Development of a Water Rocket

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Abstract. In this paper is dedicated to a project concerning development of a water rocket. A main objective of the project is to develop a functional model of a water rocket with desired parameters. The development consists of the simulation models, design of the electronic circuits and practical realization. The electronics is supposed to measure pressure based altitude, accelerations and angular velocities during a flight to estimate trajectory of the rocket. Furthermore, it is also supposed to perform measuring of the rocket on the test stand when on the ground, to estimate thrust and dynamic effects in the bottle. This project is considered as an international student team collaboration.

Keywords
Water rocket, inertial sensors, pressure sensor, load cell, dynamic model simulation, model development, fast data processing.

1. Introduction

The objective of this project is the design and development of a water rocket, as well as the measurement of physical properties such as static air pressure, acceleration, angular velocities, thrust and water level in the rocket.

The objective can be split into two tasks, one performed in the air during a flight to obtain trajectory and estimate maximal altitude, and the other one performed on the ground using a test stand to obtain the information about the thrust of the rocket and design parameters.

2. Project Description

The rocket is made from a light pressure vessel (the shape is given by the combination of PET bottles which are main structural elements) partly filled with water and pressurized air. The rocket is equipped with stabilizing surfaces at the bottom of vessel, and a chamber on the top to wear the electronic components. Example of such a water rocket is shown in Fig. 1a,b.

As an international exchange agreement between CTU Prague and UPM Madrid, two Spanish students came to Prague to work on this project within their Master thesis. The project creates an opportunity to combine aeronautical and electronic knowledge in one objective which has a popular sense worldwide in education.

There are several tasks concerning this project. The project considers finished tasks in these miscellaneous fields:
1. Theoretical study of fluid dynamics inside the bottle, to calculate and simulate an accurate prediction of the movement.

2. Optimization of the volume of water and the diameter of the nozzle, to reach the maximum height while bearing in mind flight stability and minimum drag.

3. Experimental verification of parameters of the water rocket simulation model by measuring pressure, temperature and water level inside the rocket within the exhaust.

4. Design, verification and creation of a PCB board which consists in various sensors, properly selected to reduce weight, size, and power consumption.

5. Measurement of important flight parameters such as static pressure, acceleration, angular velocity, magnetic field distribution and, for the finishing touch, evaluation of reached maximum height.

3. Parts of the Project

The project is divided in three parts – water rocket model, test bed, and a trajectory measuring system. Description of these parts follows.

**Water rocket simulation model.**

1. To assemble the simulation model in Matlab Simulink for a vertical flight of a water rocket. The simulation model will be validated by measurements in the test bed.

2. To perform the optimization of initial parameters of the simulation model (e.g. volume of water, the nozzle diameter, air pressure, etc.) to achieve the maximum flight altitude for a given mass of the payload.

3. To perform the draft of size and position of aerodynamic surfaces for ensuring longitudinal stability during a vertical flight. To determine the conditions of static stability and assemble the simulation model for dynamic stability during the flight (CG position varies greatly). Required dependences of aerodynamic coefficients for different angles of attack will be determined by modeling of the air flow around the rocket in the CFD program.

**Test bed for experimental verification for a water rocket verification model.**

1. To design and develop a test stand dedicated for static experimental verification of the thrust of a rocket propulsion system. The thrust measurement will be based on the construction with strain gauges implemented to measure its time progression according to a rocket holder deformation.

2. The test stand will be also dedicated for experimental verification of parameters of the water rocket simulation model (e.g. dissipation losses, heat transfer etc.). For this purpose it will be needed to design and develop a measuring system for evaluation of pressure and temperature inside the rocket, and the level of the water in the rocket. The emphasis should be paid to the character of changes of those quantities. It has to be taken into account that those changes are rapid, i.e. in about 1.5 seconds the water is emptied and there might be a pressure drop from 10 bar to the atmospheric pressure, in the case of the temperature it might be a drop to -70 °C.

**Trajectory measuring system for a water rocket motion tracking.**

1. To design and develop a measuring system dedicated for tracking a water rocket motion. The system should enable to estimate the position, velocity, acceleration, and attitude of the rocket primary based on MEMS based inertial sensors, e.g. accelerometers and gyroscopes, aided by a pressure sensor and in the future by a GPS receiver. It has to be taken into account that the flight has four stages: a) a launch, b) a powered ascent – the acceleration is about 11 g and coasting flight, c) the descent, and d) the falling with ground reaching and recovery. The whole ascent can take about 5 to 7 seconds according to the size of the rocket and its initial inner pressure.

2. To design the software running on STM 32F405 processor. The software will communicate with sensors via I2C or SPI buses and it has to partly evaluate the stage of the flight for parachute deployment purposes. The measured data as well as raw data will be stored in a SD card or flash memory for post-flight evaluation.

3. To design and develop a parachute deployment system for rocket safe and slow descent and landing. It is very important system, because falling rocket can easily hurt people or cause harm to some property. The parachute should be deployed when the rocket reaches its highest altitude and it should have some safety mode if measurements and processor fails.

4. To verify developed systems experimentally during the flight.
4. Proposed Solution

Static thrust measurements. The test stand is designed to measure the static thrust produced by the water rocket. It is based on a single point load cell connected to differential 24-bit sigma-delta AD converter with integrated amplifier with selectable gain, suited for measurement of the load cell bridge sensors. Measuring circuit will be connected to a data logger for post-processing.

The load cell used for this stand is a 15 kg single point load cell which is a good compromise between upper and lower range estimated from the simulation model (0 up to 100 N). For detailed specification see Tab. 1. and Fig. 2.

<table>
<thead>
<tr>
<th>Rated Load</th>
<th>15</th>
<th>kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated Output</td>
<td>2.0891</td>
<td>mV/V</td>
</tr>
<tr>
<td>Max excitation</td>
<td>15</td>
<td>V</td>
</tr>
</tbody>
</table>

Tab. 1. Load cell specification.

Test Stand. The space in the laboratory is limited, so a removable structure is required. The design of a device for attaching the rocket to the load cell is needed. Its geometry depends on the load cell dimensions and the top of the bottle. It also needs to include holes for sensors’ cables and tube for pressure measurement.

The simulation model estimates a temperature drop to -70 °C inside the bottle. This change occurs in about 1.5 seconds. Therefore, a quick response of the temperature sensor is needed. The same conditions occur for the pressure sensor, in about 1.5 seconds the water is emptied and there might be a pressure drop from 10 bar to the atmospheric pressure. The water level in the bottle will be also measured.

Air supplier. A transportable air compressor is needed to supply pressurized air. Initial air pressure inside the bottle for a regular water rocket is about 10 bar.

Solution of the electronics, is briefly described by a block scheme in Fig. 4. The core of the system is uP STM32F405 which communicates via SPI and I2C bus with sensors. Measured data are stored in the SD card or in the flash memory. Some sort of user interface will take place on-board – LEDs, 7 segment display and buttons to perform all settings for flight. The uP could communicate with a computer (e.g. for online static measurements) via UART and is to be programmed with external JTAG programmer. Energy will be supplied from no-rechargeable removable 9 V battery. Although MCU and sensors use 5V, servo for the parachute deployment requires higher voltage.

4.1 Detail of the Payload

The payload placed in the nose cone contains the main electronic board with uP. There are placed sensors for measuring the altitude and navigation data. The altitude is estimated on the measuring of the static air pressure, a sensor MS5611-01BA03 is used. The trajectory will be estimated based on the measuring acceleration, angular velocities and magnetic field in three axes. The full integrated sensor MPU-9150 with 9 DoF (degree of freedom) is used for measuring all these values. The payload contains also a servo for the parachute system and power supply.

4.2 Project Planning

We considered project planning as crucial part of our work. To plan and organize our work we use mostly these means: weekly meetings, mail communication and shared folder with all data. The whole progress in the project is written down into online document and folders. We use these folders also for share partial results (as schematics, drawings and calculations) as well as datasheets of the elements we are using.
For next part of the development we defined 11 goals:

- Project definition (done)
- Simulation of bottle dynamics (done)
- Optimization to reach maximum height of flight
- Aerodynamic stability
- Design and building of test stand
- Perform the measurements
- Experimental analysis of simulation model
- Payload preparation
- Software development
- Payload manufacturing and testing
- Launch and experimental verification

5. Hardware realization

Used sensors and characteristics

MPU-9150 – accelerometer
selectable range ±2, ±4, ±8, ±16 g with 16 bit resolution

MPU-9150 – gyroscope
selectable range ±250, ±500, ±1000, ±2000 °/s with 16 bit resolution

MPU-9150 – magnetometer
range ±1200 µT 13 bit resolution

MS5611 – pressure sensor
range 10 – 1200 mbar, 24 bit resolution, resolution 10 cm in altitude

All sensors are capable to sample up to 1 kHz which is enough for supposed calculation. Electronics in the rocket is powered from two Li-Po 3.7V rechargeable accumulators with capacity 320 mAh. In Fig. 6 we can see a 3D model of the PCB which is adapted to the shape of the rocket.

6. Simulations

Several simulations of the motion of the rocket were made. On the Fig. 8 we can see velocity, which increases when rocket is flying up. Maximum height is reached when velocity is null, after that velocity decreases to negative and constant value, because acceleration is null.

The Fig. 7 shows rocket position in vertical flight within time. Preliminary results, before optimization calculates maximum height in 45 meters.

On the Fig. 9 is shown dependency of maximal height on inner pressure in the bottle and mass of water.
7. Conclusion

Although we did some work, we are still at the beginning. We managed to design the stand and prepare mathematical model of the rocket. We discussed a lot of time to define main goal which we want to achieve. Output of this was a detailed specification of payload equipment which couldn’t be designed without it. Even though most of our work is still just in our heads or computers, we consider that as a good start. Practical results will be presented on the Poster conference.

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References


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