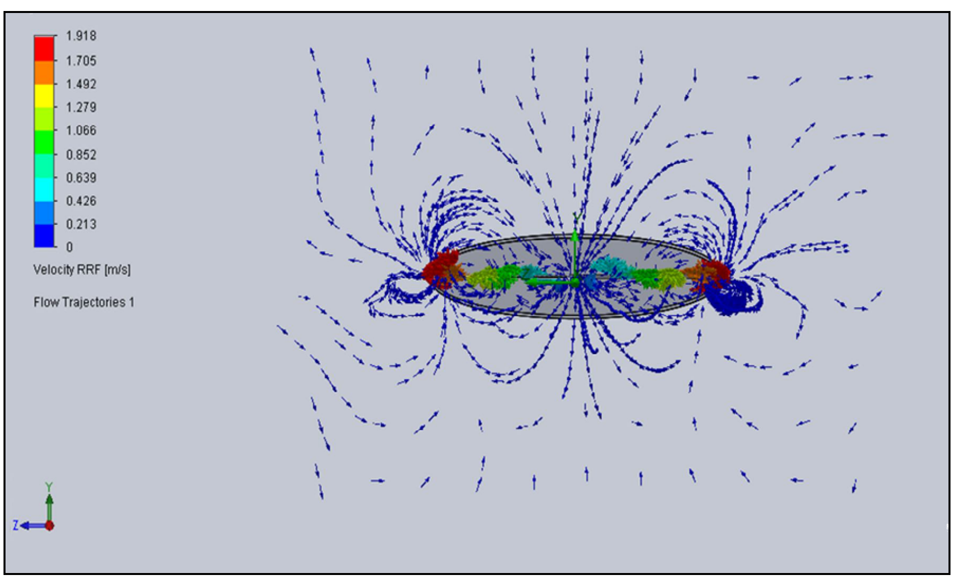
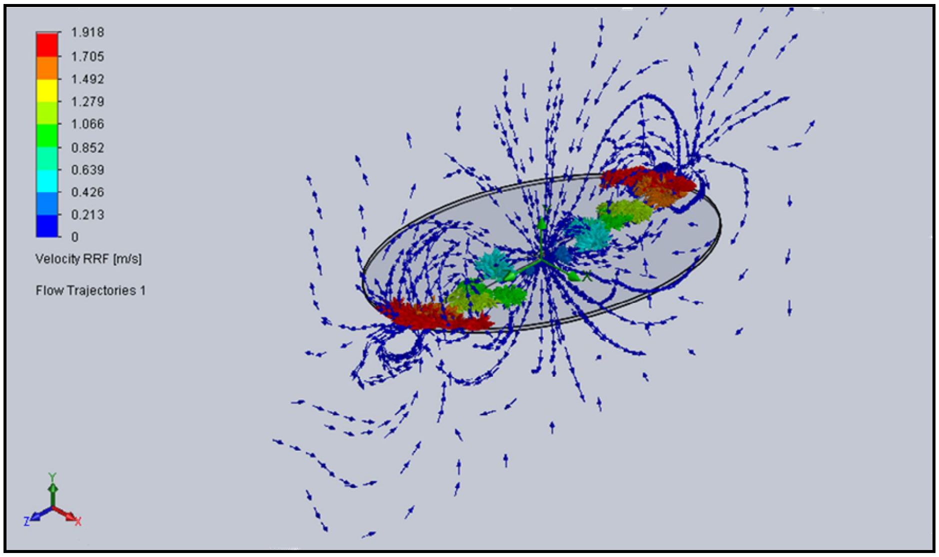


Figure 5: Rotor wake configuration during hover.

Figure 6 represents the main rotor simulation using SolidWorks-2012 during hovering condition. This simulation is conducted using similar rotor properties and conditions. The airfoil used here is NACA0014 where the chord length is 0.05m and rotor diameter is 1.34 m. The simulation was conducted without the presence of the fly-bar. Rotating at 450 rpm, the simulation is carried out with both laminar and turbulent types of flow for Temperature 293.2k and Pressure 101325 Pa. Figure 6 portrays the flow trajectory for velocity. The crucial point to be distinguished here is that the velocity is at its supreme on the tip of the rotor blades' upper surface compared to its bottom surface. The velocity amplifies exponentially from the inner to outermost section of the rotor blade. It is quite cogent that the chief ground for rotor wake is this immense contradiction in velocity at tip of the blade for the main rotor compared to other section of the blade.



(a) Front View



(b) Isometric View

Figure 6: Air flow simulation of the main rotor blade during hover (Flow Trajectory - Velocity).

4. Conclusion

According to Theodore von Karman (1954) *"the principle is most important, not the detail"* (Anderson Jr., 2011). With respect to that, the quest for finding the basic principles of the airflow pattern for the helicopter main rotor is carried out in this study. The smoke flow visualization process is exploited in order to get a better understanding of the flow behaviour and characteristics from a subscale helicopter's rotor blade. For dissimilar flight conditions the flow pattern depicted peerless behaviour and individuality. Quite a few disparate flow patterns have been recognized throughout the blade span. The centre of the main rotor hub has turbulent flow. This is due to low energy of air amassed in this region. The air encompasses high kinetic energy with a clear straight streamline pattern in the middle portion of the rotor blade. Figure 7, summarizes and elucidates the effective region of the main rotor. It epitomizes that throughout the blade span; 25 percent is stall region, 45 percent is the driving region and 30 percent is driven region moving from the centre to the outer tip of the blade. Furthermore, this study scrutinized the rotor wake system where the vortices formed below the blade at the rotor tip. The tip vortex noticeably exhibited the vortex core and vortex sheet. The flow properties of the main rotor system of a sub-scale helicopter can be correlated to a full scale helicopter. This can aid in gaining enhanced perceptive and designing helicopters with improved performance.

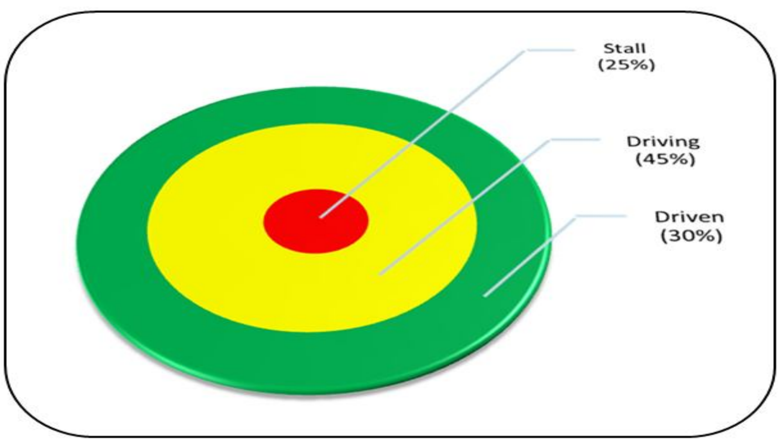


Figure 7: Effective Blade Properties.

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A Brief Author Biography

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