e-ISSN: 2582-5208
International Research Journal of Modernization in Engineering Technology and Science
(Peer-Reviewed, Open Access, Fully Refereed International Journal)
Volume:03/Issue:09/September-2021 Impact Factor- 6.752 www.irjmets.com

A REVIEW ON DESIGN FEATURES OF THE FALCON-9 SPACE LAUNCH VEHICLE

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ABSTRACT

From the start of space exploration through the Sputnik mission in 1957, there has been a lot of advancement in space technology, whether we talk about rockets or the satellites. With each rocket developed by space organizations all over the world, we have advanced each rocket with some of the other distinguishable features from the others. One such rocket is Falcon-9 developed by Space-X, which is one of the most advanced rockets of today with some distinguishable feature like reusability. This review focusses on the features which make Falcon-9 one of the most advanced rocket for today.

Keywords: Falcon-9, Space, Rocket, Falcon Heavy, Merlin Engine, Interstage.

I. INTRODUCTION

From Falcon-1 to Falcon-9 SpaceX have achieved huge advancements in space technology. Whether we talk about the retrieval of Stage-1 or the launch of 60 Starlink satellite in October 2020, Falcon-9 is undoubtedly the most advanced rocket of this period. Space exploration as it sounds by the name itself is an exceptionally fascinating subject of examination for some researchers. To know and to consider what secrets lies past the Earth has been the fundamental intention of many Space research associations. There are numerous advantages to space exploration. It permits to propel Science as well as encourages us to propel our assets. Like the Apollo Mission and the Hubble Space telescope offered numerous discoveries in cosmology and permitted us to watch worlds, stars and planets with substantially more subtleties than on earth. The vast majority of the space associations are looking for planets which can uphold human life. This aid in expanding our survivability as well as aides in finding minerals on different planets because the normal assets and minerals on earth are exhausting at a fast rate. So it is critical to look for choices or more minerals on different planets [1].

For this reason, we are sending people (space travellers) into the space utilizing different rockets [2]. One such rocket is Falcon-9. Falcon-9 is one of the most developed rockets present today with some special highlights like landing legs, reusability and so on which diminishes producing cost as well as has an extremely eased for each flight rate. Falcon-9 likewise has two variations. Falcon-9 and Falcon-9 (Heavy). These highlights of Falcon-9 makes it worthy of study [3].

There are various advantages for Falcon-9 compared to other space exploration vehicles. Longer range and payload for Mars Mission requires a large amount of food and supplies to initially establish a self-sustaining base on Mars [4]. Falcon-9's Merlin Engine has most noteworthy thrust to weight proportion of any boost engine at any point made than the engine utilized in Saturn-V and Apollo Mission and subsequently, Falcon-9 is equipped for lifting a humongous mass of around 63000 kg to the lower earth circle. Performance comparison of Falcon-9 and Falcon-9 (heavy) is given in the Table1.

Table 1. A brief comparison of Falcon-9 and Falcon-9 (heavy)

Model	**Falcon-9**	**Falcon-9 [Heavy]**
Price	$62 Million	$90 Million
Destination	**Performance**	**Performance**
Low earth orbit (LEO)	22,000 kg	63,500 kg
Geostationary transfer orbit (GTO)	8,500 kg	26,000 kg

Goods carried to Mars	4,200 kg	16,500 kg

Considering the orbit in consideration to be the low earth orbit (160-2000 km.) above earth Falcon-9 surface expendable cost is cheaper due to fixed manufacturing cost compared to other models [5]. Comparison of different models according to cost per flight are shown in Table 2.

Table 2. Cost per flight comparison of different models

Rocket	Cost per flight
Delta IV Heavy	14000 dollars/kg
Atlas V	8,300 dollars/kg
Ariane 5	7,000 dollars/kg
PSLV	6,500 dollars/kg
Falcon 9(Expandable)	4,000 dollars/kg
Falcon 9(Reusable)	2,200 dollars/kg
Falcon Heavy	1,400 dollars/kg

Another attractive and important advantage of Falcon-9 is its reusability. SpaceX has achieved reusability to a great extent by being able to land the first stage of rockets on land or drone ships and also using the landed course successfully for later missions. After 10 flights are over, the rocket is refurbished and ready for 10 more flights making the rocket's total life span of 100 flights. If reusability is achieved to the extent as planned by the SpaceX, the overall long term cost may probably drop down by a factor of 100 [6]. Additionally, Rocket launchers to the mars should have less time gap between them to ensure timely delivery of supplies or to initiate return during emergencies or even send people in batches using a single rocket, Falcon-9 takes less time interval between these stages compared to other models.

II. MODELING AND ANALYSIS

Overview of Falcon-9

Falcon-9 is a space launch vehicle (SLV) having its origin from Falcon-1 Rocket. Falcon-1 was an expendable launch vehicle developed in 2006-09 which can carry payload only once in space. The term 'Falcon' adopted from the fictional Falcon Spaceship depicted in 'Star Wars' movie and the number 9 represents the number of Merlin engines of the first stage of Falcon-9 rockets.

Specific design features of falcon-9 are explained below.

- **Engines**

Merlin Engine energises the Falcon-9. It comprises of most noteworthy pushed to weight proportion of any boost engine while ensuring the structural and thermal safety margin [7]. Merlin 1D has a thrust to weight ratio of 180 as compared to 94 of Saturn-V rockets of Apollo Missions [8]. There were a series of Merlin Engines which were gradually developed, innovated and perfected. It started with Merlin 1A engines used in the first stage of Falcon-1 rockets [9]. Hence it became the base for the development of more advanced and sophisticated Merlin Engines [10]. Merlin 1B engines were an upgraded version of Merlin 1A engines. It had higher thrust and was planned to be used on Falcon-9 but it was never used as work on Merlin 1C had started. Merlin 1C engines had powered both Falcon-1 and Falcon-9 rockets. It made the use of regenerative cooling [11]. This engine had another variant called Merlin Vacuum 1C. This had larger exhaust and nozzle with increased efficiency in the vacuum of space [12]. Merlin 1D engines were next in series. It was unique in many aspects. It has more than twice the thrust of Merlin 1A [13]. It can throttle thrust from 100% to 70%. Like Merlin 1C, it also has another variant called Merlin Vacuum 1D which can throttle down to 39% of its maximum thrust [14].

- **Octaweb Structure**

Merlin engines are arranged in an Octaweb. 'Octa' means 8 and 'web' depicts radiating lines from the centre. The Octaweb is a metal structure that supports 8 engines surrounding a central engine at the base of the launch vehicle(see Figure 1). In Falcon-9 version 1.0, the engines were configured in square 3×3 pattern but then

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improved to octaweb structure in version 1.1. This Octaweb structure simplifies the design and assembly of the engine section, streamlining the manufacturing process. This pattern also lightens the thrust structure, that is, the engine mounts and redistribute the much more powerful Merlin 1D's heavier load [15].

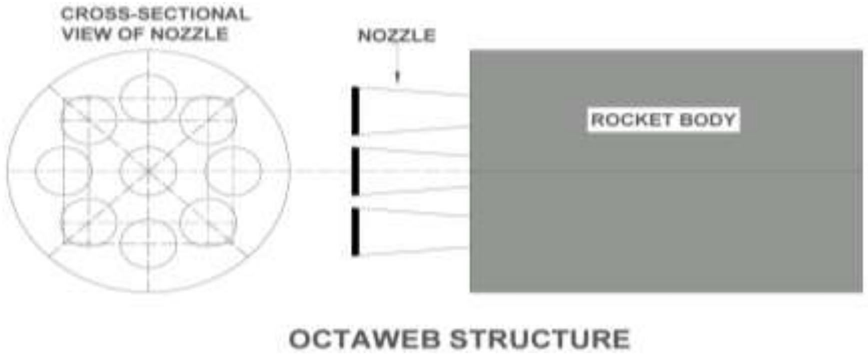

Figure 1. Octaweb structure of Merlin engines

- **Fuel Tank**

Falcon-9 tanks are made of Al-Li compound. This material is made strong and lighter than Al by the addition of Li ions. Since Lithium is the least dense elemental metal. Inside the second stage, there are two large tanks each capped with an Aluminium arch [16]. These tanks separately store liquid oxygen and rocket grade kerosene also called Rocket propellant. Liquid oxygen is the oxidizer which supports combustion in the vacuum of space [17]. Now to identify the locations of RP-1 tank and liquid oxygen tank, one interesting way is to see the landed rocket. When Falcon-9 takes off, it is completely white, but the landed one has a distinct demarcation of white and black regions [18]. This is due to the soot getting deposited on the rocket, during the re-entry burn and landing burn [19]. It doesn't get deposited on the upper half as liquid oxygen at cryogenic temperature results in ice formation, to which soot doesn't stick easily. RP-1 tank is located in the bottom and a liquid oxygen tank on top of it [20].

- **Landing Legs**

Falcon-9 is required to return to the launch site after completion of main mission requirements in the first stage. This feature of Falcon-9 makes it reusable and reduces machine expenses. For this purpose, there are four deployable landing legs which are made from state-of-the-art carbon fibre reinforced aluminium honeycomb structure (see Figure 2). It is set evenly around the base of the rocket. They are joined at the edge of the vehicle during take-off and later broaden outward and down for landing [21]. Honeycomb structures are typical or man-made structures that have the dimensions of a honeycomb to allow the minimization of the proportion of material used to show up at an inconsequential weight and material cost. They are widely used where high-strength and flat or slightly curved faces are needed. They are valuable because of their high specific strength or strength to weight ratio [22].

Figure 2. Schematic diagram of the landing legs of Falcon-9

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- **Grid Fin**

The initial stage is provided with hypersonic grid fin and not planar fins. One reason for such a design change is weight considerations. Grid fins are used during the re-entry and landing of the first stage of Falcon-9 rocket [23]. Originally, it was made from aluminium, but the latest version of Falcon-9 introduces newly forged titanium grid fins. This was done so because unlike the aluminium grid fins, the titanium is non-flammable, heat tolerant and does not require ablative paint. Thus they are much better suited to tolerate the high temperatures generated during the re-entry of the rocket in earth's atmosphere [24].

- **Nitrogen Thrusters**

The Falcon-9 first stage booster is equipped with two pods containing four nitrogen thrusters at the interstage that vent nitrogen gas. They are also called cold gas thrusters. Shortly after separating from the second stage, a short controlled blast from these thrusters flips the rocket which points the rocket engines in the backward direction, thus preparing for its return to the ground. It is quite a feat considering its size, but as the first stage is mostly out of the atmosphere so it is possible[25]. The cold gas thrusters then reorient the stage as needed with the engines pointing down so that when it hits the thicker atmosphere it is most aerodynamic to survive the heating. The thrusters provide sufficient force to control the booster's movement about the pitch, yaw and roll axes. Nitrogen gas is primarily used for thrusters due to its shortage of density, performance and lack of contamination concerns[26].

- **Interstage**

To connect the first and second stages, there is an Interstage. This contains let out and partition framework. Falcon-9 uses an all pneumatic stage separation system which utilizes gas or pressurized air. Helium is utilized as a working fluid for low-shock, an exceptionally dependable separation that can be tried on the ground [27]. The Interstage is synthesized composition involving an aluminium honeycomb center encompassed with carbon fibre sheets. Interstage is attached to the front end of the initial-stage tanks (see Figure 3). The stage separation framework situated at the front end of the first-stage tank and associates to the subsequent part. During separation of the initial stage, the interstage gets separated along with the first stage.

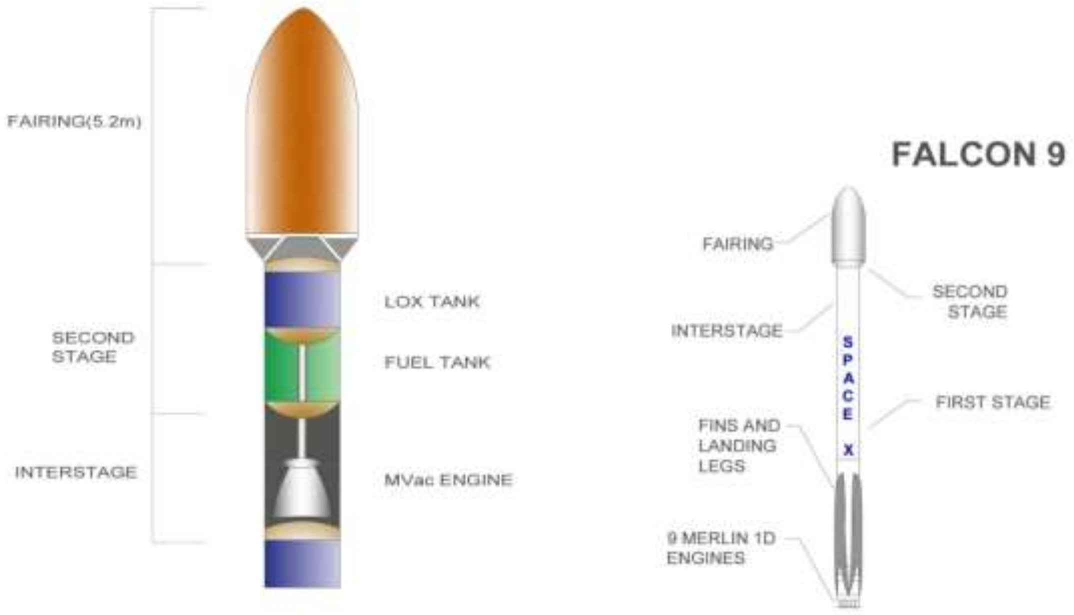

Figure 3. Parts of Falcon 9

Falcon-9's 2nd stage engine is fuelled by solitary Merlin Engine which is indistinguishable to the initial stage engine. Falcon-9 can comprise a fairing or a dragon spaceship.

(a) Fairing

A Payload Fairing is a nose cone whose primary purpose is to protect a payload against the impact of dynamic pressure and aerodynamic heating during launch through an atmosphere [28]. Not only this, it also protects the payload from all sorts of noise and mechanical vibrations in addition to electromagnetic protection. This payload can be either a satellite or a spacecraft or even a space probe.

The standard payload fairing is a typically a cone- cylinder combination. The type of fairing which separates into 2 halves (one "passive" half and one "active" half) upon jettisoning clamshell fairing. They are made of a composite structure, which comprises an aluminium honeycomb center with carbon fibre sheet created in two equal parts. Fairing is 13.1 metre (43 feet) high and 5.2 metre (17 feet) wide.

(b) Dragon Spaceship

Dragon is a free-flying shuttle intended to convey both load and individuals to circling targets. At present Dragon conveys payload to space, yet it was planned from the earliest starting point to convey people [29]. A second version of Dragon Spacecraft called as Dragon 2. The Spacecraft consists of 2 modules: the Upper Part is called as the Capsule and the lower part is called the trunk. The Capsule is recoverable and equipped with hatches and windows. The hatches acts as a passageway for loading and unloading the cargo or crew.

- **Working of Merlin Engines**

Merlin Engine energises the Falcon-9. Fuel is in liquid form (Rocket Propellant-1 or also as refined petroleum). Then we have liquid oxidizer (L.OX) or liquid oxygen. Pressure of both propellants is 50 psi. After taking the 50 psi fuel the pressure increases to 1500 psi [30]. The oxidiser pump brings pressure to 1400 psi. Fuel is revolved around nozzle and cooled. After cooling it follows and enters the combustion chamber. The turbine is connected to both the pumps. After that a pre-burner (gas generator) is also connected. The pre- burner takes small amount of fuel and oxidiser. Then the pre-burner sends the exhaust gas to the turbine (which is at about 1400 degree Fahrenheit) and the output is thrown out. The combustion chamber is at about 1000 psi pressure and 7000 degree Fahrenheit temperature. We have various valves present to control the flow of propellants depending upon the amount required.

- **Nozzle**

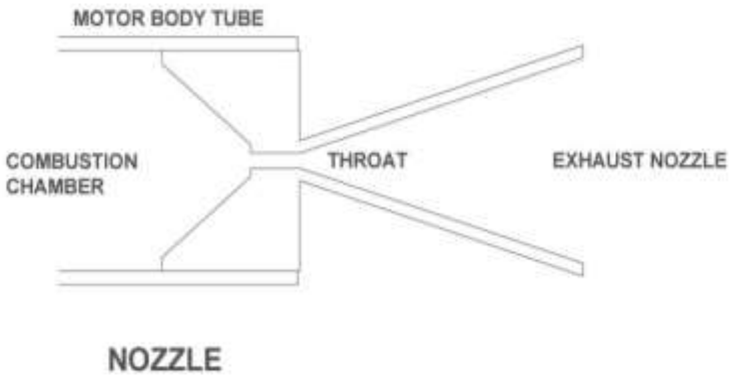

Figure 4. Nozzle

Schematic diagram of the nozzle for falcon-9 is shown in Figure 4. Velocity and area across inlet and outlet are the two basic parameters to be considered in the nozzle. Consider the inlet represented by the letter "i " and outlet by "o". Now since the fluid is flowing as streamline flow, the mass flow rate will be the same as inlet and outlet or mass is conserved [31].

$$m(i)=m(o) \quad (1)$$

⇨ $$\rho(i) \times V(i) = \rho(o) \times V(o) \quad (2)$$

⇨ $$\rho(i)\times v(i)\times A(i)\times \delta t = \rho(o)\times v(o)\times A(o)\times \delta t \quad (3)$$

Now since it is a flow at much lower velocities, density will not change and for the same time interval.

⇨ $$v(i)\times A(i)=v(o)\times A(o) \quad (4)$$

⇨ $$V(o) = \frac{[v(i)\times A(i)]}{A(o)} \quad (5)$$

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Which is the equation of continuity for a nozzle.

This equation suggests that by decreasing the area, the velocity will increase. If we decrease the outflow area, this denominator becomes more than 1 [32]. Thus the ratio of area becomes more than 1. Multiplying that by inflow velocity, the final velocity is higher. So, just by decreasing the nozzle, we can increase the velocity [33]. The question is how high, we can go? (Can we keep decreasing the velocity). Can I keep decreasing the area, to keep on increasing the velocity of fluid again and again? What is the maximum limit? The maximum limit in this scenario, is the Mach Number. The Mach Number (M) is explained as the velocity of the fluid parted by the velocity of sound, in that medium.

$$M = \frac{v(f)}{v(s)} \qquad 6$$

For subsonic fluid, M<1

For sonic fluid, M=1

For supersonic fluid, M>1

Now when the fluid velocity approaches Mach Number 1, the entire phenomena changes. Because the Mach Number is 1 of fluid flow, the localised separation of fluid molecules happen and because of these phenomena called Choking happens. When a fluid is going through a converging nozzle, this type is called converging, because the shape is converging towards the end. When a fluid is flowing through a converging nozzle, the velocity keeps on increasing until it reaches Mach number 1 [34]. When Mach Number is 1, flow is sonic, it can't increase the speed further. Why? Because localised breaking of particles happens. Now to increase the velocity, we have to increase the area now. This is what happens in the nozzle. It is also called converging-diverging (de-laval nozzle) [35].

The velocity of a fluid, flowing through a simple nozzle, be it a converging-diverging nozzle is given by a simple formula as follows:

$$\frac{dA}{A} = \frac{[dU(M^2-1)]}{U} \qquad 7$$

When the area is decreasing, that is, $\frac{dA}{A}$ is negative, which is possible only when the final area is less than the initial area. Mach number square, since the velocity is subsonic $(M^2 - 1)$ is negative as M<1 for subsonic. Now since both the terms are negative, therefore $\frac{dU}{U}$ is positive that means v>u.

When the flow approaches this constriction, Mach Number of flow is 1, this is the maximum a converging nozzle can increase the velocity of the fluid [36]. When the Mach Number is 1, then $(M^2 - 1)$=0. Since the curve is just changing here, the differential is a tangent of the slope is zero. The velocities are undefined. This is the phenomena of Choking and this region is called throat (see Figure 5).

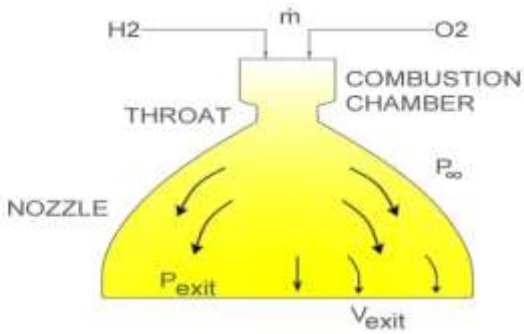

Figure 5. Nozzle

After this entry of throat, we enter into the supersonic region. The area is increasing. So $\frac{dA}{A}$ is positive [37]. The supersonic velocity, Mach number is higher than 1, so $(M^2 - 1)$ >0. The velocity of fluid $(\frac{dU}{U})$ has to be positive.

- **Autonomous Spaceport Drone Ship (ASDS)**

The ASDS provides a landing platform for Falcon-9's initial stage or Falcon Heavy Centre core. Starting with the different names of ASDS, the first ASDS was named 'Just Read the Instructions' [38]. This vessel was retired in

2015. The Second one was named 'Of Course I Still Love You' which was built for landings in the Atlantic Ocean. And it was on this drone ship that the first ever successful landing of the Falcon-9 took place on 8th April, 2016 in the CRS-8 mission. The third in sequence and second active ASDS is named after the first one, i.e. 'Just Read the Instructions'. It was built in 2015 for landings in the Pacific Ocean. The fourth in sequence is named 'A Shortfall of Gravitas', under construction as of early 2018, and it will be used on the east coast to support high flight rates for Falcon-9.

The dimensions of ASDS is slightly smaller than that of a football field. With about 300 fet in length, 170 feet in width and about 20 feet in height. ASDS is basically a refitted Cargo barge. The thrusters used in ASDS are retractable thrusters used for dynamic positioning. All these thrusters once underwater, can move 360 degrees, thereby providing smoother maneuverability.

- **Rocket Equation (Tsiolkovsky rocket equation)**

Imagine a rocket of total mass (m) and moving with a velocity (v). This is state at time t (T=t). After interval of Δt which means T=t+Δt. A small mass (Δm) of exhaust gas is ejected out. So mass of rocket is now m-Δm. Due to this change in mass, velocity has changed to v+Δv. Velocity of exhaust mass is v(e). We are not assuming the direction of the exhaust. So we just keep it upward. If the v(e) comes negative, then the direction is opposite. So we don't know in which direction this exhaust mass is going. Up, down or its just static. Also, it is very important to note the frame of reference. So now we just do a conversation of momentum balance from time t to time t+Δt.

$$m.v = (m - \Delta m).(v + \Delta v) + \Delta m.\left(v + \Delta v + v(e)\right) \qquad 1$$

Here, $(m - \Delta m).(v + \Delta v)$ is due to the rocket whereas $\Delta m.\left(v + \Delta v + v(e)\right)$ is due to the exhaust gases.

Velocity of exhaust is v(e) isn't related to rocket but initially the rocket was going with the velocity v. So from earth reference from the frame of reference of us, the velocity of the exhaust will be (v+Δv+v(e)) from the reference of us, velocity of exhaust is relative from rocket (v+Δv) and velocity of exhaust v(e).

Now let us expand this entire equation:

$$m.v= m.v+ m.\Delta v-\Delta m.v-\Delta m.\Delta v+\Delta m.v+\Delta m.\Delta v+\Delta m.v(e) \qquad 2$$

$$m.\Delta v=-\Delta m.v(e) \qquad 3$$

$$\Delta v = -v(e).\left(\frac{\Delta m}{m}\right) \qquad 4$$

Taking limiting case,

$$v(f) - v(i) = v(e).\left(\ln\left(\frac{M(i)}{M(f)}\right)\right) \qquad 5$$

Rocket equation is just a simple basic derivation from the law of conservation of momentum [38].

- **Rocket Equation Significance**

$$v(f) - v(i) = c.\left(\ln\left(\frac{M(i)}{M(f)}\right)\right) \qquad 1$$

Here, Δv=v(f)-v(i), signifies how much impulse is needed for a rocket to carry out maneuver. Maneuver like transfer from one orbit to another orbit. Lower orbit to higher orbit. This term will be used very frequently used in orbit transfer.

c- effective exhaust velocity

$\frac{M(i)}{M(f)}$ – Mass of initial rocket to final rocket (Mass ratio) 2

M(i)-M(f)=M(p) – Mass of Propellant. Mass ratio signifies how much is the mass of the propellant. If this factor is very much higher that means that the mass of the final rocket is very much less which further means that the propellant mass is very high [39].

$$\text{Propellant mass fraction}= \frac{M(i)-M(f)}{M(i)} = 1 - \left(\frac{M(f)}{M(i)}\right) \qquad 3$$

- **Perturbations in Rocket's Trajectory**

The bearing of movement of the rocket is corresponding to push. Then we have Centre of Gravity which is a point from which only the gravitational force acts. Whereas, Centre of Pressure, is a point at which the sumtotal of is related to the area of body subjected to uniform pressure, centre of gravity is related to the volume and mass distribution of the body [40]. The weight is pointed downward from the focal is related to the area of the body subjected to uniform pressure, the centre of gravity is related to the volume and mass distribution of the body [41]. The mass is pointed below from the point of convergence of gravity of the rocket (see Figure 6). The drag is equal however in the opposite way of the push. Also, the lift powers are normally opposite to the flight way except if the rocket structure is of a whimsical plan. The lift and drag of rocket vehicle are just relevant if the rocket is in an environment howsoever, least thick it may be. The essential point of aerodynamics is that, these impacts i.e. weight, thrust, lift and drag incident on the rocket are altering course in direction and magnitude throughout the flight, as they are vectors. Forces which do not gob through the centre of gravity, which is by definition the axis of rotation, are called torques. Suppose when the rocket is cruising along the direction of flight and suddenly by a gust of strong crosswind strikes near the bottom of it, which is away from the centre of gravity [42]. This will result in torque and the rocket will tend to rotate about the centre of gravity. This could result in wobbling or deviation from the actual direction of flight [43].

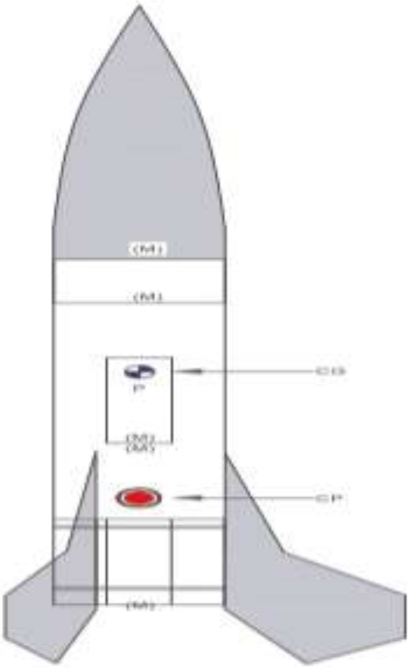

Figure 6. Centre of pressure (cp) and Centre of gravity (cg)

III. CONCLUSION

In conclusion, Falcon-9 is one of the most advanced rockets present today. Humans are constantly progressing in Space exploration and are unfolding the mysteries of Space slowly. All the Elite Space Agencies are constantly working in making Space efficient vehicles for easy Space travel. We have only touched the surface of knowledge about the Universe and there is soo much more to learn. Falcon-9 is one of the promising candidates among all the space exploration vehicles so far and pave way for much better technological advancement in this area.

IV. REFERENCES

[1] Fabignon, Yves & Anthoine, Jerome & Davidenko, Dmitry & Devillers, Robin & Dupays, Joel & Gueyffier, Denis & Hijlkema, Jouke & Lupoglazoff, Nicolas & Lamet, Jean-Michel & Tessé, Lionel & Guy, Aurelien & Erades, Charles. (2016). “Recent Advances in Research on Solid Rocket Propulsion” 10.12762/2016.AL11-13.

[2] Michael J. Russell, “Figuring out how life first took off is (much like) rocket science!”, Planetery and Space Science, , Pages 13-20, October 2019.

[3] Chris P, “Astronauts hitch first ride aboard private rocket to space station”, Engineering, August 2020, https://doi.org/10.1016/j.eng.2020.08.007.

[4] https://www.spacex.com
[5] NASA, "Falcon-9 Launch Vehicle NAFCOM Cost Estimates", NAFCOM, August 2011.
[6] Hridya N.S., "ROCKET, SATELLITE, AND LAUNCHING OF SATELLITE", Journal of Emerging Technlogies and Innovative Research, Volume 4, Issue 10, ISSN-2349-5162, October 2017.
[7] Mihir Bhagat, Etienne Dumont, "SpaceX Falcon 9 V 1.1, Falcon Heavy Remodelling; Falcon 9 V 1.1 Descent Trajectory and Performance Optimization", Institute of Space Systems, January 2014.
[8] Lei S., Guoqiang H., "Research and development on inlets for rocket based combined cycle engines", Progress in Aerospace Sciences, Volume 117, August 2020, 10.1016/j.paerosci.2020.100639.
[9] Jessica Y., Maria G.E.K, "SpaceX Falcon 9/Dragon Operations NAS Impact and Operational Analysis", DOT/FAA/TC-TB13/49 January 2014.
[10] Chris P, "Astronauts hitch first ride aboard private rocket to space station", Engineering, August 2020, https://doi.org/10.1016/j.eng.2020.08.007.
[11] Li, Yi & Fang, Jie & Sun, Bing & Li, Kaiyang & Cai, Guobiao, "Index allocation for a reusable LOX/CH4 rocket engine. Chinese Journal of Aeronautics", June 2020, 10.1016/j.cja.2020.04.017.
[12] Daiwa S., Toshiya K., "Estimating model parameters of liquid rocket engine simulator using data assimilation", Acta Astronautica, Volume 177, December 2019, https://doi.org/10.1016/j.actaastro.2020.07.037.
[13] Peng C., Qinglian L., Peng C., Lanwei C., "System scheme design for LOX/LCH4 variable thrust liquid rocket engines using motor pump", Acta Astronautica, Volume 171, June 2020, 10.1016/j.actaastro.2020.03.002.
[14] Taj W. K., Ihtaz Q, "Optimum characteristic length of gas generator for liquid propellant rocket engine", Acta Astronautica, Volume 176, November 2019, 10.1016/j.actaastro.2020.06.021.
[15] Ecker, Tobias & Karl, Sebastian & Dumont, Etienne & Stappert, Sven & Krause, Daniel., "A Numerical Study on the Thermal Loads During a Supersonic Rocket Retro-Propulsion Maneuver", July 2017, 10.2514/6.2017-4878.
[16] Jozič, & Zidanšek, & Repnik, "Fuel Conservation for Launch Vehicles: Falcon Heavy Case Study. Energies", ISSN 1996-1073, February 2020,13.660. 10.3390/en13030660.
[17] Mazzetti, Alessandro & Merotto, Laura & Pinarello, Giordano, "Paraffin-based hybrid rocket engines applications: A review and a market perspective. Acta Astronautica", Acta Astronauica, May 2016, 126. 10.1016/j.actaastro.2016.04.036.
[18] S.K.Pradhan., Vedant K., P.Kour, "Review on different materials and their characterization as rocket propellant", MaterialsToday: Proceedings, March 2020, https://doi.org/10.1016/j.matpr.2020.02.960.
[19] Gomez, Arturo & Smith, Howard, "Liquid hydrogen fuel tanks for commercial aviation: Structural sizing and stress analysis" Aerospace Science and Technology, September 2019, 105438. 10.1016/j.ast.2019.105438.
[20] V.F.Prisniakov., V.N.Serebryansky, :Mixing and cooling modelling of cryogenic fuel in liquid fuel rocket engine tanks", International Journal and Hydrogen Energy, Volume 19, Issue 3, March 1994, https://doi.org/10.1016/0360-3199(94)90099-X.
[21] Zhang, Ming & Xu, Dafu & Yue, Shuai & Tao, Haifeng, "Design and dynamic analysis of landing gear system in vertical takeoff and vertical landing reusable launch vehicle", Proceedings of the Institution of Mechanical Engineers, Part G: Journal of Aerospace Engineering, October 2018, 10.1177/0954410018804093.
[22] Blackmore, Lars, "Autonomous precision landing of space rockets", SpaceX, January 2016.
[23] Peng, Ke & Hu, Fan & Dong-Hui, Wang & Okolo, Patrick & Xiang, Min & Bennett, Gareth & Weihua, Zhang, "Grid fins shape design of a launch vehicle based on sequential approximation optimization" Advances in Space Research. July 2018, 10.1016/j.asr.2018.06.001.
[24] Faza, G & Fadillah, H & Silitonga, Faber & Moelyadi, Mochammad, "Study of Swept Angle Effects on Grid Fins Aerodynamics Performance", Journal of Physics: Conference Series 1005. 012013, April 2018, 10.1088/1742-6596/1005/1/012013.

[25] Luciano H., José Carlos de Andrade, Fernando de Souza Costa, "Experimental Investigation of a Monopropellant Thruster Using Nitrous Oxide", Journal of Aerospace Technology and Management, Volume 6, ISSN 1984-9648, December 2014.

[26] Klotz, Irene, "Musk Says SpaceX Being "Extremely Paranoid" as It Readies for Falcon 9's California Debut", SpaceNews, September 2013.

[27] Yedhu U.K., Saidalavi P., "Design and Analysis of Vented Interstage in a Typical Launch Vehicle", International Journal of Engineering Research and Technology, Volume 4, Issue 8, ISSN 2278 0181, August 2015.

[28] Aaron D. Koch, "Optimal staging of serially staged rockets with velocity losses and fairing separation", Aerospace Science and Technology, Volume 88, May 2019, https://doi.org/10.1016/j.ast.2019.03.019.

[29] Dreyer, Lauren., "Latest developments on SpaceX's Falcon 1 and Falcon 9 launch vehicles and Dragon spacecraft", March 2009, 10.1109/AERO.2009.4839555.

[30] J.E.Ellor, "The Development of the MERLIN ENGINE", SAE Technical Paper,

[31] ISSN 0148-7191, January 1994, https://doi.org/10.4271/440189.

[32] Boccaletto, Luca & Dussauge, J.-P, "High-Performance Rocket Nozzle Concept. Journal of Propulsion and Power", Journal of Propulsion and Power, September 2010, 10.2514/1.48904.

[33] Du, Zhao-bo & Huang, Wei & Yan, Li, " Investigation on the supplementary combustion scheme for the divergent section of a solid rocket engine nozzle", Energy, Elsevier, vol. 190(C), 2019, 10.1016/j.energy.2019.116295.

[34] Jiashan C., Dongzhe F., Changwan M., Qichen T, "Novel method of rocket nozzle motion parameters non-contact consistency measurement based on stereo vision", Optik, vol. 195, p. 163049, October 2019, 10.1016/j.ijleo.2019.163049.

[35] Victor P. Zhukov, "The impact of methane oxidation kinetics on a rocket nozzle flow", Acta Astronautica, Volume 161, October 2019, https://doi.org/10.1016/j.actaastro.2019.01.001.

[36] Hongwin W., Qingchun Y., Xu Xu, "Effect of thermal choking on ejection process in a rocket-based combined cycle engine", Volume 116, April 2017,
https://doi.org/10.1016/j.applthermaleng.2017.01.059.

[37] Xingkai Z., Dong W., Ruiquan L., Hui Z., Baocheng S, "Study of mechanical choked Venturi nozzles used for liquid flow controlling", Volume 65, March 2019,

[38] https://doi.org/10.1016/j.flowmeasinst.2018.12.001.

[39] Kazunori K., Yoshiaki M., Kazuyasu M., "Study of Choked flow through Convergent Nozzle", Journal of Thermal Science, Volume 19, Issue 3, pp.193-197, June 2010, 10.1007/s11630-010-0193-3.

[40] SpaceX, "Autonomous Spaceport Drone Ship", The Planetary Society, January 2020.

[41] Dvornychenko, Vladimir., "The generalized Tsiolkovsky equation", National Institute of Standards and Technology, January 1990.

[42] Espen G.H., "The ultimate limits of the relativistic rocket equation. The Planck photon rocket", Acta Astronautica, Volume 137, July 2017, https://doi.org/10.1016/j.actaastro.2017.03.011.

[43] Pamfil, Somoiag & Cristian-Emil, Moldoveanu & George, Surdu., "Studies Concerning the Evaluation of Trajectories Deviations Caused by the Perturbations Made when the Rocket Leaves the Rocket Launcher System", Proceedings of International Conference on Military Technologies, May 2007.

[44] A.J.Calise, "Energy Management and Singular Perturbations in Flight Mechanics", Volume 11, Issue 1, 1998, https://doi.org/10.1016/S1474-6670(17)66039-7.

[45] William, Sirignano & Krieg, Jeremy, "Two-Time-Variable Perturbation Theory for Liquid-Rocket Combustion Instability", Journal of Propulsion and Power. 32, January 2016, 10.2514/1.B35954.