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Design of Mars Rover-Copter System

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Abstract: - **The principal motive is to design and develop a Mars Rover-Copter, a combination of a land rover that travels on ground and a copter that travels above ground. The operation of the Rover-Copter is to explore and study the planet Mars for any signs of ancient lives. The earlier inventions in the field was analysed carefully as part of the design process of the Rover-Copter which include the specification of the design obtained in terms of the range of the size, shape, cameras, robotic arm, wheels mobility, propellers, and type of energy to be used, as well as the battery voltage. AutoCAD and ANSYS were utilized in the designing and testing process. The dimensions of the rover to be 0.70 x 0.30 x 0.49 in meters, the total length of the propellers is 1.13 meters, and the length of the robotic arm is 0.45 meter. The ANSYS was used for structural analysis drawing of the components; moreover, the deformation, equivalent strain, factor of safety, pressure, lift, drag force, and elastic stress were tested by applying different forces. ANSYS Computational Fluid Dynamics (CFD) forecast the effect of the fluid flow on the project; to evaluate the lift and drag forces generated by the propellers at several frameworks with respect to the different aerodynamics in Mars. Due to variety type of terrains on Mars such as rocky or sand landscapes, certain type of wheels were selected to meet the requirement. In addition to that, robotic arm that can extend, retract, and turn 360° around the same axis was adjusted to the rover; furthermore, a laser equipment, including a professional camera was equipped for exploration and sample testing uses. Solar panels were the main source of energy for the Rover-Copter, in which the panels charge the batteries. The material used for the whole Rover-Copter was Aluminium 7075, for the joints was AISI 1045, and for the propellers was epoxy carbon fibre. After achieving the objectives of the mission, the Rover-Copter passed the structural testing, however the Rover-Copter can be improved by using alternative type of energy such as hydrogen cells to charge faster, also use advanced materials and equipment for better sample testing and more advanced exploration trip.**

Key-Words: - **Aerodynamics; CFD; Mars Rover-Copter; Lift; Drag; Structural Analysis; Solar**

I. INTRODUCTION

Exploration is an idea that will fulfil the human curiosity in finding the answers for the mysteries of science presented in the Universe. The question that arises over the years is: how did the evolution of life happened in the solar system, and is there life in places other than Earth that existed in the beginning of the formation of this solar system? These questions lead into the identification of the habitats of life. Earth and Mars are elected as prime candidates to satisfy the criteria of habitat of life. Over the years scientists have been sending robots, copters and rovers into the red planet Mars to understand its atmosphere, composition etc. Different space agencies around the world conducted several missions targeted to Mars. The robot exploration paved the way for technologies that will support the settlement of humans in Mars. The rover led to finding a developing technology to send autonomous systems in order for them to conduct the necessary experiments on Mars.

Copters have been leading the race for Mars exploration and were considered a regular attendant to the Martian Atmosphere during several missions because of their ability to fly over terrains at a high speed. Almost every aspect of a propeller-driven aircraft performance such as hovering, take-off and cruising will be influenced by the propeller's efficiency and performance. The previous rovers that were sent by NASA had different designs and applications, some were as small as 65 centimetres long, and some were as big as 3 meters long [1]. The 2020 Mars Mission Perseverance Rover had the length of 10 feet long (3 meters), width of 9 feet wide (2.7 meters), and the height of 7 feet tall (2.2 meters) about the height of a basketball player. Having these dimensions for a rover is considered to be massive; however, the sizes depend on the objective of the mission. The main objective of the 2020 Perseverance Rover is to look for indications of ancient life and gather samples of rock and regolith for a potential return to Earth [2].

The Perseverance Rover is a heavy-weight rover in which it weighs about 1025 kilograms; furthermore, the weight of the rover can affect the speed and the energy consumption as the heaver it was the more energy is needed to move faster. Figure 1 shows the three generations of Mars Rovers [3].

Figure 1. The three Generations of Mars Rovers [3]

Ingenuity Helicopter was designed to fly to the as a part of a Perseverance rover to Mars. Being the first of its kind in terms of the rotor design made for demonstrating the technologies. The successful flight of the Ingenuity helicopter will thus prove the power flight feasibility in the Martian Atmosphere. The development of the ingenuity helicopter with the research done enabled many detailed analyses to be studied in every field. Creating a solid base in the field of UAVs flight into Mars for the future vehicles. It has two rotors that mount co-axially on top of each other. Each rotor has two blades and both rotors spin in opposite directions thus allowing the aircraft to balance the produced torque by the rotors. Co-axial rotors on the Ingenuity Helicopter improves how small rotors can generate lift. Because there is more than one rotor, this approximately will double the lift for the rotor of the same disk area helping the turbulent region of the flow in lifting downwards. The Ingenuity Helicopter is also powered by solar arrays that mount over the rotors. The mass of the system is 1.8 kg. The blades were designed for Martian Atmosphere with a varying angle of attack, lightweight and fast moving [3].

Figure 2. Ingenuity Helicopter [3]

The objective is to design and develop a Mars Rover-Copter to be sent to planet Mars. The goal of designing and developing a Rover-Copter is to explore and deeply study cache samples in the red planet, seeking for any signs of ancient life that may exist there. The terrains of Mars are rough to cruise around, in which the landscape includes a rocky surface, volcanoes, craters, canyons, and dry lake beds; however, a hybrid vehicle with specialized equipment is designed to reach and achieve the purpose of the exploration journey.

Initially in this paper, the design starts with the design a copter that can provide imaging when it detaches from the rover and hover above ground to analyse optimal routes for the rover to take. later, is designing the Rover-Copter to be light weight and small with the dimensions to be 0.70 x 0.30 x 0.49 meters and the total weight around 37 kg; furthermore, this will allow the Rover-Copter to go inside tight spaces for more in-depth exploration. With rough landscapes and currents to manoeuvre around, an important target in mobility and energy is to make the Rover-Copter capable of moving in different kind of terrains, this includes for it to be able to travel around 8 hours in 5 cm/s, and for the Copter to hover for 30 minutes straight till next charging. Lastly, building an arm adjusted to the body of the rover, which can be used to mince samples and read them using special type of professional camera.

II. LITERATURE REVIEW

Rover

The concept of building small rovers to explore mars was established in the last century in the 80s exactly. Where the main plan is to create a rover with limited mass and weight. In late 1986, they came up with a Micro-rover where its initial spectrum was believed to be very partial and small [4]. It has been difficult to the scientists to develop and improve the size, mobility, and control the rovers in terms of Mars environment and terrains. As a classification, Micro-rovers should not exceed 30 – 50 kg. Many generations of benchmarking tool vehicles have been advanced throughout the environment test. Permitting Mars exploration, some existing designs are large and some smaller. For effective results, the smaller sizes are more efficient and steadier. Under severe temperature conditions and dust contamination and unknown terrain over a challenging region, mass, volume and power limitations should be in consideration in order to meet a tight constraint design [4]. Therefore, a smaller multi-functional rover-copter is this project's goal. In addition, the designs of robotic arm that attached to the rover will be in consideration as well. There are different types of Micro-rovers which were sent to explore Mars such as Sojourner and Rockey7 as shown in Figure 3 and Figure 4.

Figure 3. Sojourner rover [4]

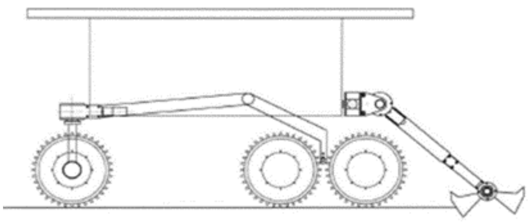

Figure 4. Side view of Rocky7 [5]

The comparison between the Sojourner and Rocky7 shows that both of them had the same shape and size dimension. The Sojourner was launched in 1996 and Rocky7 was in 1997. The mass of the Sojourner was 12 kg and Rocky7 was 11.5 kg. Moreover, the advantage of Rocky7 over the Sojourner was that the solar panel will move based on the orientation of the sun [6].

Camera

In the perseverance rover that was sent by NASA and landed in Mars Feb. 18, 2021, it had a number of 23 total camera. It included 9 engineering cameras, 7 science cameras, and 7 entry, descent and landing cameras [7].

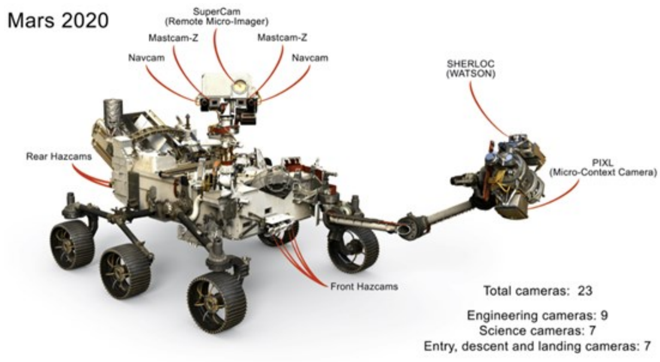

Figure 5. Cameras on the Mars 2020 Perseverance Rover [7]

The Mars 2020 spacecraft is outfitted with a suite of cameras to document the vehicle's entry, descent, and landing in unprecedented detail. Multiple cameras on various parts of the spacecraft will help engineers reconstruct how the vehicle performs during landing. [7]. Engineering cameras are separated into 3 different cameras, 1- Hazard Avoidance Cameras (HazCams), 2- Navigation Cameras (NavCams), 3- CacheCam. And finally, the science cameras include five different types of cameras, 1- Mastcam-Z, 2- SuperCam, 3- PIXL, 4- SHERLOC Context Imager, and 5- WATSON [8]. Among the camera's, the engineering camera and the Science camera such as SuperCam and PIXL are most important once [8]

Mobility

To allow exploration, the surface mobility system goes beyond the surroundings of the site landing and therefore cannot be achieved just by walking. As a result, the mobility system is important because it supports the human planetary surface exploration process [9]. The rover mobility algorithm controls the efficiency and stabilization of mobility on unidentified rough terrain such as the Moon and Mars [10]. There have been varied types and mechanisms that have been used in the mobility system which includes Rocky Bogie suspension, Rocky Bogie challenges, Wheel-Soil Interaction, Rover Wheels in Space, Wheeled rovers vs. Wheel-step rovers, Four vs. Six wheels, and Vehicle configuration requirements.

Rover robotic arm

The instrument deployment device (IDD) is another named of rover robotic arm. The main purpose of it is to help exploring the rocks and soils in advanced method. The rover robotic arm is holding specific instruments and tools needed to apply the required tests or experiments if there is a microbial life in Mars. As well as assisting scientists in getting a

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close-up observation at Mars rocks and soils [11]. As a human arm, the rover robotic arm has shoulders, elbow, and wrist to be extreme flexible to operate. Specially, like a geologist, the arm helps scientists to stretch, curve and slope to the rocks where the arm must be removed, microscopic pictures taken, and the composition of rocks and soils analysed. The concept of the robotic arm is the same in each different design of a Mars rover. However, the only difference is about the end effector which is the main part that operates to serve the main aim.

The first Micro-rover was having a robotic arm is Rocky7 which represents that the reason of improving sojourner within a year. Perseverance rover robotic arm was the newest arm in the market. For maximum flexibility and movement, it has joints as it mentioned above. However, the end effector part is a multi-functional since it consists of many components in which it carries scientific cameras, x-ray, sensors, drills, etc. The purpose of having these tools is to collect and analysed the elemental compositions and minerals exists in Mars surface in up-to date way. In the Japanese experiment module remote manipulator system, the arm has the same mechanism and objective of the rover's arm. Therefore, it consists of an arm attached to the system with 6 main joints and DOF. Where the components for experimentation are developed to manage and relocate as shown in Figure 6 [12].

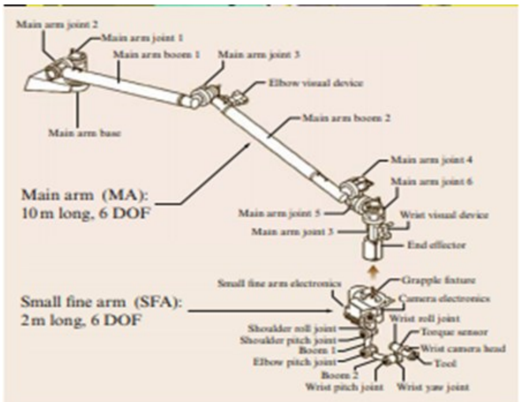

Figure 6. The Japanese module manipulator system [12]

Propeller

An aircraft propeller is known to consist of two or more blades with a central hub where the blades will be attached. Regarding each blade of the aircraft propeller is a rotating wing. Their construction results in propeller blades that are similar to airfoils and will eventually be producing forces that will be creating the thrust to pull, or push, the vehicle through the air. While the engine will furnish the needed power for rotating the propeller blades through the air at speeds that are considered high, afterwards the propeller will transform rotary power of the engine to forward thrust. The blade element of the cross-section of any propeller is an airfoil that can be compared to a cross-section of an aircraft wing. With one surface of this blade being cambered like the upper surface of an aircraft wing and the other surface being flat like the bottom of a wing's surface. A line that is imaginary and is drawn through the blade from leading edge to trailing edge is a chord line. Similar to a wing, the thick edge of the blade is the leading edge, and this edge meets the air while propeller is rotating. Measured in degrees, is the blade angle and is between the chord and plane of rotation. This angle can be measured at a specific point along the blade's length. Pitch is not a blade angle but is mostly found by the blade angle. Increasing or decreasing the blade angle will result in an increase or decrease of the pitch.

Throughout the design phase, the goal is to design a highly aerodynamic performance rover and copter that will satisfy the mission requirements. The copter aims to fly and explore the Martian atmosphere at a range of 10m. Designing a propeller specifically for the copter's propulsion system and the required performance such as propellers moving at a fast speed ranging from 1000-4000 RPM, and to generate a good amount of lift with minimum drag. The design must best meet the mission and aerodynamic requirements.

III. DESIGN OF MARS ROVER-COPTER

In the design of the Mars Rover-Copter, there are many parts to be considered. The introductory part of the paper discussed about the rover, copter, propeller, mobility, camera as well as the robotic arm. Initial focus of this section starts with the mobility of the rover. The wheel-soil interaction plays a vital role in the mobility of the rover. The soil mechanics principles are based on M. G. Bekker's original model in 1956. M.G. Bekker worked on the development of mathematical models to describe the movement of rolling vehicles engaging with vehicle's surface and to specify parameters for soil qualities especially.

Table 1. A set of soil parameter identified by Bekker

Parameter	Property
c	Soil cohesion
φ	Internal friction angle
k_φ	Frictional soil modulus

k_c	Cohesive soil modulus
n	Soil deformation exponent
κ	Soil shear deformation modulus

These factors enable the performance of different rolling systems to be calculated and so predicted. The vertical load behaviour of the soil is n, kφ and kc, while horizontal shear stress reactions is determined by c, φ and κ. Consequently, the ability of a land to support the load of a vehicle and create tractive stress may be determined since all values were obtained. The association between normal stress and shear strength can indeed be described as:

$$\tau = c + \sigma \tan \varphi \quad (1)$$

Where c is the cohesion of the soil, which is really a shear strength soil element independent of the cross friction φ. Electrostatic forces, cement or roots cohesion can induce this. By the formula between Bernstein and Bekker.

$$H_{max} = Ac + W \tan \varphi \quad (2)$$

H_{max} can be found for maximum tractive force. Where A is on the ground the wheel's adhesion, and W the wheel load is. Drawbar pull DP of the powered system, which is transferred to the soil efficiently, is determined by the divergence of driving force H and the sum of driving resistance R, depending on the qualities of the soil and in particular the type of wheel utilized.

$$DP = H - \sum R \quad (3)$$

As already established, the rover's energy use is a significant element, because that affects the range before recharging for a mobile system. The battery system dimensions can also be measured by energy efficiency. The much more effective, the smaller the battery, the more area for the research payload is available. The drawbar pull is an excellent metric for determining the capacity of a certain system to travel over the earth, however the driving torque T, which describes the force employed under a certain instant circumstance, should be taken into consideration to quantify its efficiency. Then the shaft power output in the engine gap through electric power defines the general efficiency of drives [13]. The wheel parameters drawbar pulls, and torque can be rewritten in the following terms:

$$\eta = \frac{DP}{T} \quad (4)$$

Propeller

An airfoil is a body of a shape that when this airfoil is placed in airstreams, it will produce an aerodynamic force. The force has many purposes such as propeller blades and turbine blades in jet engine. The angle of attack (AOA) is when an aerodynamic force is produced due to the airfoil being cut through relative wind. The force is broken down into two, the lift and drag. The lift force is the force from the air that acts on the airfoil and is perpendicular to the relative wind and opposes the weight downward force. Weight is load combined from the whole aircraft. The drag force is the retarding force because of the disruption of airflow and is parallel to the relative wind. The angle of attack is located between chord line and relative wind. Drag opposes Thrust. Thrust is the forward force that the rotor produces and is parallel to relative wind.

The airfoil can be symmetric and non-symmetric. A symmetrical airfoil has identical upper and lower surfaces. Also a symmetrical airfoil have the same mean camber line and chord line but no lift will be produced at zero. For Example the NACA series airfoils; 4-digit NACA airfoil: NACA 0015, where the first two digits 00 indicating that no camber is presented and the l00ast two digits 15 indicating that 15% thickness to chord length ratio is presented. The non-symmetrical airfoil is known to have different upper and lower surfaces while also having a greater curvature above the airfoil's chord line but lift will be produced at zero. For example NACA 2412 where the first two digits 24 indicating 2% maximum camber is presented and located 40% from leading edge while the last two digits 12 indicating 30% maximum thickness to chord length ratio is presented.

Lift Equation

$$L = \frac{(C_L * \rho * V^2 * A)}{2} \quad (5)$$

Lift = Coefficient of Lift * Density of air on Mars * Velocity of airfoil squared * Wing Area (Planform Area) / 2

Weight Equation

$$W(\text{Weight}) = m(\text{mass}) * g(\text{gravitional acceleration on Mars}) (6)$$

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Drag Equation

$$D = \frac{C_D * \rho * V^2 * A}{2} \quad (7)$$

Drag = Coefficient of Drag * Density of air on Mars * Velocity of airfoil squared * Wing (reference) Area / 2

Induced Drag Coefficient Equation for Finite wing (3D)

$$C_{D,i} = \frac{(C_L^2)}{\pi e AR} \quad (8)$$

Induced Drag = (Coefficient of lift squared) / (πe*Aspect Ratio)

To yield minimum induced drag, e = 1 and this case is called the elliptical lift distribution.

Induced angle of attack

$$\alpha_i = \left(\frac{C_L}{\pi AR}\right) \quad \textbf{(9)}$$

Lift- curve slope of finite wing (Relation between a and a_0)

$$\frac{dC_L}{d\alpha} = a = \left(\frac{a_0}{1 + \left(\frac{a_0}{\pi AR}\right)}\right) \quad (10)$$

Total Drag coefficient Equation

$$\text{Total Drag coefficient } (C_D) = c_d + C_{D,i} \quad (11)$$

Aspect Ratio

$$AR = \frac{b}{c} = \frac{b}{c} \times \frac{b}{b} = \frac{b^2}{A} \quad (12)$$

Aspect Ratio = Span squared / Area

IV. DESIGN OF COMPONENTS OF THE ROVER-COPTER

Wheels of the rover

Wheels of a rover consists of rocker bogies and a main body of six or four wheels. The Suspension rocker bogie type enables the rover to increase strength during obstacle through uneven surfaces by allowing multiple wheels which stay in contact with rough ground [14]. Almost all rovers for Mars has six wheels, due its effectiveness in reducing surface pressure, that also certainly is really not necessary on Mars, where the low level of weight and the almost complete lack of humidity and biological products of soil are adequate for four wheels [15]. During complex terrain surfaces having wheels with grousers or cleats will help to offer better durability in both soft and hard rocks through its surface. Meanwhile, due to the materials used in the wheels there are several such as aluminium alloy, steel, and carbon fibre. Ability to distinguish between what is the best design of the mobility system of the wheels will be provided in detailed. The decision matrix was performed for the wheels as in Table 2.

0 = Poor | 1 = Satisfactory | 2 = Good | 3 = Very Good | 4 = Excellent

Table 2. The decision matrix for the wheels

Criteria	**Weighing Factor**	**Continuous tracked**	**Wheels**	**ExoMars wheels**
Complexity	5%	4	1	2
System size	12%	3	4	3
Flexibility	10%	4	2	4
Durability	4%	4	3	3
Ease of assembly	5%	2	3	4
Weight	18%	3	4	4
Mobility	20%	3	3	3
Material	17%	3	2	3
Cost	9%	2	4	3
Total	100%	3.11	2.88	3.22

Based on the decision matrix, the convenient designs to use would be either continuous tracked wheel or the ExoMars wheels. Meanwhile, due to the final design the preferred design would be the ExoMars wheels.

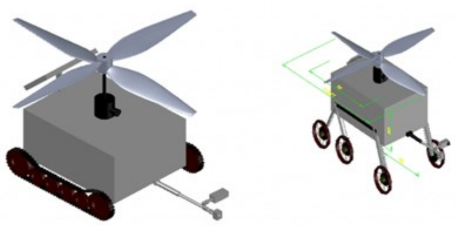

Figure 7. Design of continuous tracked on the left and ExoMars on the right

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Robotic arm of the rover

The robotic arm's main aim is to help to explore rocks and soils with the use of specialized tools and instruments to test whether the life on Mars is microbial. It's just as a human arm that's flexible enough to move its shoulders, elbow, and hand. The DOF has to do with the arms, it usually contains 5 DOF known as azimuth shoulder joint, shoulder elevation joint, elbow joint, wrist, and end-effector joint. The decision matrix was performed on robotic arm with camera and laser cutting machine as well as on robotic arm with a container and with drilling bit and gripper based on the criteria such as complexity, system size, movement, flexibility, and durability, ease of assembly, weight, control system, cost, and ease of use. From the decision matrix, it was found "Robotic arm with a camera and laser cutting machine" is better than the other.

Rotor

The rotor system of a copter is a rotating part that will generate lift. This rotor will consist of several components such as 1- Mast, 2- Hub and 3- Rotor Blades. Decision matrix was performed on the selection of Single –Rotor and Coaxial Rotor based on the parameters such as lift, drag reduction, simplicity of structure, cruise efficiency, hover efficiency, and compatibility. Based on the decision matrix, the best design for the rotor was the coaxial rotor.

Air foil Selection

The NACA air foil stands for the National Advisory Committee for Aeronautics. The NACA 0012 air foil from the air foil family series of NACA air foil was selected. The NACA air foil family series ranges from one-digit series to sixteen-digit series. NACA 0012 like any other NACA 00xx is symmetrical. The 00 is indicating this air foil has no camber. On the other hand, the digits 12 are indicating the air foil has 12% thickness to chord length ratio.

Specification for propeller includes Container (Shape: Variable pitch propeller, Rotor Configuration: CoAxial Rotor ,Material: Epoxy Carbon-Fiber, Chord length: 0.079 m, Span: 1.132 m), Energy(Energy supplier: Solar panel, battery) and Operating Conditions (Acceleration: 148.2 m/s (2500 RPM)), Test requirements (ANSYS Simulations), Production (Modified to suit Martian atmosphere.), and Cost (Manufacturing cost less than: $3500, Material cost less than: $3500).

Modified final design

The final modified design based on the design requirements and literature review is shown in Figure 8.

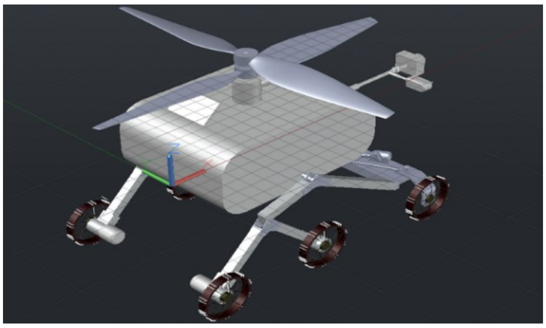

Figure 8. Modified Final Design

V. METHODOLOGIES

Based on the literature review and designing of components of the rover copter, the calculation was performed based on the following parameter as tabulated in Table 3.

Table 3. The calculations tabulated data

Parameter	Symbol	Value
Rocker Bogie required length	l_d	58.73 cm
Rocker Bogie angle of the reference line	θ_d θ_2 θ_3	-113.82 34.68 $-289°$
Rocker Bogie angular velocity	ω_3	$91.7 rads^{-1}$
Rocker Bogie velocity at point C	v_c	$11015.85\ cms^{-1}$
Rocker Bogie acceleration in x-axis and y-axis	a_x a_y	$-442160\ cms^{-1}$ $97233.68 cms^{-2}$
Diameter	D	1767.04cm
Rocker Bogie Acceleration at point B	a_B	$552387.1831 cms^{-}$
Total Weight	W_{tot}	139.5 N
Rover weight divided by 2	$W_{(2motors)}$	69.75 N
Friction coefficient	μ_k	0.484

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Radial Force	F_r	67.518 N
Torque	T	3.376 N. m
Power required	P	1272.71 W
Angular velocity	ω	$10.47\ {}^{rad}/_{s}$
Angle	ϕ	30°
Angle of connecting rod	γ	150°
Displacement	x	= 812.25 cm = 8.1225 m
Velocity	v	= 278.41 cm/s = 2.7841 m/s
Angular velocity of link 1	$\dot{\gamma}_{l1}$	7.85
Angular velocity of link 2	$\dot{\gamma}_{l2}$	7.85 rad/s
Angular acceleration of link 2	$\ddot{\gamma}$	$9585.87\ cm/s^2$ = $95.8587\ m/s^2$
Overall load	F_1	1000 N
Torque	T	142.50 N.m
Force on the right wheel	F_p	359.18N
Area	A	$78.54\ cm^2$
Force on link 2	F_c	414.74 N
Stress on link 2	S_c	$528.07\ N/m^2$
Force on bearing at pinpoint of rod and crankshaft	F_B	-414.74 N
Thrust force link 1	F_T	207.37 N
Stress on link 1	S_B	$-264.03\ N/m^2$
Torque on link 1	T	25 N.m
Mean Aerodynamic Chord (MAC)	C	0.079 m
Area (Planform)	A	$0.09\ m^2$
Taper ratio	λ	0.34
Aspect Ratio	AR	14.24
Weight	W	25.63 N
Coefficient of lift	C_L	1.297

Lift-curve slope	a	$5.51\ rad^{-1} = 0.096\ degree^{-1}$
Induced Drag	$C_{D,i}$	0.037
Drag	D	0.988 N
Rotational Speed (RPM)	w	2500 RPM
Acceleration (energy)	a	$1.128 \times 10^{-3}\ m/s^2$
Force (energy)	F	7.77192×10^{-3} N
Work (energy)	W	0.0355 joules
Power (energy)	P	3.944×10^{-4} watts per second
Total flight energy	E	0.71 joules for 30 minutes of flight
Distance (energy)	x	8640 meters of daily travel
Acceleration (energy)	a	$0.0020833\ m/s^2$
Force (energy)	F	0.078212 N
Work (energy)	W	676 joules
Power (energy)	P	0.0235 watts every 8 hours
Velocity of air (energy)	V = U	32km/h = 0.89 m/s
Lift force times 3 (energy)	L	76.89 N
Energy	E	123,178 joules
Power (energy)	P	68.4321 watts per 30 mins of flight
Drag force times 3 (energy)	D	2.964 N
Distance (energy)	x	6000m
Energy due to drag	E	17,784 joules
Power	P	9.88 watts per 30 minutes of flight
Total Power (During flight)	P	79.0221 watts
Energy per 4680 battery cells	E	9.88 watt-hours per battery
Energy	E	39.669-watt hours per operation shift
Number of batteries required	z	4.015 batteries
Battery pack volume	V	$0.008508\ m^3$

Distance from center of mass for robotic arm	x	4.5334 cm = 0.045334 m
Torque robotic arm	T	0.39266 N·m

VI. RESULTS AND DISCUSSION

Structural analysis results and analysis

Advanced computer modelling and finite element structure analysis for constructing a solid rover-copter are utilized as virtual prototype methods to perfect the rover-copter at the initial design stage and in the development process for improving the construction. Construction optimization is utilized to reduce tension in the rover-copter under stress limits, factors, and variables. The results reveals that a finite element process analysis can improve the rover-copter's design and provide feedback on the structure and materials. Exploration expeditions have taken place with robots in recent space history. These highly complicated devices are designed to perform and a broad range of duties in all demanding settings [16] Agencies efforts between these new actors and governmental entities could solve a number of problems and strengthen the public's commitment and interest by pooling resources and knowledge. The evaluation and the maximization of mobility, bodily life and other elements that exist on the rover-copter is an important factor when constructing a planetary explore rover. For example, robotic arm integrated and copter. This means that rovers are tested under appropriate conditions, the expectations are imitated, and the design is adapted to increase the total capacity in the mission. With these results and in conjunction with input, efficient copter-rover research can be built. For force computation to characterize the material's physical characteristics, the 3D model was moved to a software known as ANSYS. The initial stage was to design the rover copter using AutoCAD. A hollow-fit design was designed to decrease the weight of the entire rover. After the model was established, the design meshed using the ANSYS meshing tool. The rover-copter is static and before meshing, the material properties were applied. The body of the rover is the heart of the entire design and ties together all the elements. The weight of the rover copter is the only force used for the structural study. A structural analyzes are highly significant and the maximum and lowest values are to be determined as follows:

- Equivalent Stress.
- Equivalent Strain.
- Total deformation.
- Safety factor.

Rover-copter

After generating the mesh of the model constrains and loads were applied on the model to perform analysis. The figure below shows all the loads and constrains applied on the model.

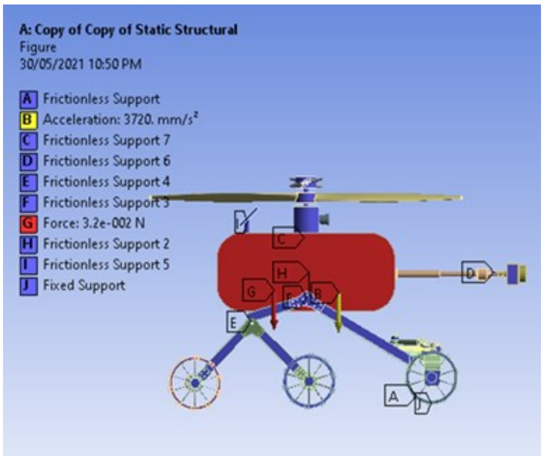

Figure 9. Shows the Static structural of the rover-copter side view.

After completing the simulation, the results were added to the solutions and the plots for them were generated

Results:

Table 4. The rover-copter ANSYS analysis

Object name	**Maximum**	**Minimum**
Equivalent stress units	1.9904 MPa	4.68E-08 MPa
Equivalent strain units	2.85E-05 mm/mm	6.60E-13 mm/mm
Total deformation units	0.0031136 mm	0 mm
Factor of safety	15	1.75

From the Table 4, the rover-copter ANSYS analysis it could be seen that the value of the stress produced in the model ranges from a value of 1.99 MPa to 4.68e-8 MPa. The highest stress experienced by the wheel spokes as they are carrying the complete load of the rover.

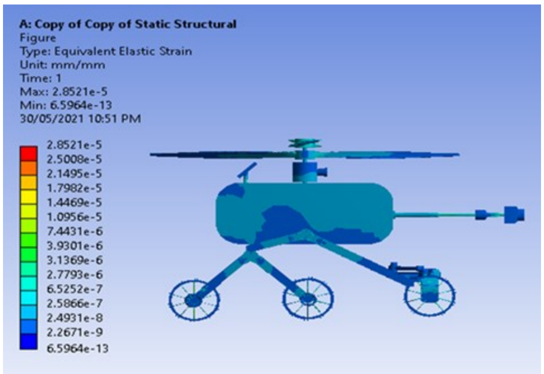

Figure 10. Equivalent strain of the rover-copter side view

From the simulation it was observed that the rod of the robotic arm and the spokes of the wheel experience the highest value of the strain

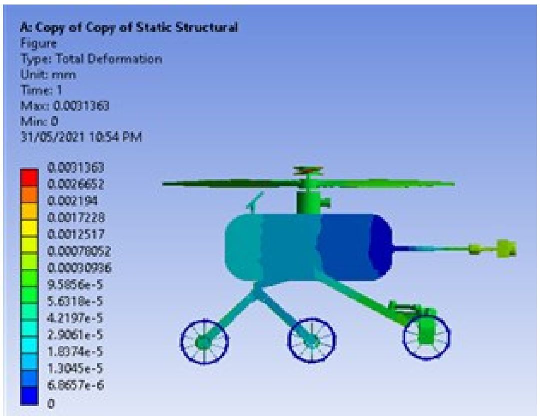

Figure 11. Deformation of the rover-copter side view.

The value of the total deformation produced in the model ranges from a value of 0.00311363 m to 0. 00311363 m. It could be seen that the end of the robotic arm and the blades of the copter undergo maximum deformation. And the safety factor for the rover the lowest value of the safety factor is 1.75 which is high enough to keep the rover safe, spokes of the wheel have lowest factor of safety, so they are the most vulnerable to an accident. To further improve the model to increase the safety factor design for the spokes could be modified. In addition, it could be seen that even though the spokes of the wheel have very small value for the factor of safety it's still in the acceptable range, but design could be improved further by improving the design of the spokes which will result in less stress and higher value of the factor of safety.

Air foil NACA 0012 analysis

The selected airfoil is NACA 0012. The simulations were performed by ANSYS (CFD) [17-19]. The results of the simulations will be as follows:

- CFD was performed on the airfoil because it is dynamic in Martian atmosphere.
- CFD simulations for pressure, velocity and velocity streamlines were applied.
- Simulations of lift and drag implemented at AOA 7 degrees.

Results:

The Airfoil NACA 0012 analysis values for the velocity plane was 1.833e^{02} m/s^2 maximum and 0.00 m/s^2 minimum. Similarly on the pressure plane -1.005e^{05} Pa maximum and -1.010e^{05} Pa minimum. And on the velocity streamlines 1.833e^{02} m/s^2 maximum and 0.00e^{00} minimum.

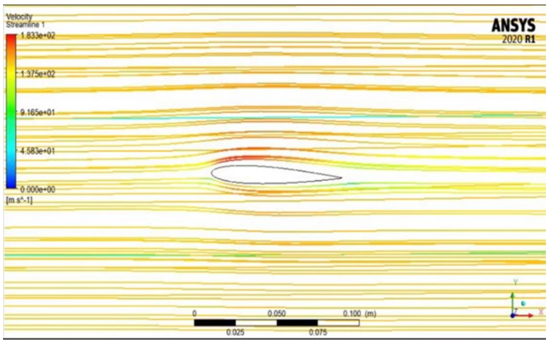

Figure 12. Velocity streamline value for NACA 0012 using ANSYS CFD.

Table 5. NACA 0012 values

Velocity (m/s)	Angle of attack	Lift (N)	Drag (N)	L/D
148.2	7	3.27	1.38	2.37

Propeller Simulations

Since the propellers are very important for the copter to take-off, hover, and cruise it should be simulated separately from the whole design. The performance of the copter will hugely be dependent on the aerodynamic performance and efficiency of this propeller [20-23]. Based on the previous studies made during phases, a variable pitched propeller with four blades that are made of carbon fibre composites are implemented. The results of the ANSYS simulations and AUTOCAD are displayed as follows:

- Design was imported from AutoCAD with specified dimensions.
- Mesh is hidden.
- CFD was applied for pressure and velocity to the propellers.
- Static Structural analysis is used for von-mises stress, total deformation, elastic strain and safety factor.

Results:

Table 6 Propeller ANSYS CFD results

Object Name	Maximum	Minimum
Pressure Contour (Pa)	-1.012e^{05}	-1.031e^{05}
Velocity Plane (m/s^2)	3.461e^{02}	0.000e^{00}

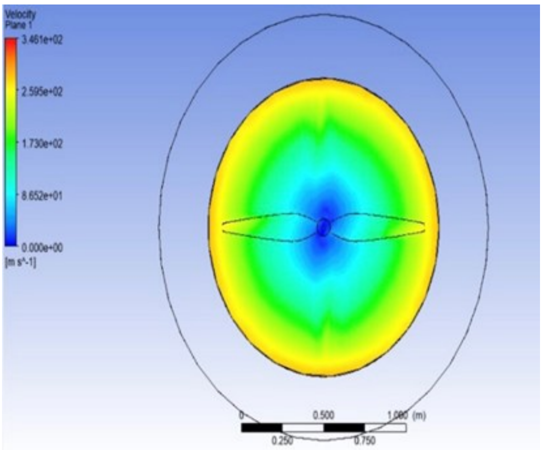

Figure 13. Velocity plane for the propeller using ANSYS CFD.

To perform the static analysis of the blades under the operating conditions in order to calculate the stresses and strains produced, at first CFD analysis was performed using ANSYS Fluent in order to find the characteristics of pressure at the propellers where no maximum while the velocity behavior indicates a minimum value at the hub while increases around the edges then the results for the pressure on the blade were used to calculate the stresses in the blades. After completing the model in AutoCAD, it was imported to the space claim (shown in the figure above) and geometry was prepared for the analysis after performing the CFD analysis static structural analysis was initiated. Model was imported to the meshing tool and meshing was performed. After performing the meshing fixed supports were applied at the center of the blades where they will be attached to the shaft of the copter and then the blades pressure data was imported to the static structural. Then the pressure data was applied and the model was solved and values and maps for different parameters were generated.

Table 7 Propellers ANSYS analysis.

Object Name	Maximum	Minimum
Equivalent stress	1.1162	6.57E-05
units	MPa	MPa
Equivalent strain	0.00010943	9.27E-07
units	mm/mm	mm/mm
Total deformation	0.53315	0
units	mm	mm

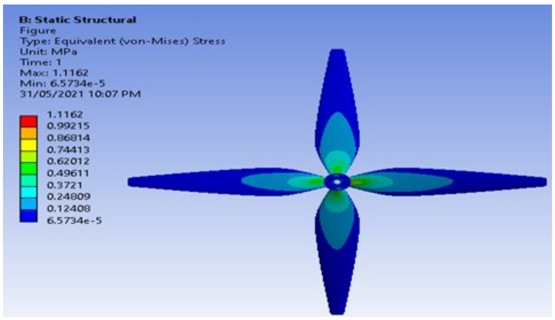

Figure 14. Equivalent stress of the propellers using ANSYS static structural

Figure 14 shows the stress produced in the blades that stress is high near the hub end and is low near the tips of the blades. That is why the root of the blade is designed thick to compensate for the higher value of the stresses produced there, while tips are designed thin because there is not much stress acting on the tips. The other figure above shows the strain produced in the blades and it could be indicated that the value of the strain produced is high near the base of the blades due to higher value of the stress there. From the analysis the total deformation produced in the blades and the value of the total deformation is higher near the tip as they are the parts which deform the most. Finally, the simulations of the epoxy carbon fiber blades were analyzed. The pressure contour and velocity plane were simulated using ANSYS CFD while the von-misses stress, total deformation, elastic strain were obtained using static ANSYS structural simulations. For all results, values of maximum and minimum values are tabulated clearly.

Copter Simulations

The Coaxial copter was simulated to test its aerodynamic performance in Martian Atmosphere. Since the copter has to pre-map the terrain for the rover, several tests were conducted on the final design of the copter since it is very important to determine its capability of operating in Mars and reach the specified objectives. CFD and Static Structural simulations applied as shown below.

Results:

The copter ANSYS CFD analysis showed that the maximum velocity vector was $3.185e^{05}$ m/s and minimum was 0.00 m/s and the pressure contour was $4.58e^{02}$ Pa maximum and $-1.082e^{03}$ Pa minimum. The lift produced by the blades is positive while the lift produced by the copter is negative due to the downward airflow acting on the copter.

To perform the static structural analysis of the copter model was prepared in AutoCAD and was imported to the Space Claim. In addition, importing the geometry meshing was performed on the model. After performing the meshing fixed supports were applied to the model it was decided to apply the fix supports on the tips of the blade to see if blades can support the weight of the copter. After applying the fixed supports, gravitational acceleration was applied to the model as per the value of gravity on surface of the mars. Friction less supports were applied to the model to stop the rotation of the model. After applying the frictionless support model was solved and plots for different parameters were generated.

The Figure 15 show the stresses produced in the model under the weight of the copter. Also, show the strain produced in the copter under the gravity of the mars, maximum strain was observed near the tips of the blade and the base of blades.

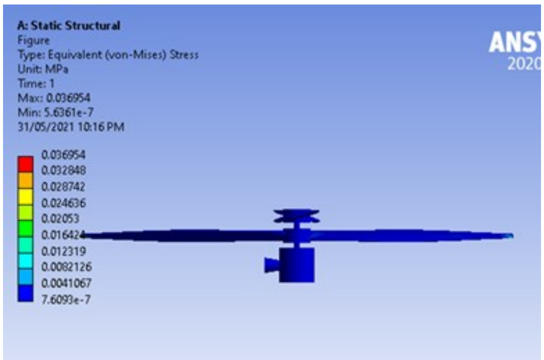

Figure 15. Equivalent stress of the copter side view

The copter ANSYS analysis were that the maximum equivalent stress was 0.036954 MPa (max) and 5.6361e-7MPa (min), the equivalent strain was 2.648e-7 (max) and 4.6785e-11 (min), the total deformation was 3.5868e-6 mm (max) and 0mm (min).

In short, the rover-copter model properties were determined using ANSYS Static Structural. The sole restriction was the high number of safety factors that can be described as the material utilized such as 7075 aluminum, steel, and carbon fiber.

VII. CONCLUSION

The fundamental idea behind this project's study paper is a rover-copter that can assess scientists and geologists in Mars without any human involvement. This chapter unites the main purpose. Scientists get the help to understand other planets and what are they made of using rovers. Different types of rocks are made in Mars and each type is uniquely made up of combination of substances. Rover-copter can drive throughout to different areas and study the planet with facing the challenges it has. As to promote the rover-copter project it is indeed important to keep in mind which company and manufacturer would like to purchase it. The main benefit in the project is that it is small and is not heavy in weight. Therefore, space agencies and organizations prefer to use a rover-copter in order to explore and analyses the outer planets as well as to protect the health of people in space sector. As a result, as technology advances, the rover-copter of this research was customized into different forms of usage to test Mar's soil and rocks. The function of the copter is to scan the right path for the rover to maneuver. In addition, the copter is like the brain of the copter in which it scans and gets back to the rover to give it a clear path to take. The design drawing was modelled using AutoCAD meanwhile, the statics structural and the ANSYS computational fluid dynamics "CFD" results were applied to get different forces and conditions that are required to analyze the mechanical properties and aerodynamics properties of the rover-copter.

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