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Analysis of Water Rocket Launch Test With Carbon Fiber Material Using Telemetry System

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Abstract. *Rocket technology with water propellant is becoming more popular and as an alternative to be applied to education and recreation, such as industry and the military. The use of water rockets as an easy, safe, and inexpensive means of measuring physical parameters at heights above the earth's surface is being intensively carried out. One alternative solution is aerodynamic water rocket technology equipped with a telemetry system. The rocket used for the test launch is made from untested carbon fiber. Flight test settings by filling 1/3 of the tube volume with water and a pressure of 1,379,000 Pa. The results of the water rocket launch show a maximum height of 80.77 m. Changes in acceleration on the x-axis, y-axis, and z-axis indicate the normal motion of the flying rocket. Analysis of stability and control of the rocket is seen in the measurement of the tilt angle of roll, pitch, and yaw. When the rocket moves or tilts, the angle measured corresponds to the tilt. In the roll condition, the rocket moving from launch to landing shows the rocket's rotational motion at an angle of approximately 20^o. The potential of water rockets that can still be developed, needs to be increased the reliability of water rockets both in terms of utilization and research.*

Keywords: *rocket, telemetry system, stability, control.*

Abstrak. Teknologi roket dengan propelan air menjadi lebih popular dan sebagai alternatif untuk diterapkan untuk pendidikan dan rekreasi, seperti industri dan militer. Penggunaan roket air sebagai sarana yang mudah, aman, dan murah dalam pengukuran parameter fisik pada ketinggian di atas permukaan bumi sedang gencar dilakukan. Salah satu solusi alternatif adalah teknologi roket air aerodinamis yang dilengkapi dengan sistem telemetri. Roket yang digunakan untuk uji luncur berbahan dasar serat karbon yang belum teruji. Pengaturan uji terbang dengan mengisi air 1/3 volume tabung dan tekanan 1,379,000 Pa. Hasil peluncuran roket air menunjukkan ketinggian maksimum 80.77 m. Perubahan percepatan di sumbu x, sumbu y, dan sumbu z menunjukkan gerak normal roket terbang. Analisis stabilitas dan kendali roket terlihat pada pengukuran sudut kemiringan roll, pitch, dan yaw. Ketika roket bergerak atau miring, sudut yang diukur sesuai dengan kemiringan. Pada kondisi roll, roket bergerak dari waktu peluncuran sampai pendaratan menunjukkan gerakan perputaran roket pada sudut kurang lebih ± 20°. Potensi roket air yang masih dapat dikembangkan, perlu ditingkatkan kehandalan roket air baik dari segi pemanfaatan maupun penelitian.

Kata kunci: roket, sistem telemetri, stabilitas, kendali

INTRODUCTION

Rocket technology is an important application in aeronautical or space technology. In everyday use, rocket technology mostly uses chemical propellants or chemical-based combustion [1]. This requires very complicated operations, expensive technology, spends a lot of time preparing for launch and security aspects also need to be considered. However, large-scale rocket technology, such as space shuttle launches, has been able to be launched by scientists and technicians.

Recently, water propellant-based rocket technology has shown interesting potential in various fields of application, such as for military (industrial) [2], recreation and also for education [3] [4]. The benefits gained in the development of water rocket technology are aspects of undeniable safety, mobility (launching can be done anywhere) and environmental friendliness. From a financial point of view, water rocket technology is very cheap when compared to combustion-based ones. Due to the superiority of these aspects, water rockets tend to be more widely used for recreational and educational purposes. The use of water rockets in other applications such as military or industrial is still minimal.

An important benefit of implementing water rocket technology is the measurement of physical parameters when gliding into the air (when at an altitude above the earth's surface). Like the temperature in the cloud mass, remote object sensing, even in military technology can be used to monitor enemy activity through video recording. It is possible to do this using other technologies (besides water rockets, such as satellites), but it will cost a lot of budget and complex operations. Even in the military world, it is something that is quite expensive if enemy surveillance is carried out via satellite or reconnaissance aircraft. For this reason, it is necessary to design and build a water rocket capable of flying as high as 300-500 m above ground level.

The method of measuring physical parameters when a water rocket is above the height of the earth's surface becomes very crucial and interesting in rocket technology systems. Rocket technology systems equipped with wireless remote measurement methods (telemetry systems) are an alternative. This is because, measurements can not always be done directly. In certain circumstances, during extreme conditions or in places that cannot be reached at any time, it is often difficult to carry out direct measurements and observations.

For this reason, in this research a study was carried out on the design of an aerodynamic water rocket system with a telemetry system. The body of the rocket is made of carbon fiber which is light and strong so it can withstand high pressure water propellant up to 1,000 psi or 6,894,757 Pa. The rocket will also be equipped with an accelerometer sensor (on the altimeter), which is connected to the transmitter and receiver units at the station. It is expected to obtain data wirelessly in real time on physical parameters when the water rocket is launched into the air. The design of the rocket is carried out by emphasizing aspects of aerodynamic studies, while the telemetry system is built using commercial sensors on the market.

METHODOLOGY

The basic problem in rocket technology is how to obtain thrust, drag, and change in rocket mass as a function of time in order to obtain acceleration, speed and position when the rocket is flying. The most popular rocket mathematical model is the Tsiolkovsky rocket equation [5] derived from Newton’s Second and Third Laws. Within the principle of water rocket propulsion, there will be a change in momentum due to the change in rocket mass with time. Through Newton’s Second Law obtained **Equation 1.**

$$\sum_i F_i = m\frac{dv}{dt} + v_e\frac{dm}{dt} \qquad (1)$$

with $\sum_i F_i$ is the forces that affect the motion of the rocket, m is the rocket mass, v_e is the velocity of the rocket mass injection, $\frac{dv}{dt}$ and $\frac{dm}{dt}$ is successively showing the change in speed and change in rocket mass with time. If it is assumed that there is no external force ($\sum_i F_i = 0$) and the injected mass (lost rocket mass) as

$-dm$, then **Equation 1** changes to **Equation 2**.

$$-v_e \frac{dm}{dt} = m\frac{dv}{dt} \quad (2)$$

By carrying out the process of integration and simplification of **Equation 2** we will get the value of the change in rocket speed as **Equation 3.**

$$\Delta v = v_e \ln(\frac{m_o}{m}) \quad (3)$$

with m_0 is the initial mass of the rocket (plus propellant material). This **Equation 3** is known as the Tsiolkovsky Rocket Equation.

In the real launch of water rockets, the earth's gravitational force, aerodynamic drag has a significant effect on the rocket's motion and the rocket's flight path. **Figure 1** shows the schema of the processes and forces that affect the rocket's motion. In view of this, **Equation 1** will be corrected as **Equation 4**.

$$m\frac{dv}{dt} = -mg - \frac{1}{2}C_D\rho A v^2 + v_e\frac{dm}{dt} \quad (4)$$

where $F_g = -mg$ is the gravitational force of the earth, $F_D = -\frac{1}{2}C_D\rho A v^2$ expresses the drag force (air resistance) and $F_T = v_e\frac{dm}{dt}$ is the force of rocket thrust. Equation (4) is an interesting and challenging thing to do either analytically, numerically, or experimentally proven.

The water rocket body prototype made from carbon fiber with a tube diameter of 20 mm and the body length of the water rocket is 170 cm is shown in **Figure 2**. This prototype has not yet been tested. The first step of the implementation of this research is the design of a launcher system (launcher) consisting of a rocket holder, a nozzle system that is connected to a scuba

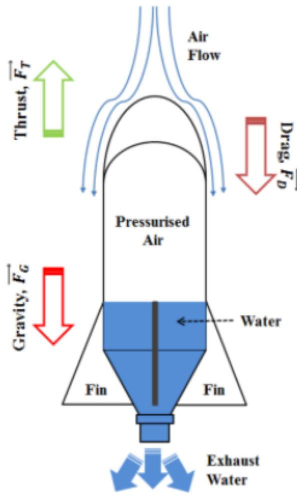

Figure 1. The forces acting on the water rocket system [5]

device (diving tube) as a source of high air pressure. The second step is to design a telemetry system to measure physical parameters when the rocket flies using a parachute. A commercial bluetooth technology based wireless AltimeterThree system [6] is used to measure the altitude of a rocket and the acceleration of each axis of the rocket at launch. This system is able to record position data as a function of time based on changes in air pressure with elevation. Data can be recorded using a smartphone or tablet device. Then the data is send online via email to computer unit in the laboratory for further processing. **Figure 3** shows the flight test set up and how the AltimeterThree telemetry attachment process to the water rocket body. The final step is the set up and preparation for the rocket launch in the paddy field.

Figure 2. Design of a water rocket from carbon fiber with a tube diameter of 20 mm and the body length of the water rocket is 170 cm

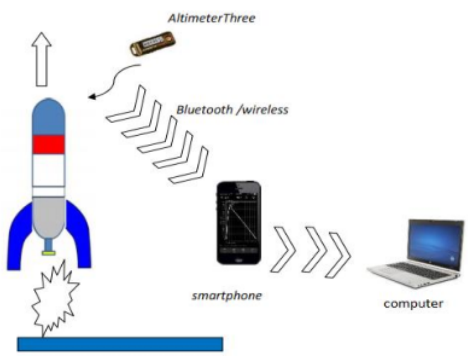

Figure 3. Diagram of set up water rocket with telemetry system

RESULT AND DISCUSSION

Figure 4 shows the trajectory of the rocket movement of the telemetry system. This altitude representation shows that the rocket experiences the motion of the bullet, its trajectory is parabolic. The water rocket launch test was carried out at a pressure of 1,379,000 Pa and a launch angle of 85°. The basic material of this water rocket uses carbon fiber. Carbon fiber has several advantages, including the nature of the material being light, strong, and can reduce the transfer of excess heat generated in the nozzle to the rocket body. The resultant combustion chamber temperature increases and the resulting thrust will also increase. Utilization of the properties of carbon fiber can increase its maximum height greater than plastic bottle materials. When the combustion time is long, the thrust generated increases due to the increased pressure [7]. The maximum height of a water rocket with a plastic bottle base is 32 m with the same nozzle diameter [8]. While the maximum height of the fiber-based rocket can reach 80.77 m in 4.20 s.

The flight profile of the rockets tested was generally the same [9]. The first phase is the thrust phase which starts right after ignition. During the thrust phase, the rocket gains all of its upward acceleration. The combustion time of the motor will determine the length of the thrust phase. Burn time is measured at 0.30 seconds with the maximum speed achieved is 35.36 m/s. After the push phase, the delay phase begins. During this phase there is no thrust coming from the motor. In this phase, the rocket begins to slow down and may reach its peak. The time it takes from the end of the thrust phase to the top of the rocket's flight, then the time it takes the rocket to move from apogee to ejection. This time is known as the delay time, which is the total time the rocket launches before ejection. The speed with which the rocket returns to the ground depends on the size and efficiency of the recovery device. It's generally to lower the rocket slowly so it doesn't get damaged. The recovery phase begins when the ejection charge is fired and the parachute is pushed out. In this test flight, the rocket descends at a speed of 22.13 m/s.

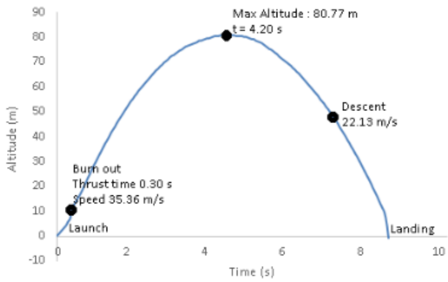

Figure 4. The results of the movement of a water rocket with a telemetry system

The use of a wireless system based on Bluetooth Altimeter Three technology is able to record position data as a function of time based on changes in air pressure to altitude position. The results of the telemetry system show the movement of the water rocket in three dimensions, three axes, namely the x-axis (pitch), the y-axis (roll), and the z-axis (yaw). The data recorded is the impact of gravity on dynamic acceleration in three directions which has been adjusted to the earth's gravity point [10]. **Figure 5** shows the acceleration test data on the x-axis, y-axis, and z-axis. **Figure 5** shows the acceleration on each axle as the rocket moves upwards to reach its maximum altitude then changes direction as it descends towards a ground point. The results of the movement show the same acceleration pattern on all three axes. The change in acceleration on the three axes indicates the normal motion of the flying rocket. At an interval of 5.00 seconds, the acceleration of the three axes changes significantly before finally increasing. This indicates a significant noise to the flying rocket.

Rocket movement is divided into two types, namely aerodynamic and non-aerodynamic. Aerodynamic movement relies entirely on fast-moving winds, this method can occur in fast-moving rockets that get a lot of wind. Based on **Figure 5** shows that in the early days before the launch, the telemetry system has detected a small movement due to the installation of the system in the nose cone. The initial system data shows that the three axes of the accelerometer sensor read data on the acceleration of the rocket's movement on each axis. In the y-axis direction (roll) means controlling the movement of the rocket to rotate right and left. The x-axis direction (pitch) means controlling the movement of the rocket up and down. The direction of the z axis (yaw) can control the movement of the rocket to the right and to the left. The acceleration of the three axes shows the control of the movement of the rocket so that an aerodynamic force occurs [11].

Monitoring the attitude of the rocket's motion on the roll, pitch, and yaw angles can be calculated using a formula equation to find the angles of the three axes [10]. **Figure 6** shows the roll, pitch, and yaw angles with respect to time. The trend graph in **Figure 6** is almost the same as **Figure 5**. **Figure 6** shows the angle of each movement of the rocket in order to keep the rocket's position changing by utilizing wind pressure. Every movement of the rocket is kept from rotating to the right and left (roll), up and down (pitch), moving right to left (yaw). The results of the test show that the measured pitch angle is in the range -90^{o} to $+90^{o}$, the roll angle measured is in the -45^{o} to $+45^{o}$ range, while the yaw angle is measured in the -90^{o} to $+90^{o}$ range. In the measurement test when the rocket is at rest, the pitch and yaw slope data shows a change. When the rocket moves or tilts, then the angle measured is in accordance with the tilt angle.

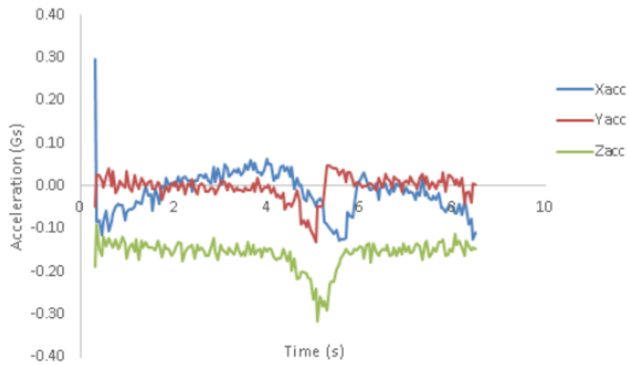

Figure 5. The results of testing the acceleration of rocket motion on 3 axes

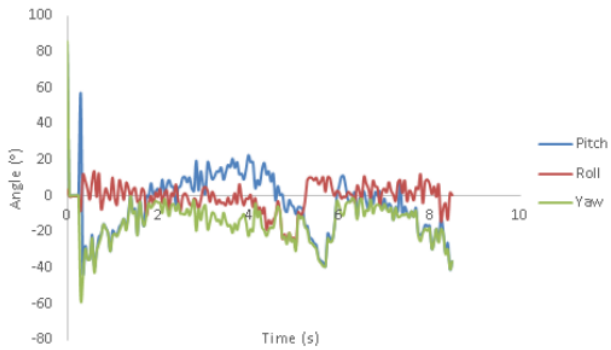

Figure 6. Roll, pitch, and yaw angles of rocket motion

Figure 7 shows the result of the height of the rocket from the surface. The comparison results show that the height of the rocket with air pressure is inversely proportional. The higher an altitude above sea level, the air pressure decreases, and vice versa. This is because the number of molecules and atoms in it is decreasing [12]. Air pressure is one of the factors that can affect and determine air density. In accordance with the formulation of the height of the rocket using air pressure [13]. Each 1 Pa change is equal to 0.085 meter from the surface.

The results of data analysis from measurements and calculations show that the rocket's motion profile has been detected properly. The use of carbon fiber rocket material provides the advantage of increasing the maximum altitude. The stability and control of the rocket's motion can be seen from the angle of inclination on the three axes (x, y, and z). The three axes provide control over the movement of the rocket from launch to landing. The roll angle shows that when the rocket is launched until the landing, the movement of the tilt of the rocket's motion does not experience a relatively large rotation.

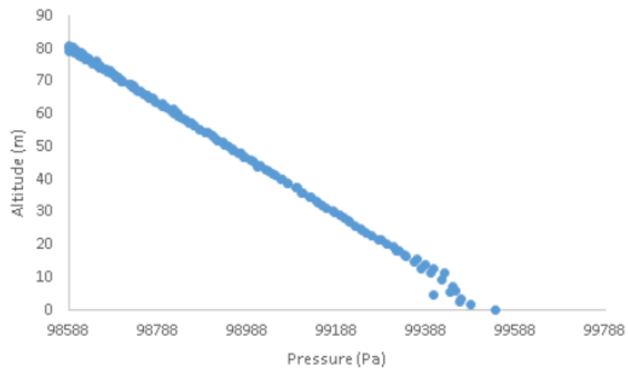

Figure 7. Comparison between pressure and altitude of rocket movement

CONCLUSION

The results of the 1,379,000 Pa pressure rocket launch test resulted in a maximum altitude of 80.77 m for 4.20 seconds. Search results and rocket control can be seen from roll, pitch and yaw angles. In tilt measurement, when the rocket is at rest, the pitch and yaw slope data changes. When the rocket moves or tilts, the angle measured corresponds to the tilt. In the roll condition, the rocket moves from the time of launch until it shows the rotational motion of the rocket to the right and left at an angle of approximately $\pm$ 20°. Although the results obtained have not reached the desired target, this water rocket can be used to analyze kinematic motion. Therefore, seeing the potential that can still be developed, it is necessary to increase the reliability of the rocket both from utilization and research.

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