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Structural Analysis of Active Winglet for Motorcycle

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Abstract: In this study, we will be performing structural analysis on the motorcycle winglet. The type of winglet used in this analysis is a square winglet from Aprilia RSV4 RF. The flap inside the winglet will be a NACA 6412 airfoil which will be placed upside down to generate downforce. It is very complicated to get results from the winglet. the analysis will be carried out on an active winglet. we will be considering 5 scenarios in Computational fluid dynamics, and 4 in the static, and 6 in vibration analysis. The CFD analysis will be done to obtain the force which later will be applied in the static analysis and vibration analysis to check the vibration frequency at different modes. The material used for the wing and for the body of the motorcycle will be carbon fiber reinforced polymer. As we will be changing the angle of the flap which is present in the winglet it necessary to check whether the CFD results are practical example the forces, coefficient of drag, etc. to prove that the design works. The FEA will help us prove that the design is safe. The model is designed in the Onshape which is a CAD modeling tool and the analysis will be done on the Simscale.
Keywords: Winglet, FEA, vibration, airfoil, harmonic

I. INTRODUCTION

A. Background of Winglet

The most important thing when it comes to the handling of the vehicle is its aerodynamics. Other than the fairing the part which lately introduced is the winglet. It produces downforce, therefore, reducing the chances of wheelie while exiting a corner. Also acts as an anti-wheelie device. 2016 was the year when the winglet was introduced in MotoGP for the first time by the Ducati. It was previously introduced in 2010 but the riders during the testing said it did not make much of a difference so the idea was skipped by the manufacturer. In 2019 Ducati launched its V4R which was the first production motorcycle which was equipped with a winglet later followed by Aprilia which had a Square shaped winglet. In the same year, Honda unveiled that it was working on an active winglet which was going to be introduced on the 2020 CBR 1000r fireblade but was not introduced as it is still under development.

Aerodynamics is the most crucial thing when it comes to the efficiency or handling of the vehicle. the same thing applied in the case of motorcycles. A car has four wheels and a motorcycle as two so cars are definitely more stable are easy to handle. When it comes to motorcycles there is no wind protection or extra wheels which will help in balancing the motorcycle. So, how the motorcycle behaves completely depends upon the rider. This is why winglets were introduced to give an extra bit of confidence to the rider. The main moto of the winglet is to provide downforce and keep the front end of the motorcycle down. Let's consider rider is exiting a corner and the motorcycle wheelies now the front wheel which steers the motorcycle is in the air and the bike goes wide the rider tries to shift the weight forward but it is not enough in this situation even a small amount of downforce can make a huge difference.

II. PROPOSED IDEA

The fixed winglet generates downforce but as we known downforce also creates drag which reduces the top speed of the motorcycle in order to reduce this drag active winglets are used which will improve the airflow. As the winglet is active there are going to be moving parts means there is a need for testing the structural rigidity and the vibration caused by the part. The type of winglet design on which the analysis will be carried out is the square shaped winglets which are integrated into the fairing which produce less vortex when compared with the cantilever design the vortex makes the motorcycle behind unstable. The downforce created by the square winglet is less than the cantilever which makes it easy for the rider to switch direction.

III. AIM OF THE PROJECT

This research project's aim is to study the behavior of the winglet when different loads are acting on it. Sudden change in the momentum can cause the motorcycle to lose its balance so to solve this problem perfectly positioned winglet is important so it is necessary to perform a CFD analysis. As the winglet is attached on the side of the fairing it will vibrate which affects the overall aerodynamics of the motorcycle so to understand this a modal analysis will also be carried out.

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IV. AIRFOIL NACA 6412

The design of the flap inside the winglet is derived from the NACA 6412. It is generally used in aeronautical applications. As this flap used in the motorcycle winglet, it will be small in size when compared to the wing on the aircraft. Hence, this airfoil was the choice because the camber on this airfoil shape is high when compared to the other airfoil.

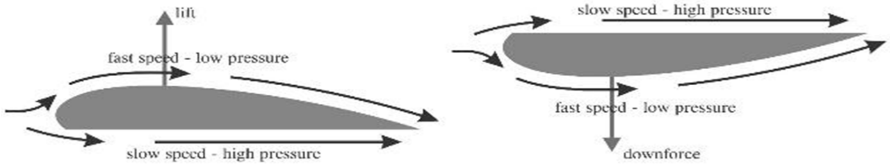


Figure 1 Air flow around the Air-foil

In the aircraft, this is used create to lift. Lift occurs when the fluid in which the air around the airfoil exerts pressure on it in the perpendicular direction as shown in the left image in **Figure .** The other advantage of this design was it created less drag, good amount of lift, and was specially designed for high speed. In our study, we need it to create a downforce. So the design was flipped upside down. **Figure** shows the representation of how the wing will look when flipped

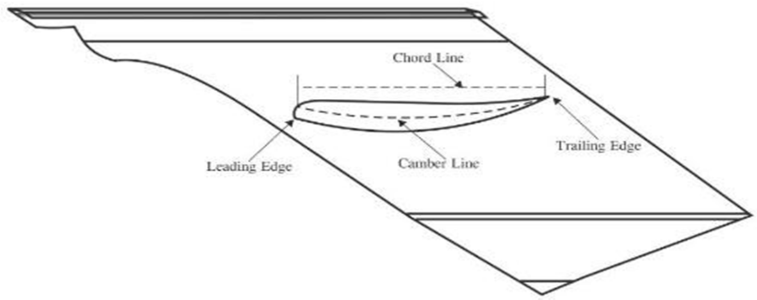
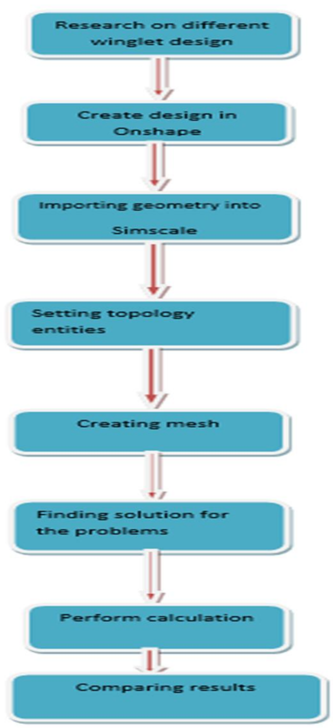


Figure 2 Position of the Air-foil on the winglet

The chord line which is the length from the leading edge of the flap to the trailing edge of the flap is 0.105m. after the sketch was ready it was extruded to 0.036m.

V. METHODOLOGY



VI. GEOMETRY

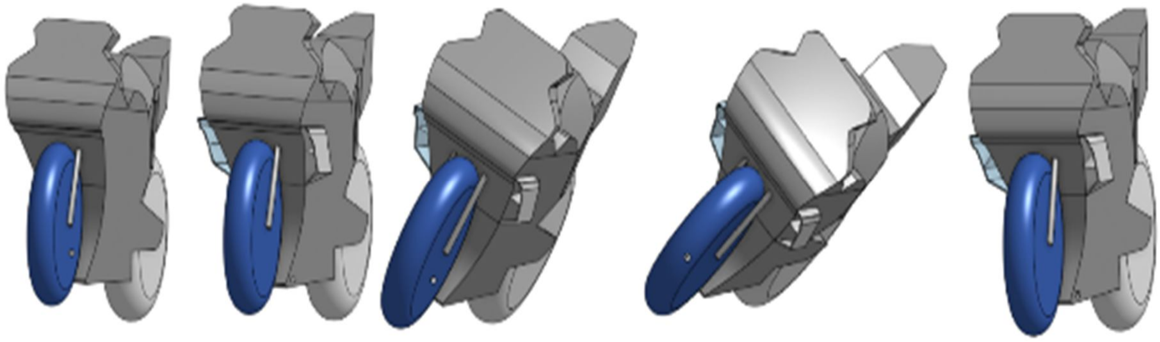


Figure 3 Left to right without winglet, winglet, lean angle 30°, lean angle 50° and winglet while braking

The model was made using Onshape. Onshape is a free online based CAD software which can be operated via windows, android and IOS. The performs of this software is based on the servers. Designing is the most important part before analysis. So it is necessary to design the CAD model properly. The CAD model is made using the original dimension of a motorcycle. The length is 2 m, 0.6 m in width, and 1.1 m in height. The CAD model was designed in a way to replicate the real model to get as accurate results as possible. We will be comparing 5 models in CFD 2 with the active winglet leaned at an angle of 30° and 50°, with winglet, without winglet, and the flap inside the winglet is kept at -18° while braking.

In the 2nd image from the left, the flaps inside in are kept straight to produce less drag but also some downforce. In the image in which the in leaning at 30° the flap on the left side of the motorcycle is kept at a positive 3° angle whereas the flap on the right is kept at a negative 3° angle the same goes for the motorcycle having a lean angle of 50° but the angle of the flap is changed like the left having positive 4° and right negative 4°. The reason for this was if we have more downforce while cornering we maintain a higher speed without having a risk of running wide this is what the flap with a positive angle will do. The generation of downforce means the rider will have to put more effort while changing directions from one corner to another so to cope up with this issue the flap on the other side has an angle that will create lift and will help to reduce the efforts that the rider puts while changing the direction of the motorcycle.

VII. RESULTS

A. CFD Analysis

Following is the results discussion of the geometries on which the CFD analysis was carried out. It was done to find out whether the geometries designed giving us the practical results or not. According to the internet, a bike has a cd of 0.7 with a rider, when tucked in 0.6 and the bike which has the least amount of cd with the rider tucked in is the Suzuki Hayabusa which is 0.55. the reason the cd increases is due to the legs and hands of the rider as they cannot be covered completely. As the frontal area increases of the cd also increases.

Figure 5 shows the data of the motorcycle with a winglet. This analysis performed here is on the motorcycle without the rider. Figure 4 shows the results of the motorcycle having no winglets and the values which we are getting are also practical which means the design is correct. As it can be seen in Figure 5 there is an increase in the coefficient of drag this is due to the addition of the winglet. When we compare the data of Figure 5 and Figure 4 there is a difference in the lift values the negative value denotes the amount of downforce created.

The unit for all the values is in Newton's. It is clearly seen that the values of the geometry having a winglet are more than that geometry without a winglet. The angle of attack of the flap is kept at 18° while braking which again has increased the coefficient of drag. There is also a good amount of drag increase which will help the motorcycle while braking. This drag force will further increase when a rider sits on it which will make braking even more effective. The cd is max while leaning which is 0.65 which will increase when the rider sits on it. The maximum value of cd is 0.77 with the rider which is more than our value which shows that the design is giving a practical value while leaning also. This shows that the values can be used for the static analysis which is the main objective of this study.

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Velocity	Drag	Lift
20	6.68	-39.15
30	10.87	-60.86
40	15.08	-86.67
50	20.55	-119.14
60	29	-158.43
70	34.06	-200.14
80	41.62	-243.87
90	57.29	-292.87
100	58.89	-358.16

Velocity	CD	CL
20	0.25	-1.39
30	0.26	-1.39
40	0.25	-1.38
50	0.25	-1.38
60	0.27	-1.41
70	0.26	-1.41
80	0.25	-1.39
90	0.28	-1.38
100	0.24	-1.42

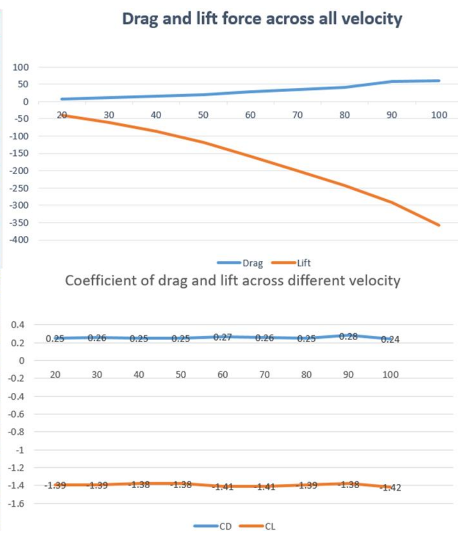


Figure 4 Without winglet

Velocity	drag	Lift
20	12.19	-43.9
30	19.86	-68.34
40	27.31	-96.12
50	37.52	-130.16
60	48.41	-173.9
70	62.91	-219.48
80	77.37	-269.31
90	92.21	-332.75
100	109.95	-393.39

Velocity	CD	CL
20	0.39	-1.36
30	0.4	-1.36
40	0.38	-1.33
50	0.39	-1.32
60	0.38	-1.35
70	0.39	-1.35
80	0.39	-1.34
90	0.38	-1.33
100	0.39	-1.36

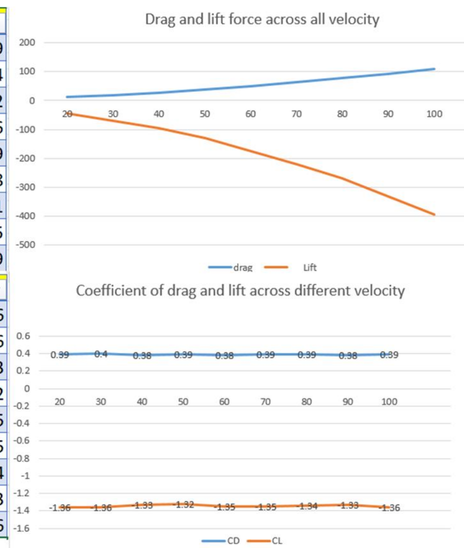
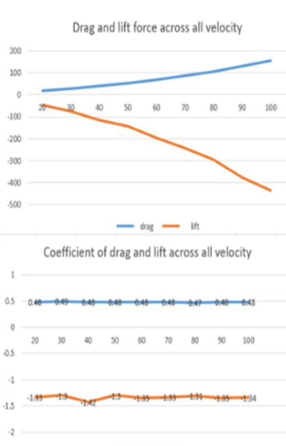


Figure 5 With winglet

Velocity	drag	lift
20	16.93	-48.34
30	27.23	-73.89
40	38.72	-115.42
50	52.49	-144.87
60	68.63	-196.32
70	87.58	-243.43
80	106.16	-296.7
90	130.63	-377.16
100	156.03	-437.37

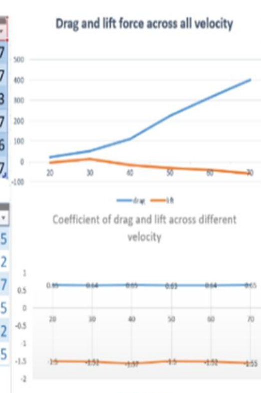
Velocity	CD	CL
20	0.48	-1.33
30	0.49	-1.3
40	0.48	-1.42
50	0.48	-1.3
60	0.48	-1.35
70	0.48	-1.33
80	0.47	-1.31
90	0.48	-1.35
100	0.48	-1.34



Braking

Velocity	drag	lift
20	22.63	-6.77
30	50.18	13.67
40	111.69	-18.73
50	223.85	-31.17
60	314.2	-40.76
70	400.84	-58.27

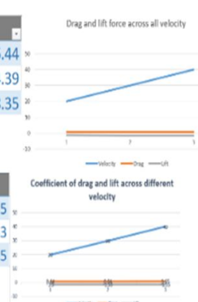
Velocity	CD	CL
20	0.65	-1.5
30	0.64	-1.52
40	0.65	-1.57
50	0.63	-1.5
60	0.64	-1.52
70	0.65	-1.55



lean angle 30°

Velocity	Drag	Lift
20	22.67	-6.44
30	58.09	-14.39
40	127.43	-18.35

Velocity	Drag	Lift
20	0.64	-1.5
30	0.64	-1.53
40	0.65	-1.55



lean angle 50°

Figure 6 Drag, lift, CD and CL of braking, lean angle 30° and 50°

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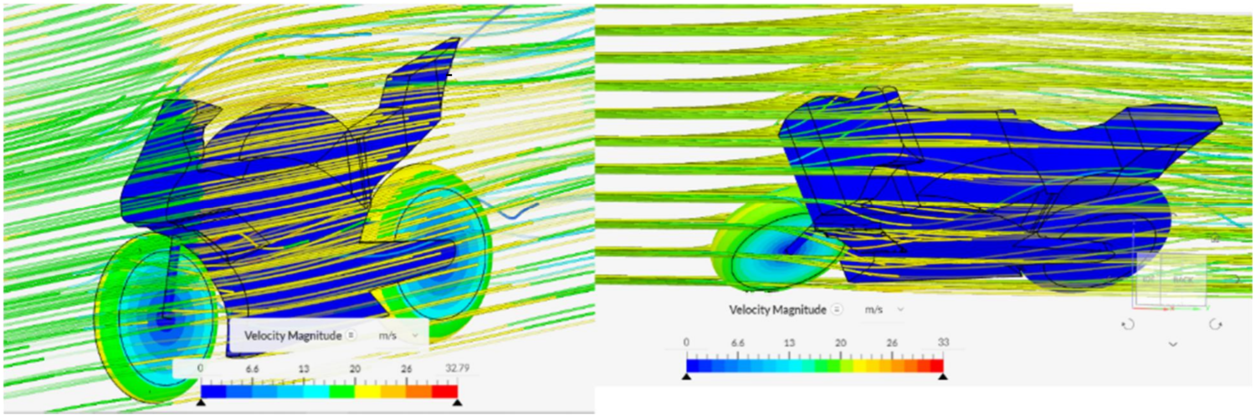

Figure 7 flow of air around the motorcycle while accelerating and cornering

The turbulence flow around the motorcycle shows that there no generation of vortex around the winglet. the vortex is caused by the regular cantilever style winglet. A vortex is basically a flow of air in a circular direction. The generation of vortex may make the motorcycle behind unstable which may lead to a serious accident and also makes the overtaking difficult. So it shows that using a closed design or a square winglet was successful.

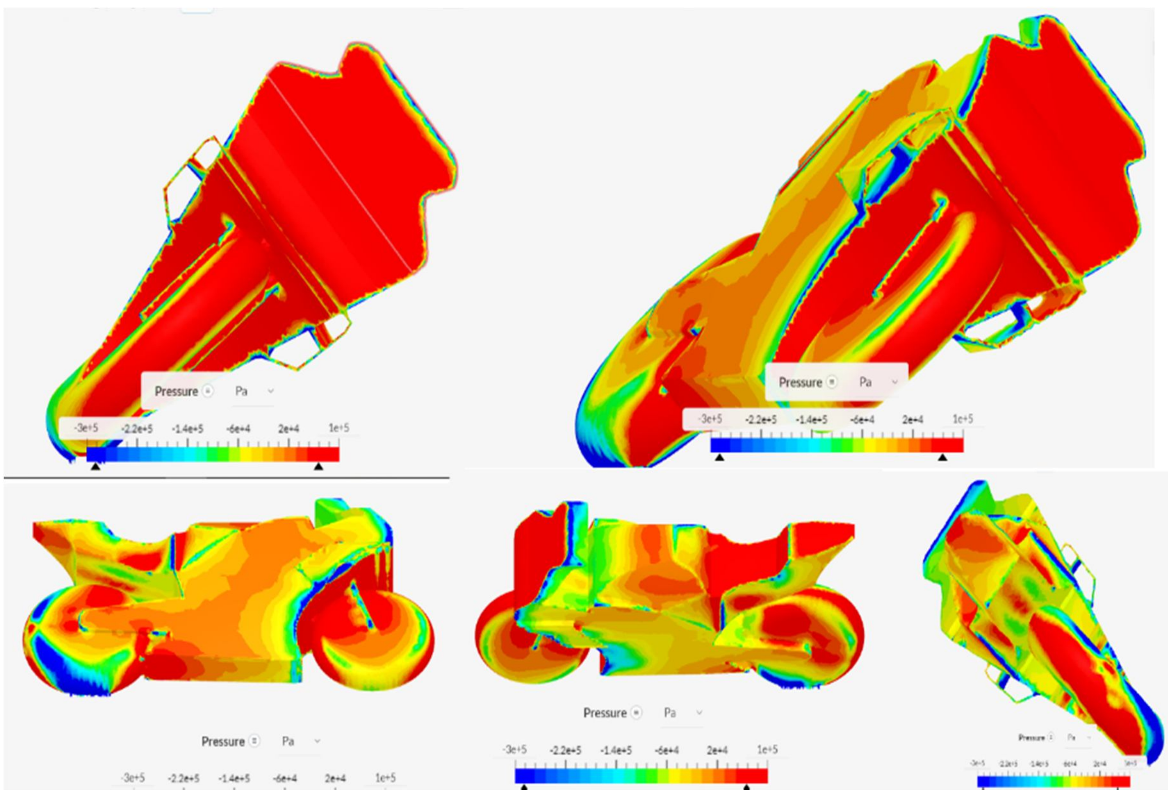

Figure 8 Pressure plot while lean at 50°

In Figure 8 the photo shows the pressure plot of the bike while leaning at 50° from all the angles. It represents the pressure contour plot. The winglets on both the sides of the motorcycle show generation of the low pressure which is creating suction in the bottom of the winglet and as expected there is a generation of a high pressure are on the top of the winglet which means the winglet is generating downforce. When the motorcycle leaning the downforce increases but it also brings lateral force along with it which makes the motorcycle run wide while cornering. To solve this problem, we have kept the flap on the left at a negative angle and the flap on the right at positive which generate less downforce or some amount of lift which will help the motorcycle take like it is on rails This way the rider will have to put less effort while flicking the motorcycle from one corner to another.

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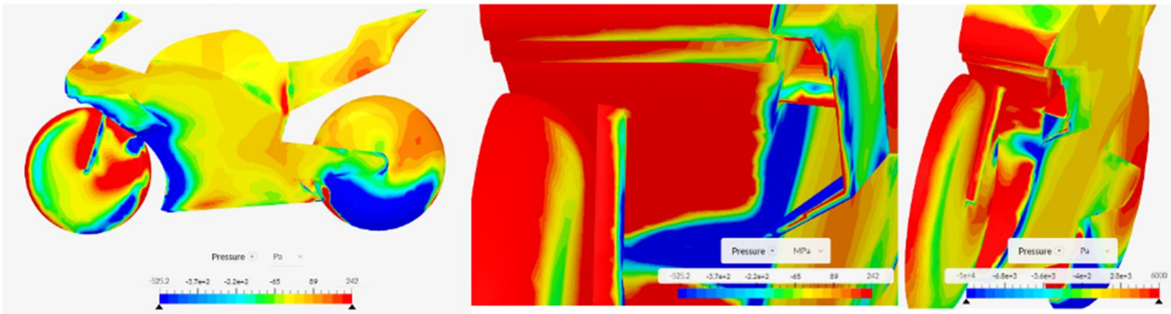

Figure 9 While moving straight and braking

Figure 9 shows the pressure plot of the motorcycle while moving in a straight line and braking. From the left the first image shows the side of the motorcycle while accelerating, the second shows a close up view of the winglet while accelerating and the last shows the close up view while braking. Again as expected above image shows that there is suction created underneath the winglet and following by the high pressure area on the top of the winglet creating downforce. And also in the last image which is while braking the whole upper part of the flap is red which shows it will help the motorcycle slow down.

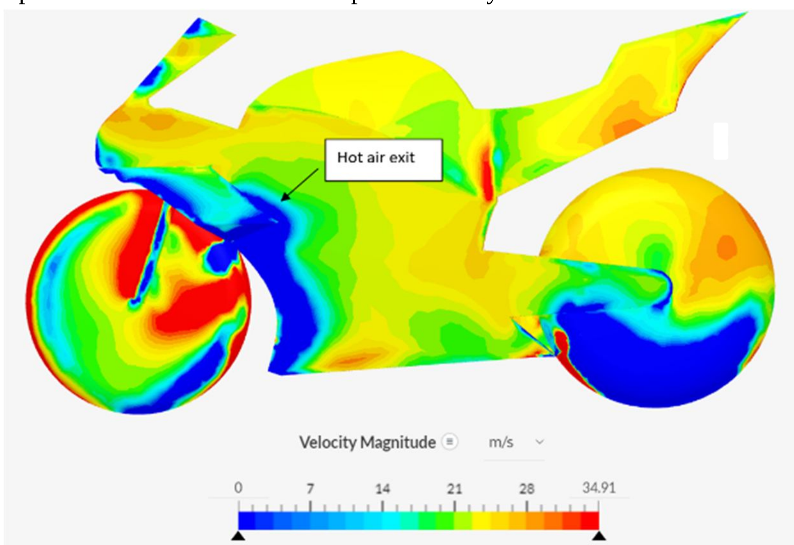

Figure 10

Figure 10 shows another advantage of the winglet which will be very useful in normal riding conditions. As we know the bikes with fairings heat up as their structure is closed. The arrow in the image point to the air exit. The suction near the hot air exit also helps in the cooling of the motorcycle.

B. Frequency Analysis

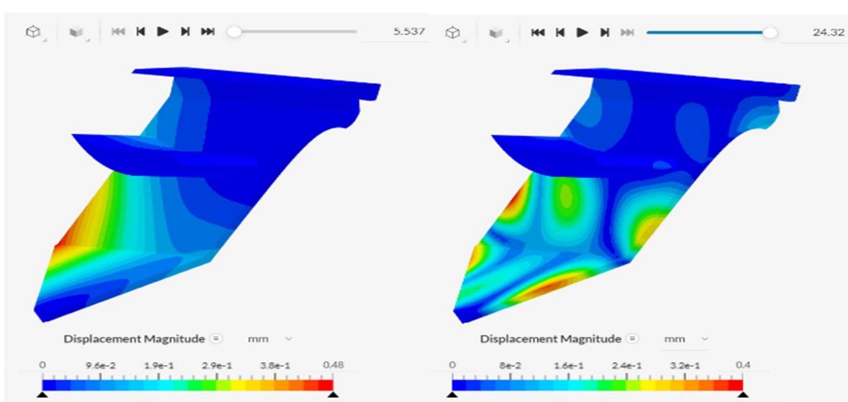

Figure 11

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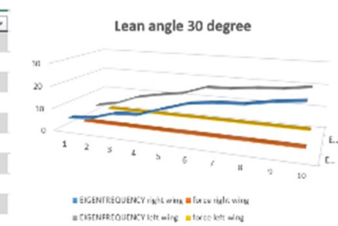
The frequency analysis is also called modal analysis. When any force is applied to an object it either moves or vibrates. Every object has its own natural frequency at which it will vibrate. hence the frequency analysis is done to check the natural frequency of the object at which it will vibrate without the application of any external load. The results in the Frequency analysis show how rigid the structure is, $[M][\ddot{U}] + [K][U] = [0]$ this is the equation for the modal analysis where [M] stands for mass, $[\ddot{U}]$ for acceleration, [K] is for stiffness and [U] is for the position. In this, the damping and applied force are ignored. The lower modes have high energy when compared to the higher modes. Figure 11 shows the contour of displacement magnitude at two different modes. The image on the left is the Frequency at mode 1 and the image on the right shows the frequency at mode 10. Each mode has its own displacement which means it deforms in its own direction. In some mode the part will displace in x-direction, some in y, and some in z as there is no direction given in the modal analysis. In Figure 11 both the images have a red part which shows where the maximum displacement will take place. The maximum displacement is also 0.48 mm which safe which is at the lowest frequency and 0.4 which is at the highest frequency. Hence, we have done that in the static analysis where we have given direction to the load. Figure 11 shows the results when the motorcycle is at zero lean angle.

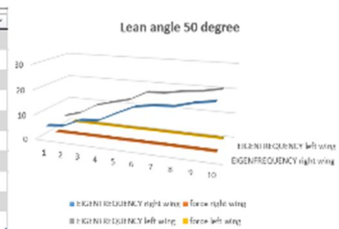
Lean angle 30 degree

EIGENMODE	EIGENFREQUENCY right wing	Disp. right wing	EIGENFREQUENCY left wing	Disp. left wing
1	5.27333	0.47	5.02403	0.44
2	6.10757	0.41	7.10525	0.41
3	9.32519	0.42	11.1143	0.46
4	9.94717	0.4	13.1797	0.4
5	13.5759	0.4	14.82	0.41
6	16.9499	0.47	18.5119	0.45
7	18.2857	0.43	18.8433	0.43
8	18.9499	0.47	20.1046	0.42
9	20.8497	0.46	20.6815	0.41
10	22.1863	0.42	22.2287	0.41



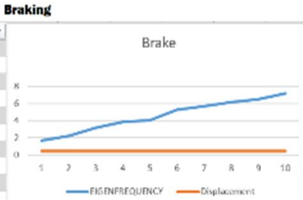
Lean angle 50 degree

EIGENMODE	EIGENFREQUENCY right wing	Disp. right wing	EIGENFREQUENCY left wing	Disp. left wing
1	5.17432	0.41	5.02903	0.43
2	5.80217	0.4	7.06869	0.41
3	8.96705	0.43	11.0675	0.46
4	9.45719	0.4	13.0067	0.4
5	13.0531	0.4	14.7644	0.41
6	16.3406	0.44	18.4409	0.46
7	17.5935	0.45	18.7324	0.43
8	17.9375	0.44	20.0036	0.4
9	19.901	0.41	20.7341	0.41
10	21.1278	0.4	22.1523	0.4



Braking

EIGENMODE	EIGENFREQUENCY	Displacement
1	1.6911	0.42
2	2.19321	0.4
3	3.16335	0.41
4	3.85815	0.4
5	4.03538	0.41
6	5.27466	0.44
7	5.69066	0.4
8	6.13464	0.41
9	6.48143	0.4
10	7.19533	0.4



Straight with no lean angle

EIGENMODE	EIGENFREQUENCY	Dispalcement
1	5.53664	0.48
2	9.44075	0.4
3	11.4113	0.46
4	14.8322	0.41
5	17.8411	0.42
6	18.92	0.41
7	20.2622	0.49
8	20.7051	0.43
9	22.2019	0.45
10	24.3193	0.4

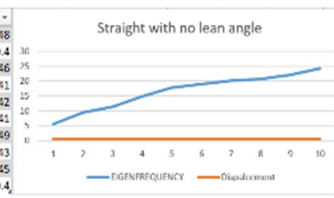


Figure 12

Figure 12 shows the frequency and displacement across various modes across all the scenarios. As the angle of the flap changes in all the scenarios, it was necessary to run a modal analysis on all the. In Figure 12 you can see that while leaning at both the angle and when the bike is moving straight the eigenfrequency values are almost identical as the angle of the flap is similar. The bike having a lean angle of 50 degree has its flap on the right tilted at – 4 degrees (the front part of the winglet pointing downwards) and left winglet at 4 degrees (the front end of the flap pointing upwards) same with the bike having lean angle of 30 degrees but right flap tilted at – 3 degrees and the right to 3 degrees. When the bike has leaned the winglet on the left in both the cases has the same identical value but there is a slight drop in the frequency across the left winglet of the bike having a lean angle of 50 degrees. Similarly, when compared to the right side of both scenarios of the bike while leaning the frequency is less across the bike having 50-degree lean angle. The frequency values are marginally high when the flap is at 0 degree which is when the bike is moving straight. The winglet while braking has the highest value which -18 degrees (front pointing downwards). The frequency is the least in this case. So, when it comes to vibration it was observed that when the flaps angle of attack increases or decreases there is variation in the frequency. The winglet with the flap having an angle of attack of -18 degree has the least amount of vibration frequency across all the 10 modes. Figure 13 shows that the flap acts as a support to the winglet which may be the cause of less vibration. The highest displacement amongst all the scenarios is 0.49 mm which proves that our design is safe.

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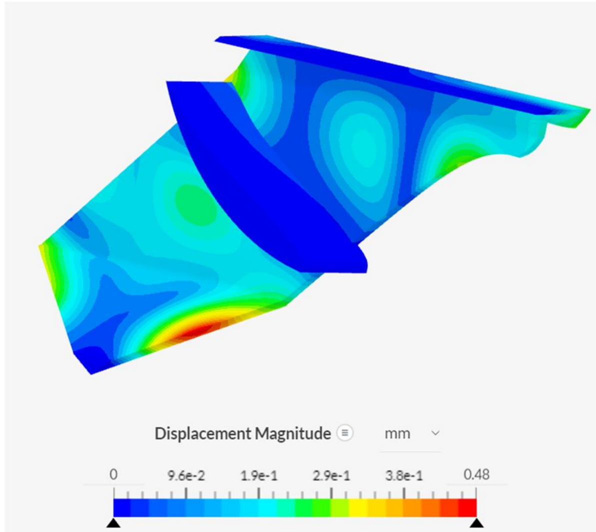

Figure 13

C. *Static Analysis*

Velocity	Von mises stress	Displacement magnitude
20	0.74	0.0002
30	1.16	0.0003
40	1.16	0.0005
50	2.2	0.0007
60	2.9	0.001
70	3.7	0.001
80	4.5	0.001
90	5.6	0.001
100	6.6	0.002

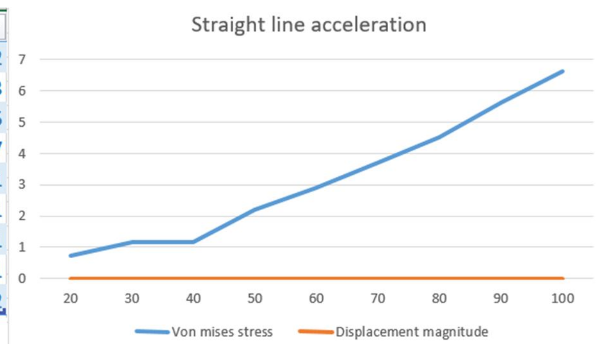

Figure 14

Velocity	Von mises stress	Displacement magnitude
20	0.74	0.01
30	1.14	0.02
40	1.7	0.05
50	2.2	0.05
60	3	0.07
70	3.7	0.09
80	4.5	0.1
90	5.8	0.2
100	6.7	0.2

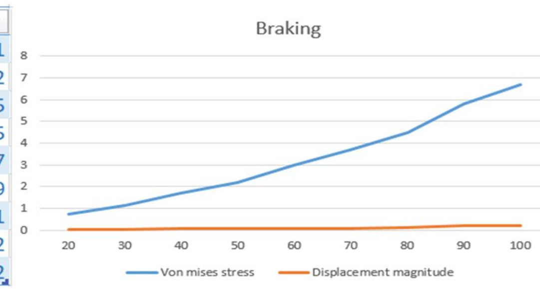

Figure 15

Velocity	Von mises stress	Displacement magnitude
20	0.11	0.02
30	0.25	0.03
40	0.56	0.03
50	1.1	0.04
60	1.6	0.05
70	2	0.06

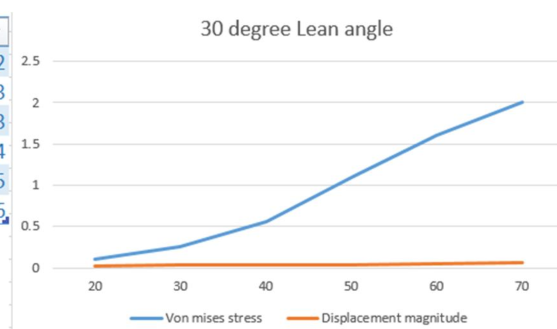

Figure 16

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Velocity	Von mises stress	Displacement magnitude
20	0.12	0.03
30	0.3	0.04
40	0.66	0.04

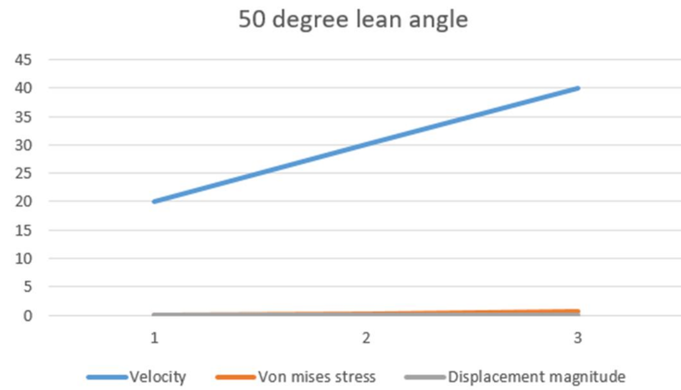

Figure 17

There is 4 static analysis carried out. This 4 analyses include acceleration, braking, the lean angle at 30° and the lean angle at 50°. These are the four major parts at which the angle of the winglet changes. So it was necessary to check the stress and deformation of the winglet at different possibilities. The winglet while accelerating and braking was tested at 9 different values of the force. The stress is calculated in newton's and the displacement in mm. the maximum allowable stress for the CFRP is 1200 mpa(Syamsir et al., 2012) and the maximum amount of stress produced across any of the is 6.7 mpa which makes the winglet safe. The maximum displacement is 0.09 mm which makes the winglet very stable.

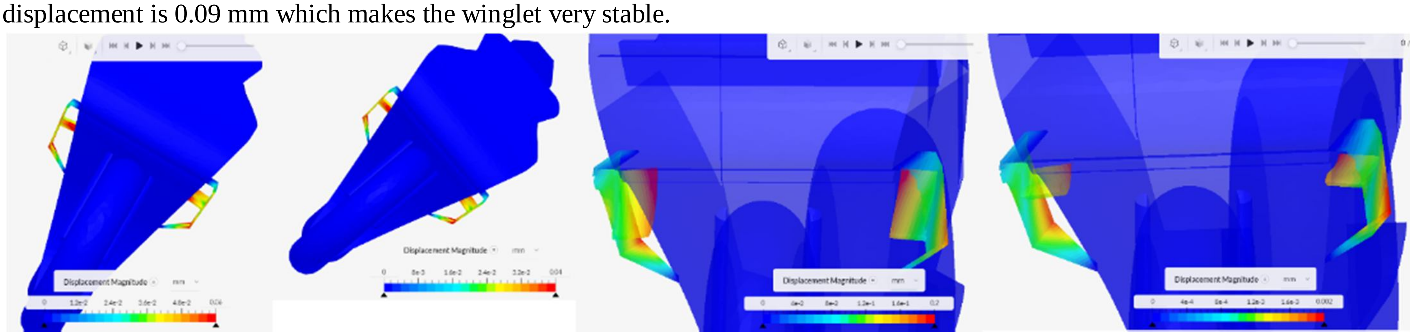

Figure 18 From left to right Deformation at lean angle 30°, lean angle 50°, braking, and straight line acceleration

Figure 18 shows deformation at different scenarios. All the results above are taken from the situation where there is maximum load acting on the winglet. To get a view of how the winglet will perform at maximum load. At a lean angle of 30°, the maximum speed was set to 70m/s because it the most speed at that particular angle a bike can achieve. The force applied at 70m/s was 400.84 mpa. And the highest deformation according to the software is 0.06 at the point where the air will be obstructed the most which is acceptable. At a lean angle of 50° at the same point, the maximum speed was kept at 40m/s and the maximum deformation was 0.04 at the same points as the when at 30° but less deformation. The 3rd image in Figure 18 which shows the angle of the flap while braking, again as mentioned before is deforming at the same point where there will be more obstruction of air, and the value that we getting is 0.2 mm which is larger when compared to other scenarios but still not in the way that it will affect the handling of the motorcycle. The last image in the flaps inside the winglets is at 0° has the least amount of deformation which is 0.002 mm. In case, if the deflection in any of the situations mentioned above would have been above 1 mm may affect the aerodynamics of the motorcycles which will eventually affect the handling characteristics of the motorcycle.

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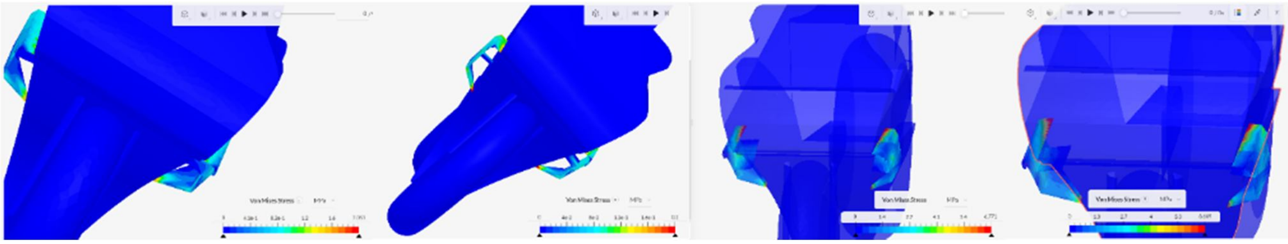
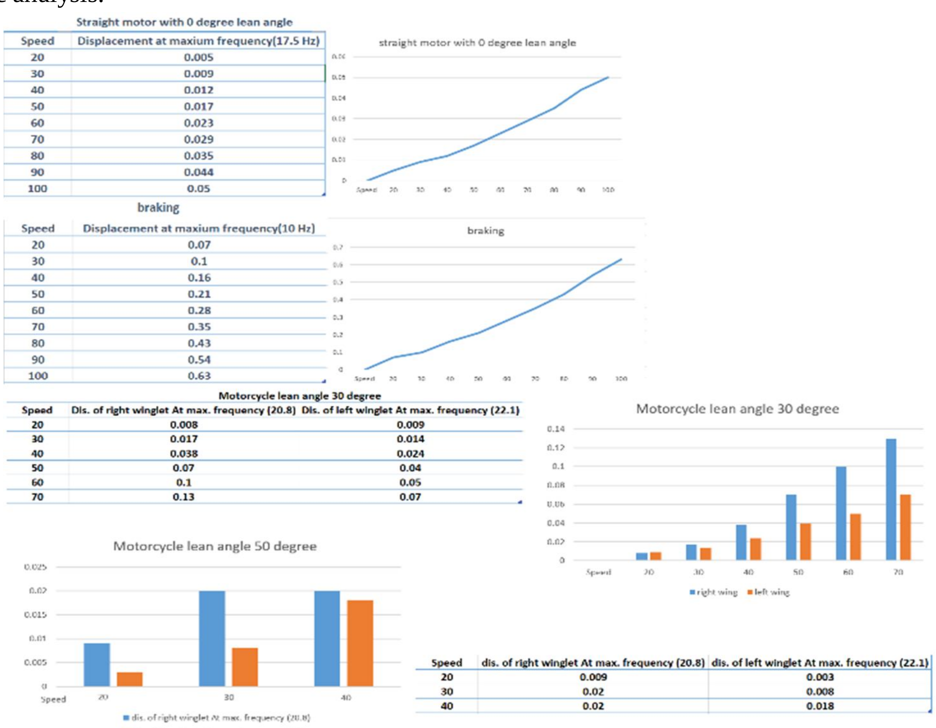


Figure 19 From left to right stress at lean angle 30°, lean angle 50°, braking and straight line acceleration

Figure 19 shows the stress acting on the different points on the winglet. All the scenarios shown in the image above are taken from the maximum load at which it was tested. The maximum allowable stress of CFRP is 1200 mpa. In all the images we can see that the stress is acting on the point where the winglet is attached to the fairing as expected. The maximum value which we are getting is 6.7 and 6.6 which mean the design is absolutely safe.

D. Harmonic Analysis

The harmonic analysis defines the steady state response of the object on which sinusoidal load with respect to time is subjected. Different from the transient. Dynamic analysis, the harmonic analysis does not solve the time-history response of the structure. It treats the structure's dynamic behavior in the frequency domain instead of the time domain. hence, the interpretation of the harmonic analysis results becomes very different from static analysis. What we are looking for in this analysis is excessive motion, stress, and vibration all of this occurs at a certain frequency. Harmonic analysis helps use verify whether the designed object can successfully overcome the resonance or not. All the input loads given in this analysis are sinusoidal which is the same frequency. The equation solved by the finite element solver in harmonic analysis is $\mathbf{F_i = (F_i)_{max} \sin(\omega t + \theta_i)}$. The input and output are sinusoidal in harmonic analysis.



Straight motor with 0 degree lean angle

Speed	Displacement at maxium frequency(17.5 Hz)
20	0.005
30	0.009
40	0.012
50	0.017
60	0.023
70	0.029
80	0.035
90	0.044
100	0.05

braking

Speed	Displacement at maxium frequency(10 Hz)
20	0.07
30	0.1
40	0.16
50	0.21
60	0.28
70	0.35
80	0.43
90	0.54
100	0.63

Motorcycle lean angle 30 degree

Speed	Dis. of right winglet At max. frequency (20.8)	Dis. of left winglet At max. frequency (22.1)
20	0.008	0.009
30	0.017	0.014
40	0.038	0.024
50	0.07	0.04
60	0.1	0.05
70	0.13	0.07

Speed	dis. of right winglet At max. frequency (20.8)	dis. of left winglet At max. frequency (22.1)
20	0.009	0.003
30	0.02	0.008
40	0.02	0.018

Figure 20

The above results are from harmonic analysis. Each speed had 9 frequencies so only the frequencies having the maximum displacement were taken across all the scenarios. The unit in which the displacement is measured is in mm. the lowest displacement across all the scenarios was 0.003 mm which was on the left winglet while cornering at 50-degree angle and the maximum displacement was at winglet whose flap was – 18 degrees which while braking as it had the maximum load despite having maximum displacement amongst all the frequency was least at 10 Hz. Looking at all the results proves that the design is safe.

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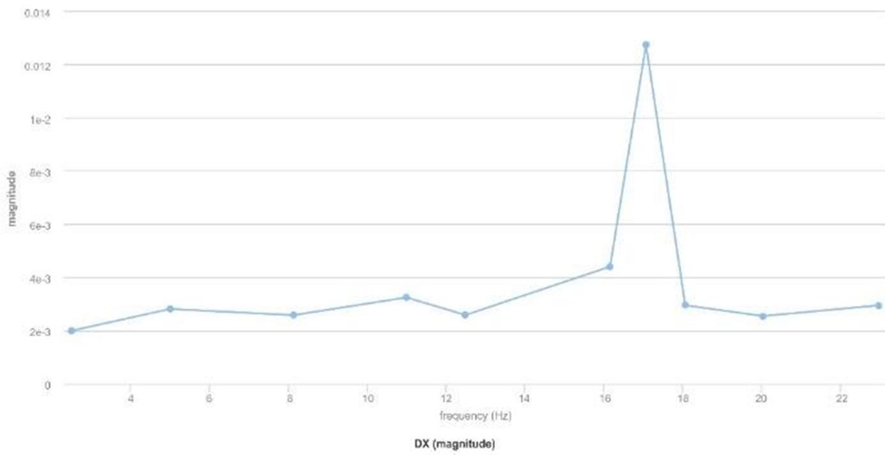

Figure 21

Figure 21 shows the frequency of the winglet when it is straight. The graph in the image above shows the results of the bike moving at 50 m/s. the reason it was named as 50 m/s because the values added in the force were taken from the CFD analysis when the bike was running at 50 m/s. If we recollect the data of frequency analysis at 0-degree lean which is mentioned in the boundary condition of harmonic analysis, we can see that peaks are occurring at the same frequencies.

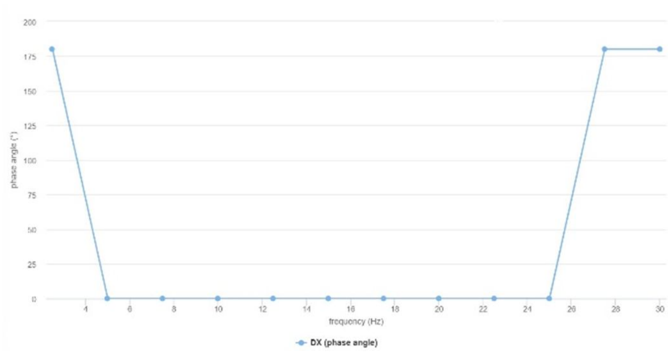

Figure 22

The phase angle is 0 and 180-degree which shows that the peak in displacement and force will be at the same time.

VIII. CONCLUSION

The main objective of doing the structural analysis was to check whether the winglet is feasible or not. The design used in this study is from an existing design. From an Aprilia RSV4 RF, it is a square shaped winglet that has a flap in it. In the existing design, the flap does not move. But in this study flaps inside this winglet move according to the input given to the motorcycle. The change in angle of the flap changes the behavior of the winglet and also changes the character of the part. At first, the CFD analysis at two lean angles at 30 and 50 degrees, while braking the flaps were at 18-degree and while going straight they were kept straight at a 0-degree angle. In the CFD analysis all the results came were practical the maximum cd achieved at all the analyses was 0.65. A test was also done on the geometry which had no winglets. This was to check how effective the winglet was after adding the motorcycle fairing. The force values from the CFD analysis were used in static analysis to see the amount and stress and displacement caused by the wind on the winglet. 6.7 mpa was the maximum stress and the maximum displacement caused was 0.09mm which makes the design safe. Frequency analysis was also carried which showed the natural frequency of the winglet. The maximum frequency achieved was 22.93. The frequency analysis was carried out before the static analysis which shows the natural frequency but as there was no direction given to force therefore a static analysis was carried out in which it was possible to give direction to the force. The results that we got from the harmonic analysis were somewhat similar to that of the natural frequency and the values that we got were again safe. The main purpose of doing the harmonic analysis was to see what would be the resonance.

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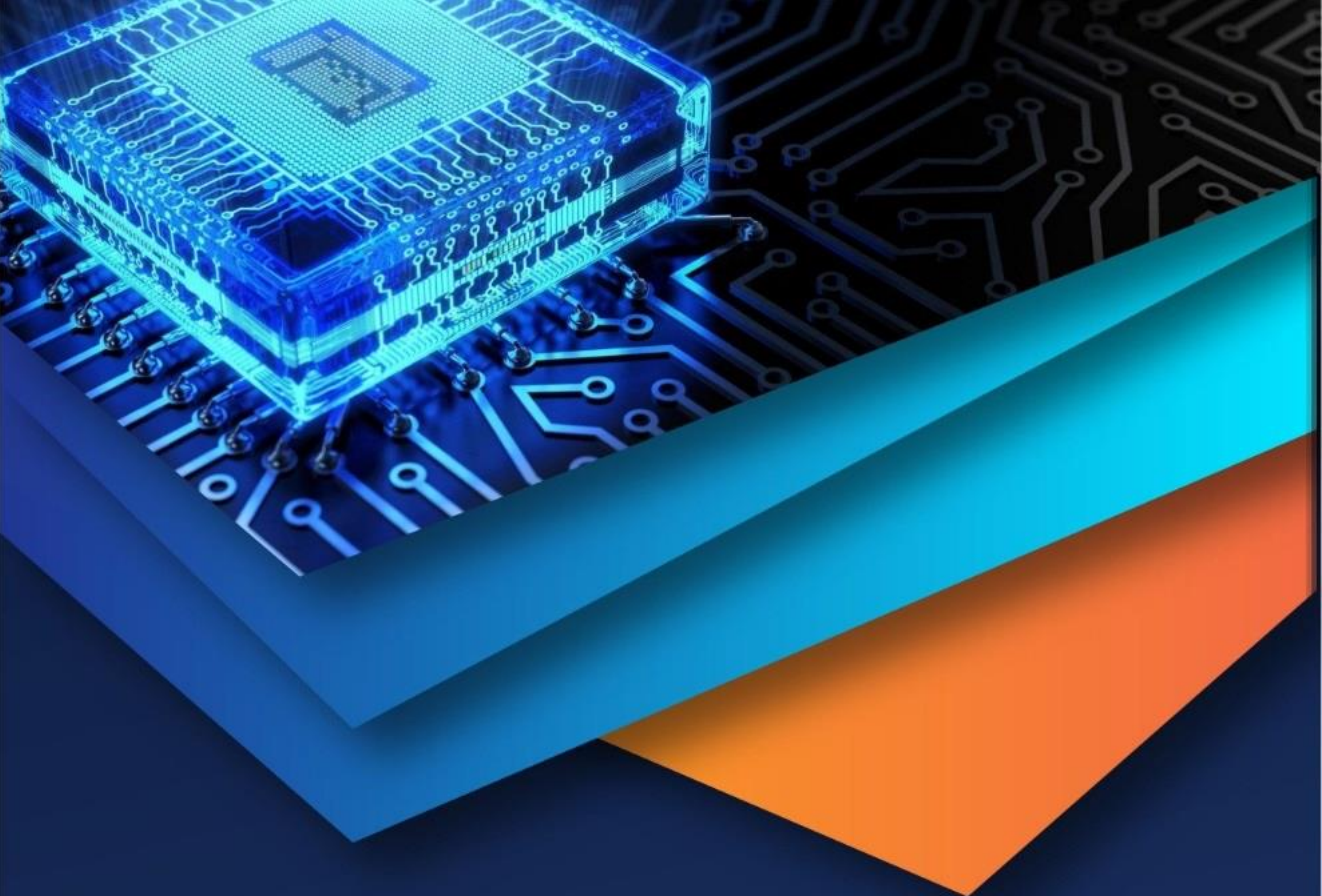

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