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An Investigation: Effect of Resistance for Different Passenger Cars

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Abstract : As the price of fuel grows, automakers are becoming more concerned about building fuel-efficient vehicles. Aerodynamic efficiency or ensuring a car meets as little resistance as possible from the air it moves through, is one facet of automotive design that contributes to fuel savings. The less fuel it takes to go at any given speed, the more aerodynamically efficient it is. The more quickly the automobile drives, the more crucial it is to reduce air resistance, or drag. So, in this study, automobiles from various categories, such as hatchbacks, sedans, and sport utility vehicles (SUVs), were chosen and their air resistance at a specific speed was calculated. A comparison of air resistance owing to frontal area, as well as the power necessary to drive different vehicles, has been graphically illustrated in this paper.

IndexTerms **- Frontal projected area, Drag force, Air resistance, Rolling resistance, Power of propulsion**

I. Introduction

India hold 5th position among world automobile market by selling more than 34 lakh units of both passenger and commercial vehicles in 2020. In 2019, it holds the 7thposition in manufacturing of commercial vehicles. It has been also seen that two wheelers segment dominates over other automobile sector in recent days. In addition, the on growing culture of exploring rural market further assist in developing the sector. India is one of the eminent automobile exporter for both passenger and commercial vehicles and it tends to enlarge its growth in upcoming days with some expected initiative by Government of India. Major enterprises in India are Maruti Suzuki, Honda, Hyundai, Mahindra Tata Motors etc.

Fuel consumption reduction is a fundamental priority of vehicle development in order to conserve energy and safeguard the global environment. In vehicle body development, reduced drag is critical for lowering fuel consumption and improving driving performance, and if an aerodynamically improved body is also aesthetically appealing, it will assist greatly increase the vehicle's appeal to potential purchasers. [1].

Fuel economy is more important to Indian buyers than safety and luxury. As a result, in order to meet market demand, automobile manufacturers have realised the importance of using aerodynamics in the production process in recent years. They have chosen automobiles that can readily cut through the air with minimal resistance since they are aware that how a vehicle cuts through air has a significant impact on fuel economy. When constructing an automobile, the frontal area is the first thing that is taken into account. The goal of this project is to investigate how it affects the amount of power consumed and, as a result, the mileage.

II. Objective of the Study

The key aim of the paper is to studythe drag coefficient is a measurement of how much an item resists movement through a fluid like water or air.

The drag coefficient of the automotive's frontal area will be compared here. The frontal area is where an automobile collides with the air. The product of the frontal area and the drag coefficient determines the vehicle's overall air resistance. Aerodynamic Drag is the force imposed by air on someone moving through it. The concept automobile bionic vehicle is supposed to have an excellent aerodynamic form. One explanation is because it has a greater frontal area. The teardrop/air foil form is often thought to have the lowest drag coefficient. For speeds below the speed of sound, the teardrop is the most aerodynamically efficient shape. The teardrop has a rounded nose that tapers as it moves backward, resulting in a slender, rounded tail that gently pulls the air surrounding the item back together instead of inducing eddy currents [6]. The drag coefficient of a car's form determines its aerodynamic efficiency (generally known as its C_d). A minimal drag coefficient based on the frontal area as low as 0.05 can be achieved, matching that of streamlined bodies in open air.If the base area and frontal area are near in size, the bluff body's drag may be proportional to the frontal area. The total resistance, which is the notion of aerodynamic vehicle performance, may be calculated as the product of frontal area and drag coefficient. A flat plate held at right angles to the airflow, for example, has a C_d of 1.25, but the most efficient production automobile forms now have a C_d of around 0.28. The Frontal Area refers to the overall size of the fascia, non-flat hood, and canopy. When an automobile drives through the air, designers aim to make the frontal area as small as possible to limit the number of surfaces that the air comes into contact with. One of the most essential variables in a shape's capacity to fly through air swiftly is the size of the frontal area, independent of angle.

After all of the data had been computed, gathered, and structured properly, the data was graphically depicted to better comprehend the coefficient of drag (C_d) on the frontal projected area of an automobile.

III. Area of Study

This study is based on Air resistance, rolling resistance & Power propulsion. All the parameter implemented on different types of vehicles.

IV. Factor affecting the resistances of an automotive

IV.i Air Resistance (Aerodynamic Drag)

The forces that oppose an object's relative motion as it moves through air are referred to as air resistance. These forces work in the opposite direction of the oncoming flow velocity, slowing the object down. Because drag is a component of the net aerodynamic force acting in the opposite direction of motion, it is directly proportional to velocity, unlike other resistance forces.

Air resistance is created by the object's leading surface clashing with air molecules, to put it another way. As a result, the item's speed and the cross-sectional area of the object are the two most important factors that impact the amount of air resistance. When a result, as speeds and cross-sectional areas increase, air resistance increases.

Drag refers to forces acting in the opposite direction of thrust as well as forces acting perpendicular to it in aerodynamics and flight (i.e., lift). Atmospheric drag may be both a positive and negative force in aerodynamics, depending on the situation. It wastes fuel and limits efficiency during lift-off, but it saves fuel when a spacecraft returns to Earth from orbit [7].

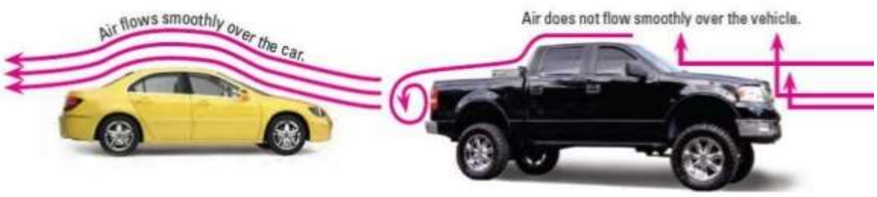

Fig. 1. Air Flow pattern

IV.ii Rolling resistance

Force required per unit weight to move a vehicle on a plane surface at constant low speed when air drag is minimum without apply any brake is called tolling resistance. In addition, wheel resistance, wasted vibration energy due to uneven roadbed also included here. In wide sense energy loss due to rubber tyre, wheel deformation in small sliding contact also termed as rolling resistance.

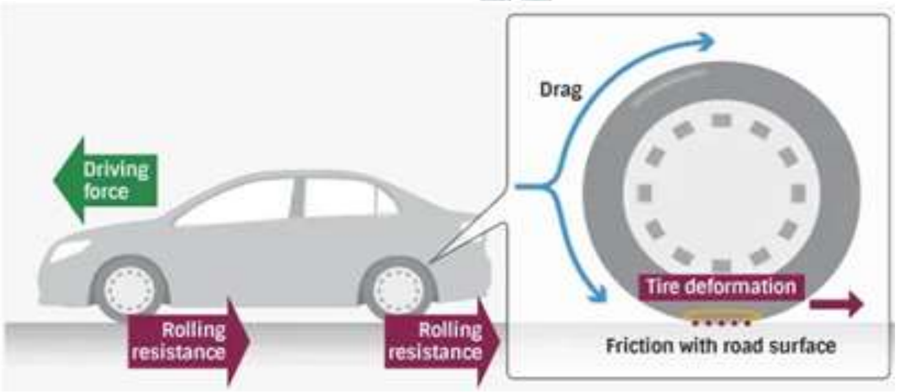

Fig. 2. Rolling resistance affects fuel efficiency

Due to the increase of this force fuel efficiency decreases. So, engine must have to overcome this to move the engine.

IV.iii Power of Propulsion

When air resistance, rolling resistance, and slope resistance are all present, it is defined as the amount of force required to move a vehicle. An engine or motor (also referred to as a power plant) and wheels and axles, propellers, or a propulsive nozzle are used to create force in a technological system. Clutches or gearboxes may be required to connect the motor to axles, wheels, or propellers [8].

Propulsion systems with a source of mechanical power (some type of engine or motor, muscles) and a manner of applying that power to generate force include wheels and axles, propellers, a propulsive nozzle, wings, fins, or legs. Additional components, such as clutches, gearboxes, and so on, may be required to connect the power source to the force-generating component.

The term propulsion is derived from two Latin words: pro meaning before or forwards and pellere (Latin of propel) meaning to drive.

V. Calculation of different types of resistance

V.i. Air Flow Resistance

Air resistance faced by a moving vehicle or aerodynamic drag force can be expressed as follows.

$\text{Aerodynamic Drag exerted} = C_d \times A \times \frac{1}{2}\rho V^2$ (1)

Where Cd= drag coefficient, taken as 0.4by ignoring side wind effects.

ρ = density of air (1.165 kg/m3), V = relative velocity of the vehicle (m/s) taken as 50km/hr, A = characteristic area.

To select characteristic area, further study is required regarding aerodynamic drag which is a combined effect of skin friction drag, induced drag and normal pressure drag. Former is due to fluid friction which causes loss of momentum of stream. Induced drag is generated by the passage of an airfoil through the air and the normal pressure drag is pressure induced normal to the surface. As the flow separation at the rear part of the vehicle lowered the pressure so normal pressure drag induced a net force which can able to oppose its motion. Normal pressure drag has the higher value compared to other pressure drags though skin friction drag plays a great roll in long vehicle like railway coach. So, in case of aerodynamic drag normal pressure drag is the major contributor over others and for approximation of characteristic area projection of the front side of the vehicle has to be taken care of.

Drag equation i.e. the mathematical measure of air resistance can be determined by equation (1). Air resistance has an impact on the car performance, stability and depends upon the shapeof the vehicle, velocity and the wind velocity. In general, air resistance can be expressed as:

Ra = KaAV2

Where

A = Projected frontal area, m2,

V = Speed of the vehicle, km/h,

The value of Coefficient of air resistance (Ka) differs for different vehicle.

for streamlined cars Ka (N-h2/m2-km2) is taken as 0.023, for average car it is 0.03, for trucks and lorries it is taken as 0.045.

VI.i Power of Propulsion

Resistance offered by the aerodynamic forces on a moving vehicle is termed as rolling resistance. Aerodynamic forces, such as wind or air resistance, and road resistance, which is commonly referred to as rolling resistance, impede the motion of a vehicle travelling on a road. Additionally, a vehicle also has to overcome a grade resistance while it travels on an inclined path and a component of its own weight has to be lifted vertically [9].

Hence, power required to move a vehicle can be expressed as follows:

$$\text{Power required by the vehicle } (P_V) = \frac{\text{Total resistance(R)} \times \text{Speed of the vehicle(V)}}{3600}$$

Where,

R = Air resistance (Ra)+Rolling resistance(Rr)

For inclined road R= Air resistance (Ra)+Rolling resistance(Rr) + Grade resistance (Rg)

VI.ii Rolling resistance

Rolling resistance depends upon nature of road surface, types of tyrei.e.pneumatic orsolid rubber type, vehicle weight, vehicle speed

Mathematically rolling resistance is pressed as -

Rr = KW

Where,

W = vehicle weight, N

K = constant that depends upon the nature of road surface and types of tyres used

The value of K differs for different vehicle.

for good roads is taken as 0.0059, for loose sand roads0.18, for a representative value it is 0.015.

In addition, expressionfor the rolling resistance is also expressed as

Rr = (a + b × V) W

Where, V = vehicle speed, km/h., Mean values of a and b are taken as 0.015 and 0.00016 respectively.

Table. 1. Coefficient of rolling resistance

Types of vehicle	Surfaces		
	Concrete	Medium Hard Soil	Sand
Passenger Cars	0.015	0.08	0.30
Trucks	0.012	0.06	0.25
Tractors	0.02	0.04	0.20

VII. RESULTS AND DISCUSSIONS

i. Hatchbacks without driver

Table. 2. Hatchbacks without driver

Model	Weight : Kerb (ton)	Projected Frontal Area (m^2)	Air Resistance (Ra)	Aero Dynamic Drag force	Rolling Resistance(Rr)	R=Ra+Rr	POWER(KW) Required to Propel the Vehicle
Maruti Suzuki WagonR	0.845	2.1708	168.237	1264.491	190.463	358.7	4.981944444
Maruti Suzuki Swift	0.905	2.12364	164.5821	1237.0203	203.987	368.5691	5.119015278
Maruti Suzuki Baleno	0.935	2.10796	163.3669	1227.8867	210.749	374.1159	5.196054167
Tata Tiago	0.982	2.059356	159.60009	1199.57487	221.3428	380.9429	5.290873472
HyundaiSantro	1	2.05296	159.1044	1195.8492	225.4	384.5044	5.340338889
Hyundai Grand i10 Nios	1.036	2.04288	158.3232	1189.9776	233.5144	391.8376	5.442188889
Volkswagen Polo	1.072	1.9766864	153.193196	1151.41983	241.6288	394.822	5.483638833
Honda Jazz	1.085	2.0924288	162.163232	1218.83978	244.559	406.7222	5.648919889
Hyundai i20	1.119	2.1371	165.62525	1244.86075	252.2226	417.8479	5.803442361
Tata Altroz	1.15	2.138292	165.71763	1245.55509	259.21	424.9276	5.901772639

For the analysis of power requirements for Hatchback cars, ten sets of cars were chosen. Table. 2. shows that the TATA Altroz has the highest Kerb weight of 1.15 ton. As a result Kerb weight increased, the rolling resistance is at its greatest value of 259.21 N, resulting in a higher power requirement to operate the car. In contrast to other vehicles, the TATA Altrozrequires the most power with

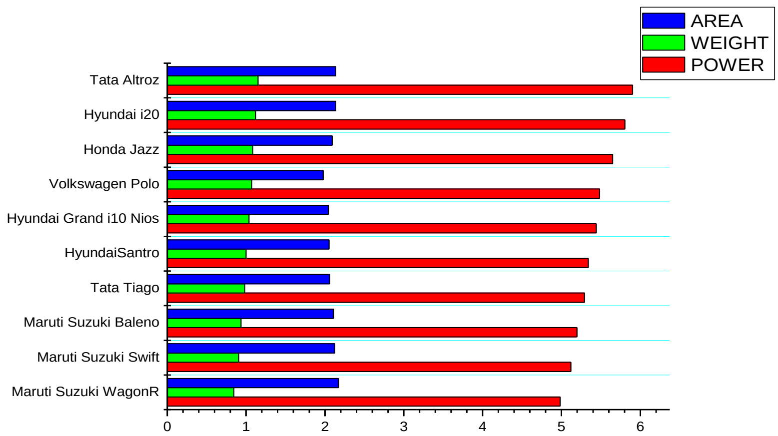

Fig. 3. Hatchbacks without driver

5.901772639 kW. Also, according to the results, the frontal projected area is not the highest, implying that air resistance is not the largest, but the combined resistance (Air resistance + Rolling resistance) effect is greater, resulting in a higher power required in the TATA Altroz. The same result may be seen in Fig. 3.

ii. Sedan without driver

For Sedan cars, ten sets of cars were chosen for power requirements analysis. According to Table 3, the Tayota Camry has the greatest Kerb weight of 1.84 ton. Because of this Kerb weight, the rolling resistance is likewise the highest in

Table. 3. Sedan without driver

Model	Weight : Kerb (ton)	Projected Frontal Area (m^2)	Air Resistance (R_a)	Aero Dynamic Drag force	Rolling Resistance(R_r)	Total Resistance (R)=R_a+R_r	POWER (KW) Required to Propel the Vehicle
Maruti Suzuki Dzire	1.735	2.10282	162.96855	1224.89265	206.241	369.20955	5.127910417
Hyundai Aura	1.68	2.04288	158.3232	1189.9776	239.8256	398.1488	5.529844444
Honda Amaze	1.695	2.170956	168.24909	1264.58187	238.6986	406.94769	5.65205125
Maruti Suzuki Ciaz	1.73	2.05524	159.2811	1197.1773	255.829	415.1101	5.765418056
Toyota Yaris	1.73	2.06908	160.3537	1205.2391	255.829	416.1827	5.780315278
Volkswagen Vento	1.699	1.9939464	154.530846	1161.473778	265.7466	420.277446	5.83718675
Honda City	1.748	2.0822176	161.371864	1212.891752	273.6356	435.007464	6.041770333
Hyundai Verna	1.729	2.04022	158.11705	1188.42815	284.004	442.12105	6.140570139
Honda Civic	1.799	2.0623736	159.833954	1201.332622	293.02	452.853954	6.28963825
Toyota Camry	1.84	2.14176	165.9864	1247.5752	375.291	541.2774	7.517741667

value (375.291 N), increasing the power required to operate the vehicle. In comparison to others, the power required for the Toyota Camry is 7.517741667 kW.

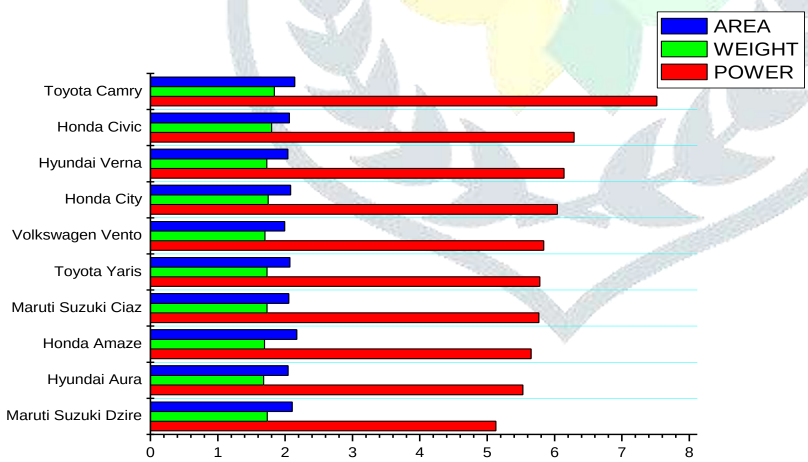

Fig. 4. Sedan without driver

Also, according to the results, the frontal projected area is not greatest, and thus air resistance is not maximum, but the combined resistance (Air resistance + Rolling resistance) effect is greater, which contributes to an increase in power required in the Toyota Camry. Also Fig. 4. indicating Toyota Camry has highest power requirement.

iii. Sports Utility Vehicle (SUV) without driver

For the examination of power needs for Sports Utility Vehicle (SUV) cars, ten sets of cars were chosen. Table 4 shows that the Mahindra XUV 500 has the highest Kerb weight of 2.51 ton. As a result of the increased kerb weight, the rolling resistance is at its greatest value of 565.754 N, resulting in a higher power needed to operate the car. In contrast to other vehicles, the Mahindra XUV 500 requires the most power with 10.51679008 kW.

Table. 4. Sports Utility Vehicle (SUV)

Model	Weight : Kerb (ton)	Projected Frontal Area (m^2)	Air Resistance (R_a)	Aero Dynamic Drag Force	Rolling Resistance (R_r)	Total Resistance $(R)=R_a+R_r$	POWER(KW) Required to Propel the Vehicle
Hyundai Creta	1.367	2.34132	181.4523	1363.8189	308.1218	489.5741	6.799640278
Kia Seltos	1.361	2.3688	183.582	1379.826	306.7694	490.3514	6.810436111
Tata Harrier	1.575	2.5849312	200.332168	1505.722424	355.005	555.337168	7.713016222
MG Hector	1.687	2.58368	200.2352	1504.9936	380.2498	580.485	8.062291667
Mahindra Thar	1.75	2.6414704	204.713956	1538.656508	394.45	599.163956	8.321721611
Tata Safari	1.825	2.7061472	209.726408	1576.330744	411.355	621.081408	8.626130667
Toyota Fortuner	1.955	2.72314	211.04335	1586.22905	440.657	651.70035	9.05139375
Mahindra Scorpio	1.92	2.90472	225.1158	1691.9994	432.768	657.8838	9.137275
Ford Endeavour	2.415	2.7466824	212.867886	1599.942498	544.341	757.208886	10.51679008
Mahindra XUV500	2.51	2.69892	209.1663	1572.1209	565.754	774.9203	10.76278194

Also, according to the results, the frontal projected area is not the highest, implying that airresistance is not the largest, but the combined resistance (Air resistance + Rolling resistance) impact is greater, resulting in a higher power need in the Mahindra XUV 500. The similar result may be seen in Fig. 5.

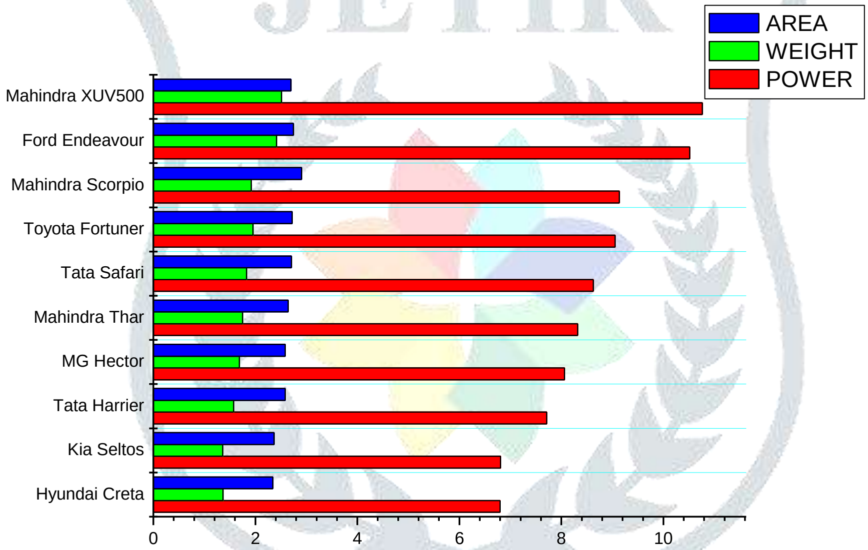

Fig. 5. Sports Utility Vehicle (SUV)

iv. Hatchbacks with driver

For the analysis of power requirements for Hatchback cars, ten sets of cars were chosenwith one driver where assume weight of drive 60Kg. Table. 5. shows that the TATA Altroz has the highest Kerb weight of 1.21ton. As a result of the increased kerb weight, the rolling resistance is at its greatest value of 272.734N, resulting in a higher

Table. 5. Hatchbacks with driver

model	weight with driver	Area in m^2	Air resistance (R_a)	Aero dynamic dragforce	rolling resistance (R_r)	$R=R_a+R_r$	POWER (kW)
Maruti Suzuki WagonR	0.905	2.1708	168.237	1264.491	203.987	372.224	5.169777778
Maruti Suzuki Swift	0.965	2.12364	164.5821	1237.0203	217.511	382.0931	5.306848611
Maruti Suzuki Baleno	0.995	2.10796	163.3669	1227.8867	224.273	387.6399	5.3838875
Tata Tiago	1.042	2.059356	159.60009	1199.57487	234.8668	394.46689	5.478706806
HyundaiSantro	1.06	2.05296	159.1044	1195.8492	238.924	398.0284	5.528172222
Hyundai Grand i10 Nios	1.096	2.04288	158.3232	1189.9776	247.0384	405.3616	5.630022222

Volkswagen Polo	1.132	1.9766864	153.193196	1151.419828	255.1528	408.345996	5.671472167
Honda Jazz	1.145	2.0924288	162.163232	1218.839776	258.083	420.246232	5.836753222
Hyundai i20	1.179	2.1371	165.62525	1244.86075	265.7466	431.37185	5.991275694
Tata Altroz	1.21	2.138292	165.71763	1245.55509	272.734	438.45163	6.089605972

power requirement to operate the car. In contrast to other vehicles, the TATA Altrozrequires the most power with 6.089605972kW. Also, according to the results, the frontal projected area is not the highest, implying that air resistance is not the largest, but the combined resistance (Air resistance + Rolling resistance) effect is greater, resulting in a higher power required in the TATA Altroz. The same result may be seen in Fig. 6.

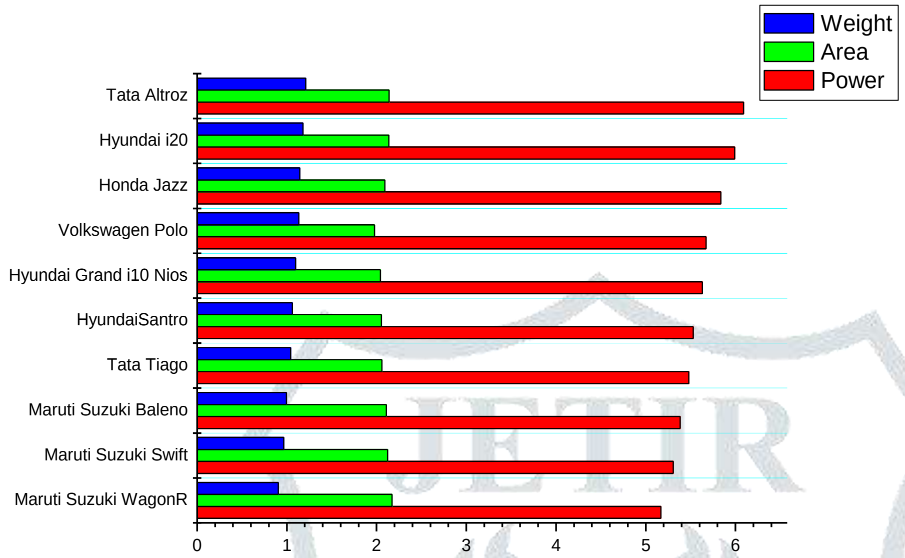

Fig. 6. Hatchbacks with driver

vi. Utility Vehicle (SUV)with driver

For the examination of power needs for Sports Utility Vehicle (SUV) cars, ten sets of cars were chosen with one driver where assume weight of drive 60Kg. Table 7 shows that the Mahindra XUV 500 has the highest Kerb weight of 2.57ton. As a result of the increased kerb weight, the rolling resistance is at its greatest value of 579.278N, resulting in a higher power needed to operate the car. In contrast to other vehicles, the Mahindra XUV 500 requires the most power with 10.95061528 kW.

Table. 7. Sports Utility Vehicle (SUV)

model	weight with one driver	weight (W)	Area in m^2	Air resistance (Ra)	Aero dynamic dragforce	rolling resistance(R_r)	$R=R_a+R_r$	POWER(KW)
Hyundai Creta	1.427	13984.6	2.34132	181.4523	1363.8189	321.6458	503.0981	6.987473611
Kia Seltos	1.421	13925.8	2.3688	183.582	1379.826	320.2934	503.8754	6.998269444
Tata Harrier	1.635	16023	2.5849312	200.332168	1505.722424	368.529	568.8612	7.900849556
MG Hector	1.747	17120.6	2.58368	200.2352	1504.9936	393.7738	594.009	8.250125
Mahindra Thar	1.81	17738	2.6414704	204.713956	1538.656508	407.974	612.688	8.509554944
Tata Safari	1.885	18473	2.7061472	209.726408	1576.330744	424.879	634.6054	8.813964
Toyota Fortuner	2.005	19649	2.72314	211.04335	1586.22905	451.927	662.9704	9.207921528
Mahindra Scorpio	1.98	19404	2.90472	225.1158	1691.9994	446.292	671.4078	9.325108333
Ford Endeavour	2.475	24255	2.7466824	212.867886	1599.942498	557.865	770.7329	10.70462342
Mahindra XUV500	2.57	25186	2.69892	209.1663	1572.1209	579.278	788.4443	10.95061528

Also, according to the results, the frontal projected area is not the highest, implying that air resistance is not the largest, but the combined resistance (Air resistance + Rolling resistance) impact is greater, resulting in a higher power need in the Mahindra XUV 500. The similar result may be seen in Fig. 8.

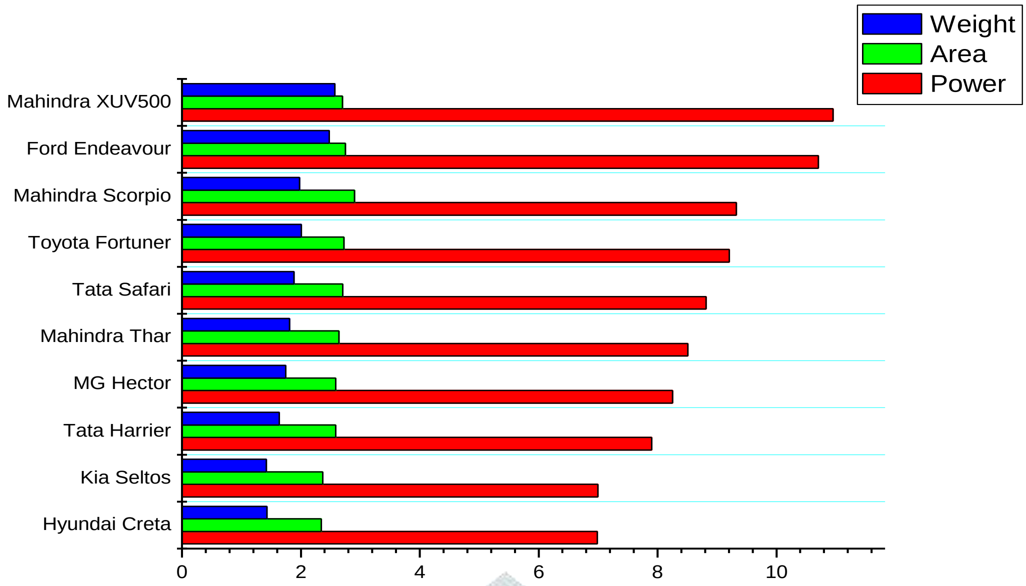

Fig. 8. Sports Utility Vehicle (SUV)

VIII. CONCLUSION

There are three sorts of resistances that a car encounters when in motion: air resistance, grade resistance, and rolling resistance, and these are the parameters to consider when determining the power necessary to drive or push a vehicle.

An automobile's frontal projected area has a significant impact on its ability to travel through air fast. The coefficient rolling resistance of every vehicle is determined by the road surface and vehicle type.

According to the research, the most fuel-efficient hatchback car for any client is the **Maruti Suzuki WagonR.**

The frontal area of the **Maruti Suzuki Dzire** is unimpressive, but due to the low weight of the vehicles in its class, it is the most mileage-efficient car.

According to the information presented above, the most fuel-efficient **SUV** for any client is the **Hyundai Creta**.

The variance in power required by vehicles with varied frontal areas has been assessed on a small sample set of Top 10 **Sedan**, **Hatchback**, and **SUV** in this research study. This project model may be used on a wider collection of data. This allows comparisons of the variance in the value of the power required by vehicles with varying frontal areas under various settings. A star rating may be provided to each car by considering correct standards, which will eventually assist buyers in selecting the finest (efficient) product available.

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