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Kinematic Simulation of a universal rescue vehicle

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Abstract. The rescue of people in disaster through autonomous means of evacuation in some cases is the only way to save their lives. Rescue Mission often takes place in remote locations. The paper studies modeling of a universal rescue vehicle with a rotary-screw propeller.

1. Introduction

A universal rescue vehicle (URV) is a passenger all-terrain vehicle of amphibious type, which is provided with four screw propellers, two on each side of the vehicle (see figure 1).



Figure 1. A universal rescue vehicle

Figure 1 illustrates the reason for using "breaking" screws, which is the increase of floatation ability. Another reason for the use of screw propellers is connected with providing floatation on the water, because screws are hollow and their volume provides additional positive floatability of the whole vehicle.

Thus, a universal rescue vehicle can move on both a hard road and a non-cohesive supporting base, including water floatation.

2. Kinematic scheme of the Universal rescue vehicle.

Let us consider the kinematic scheme of the Universal rescue vehicle (see figure 2).

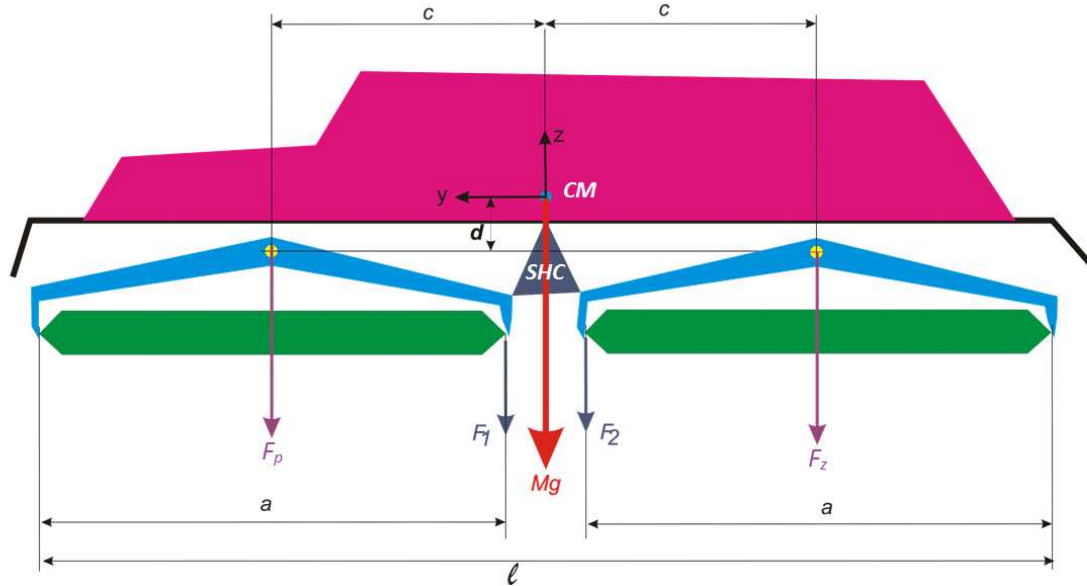


Figure 2. The kinematic scheme of the URV

In this scheme, we denote CM – center of mass. The fact that CM is exactly halfway between the axes of the mounting screws is quite logical – for the same load of the screws when moving horizontally. In a real situation, of course, it can be (and it is) not. There are many possible reasons for it: from different amount of residual fuel in the tanks to improper seating of passengers in the compartment. But here, we consider the situation when everything is perfect. Then we denote Mg – gravity of the USV center of mass, axes y and z denote the base coordinate system (BCS) of the unit (it is more logical to place it in the center of mass), F_p – a component of the USV force of gravity attributable to the front screw, F_z – a component of the URV gravity attributable to the rear screw.

For simplicity, we assume that the URV is provided with only two screws - front and rear. We "forget" that the URV has a third dimension – width and, accordingly, four screws. For an ideal situation, which is shown in figure 2, front and rear powers will be equal and will be exactly half of the USV gravity. Abbreviation SHC denotes the system of hydraulic cylinders, providing rotation of the screws. Accordingly, the strengths of these cylinders are designated as F_1 and F_2 . In the described ideal situation, these two forces are equal to zero [1].

3. Model of the cylinder in water

We assume the distance from the BSC to the axes of rotation of the screws in a horizontal plane to be denoted as c and a vertical shift - as d [2].

Let us try to calculate the depth of immersion of a hollow cylinder of known weight and dimensions. For simplicity, we assume that we just have a cylinder without cone "caps" at the ends. Let the ratio of the weight of the cylinder and the weight of the displaced water be denoted by ξ .

The first case is the cylinder stands in water vertically. This option does not seem the most obvious, but it is the easiest, so we will consider it at first. Let's consider figure 3, which shows the cylinder in water.

Here, required distance h is easy to find:

$$h = a \left(\frac{1}{2} - \xi \right),$$

here all symbols are denoted above.

The second case – the cylinder lies horizontally in water. Here, the situation is more complicated, let us consider figure 4

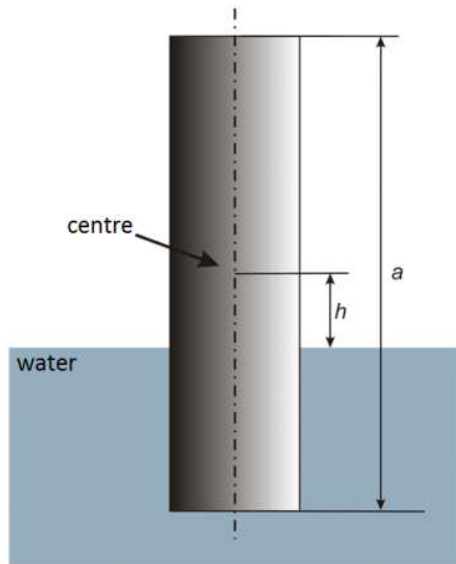


Figure 3. The cylinder stands vertically in water

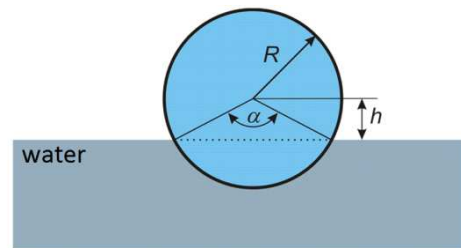


Figure 4. The cylinder lies horizontally in water. The end view

Obviously, the ratios of volumes ξ are equal to the ratio of areas of a circle segment below the dotted line and the area of the circle. Therefore, we can bring a three-dimensional problem to a flat one, shown in figure 4.

It is easy to obtain a formula for the ratio of the volumes:

$$\frac{\text{Arc cos} \frac{h}{R}}{2\pi} - \frac{h}{\pi R^2} \sqrt{R^2 - h^2} = \xi.$$

This shows that the equation for desired height h is strongly nonlinear, which is bad. We substitute $\text{Arc cos} \frac{h}{R}$ with $\frac{\pi}{2} - 1.25 \frac{h}{R}$ that is justified because graphics for modeling coincide (see figure 5).

As a result, we get the equation of the 4th degree, the solution of which is expressed by a "long" formula, which occupies an entire page. No need to bring it here [3].

Again, for modeling purposes, it is sufficient to substitute the circle by the square of the same area (see figure 6).

Here a is the size of the side of the square. In order to have the same area as the circle does, the square must have sides equal to:

$$a = \sqrt{\pi R}.$$

Now, we get the familiar expression for height h :

$$h = a \left(\frac{1}{2} - \xi \right).$$

Third, the most common case – when the cylinder is at angle α to the water surface (see figure 7).

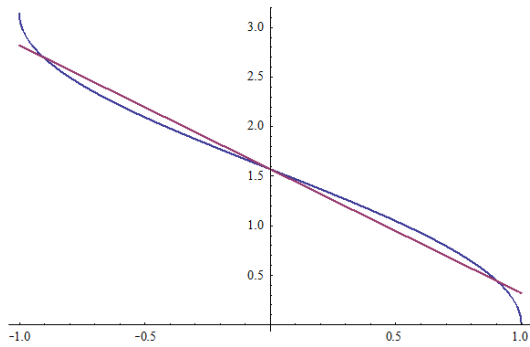


Figure 5. Graphics $\text{Arccos}x$ (blue curve) and $\frac{\pi}{2} - 1.25x$ (red curve)

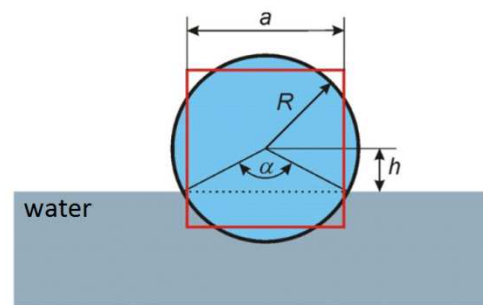


Figure 6. Replacement of the circle with the square

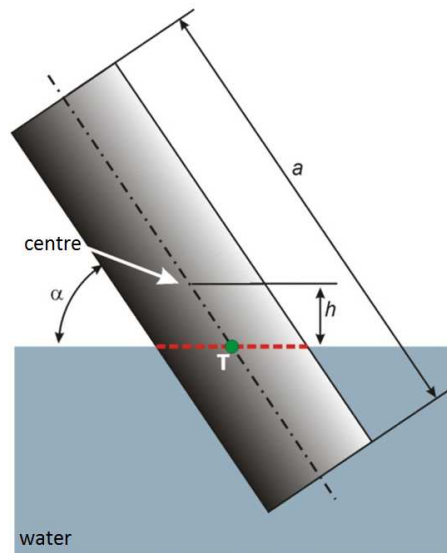


Figure 7. The cylinder is tilted

Here, the red dotted line shows the level of the water surface. When tilting the cylinder, it can be assumed that the cylinder is rotated around point T , highlighted in figure 7 as a green dot. Therefore, the value of h is calculated by a simple formula:

$$h = a \left(\xi - \frac{1}{2} \right) \cos \alpha .$$

4. Modeling of driving of the universal rescue vehicle from the water to the ice

Based on these formulas, we can calculate the position of the URV at its various positions, both in water and when driving over hard surfaces (shore or ice). Let us consider the efforts that arise in such movements (see figure 8) [3].

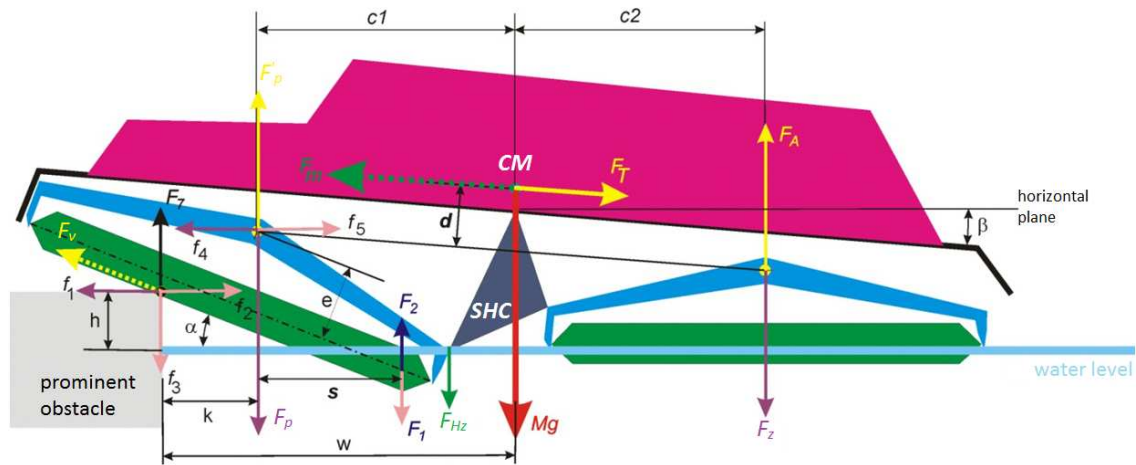


Figure 8. Demonstration of driving on an obstacle

The following forces are denoted here:

- 1) Mg – weight of the URV;
- 2) F_A и F'_p – reaction in the suspension point of the screws;
- 3) F_z и F_p – load at the point of suspension of the screws;
- 4) F_{Hz} – the force of the hydraulic cylinder by the tilted screw;
- 5) F_1 и F_2 – part of the gravity attributable to the front end of the screw and the corresponding buoyancy force;
- 6) F_7, f_1, f_2 и f_3 – forces arising from the support of the front screw on the obstacle;
- 7) F_v – the strength of the screw screwed into an obstacle;
- 8) F_m – tractive force required for the movement of the unit.

To raise an obstacle, screwing force F_b is not enough, because this force depends on pressure force f_3 , and it is may be inadequate at the initial moment, because it depends on the values of w and F_1 :

$$f_3 = Mg \frac{c_2}{w} - F_1.$$

Traction force of the screw in water is negligible, so the URV must be equipped with additional propulsion – a water jet.

Knowing the linking coefficient of the prominent obstacle, which is similar to the coefficient of friction, it is possible to calculate the force required for the movement of the Universal rescue vehicle:

$$F_m = F_v \frac{\cos \alpha}{\cos \beta} + F_T,$$

where α – the angle of the screw to the horizon, β – the angle of URV body to the horizon angle, F_T – the water jet traction force.

Let us calculate the required tractive force of the water jet. When moving the unit, the main force of resistance is the force of gravity, as the URV is being lifted onto the obstacle. Therefore, force f_3 is to be projected onto the axis of force F_v

$$f_3 \sin \alpha = F_T \frac{\cos \beta}{\cos \alpha} + F_e = F_T \frac{\cos \beta}{\cos \alpha} + \vartheta f_3 \cos \alpha,$$

where ϑ – the linking coefficient of the screw on the material obstacles. So, the required water jet tractive force is:

$$F_T = \frac{\cos \alpha}{\cos \beta} f_3 (\sin \alpha - \vartheta \cos \alpha).$$

4. Conclusion

Work on modeling and the creation of a universal rescue vehicle is only at its very beginning. Nevertheless, it is clear that the crossing possibility of the URV in almost any conditions is almost limitless. At present, the prototype of the vehicle is being manufactured: it will begin to be tested this year.

5. Acknowledgments

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