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UNMANNED AERIAL VEHICLE APPLIANCE IN MICROGRAVITY RESEARCH

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Abstract. Microgravity experiments are important in field of space development; they give the possibility to simulate near-space conditions to test new systems and subsystems for space or to perform researches in various fields. The existing platforms, to perform reduced gravity experiments, allow us to achieve the targets of the researches. Otherwise these platforms are either very expensive or very short duration. Another key issue is the repeatability of the experiment. Fast repeatability platform (ensuring fast turn-around time), can guarantee only few seconds of microgravity time. For these reason, there is the need of platforms for microgravity experiments that will cover the needs of all the experiments that cannot fit into required time, cost and repeatability of any other experiment methodology. The paper explains the mission plan and first scientific data of parabolic unmanned plane research.

Keywords: UAV, parabola flight, microgravity research.

Introduction

Testing of the instrumentation that is intended to be used in space applications is a complex and expensive task due to difficulties of simulating of hostile space environment on the ground. One of such extremely complex tests is the low gravity testing. Due to gravity of the Earth simulating low (or zero) gravity conditions is extremely difficult and demanding task (Anderson 1992). Reduced gravity conditions can be simulated on Earth implementing several technological solutions: drop in the vacuum tower, "*ZeroG*" aircraft parabola flights, sounding rockets or balloons. Vacuum tower drop tests are possibly the best representation of low gravity conditions for scientific and testing applications so far, nonetheless cost of the facilities and the experiment itself is very high and unaffordable for most of the smaller laboratories and experiments (Dreyer 2006). "*ZeroG*" aircraft flights – the technology which has been matured for training of Astronauts can be implemented for testing of space equipment, nonetheless again the cost of operating the full aircraft performing parabola flight is very high and therefore normally unaffordable for smaller experiments. Sounding rocket or Balloon flight – that is possibly the most affordable means of simulating the low gravity environment so far (Haber, H., Haber, F. 2004). Nonetheless implementation of such high flying and quite dangerous vehicles as sounding rockets or balloons (launching, high altitude flight, recovery) impose strict safety requirements and tests can be performed in only several locations in Europe, which on its turn impose prohibitive costs and slow testing procedures (Hart *et al.* 2011).

The goal of the project is to develop affordable low gravity simulation system which could be used in multiple locations in Europe with low operational cost. Such system could be the low quick test option for small space intended equipment or other experiments (Jules *et al.* 2010).

This paper explains possibility to design low-cost UAV platform and first scientific data from initial testing.

Concept of unmanned aerial vehicles microgravity research platform

The concept is to achieve the reduced gravity condition using the parabolic flight principle on unmanned planes. Only recently it been started to considerate the use of parabolic flight on UAV. The method is already used with large plane and well known (Shin-Ichiro, Shotaro 2010). The example of flight path you can see in Figure 1.

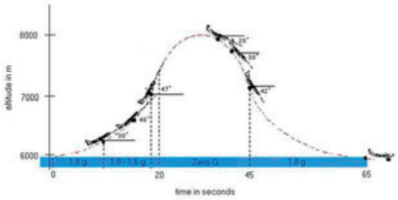

Fig. 1. Parabolic flight path

The equations of motion for the plane (considered as a point mass) are from Eq. (1) to Eq. (5):

$$m \cdot a_X = T - D \quad (1)$$

$$m \cdot a_Y = L - W \quad (2)$$

Equations for reduced gravity conditions:

$$T{=}D \text{ and } L{=}0 \quad (3)$$

$$a_X(t) := 0 \quad (4)$$

$$a_Y(t) := -g \quad (5)$$

The first concept, "*MOA-1*" aircraft (see Fig. 2), the low-cost gravity system is a plane that is suitable for all experiments of small size and with small budget both in term of time and money.

The systems are a modified "*AT-1*" plane to include the payload capsule and the service module and the flight heritage is proven. The configuration is a single engine piston. It can achieve multiple parabolic flight for 1 hour and 30 minutes of mission. The system can be re-flown in 15 minutes. The payload capability is up to 2 kg and the maximum take-off weight is 25 kg. Experiments could be performed practically any place in Europe, close to the places of development or any other facilities. The expected g-level of this platform is between 0.05 and 0.1g. At this moment plane is under testing.

The scheme shown in Figure 3 of plane subsystem is thought to reach an elevate and rapid level of integration of the payload with the plane. The plane will be provided with a Payload Capsule where it will be possible to decide the level of pressure and temperature, to achieve the closer space condition possible. The plane will be also provided

Fig. 2. The "MOA-1" unmanned aerial vehicle

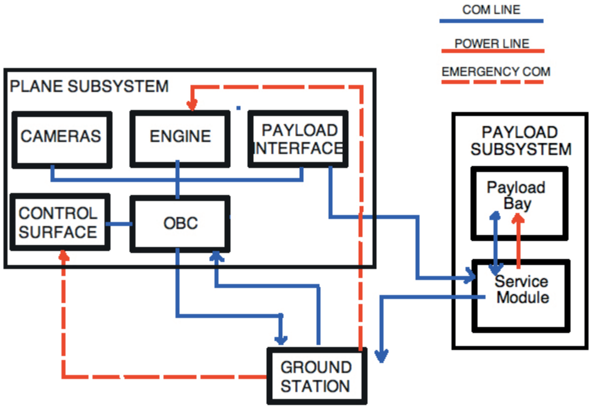

Fig. 3. Plane subsystems scheme

with a service module to feed the experiment during the flight. The service module will also provide the data link with the experiment and information on the plane status thanks to dedicated and precise sensors.

The other components of the plane are: the on-board computer (OBC) that will provide the automatic control of the plane and the management of the flight path thanks to sensors and software. The camera will provide images of the payload and form the plane (useful for its control). The powerplant (engine, fuel and plane battery) will be also managed by the OBC. A payload interface will ensure the electrical and electronic rapid integration of the payload with the rest of the plane.

Initial testing

In initial test phase flight path and flight dynamics was tested with flight simulator. "*JSBSim*" an open source flight dynamics model connected with "*Mission Planner*" flight control software to test and identify areas of development was used. Aircraft flew multiple parabolas. Data showed that even average speed small UAV can achieve +/–0.1 g-level for around 3 seconds (Fig. 4).

Data helped to optimize flight path and confirmed previous calculations. Typical parabola manoeuvre test flight aircraft was flying maximum air speed of 34.1 m/s and starting parabola manoeuvre. At speed of 20.1 m/s aircraft reduce throttle and starts microgravity simulation period. Aircraft fallows ballistic trajectory and latter enters horizontal flight stage (Pletser 2004). The quality and duration of microgravity is evaluated using the control system and the simulator. Parabola manoeuvre evaluated by defying acceleration index as Eq. (6) to evaluate magnitude of g-level.

$$g\,level(g) = \frac{\sqrt{a_x^2 + a_y^2 + a_z^2}}{g} \quad (6)$$

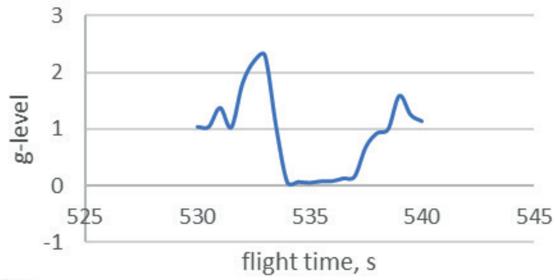

Fig. 4. Typical g- level test result during simulator parabola fight

As shown in Figure 4 aircraft managed to achieve 3,7 seconds' microgravity time. In addition, g- level acting on aircraft was around 0.059 g all this period.

Actual unmanned aerial vehicle test

Existing electric-motor-driven model airplane has been selected for phase II test to make vehicle small as possible for easy handling while accommodating onboard avionics including flight control module in flight test. Test aircraft with 1.8 m of wing span and 4 kg shown Figure 5.

The specification of aircraft is shown in Table 1.

Fig. 5. Test-bed aircraft

Table 1. Specifications of test- bed vehicle

Specifications	Value
Gross weight (kg)	4.00
Wing area (m^2)	0.45
Maximum speed (m/s)	20

The results of parabolic manoeuvre shown in Figure 6. It shows time history of acceleration components and the g-level.

Manoeuvre as discussed in paragraph 3.1 initiated from trimmed level flight and maximum motor RPM and acceleration acting on aircraft (z) axis $a_z = 9.81$ m/s^2. At pull-up and entering level flight points aircraft is affected by maximum load g-level = 2.4. Aircraft achieved typical 1.7–1.9 seconds' microgravity time. During microgravity period g-level holds approximately 0.062 g.

An interesting question is what criteria determine and constrain the amount of time spent in freefall. The most

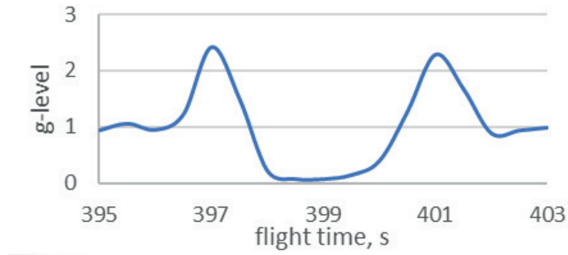

Fig. 6. Typical g- level test result during real parabola fight

important criterion is the earth-vertical component of airspeed at push-over, which is calculated in Eq. (7).

$$V\nu = V \cdot \sin(\theta) \quad (7)$$

Thus, to increase the earth-vertical component of airspeed, either the total airspeed can be increased, or the pitch angle of the aircraft can be increased. Equally important, if pitch angle is increased, negative load on aircraft and research samples during pull-up stage of parabola increases (Pletser *et al.* 2003).

To elaborate, aircraft "*MOA-1*" discussed in paragraph 2, has maximum air speed of 50 m/s. During following testing phases, it is expected reach up to 9 seconds of microgravity time which is sufficient for many smaller research laboratories and testing's.

Conclusions

The paper proposed a study of a UAV research platform. Witch can achieve relevant results in the field of microgravity research (Hofmeister, Blum 2015). The planes will be a new platform for small payload and will offer possibility for low-cost, fast turn-around time microgravity testing. It offers possibility to make initial microgravity researches available worldwide. The research does not want to replace any existing method in the field of research, but it wants to give a complementary solution for experiments with requirements that meet the performances of the solution proposed.

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BEPILOČIO ORLAIVIO NAUDOJIMAS MIKROGRAVITACINIAMS TYRIMAMS

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Santrauka

Šio darbo tikslas – analitiškai ir eksperimentiškai ištirti bepiločio orlaivio naudojimą nulinės (sumažintos) gravitacijos sąlygoms simuliuoti. Darbe aprašytos ir palygintos jau esamos mikrogravitacijos tyrimų platformos. Akivaizdu, kad reikalinga pigesnė ir prieinamesnė tyrimo platforma. Darbe analizuojama bepiločio orlaivio naudojimo galimybė, parinktas ir išbandytas parabolinio skrydžio algoritmas orlaivio tyrimų platformos koncepcijai, atlikti skrydžiai su simuliatoriumi ir realiu orlaiviu.

Reikšminiai žodžiai: bepilotis orlaivis, mikrogravitacija, tyrimų platforma.