

CFD Analysis of Airflow around A F1 Race Car to Test Aerodynamics

N. Lenin Rakesh, Prabhu Teja, M. Sandeep, M. Madini Babu and
M. Sai Pavan

Abstract--- *The sport of Formula 1 (F1) has been a proving ground for race fanatics and engineers for more than half a century. With every driver wanting to go faster and beat the previous best time, research and innovation in engineering of the car is really essential. Although higher speeds are the main criterion for determining the Formula 1 car's aerodynamic setup, post the San Marino Grand Prix of 1994, the engineering research and development has also targeted for driver's safety. The governing body of Formula 1, i.e. Fédération Internationale de l'Automobile (FIA) has made significant rule changes since this time, primarily targeting car safety and speed. Aerodynamic performance of a F1 car is currently one of the vital aspects of performance gain, as marginal gains are obtained due to engine and mechanical changes to the car. Thus, it has become the key to success in this sport, resulting in teams spending millions of dollars on research and development in this sector each year. Although F1 car aerodynamics is at a highly advanced stage, there is always potential for further development.*

Keywords--- *Test Aerodynamics, Airflow, CFD Analysis.*

I. INTRODUCTION

The sport of Formula 1 (F1) has been a proving ground for race fanatics and engineers for more than half a century. With every driver wanting to go faster and beat the previous best time, research and innovation in the engineering of the car are really essential. Due to the marginal gains that can be obtained by engine and mechanical changes to the car, aerodynamics of a F1 car has become one of the major aspects of performance gain. Thus, it is a key element to success in the sport, resulting in teams spending millions of dollars on research and development in this area every year. A Formula 1 car is an open-wheeled rear-wheel drive vehicle, the design of which is regulated and governed by strict set of rules. According to Willem Toet (Toet, 2013), the key attributes of a current F1 car are:

1. A top speed of up to 350kph (217.5mph), depending on the circuit.
2. Acceleration of 2.6 secs for speed range of 0 – 100kph (0 – 62.14mph).
3. Deceleration from 200 – 0kph (124.27 – 0mph) in about 2.0 secs.
4. Loads of $\geq 5g$ in braking (longitudinal acceleration) and $\geq 4g$.
5. No movable aerodynamic components of bodywork, except F1 body regulated DRS system.

N. Lenin Rakesh, Assistant Professor, Department of Mechanical Engineering, BIST, BIHER, Bharath Institute of Higher Education & Research, Selaiyur, Chennai.

Prabhu Teja, UG Scholar, Department of Mechanical Engineering, BIST, BIHER, Bharath Institute of Higher Education & Research, Selaiyur, Chennai.

M. Sandeep, UG Scholar, Department of Mechanical Engineering, BIST, BIHER, Bharath Institute of Higher Education & Research, Selaiyur, Chennai.

M. Madini Babu, UG Scholar, Department of Mechanical Engineering, BIST, BIHER, Bharath Institute of Higher Education & Research, Selaiyur, Chennai.

M. Sai Pavan, UG Scholar, Department of Mechanical Engineering, BIST, BIHER, Bharath Institute of Higher Education & Research, Selaiyur, Chennai.

The cars are optimized for each and every circuit, starting from a base design at the start of the season. The base design changes every year in order to comply with the new sets of rules and regulations imposed. The rate of evolution of the car over a season is so high, that the end of the season car is normally a full second faster than the base design at the start of the season.

History of Development of Aerodynamics in Formula 1

First Formula 1 car designed in 1950. (Hanlon, 2010)

The first Formula 1 championship season started in the year 1950. The era from 1950-1957 mainly comprised of front-engine, front-wheel drive cars, with absolutely no aerodynamics involved. As there were no strict rules about designing the car (mainly the dimensioning of the car), there was a lot of freedom for designers to come up with innovative designs. Through the seasons, the cars' height started becoming lower (to seek advantages of low center of gravity), radiators and air intakes became bigger to increase engine power and efficiency, wheels became smaller and wider to provide more stability and grip, engines started moving towards the rear, and so on, all in order to go faster.

Front Wings

The front wing is considered to be, aerodynamically, the most efficient and the most important device on the F1 car, as it is the first component of the bodywork to come in contact with the undisturbed air. It is primarily responsible for generating downforce to aid high cornering speeds. The wings are inverted (in comparison to aircraft), with the suction side of the airfoil towards the ground, in close proximity to it. This is done to take advantage of ground effect, which are discussed in detail in Section 2.2. The design of the front wing is mainly dictated by the flow field required by the rest of the car. It might be required to sacrifice some downforce at the front wing to improve the overall aerodynamic balance and performance of the car.

Downforce

The length and, to some extent, the design of the front wing is governed by the rules stated by the FIA. Currently, the front wing span is fixed at

doesn't contribute to the downforce (Toet, 2013). The modified splitter plates that structurally connect the body with the wing are used to channelize the flow underneath the floor. As seen in the figure, there are multiple flaps, guide vanes and specially crafted endplates on the front wing. The main purpose of the flaps is to increase the downforce levels. The slots and guide vanes are used to divert the airflow, either towards the radiators and underneath the bodywork

or around the tires. The performance of the front wing is also dependent on the presence of the front wheels. Agathangelou & Gascoyne (Agathangelou & Gascoyne, 1998) stated that as the wheel rotates at high velocities, a high-pressure zone forms in region upstream of the tire contact patch, due to the jetting effect. It was a result of interaction between the contact patch of the tire and the airstream incident on it. The airflow squeezes out from either sides of the wheel, thus creating

jet vortices that reduce the effectiveness of the front wing. Jasinski & Selig (1998) made a similar observation. Hence, the endplates and guide vanes on modern F1 cars are designed in such a way that they divert the flow away from the tires. Endplates also help control the wingtip effects associated with finite spans. This also helps in increasing the downforce at wing tips

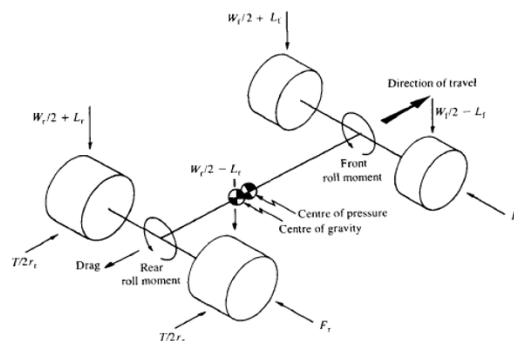
(Dominy, 1992). The wake generated from the front wings influences the airflow over rest of the body, in particular towards the radiators, thus influencing the cooling performance of the car. The greater the incidence of the airfoil, the greater is the influence of its wake on the cooling flow

(Dominy, 1992). Thus, the design of the front wing is based on downforce requirements at the front and airflow to different components of the car. Jasinski & Selig (1998) identified crucial factors affecting the design of the front wing. It was noted that a flap deflection of 100 improved the CL by 0.5, with no significant change in drag coefficient. The added area due to the use of flap also aided to the increment of the lift coefficient of the wing, due to increase in aerodynamic loading. The authors also stated that increase in endplate planform improves overall lift coefficient of the wing and also aids in reduction of drag coefficient.

Rear Wings

While the front wing is considered to be the most efficient component of the F1 car, the rear wing, on the contrary, is highly inefficient. The airflow over the rear wing is very complex, as it is exposed to unsteady, turbulent flows arising from the front wing, wheels, cockpit, radiators, air intake, exhaust and other numerous other upstream influences. Due to these turbulent flows, the performance of the rear wing is significantly reduced. Aerodynamic stability of the car is important for peak performance of the car as well as driver's safety. To maintain the aerodynamic balance, the rear wing is required to produce almost similar, if not more, levels of downforce. Huge oversteer occurs for the car while negotiating a turn, if the location of center of gravity is aft of that of the aerodynamic center of pressure along the car's length. Therefore, to generate large amount of downforce from the rear wing exposed to 18 turbulent air the flaps are deflected to very high angles. Such high values of camber, however, results in significant increase in drag. As seen from, the rear wing contributes 28% of the total drag. Thus, the design of rear wing becomes a tradeoff study between management of

lift and drag values. Optimum balance being dependent on the lift coefficients of the wings, therefore, becomes a function of the track.



Even with such high drag penalty, rear wing is a very important component of the F1 car. Generally, it is structurally stronger as compared to front wing. No changes are made to the rear wing once the setup is complete. The aerodynamic balance is changed by changing the incidence of the front wing. Loss of the rear wing during a collision can create loss up to 40 %

of the total downforce (Toet, 2013), and render the car un-drivable. Loss of front wing can be fixed by changing the nose section, which can be replaced in less than 10 secs. A typical rear wing for a present day F1 car is shown in

Ground Effect Aerodynamics

Ground effect aerodynamics is basically generation of downforce by maintaining low clearances between the underside of the car and the track. The air flowing beneath the car accelerates as it channels under the nose of the F1 car towards the floor of the car. At the same time, as the freestream velocity over the car is slower when compared the bottom, it creates a pressure differential. This results in generation of downforce. Dominy (Dominy, 1992) states that the undertray of the F1 car is situated little behind the nose, as the designers need to push the low pressure zone to as rearward position as possible. A separation bubble is formed at the leading edge of the undertray, where the flow separates due to its sharp edge and forms underneath it. With the area of entry reduced even further, the airflow gains more acceleration. Addition of diffuser behind the undertray creates a further low pressure zone around the transition point between the undertray and the diffuser. The generation of a low pressure zone helps in drawing out the accelerating airflow beneath the car. As shown in Fig 2.1, the floor and diffuser combination provides for 55% of the total contribution. Ground effect also help increase the effective downforce generated by the wings in close proximity to the ground. Investigations conducted by Zerihan and Zhang (Zerihan & Zhang, 2000) and Ranzenbach and Barlow (Ranzenbach & Barlow, 1996) found out that under the influence of ground effects the downforce on a single element increased up to a certain maximum.

CATIA

Catia is a multi-platform software suite for computer- aided design (CAD), computer –aided manufacturing (CAM), computer –aided engineering (CAE), PLM and 3D, developed by the French company Dassault systems. Catia offers a solution to shape design, styling, surfacing workflow and visualization to create, modify and validate complex innovative shapes from industrial design to class-A surfacing with the ICEM surfacing technologies. CATIA supports multiple stages of product design whether started from scratch or from 2D sketches. Sketcher to create basic shape of heat exchanger. Part Modelling - TO Develop a 3D model from basic sketch Assembly Design TO assembly the heat exchangers

ANSYS

Fluent software contains the broad, physical modelling capabilities needed to model flow, turbulence, heat transfer and reactions for industrial applications. These range from air flow over an aircraft wing to combustion in a furnace, from bubble columns to oil platforms, from blood flow to semiconductor manufacturing and from clean room design to wastewater treatment plants.

Fluent spans an expansive range, including special models, with capabilities to model in-cylinder combustion, aero-acoustics, turbomachinery and multiphase systems. Fluent also offers highly scalable, high-performance computing (HPC) to help solve complex, large-model computational fluid dynamics (CFD) simulations quickly and cost-effectively.

Ansys, Inc. is a public company based in Canonsburg, Pennsylvania. It develops and markets engineering simulation software. Ansys software is used to design products and semiconductors, as well as to create simulations that test a product's durability, temperature distribution, fluid movements, and electromagnetic properties. Ansys develops and markets Finite Element Analysis software used to simulate engineering problems. The software creates simulated computer models of structures, electronics, or machine components to simulate strength, toughness, elasticity, temperature distribution, electromagnetism, fluid flow, and other attributes. Ansys is used to determine how a product will function with different specifications, without building test products or conducting crash tests. For example, Ansys software may simulate how a bridge will hold up after years of traffic, how to best process salmon in a cannery to reduce waste, or how to design a slide that uses less material without sacrificing safety. Most Ansys simulations are performed using the Ansys Workbench software, which is one of the company's main products.

II. SUMMARY AND RESULTS

i. The objective of this study was to develop a methodology to create plots depicting the sensitivity of lap times performed by a F1 car around a particular track to the aerodynamic coefficients of the front and rear wings.

ii. After providing a historical background of the sport of Formula 1 and developments in the field of race aerodynamics in this sport, a literature review was conducted to develop a focus area for this research study.

iii. An introduction was provided for the genetic algorithm (CMA-ES) used for optimization of key variables. Also, AeroLap, which is a lap simulation tool used for simulating an actual F1 race, was presented and the key components being used for the study were briefly described.

iv. Malaysian F1 GP track was selected for the study, as this track is a perfect mix of long straights that require drag reduction as main design philosophy, and fast corners that require high levels of downforce.

v. The track boundaries and centerline were established using a geo-mapping tool called ArcGIS. With X and Y coordinates for the data points collected being established, the radius of curvature was calculated for the turns, using Taubin's method.

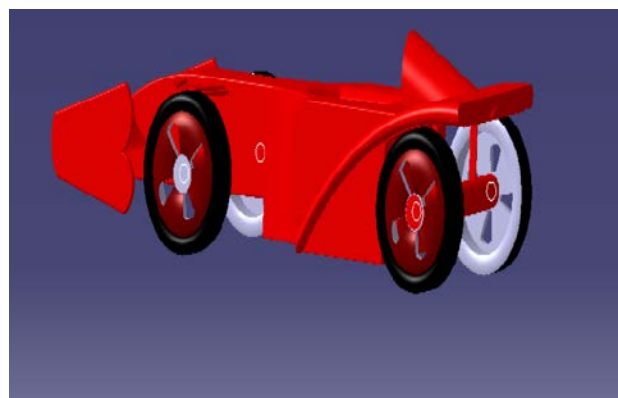
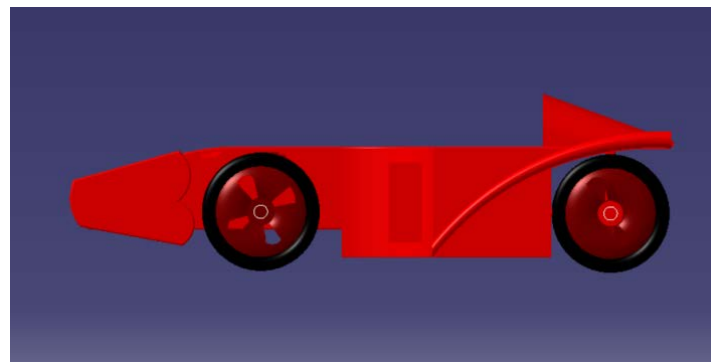
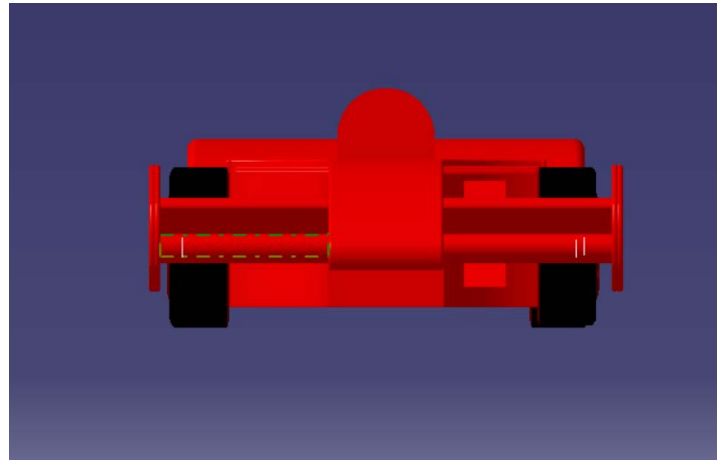
vi. An optimization using CMA-ES was performed to determine the optimal racing line used along the track. The resulted best lap time was 1.699 seconds faster than the lap performed by an actual F1 car with similar setup. However, the distance covered was 69 m lesser.

Assuming that the total error was due to mapping issues only, the normalized lap time with same distance as an official lap length was found out to be 0.542 seconds quicker.

vii. It was established that the total value of aerodynamic forces can be calculated as superposition of the aerodynamic forces generated by individual components, namely, front assembly, rear wing assembly, and body without wings.

viii. The base values of the aerodynamic coefficients of body without wings were established, as the front wing and rear wing coefficients were required to be optimized with no change in aerodynamic setup of the body.

ix. Once the base values of all the required components were established, and the car setup's variables being locked, the optimum values of lift and drag coefficients for the front and rear wings were calculated using CMA-ES and AeroLap



REFERENCES

- [1] Thooyamani, K.P., Khanaa, V., & Udayakumar, R. (2014). Virtual instrumentation based process of agriculture by automation. *Middle-East Journal of Scientific Research*, 20(12): 2604-2612.

- [2] Udayakumar, R., Kaliyamurthie, K.P., & Khanaa, T.K. (2014). Data mining a boon: Predictive system for university topper women in academia. *World Applied Sciences Journal*, 29(14): 86-90.
- [3] Anbuselvi, S., Rebecca, L.J., Kumar, M.S., & Senthilvelan, T. (2012). GC-MS study of phytochemicals in black gram using two different organic manures. *J Chem Pharm Res.*, 4, 1246-1250.
- [4] Subramanian, A.P., Jaganathan, S.K., Manikandan, A., Pandiaraj, K.N., Gomathi, N., & Supriyanto, E. (2016). Recent trends in nano-based drug delivery systems for efficient delivery of phytochemicals in chemotherapy. *RSC Advances*, 6(54), 48294-48314.
- [5] Thooyamani, K.P., Khanaa, V., & Udayakumar, R. (2014). Partial encryption and partial inference control based disclosure in effective cost cloud. *Middle-East Journal of Scientific Research*, 20(12), 2456-2459.
- [6] Lingeswaran, K., Prasad Karamcheti, S.S., Gopikrishnan, M., & Ramu, G. (2014). Preparation and characterization of chemical bath deposited cds thin film for solar cell. *Middle-East Journal of Scientific Research*, 20(7), 812-814.
- [7] Maruthamani, D., Vadivel, S., Kumaravel, M., Saravanakumar, B., Paul, B., Dhar, S.S., Manikandan, A., & Ramadoss, G. (2017). Fine cutting edge shaped Bi₂O₃rods/reduced graphene oxide (RGO) composite for supercapacitor and visible-light photocatalytic applications. *Journal of colloid and interface science*, 498, 449-459.
- [8] Gopalakrishnan, K., Sundeep Aanand, J., & Udayakumar, R. (2014). Electrical properties of doped azopolyester. *Middle-East Journal of Scientific Research*, 20(11). 1402-1412.
- [9] Subhashree, A.R., Parameaswari, P.J., Shanthi, B., Revathy, C., & Parijatham, B.O. (2012). The reference intervals for the haematological parameters in healthy adult population of chennai, southern India. *Journal of Clinical and Diagnostic Research: JCDR*, 6(10), 1675-1680.
- [10] Niranjana, U., Subramanyam, R.B.V., & Khanaa, V. (2010, September). Developing a web recommendation system based on closed sequential patterns. In *International Conference on Advances in Information and Communication Technologies*, 101, 171-179. Springer, Berlin, Heidelberg.
- [11] Slimani, Y., Baykal, A., & Manikandan, A. (2018). Effect of Cr³⁺ substitution on AC susceptibility of Ba hexaferrite nanoparticles. *Journal of Magnetism and Magnetic Materials*, 458, 204-212.
- [12] Premkumar, S., Ramu, G., Gunasekaran, S., & Baskar, D. (2014). Solar industrial process heating associated with thermal energy storage for feed water heating. *Middle East Journal of Scientific Research*, 20(11), 1686-1688.
- [13] Kumar, S.S., Karrunakaran, C.M., Rao, M.R.K., & Balasubramanian, M.P. (2011). Inhibitory effects of *Indigofera aspalathoides* on 20-methylcholanthrene-induced chemical carcinogenesis in rats. *Journal of carcinogenesis*, 10.
- [14] Beula Devamalar, P.M., Thulasi Bai, V., & Srivatsa, S.K. (2009). Design and architecture of real time web-centric tele health diabetes diagnosis expert system. *International Journal of Medical Engineering and Informatics*, 1(3), 307-317.
- [15] Ravichandran, A.T., Srinivas, J., Karthick, R., Manikandan, A., & Baykal, A. (2018). Facile combustion synthesis, structural, morphological, optical and antibacterial studies of Bi_{1-x}Al_xFeO₃ (0.0 ≤ x ≤ 0.15) nanoparticles. *Ceramics International*, 44(11), 13247-13252.
- [16] Thovhogi, N., Park, E., Manikandan, E., Maaza, M., & Gurib-Fakim, A. (2016). Physical properties of CdO nanoparticles synthesized by green chemistry via *Hibiscus Sabdariffa* flower extract. *Journal of Alloys and Compounds*, 655, 314-320.
- [17] Thooyamani, K.P., Khanaa, V., & Udayakumar, R. (2014). Wide area wireless networks-IETF. *Middle-East Journal of Scientific Research*, 20(12), 2042-2046.
- [18] Sundar Raj, M., Saravanan, T., & Srinivasan, V. (2014). Design of silicon-carbide based cascaded multilevel inverter. *Middle-East Journal of Scientific Research*, 20(12), 1785- 1791.
- [19] Achudhan, M., Jayakumar M.P. (2014). Mathematical modeling and control of an electrically-heated catalyst. *International Journal of Applied Engineering Research*, 9(23), 23013.
- [20] Thooyamani, K.P., Khanaa, V., & Udayakumar, R. (2013). Application of pattern recognition for farsi license plate recognition. *Middle-East Journal of Scientific Research*, 18(12), 1768-1774.
- [21] Jebaraj, S., Iniyana S. (2006). Renewable energy programmes in India. *International Journal of Global Energy Issues*, 26(43528), 232-257.
- [22] Sharmila, S., & Jeyanthi Rebecca, L. (2013). Md Saduzzaman., Biodegradation of domestic effluent using different solvent extracts of *Murraya koenigii*. *J Chem and Pharm Res*, 5(2), 279-282.

- [23] Asiri, S., Sertkol, M., Guner, S., Gungunes, H., Batoo, K.M., Saleh, T.A., Manikandan A., & Baykal, A. (2018). Hydrothermal synthesis of $\text{CoZnMn}_{1-2y}\text{Fe}_2\text{O}_4$ nanoferrites: magneto-optical investigation. *Ceramics International*, 44(5), 5751-5759.
- [24] Rani, A.J., & Mythili, S.V. (2014). Study on total antioxidant status in relation to oxidative stress in type 2 diabetes mellitus. *Journal of clinical and diagnostic research: JCDR*, 8(3), 108-110.
- [25] Karthik, B. (2014). Arulselvi, Noise removal using mixtures of projected gaussian scale mixtures. *Middle-East Journal of Scientific Research*, 20(12), 2335-2340.
- [26] Karthik, B., Arulselvi, & Selvaraj, A. (2014). Test data compression architecture for low power VLSI testing. *Middle - East Journal of Scientific Research*, 20(12), 2331-2334.
- [27] Vijayaragavan, S.P., Karthik, B., & Kiran Kumar, T.V.U. (2014). Privacy conscious screening framework for frequently moving objects. *Middle-East Journal of Scientific Research*, 20(8), 1000-1005.
- [28] Kaliyamurthie, K.P., Parameswari, D., & Udayakumar, R. (2013). QOS aware privacy preserving location monitoring in wireless sensor network. *Indian Journal of Science and Technology*, 6(5), 4648-4652.
- [29] Silambarasu, A., Manikandan, A., & Balakrishnan, K. (2017). Room-temperature superparamagnetism and enhanced photocatalytic activity of magnetically reusable spinel ZnFe_2O_4 nanocatalysts. *Journal of Superconductivity and Novel Magnetism*, 30(9), 2631-2640.
- [30] Jasmin, M., Vigneshwaran, T., & Beulah Hemalatha, S. (2015). Design of power aware on chip embedded memory based FSM encoding in FPGA. *International Journal of Applied Engineering Research*, 10(2), 4487-4496.
- [31] Philomina, S., & Karthik, B. (2014). Wi-Fi energy meter implementation using embedded linux in ARM 9. *Middle-East Journal of Scientific Research*, 20, 2434-2438.
- [32] Vijayaragavan, S.P., Karthik, B., & Kiran Kumar, T.V.U. (2014). A DFIG based wind generation system with unbalanced stator and grid condition. *Middle-East Journal of Scientific Research*, 20(8), 913-917.
- [33] Rajakumari, S.B., & Nalini, C. (2014). An efficient data mining dataset preparation using aggregation in relational database. *Indian Journal of Science and Technology*, 7, 44-46.
- [34] Karthik, B., Kiran Kumar, T.V.U., Vijayaragavan, P., & Bharath Kumaran, E. (2013). Design of a digital PLL using $0.35\ \mu\text{m}$ CMOS technology. *Middle-East Journal of Scientific Research*, 18(12), 1803-1806.
- [35] Sudhakara, P., Jagadeesh, D., Wang, Y., Prasad, C.V., Devi, A.K., Balakrishnan, G., Kim B.S., & Song, J.I. (2013). Fabrication of Borassus fruit lignocellulose fiber/PP composites and comparison with jute, sisal and coir fibers. *Carbohydrate polymers*, 98(1), 1002-1010.
- [36] Kanniga, E., & Sundararajan, M. (2011). Modelling and characterization of DCO using pass transistors. In *Future Intelligent Information Systems*, 86(1), 451-457. Springer, Berlin, Heidelberg.
- [37] Sachithanandam, P., Meikandaan, T.P., & Srividya, T. Steel framed multi storey residential building analysis and design. *International Journal of Applied Engineering Research*, 9(22), 5527-5529.
- [38] Kaliyamurthie, K.P., Udayakumar, R., Parameswari, D., & Mugunthan, S.N. (2013). Highly secured online voting system over network. *Indian Journal of Science and Technology*, 6(S6), 4831-4836.
- [39] Sathyaseelan, B., Manikandan, E., Lakshmanan, V., Baskaran, I., Sivakumar, K., Ladhumananandasivam, R., Kennedy, J., & Maaza, M. (2016). Structural, optical and morphological properties of post-growth calcined TiO_2 nanopowder for opto-electronic device application: Ex-situ studies. *Journal of Alloys and Compounds*, 671, 486-492.
- [40] Saravanan, T., Sundar Raj M., & Gopalakrishnan K. (2014). SMES technology, SMES and facts system, applications, advantages and technical limitations. *Middle - East Journal of Scientific Research*, 20(11), 1353-1358.
- [41] Kavitha, A., & Dr.AyyaMuthu Kumar, D. (2019). Different Traffic Profiles for Wireless Network. *Bonfring International Journal of Software Engineering and Soft Computing*, 9(1), 17-19.
- [42] Gowsalya, R., & Dr.Thirumoorthy, P. (2019). A Survey on Big Data Security and Related Techniques to Improve Security. *Bonfring International Journal of Software Engineering and Soft Computing*, 9(2), 1-4.
- [43] Rajesh, R., Aruna, R., Bhuvanewari, D., Devi, Y., & Jeevitha, K. (2017). Handover Schemes in Heterogeneous LTE Network. *The SIJ Transactions on Computer Networks & Communication Engineering (CNCE)*, 5(3), 4-7.
- [44] Anbuselvan, N., Rajesh, R., Haridoss, G., Ameen, P.K., Durai, G., & Aravindkumar, K. (2017). Bio-Conservation using Wavelet Analysis by Monitoring Databases. *The SIJ Transactions on Computer Networks & Communication Engineering (CNCE)*, 5(3), 8-11.

- [45] Sindhuja, S., Salma, S., Selvi, S., Shimalini, S., & Dr. Baskaran, S. (2017).DC and Breakdown Characterization of InGaAs based on HEMTs. *The SIJ Transactions on Computer Networks & Communication Engineering (CNCE)*, 5(4), 1-3.
- [46] Magesh Babu, M., Vishnu Priya, J., Vimala, K., Vithya, V., & Yuvarani Mangalam, P. (2017).A Trustworthiness of Traffic Data and Mobile Nodes using VANET. *The SIJ Transactions on Computer Networks & Communication Engineering (CNCE)*, 5(4), 9-12.
- [47] Melkeri, V.S., Vani, R.M., & Hunagund, P.V. (2018). Chess Board Shape Defected Ground Structure for Multi Band Operation of Microstrip Patch Antenna. *Journal of Computational Information Systems*, 14(5), 73 - 78.
- [48] Shama, P.S. Sekhar, P.C., Shinde, S., Kalnoor, G., Gireesha, B. and Murali Krishna.B. V. (2018). An Optimized Operation of Hybrid Wind/Battery/PV-System based Micro grid by using Particle Swarm Optimization Technique. *Journal of Computational Information Systems*, 14(5), 79 - 84.
- [49] Dr.Berin Jones, C. (2018). Bilateral Filtering with Cosine Transform based Brain Tumor Classification. *Journal of Computational Information Systems*, 14(6), 103 - 111.
- [50] Dr.Anandan, R. (2018). Environmental Waste Management Using Electronic Grid. *Journal of Computational Information Systems*, 14(6), 112 – 117.