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Analysis of the Mechanical Principle of Water Rocket Launch and Its Design

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Abstract: Water rocket is a common physical extracurricular production work. In practice, the author has found that there are many improvements available. Based on the study of the mechanical principles of water rocket launch, the performance and safety of water rocket are improved through analysis and improvement of design. At the same time, the launch of rocket, the separation of first and second stage rockets, as well as recovery are observed from multiple angles using on-board cameras, thus achieving full simulation of rocket launch.

Keywords: Water rocket, Making, Simulation.

1. Introduction

The successful launch of the SpaceX rocket was stunning to middle school students and also brought vitality to physics teaching. Many junior high schools have introduced self-made water rockets into their physics activity curriculum. Under the guidance of teachers, students closely integrate physics knowledge into extracurricular physics practice activities through hand making, brainstorming and mutual communication, from which they have gained the joy of success and developed the enthusiasm for science.[1]

2. Working Principle of Water Rocket

According to Newton's third law, when an object exerts a force on another object, the first object will experience a force in opposite direction. For example: when a balloon full of air is released, the balloon will spew gas backwards, which pushes the balloon forward. In making a water rocket, the working principle is that air is replaced by water whose density is higher and the balloon by a coke bottle.

3. Structure and Characteristics of Water Rocket

3.1. Safe and controllable launch

The launch height of water rocket is related to the amount of water in the bottle. The water rocket made with a single bottle is limited in terms of style and launch height. If multiple bottles are connected in series, the launch height of rocket can be increased to improve the simulation effect.

The author made an improvement. As shown in Figure 1, a customized interface and emitter are adopted, and a brake cable and brake lever are used to control the launch of the water rocket. A barometer is installed at the intake pipe for real-time observation of air pressure inside the bottle, and all devices are installed on the self-made launcher.[2]

Figure 1. A customized interface and emitter

3.2. Arbitrary combination of water rocket body

Conventional water rockets are launched using rubber plugs, where they are launched only when air pressure inside the bottle is sufficient to squeeze the rubber plug out of the bottle. If the plug is excessively tight and cannot be squeezed out when air pressure inside exceeds the endurance of the bottle, the water rocket will explode, causing a safety risk. Furthermore, the separation of water rocket and rubber plug cannot be predicted, resulting in poor controllability of the launch.[3]

3.3. Clever automatic separation of the first and second stage rockets

A secondary separator is used to connect the first and second stages of the water rocket. During inflation of the water rocket, the one-way valve in the separator is opened to inflate both the first stage and second stages of the water rocket. What’s more, since the pressure difference between the upper and lower stages is almost zero, the rubber tube tightly covers the organic glass tube, ensuring the tight connection of the first and second stages of the water rocket. When the water rocket is launched, after all the water in the first-stage rocket is emptied, the air pressure inside drops rapidly. At this time, the one-way valve is closed, and the air pressure inside the second stage rocket remains unchanged. Due to the higher air pressure inside the second stage rocket, the rubber tube expands to cause separation between the first and second stage water rockets. As water is ejected from the second stage rocket, there is secondary acceleration to further increase the launch height of the water rocket (the launch height is close to 100 meters when it is extremely inflated).

Figure 2 shows the second stage separator of the self-made water rocket. The changes in the pressure inside the first and second stage bottles after the launch is cleverly used to achieve automatic separation of the first and second stage water rockets.

Figure 2. Tthe second stage separator of the self-made water rocket

3.4. Reliable recovery of the water rocket

In order to ensure the reuse and safety of the experimental equipment, parachutes made of silk fabric were provided on each stage of the rocket. The parachute of the first stage rocket is installed at the connection between the first and second stage water rockets, and is triggered when they are separated. The parachute of the second stage rocket is installed in a special ejection compartment at the head of the rocket and can be released through reliable remote control. Namely, after the water rocket reaches the highest point, the parachute compartment is opened through the ground remote control, and the parachute is automatically popped out and opened to secure safe landing of the water rocket (As shown in fiuure3).

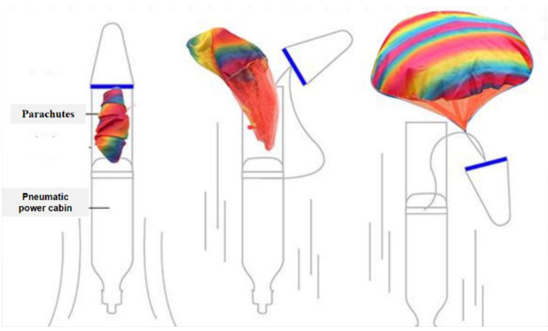

Figure 3. The landing process of the rocket

4. Making of Water Rocket

1) Make of the tail wing. Draw a total of eight tail wings with a size of about 9 cm × 4 cm on harder paper. Then, cut them one by one with scissors and pair them. Next, bend the tail wing outwards at a distance of about 1 cm from the lower edge. The middle part of the 2 tail wings is glued with double-sided adhesive. Their outer sides can also be glued with transparent tape for 2 more laps to ensure fastness.

Figure 4. Making of tail wings

2) Fixing of tail wings. First, glue a tail wing on the bottle at a location which is 5~6cm away from the bottle mouth. As to the process, 1 piece of tape is glued along the direction of the tail wing on one side, and then another piece of tape is glued on the other side. At the same time, attentions should be paid to the direction of tail wings, without mistakes. Next, glue the other tail wing at the symmetrical position of the tail wing, and the other two tail wings at the middle of the two tail wings. Finally, glue the tape horizontally for 2 laps to ensure that it will not fall, as shown in Figure 5.

Figure 5. Fixing of tail wings

3) Making of rocket head. During the flight, the smaller the air resistance, the farther the flight distance of rocket. Therefore, the flight resistance of the water rocket should be reduced. Take 1 piece of harder X-ray film and 1 coke bottle. Cut the bottle at a position which is 15 cm from the bottle mouth. Then, remove the soft head of badminton, and squeeze it from the bottom of the bottle until a part of it is protruded. Next, wrap the badminton head with the cut X-ray film for 1 lap, adjust the size and make sure they are aligned. Finally, use transparent tape for fixing and the cowling is completed, as shown in the Figure below.

Figure 6. Making of rocket head

4) Making of launcher. The launcher should be characterized by adjustable launch angle and satisfactory stability. Choose a 40 cm×25 cm wooden board as the base of the launcher. Connect 2 small wooden blocks with a hinge for adjustment of launch angle. At the same time, a screw is screwed into the wooden board at the rear end to serve as a pillar for adjustment of launch angle, and a protractor is fixed at the included angle. Then, take a 30 cm×25 cm wooden board as the upper splint, and drill a hole with a diameter of 4 cm at a distance of 8 cm from the top. 2 small holes are drilled on both sides at a distance of 6 cm from the hole, so that the iron rod with a diameter of 1.4cm is just stuffed in without falling. The entire completed launcher is shown in Figure 7.

Figure 7. Making of launcher

5. Factors affecting the Launch Height of Water Rocket and Measures for Improvement

During the test launch, it was found that some rockets failed to soar due to air leakage; some were deflected; some failed to travel far enough. There are many influencing factors of the flight of rocket, including the following:

1) The air tightness of the rocket body. The air tightness of water rocket must be guaranteed, otherwise, it cannot soar due to low air pressure caused by leakage.

2) The symmetry of tail wing. The tail wing of water rocket plays a role in adjusting its flight attitude. If it is asymmetrical, it will be deflected from the straight line.

3) Resistance and self-weight. In addition to the own weight, the rocket must also overcome the air resistance caused by high-speed flight after taking off. Therefore, it is necessary to minimize the weight of water rocket by selecting lightweight materials and reducing unnecessary decoration. Furthermore, it is necessary to reduce wind resistance by ensuring streamlined design of the front cowling and gapless pasting of tail wings, etc.

4) Pneumatic power. The air pressure inside bottles is the source of power for the water rocket, which affects the launch height. Low air pressure inside bottles is mainly caused by poor air tightness of rubber plug. Therefore, its roughness should be increased through polishing with a small file or through horizontal scrapping with a wallpaper knife. The rubber plug should be hollowed out 3 mm away from its upper and lower parts. Instead of using an air needle, a valve core is directly screwed into the rubber plug, which will increase the air pressure of bottle by 40%.

5) The amount of water in the bottles. Too much water will result in overweight, while too less water will cause inadequate kinetic energy. Therefore, the most appropriate amount should be determined through repeated experiments. As to how much weight of the rocket is appropriate, strictly speaking, it should be determined after several times of experiment. It is best that a 2.5L coke bottle be filled with an amount water whose depth is 5 to 6 cm from the bottom.

6. Making of Secondary Pressurized Water Rocket

The air pressure inside the bottle directly affects the launch height of rocket. Increasing the air pressure inside the bottle will undoubtedly boost rocket. Therefore, it is necessary to make a secondary pressurized water rocket. Since the air pressure endurance of one 2.5L coke bottle is limited, another coke bottle should be connected in series. However, it is difficult to solve the problem of air tightness between the two bottles. Our solution is adoption of a valve core plus a rubber hose.

First, use scissors to make an opening at the center of the bottom of bottle, and its size should be a little smaller than the diameter of the bicycle valve core tube; then, put the valve core with a rubber pad into the bottle, draw it out, add a rubber pad and tighten it with a screw cap. The air tightness can be tested in water after inflation, so long as there was no bubble. The other side is connected to the cap of the other bottle, or alternatively, the same method can be adopted for connection with the other bottle. In the experiments, it was found that the rocket failed to soar high due to insufficient air pressure and excessive self-weight. Therefore, 1.5 L coke bottle was used instead. After inflation, the launch height was significantly increased compared with that of a single rocket, which solved the problem of the ratio of air pressure to weight.

7. Making of Water Rocket Parachutes

The water rocket can soar vertically into the sky for a height of over 100 meters. However, the higher the it soars, the severe when it falls. Therefore, it is necessary to ensure safe landing of water rocket by providing parachutes.

1) Making process. Choose the silk fabric and cut it into a square with a side length of 80 cm. Then, fold it in half and cut it into an arc. Next, open it and sew it with a thread of an equal length of 60 cm at the 8 corners. Finally, directly tie them together.[4]

2) Opening of parachutes. The resistance gap separation is adopted: When heavy object and light objects fall at the same time, the parachute will be automatically opened caused by their different speed due to different air resistance. Therefore, the weight of head was increased to 100g. At the same time, a parachute compartment and a separation net for preventing excess tightness of parachute were made. One end of the parachute was connected to the rocket, and the other end was connected to the parachute compartment.

Notes: The parachute cannot be arranged casually. In order to ensure successful opening of parachute, it should be folded into a snake shape before being placed in the umbrella compartment. The bigger the umbrella, the less likely it will be successfully opened. Therefore, parachutes with a diameter of 60 cm were tried in the experiment. Furthermore, the material of parachutes should be as light as possible. For a water rocket provided with a parachute, the launch angle should be greater than 75° to achieve higher success rate.

8. Conclusion

Water rocket is an experiment designed to use air pressure, the biggest difference between a water rocket and a rocket is that the medium of propulsion is changed from high temperature air to water. When the nozzle is opened, the air naturally flows to the nozzle, but the water is in the way, so the water is pushed out of the rocket by the air, and the rocket gains forward speed. The physical principles contained therein are an important basis for understanding the mechanics of physics. The process of making water rockets can cultivate students' interest in learning physics.

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