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FREEFALLING BALLOON LAUNCHED LABORATORY  
FOR LOW COST MICROGRAVITY

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ABSTRACT

A new, inexpensive, open source microgravity research system is proposed for scientific use, especially by universities in developing countries, which cannot afford existing technologies like suborbital rockets. The system is composed of a robotic freefalling laboratory carried aloft by a high altitude probe flying over the sea surface using multiple helium balloons. The laboratory is released from an altitude between 10 km and 50 km to obtain 32 seconds (or multiple times of up to 32 sec) to 86 seconds of high quality microgravity. Air drag will be compensated by a small propulsion unit. At the end of the freefalling flight, the laboratory and the probe will finally parachute themselves into the sea, where they will be collected by the ship that launched them. The system is designed to be very safe and mostly reusable. It will be developed as a free worldwide collaboration and it will be used primarily by scientific institutions for fundamental and applied microgravity research. It is designed to prevent any kind of abuse or non-peaceful use. Its operation is fully automatic and allows no kind of remote control nor any directional flight and requires no telemetric control.

FULL TEXT

INTRODUCTION

The system consists of a freefall laboratory, a stratospheric probe (including helium balloons) which serves as a lifting cradle for the laboratory, and a launch and rescue ship. The laboratory has an external airframe whose

shape is designed for the lowest air drag in its flight regimes. Its final design could have small variations in the future when subsonic and supersonic tests will be performed in wind tunnels and on scaled models. The laboratory has several internal components, the most important of them being the experiments

container, a metallic hollow sphere insulated from all external influences, including vibrations and transonic shock waves.

The probe has an 8-legged conic shape. Each leg is attached to a balloon, while a 9<sup>th</sup> balloon is attached to its top. The laboratory is held at the base of the cone and it also attaches to its top. The probe has a small experiment holder to be used for high altitude scientific inquiry (astrophysical, meteorological or environmental studies) but it cannot be used for high resolution earth observation as that would break security rules about peaceful uses only, so that abuse will be made technically impossible by design.

The balloons are superpressure helium balloons designed for high altitude flight. Their shape is onion-like as usual for superpressure balloons.

The ship is an oceanic scientific ship specially equipped for installing experiments inside the laboratory and servicing all components of the system.

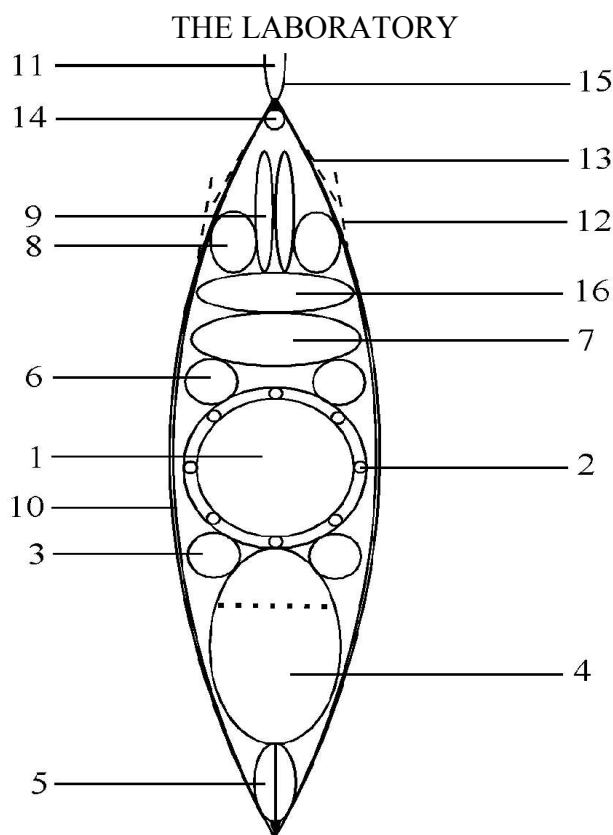


Fig. 1: Schematic representation of the laboratory's internal components

The external airframe and internal components' containers are made of lightweight alloys. 24 thin cooling tubes are attached to the inner surface of the airframe (10). A liquid coolant (probably water) released from the big coolant tank (4) is pumped into the cooling tubes, flowing from the tip to the tail. The liquid coolant, absorbing the heat of the airframe due to air friction and solar radiation, is transformed into vapour. Any increase of the temperature in the airframe results in an increase of the pressure of the vapour. This vapour is then released by a valve to a nozzle (11), generating a small vertical thrust opposing the air drag force. The quantity of thrust necessary to compensate the air drag force, thus preserving the microgravity environment, is continuously calculated by the avionics systems (7). The flow rate of the coolant is controlled by the pump (5) which connects the coolant tank to the cooling tubes. When necessary, the pressure of the liquid coolant is increased by compressed air from 4 air tanks (3) which increase the pressure of the air bubble above the level of liquid coolant in the coolant tank. A compressed air propulsion system, independent from external heat and liquid coolant, could also be employed for subsonic flight. In the supersonic flight mode a greater amount of thrust is obtained by a reaction of the vapour from the cooling tubes with an alkali metal in the combustion chamber of the nozzle (14)<sup>9</sup>.

A big vertically oriented gyro (16) and four small radially oriented gyros (6) are placed above and below the avionics compartment. The gyros have fixed axes for security reasons (to make flight guidance impossible), and can only be powered on and off all together by avionics.

The experiment container (1) is insulated from possible vibrations by 26 passive vibration dampers (2). It is also electrically, thermally and acoustically insulated. Vibration dampers will also be added to the liquid coolant tank.

An active vibrations and shock waves damping system will be studied and developed for the supersonic flight mode.

The experiment container will also contain a

sensitive 3d accelerometer which can measure the local microgravity environment using arrays of nanobalances<sup>1</sup>. This will record the quality of the microgravity during every experiment.

A thin optical fibre connects the laboratory's components in a local fast network. The components are electrically independent and use their own batteries.

The avionics compartment includes a flight computer (controlling the pump, the air tanks and the valve, and the combustion chamber of the nozzle) to regulate thrust, a GPS receiver, a satellite phone used to send SMSs with GPS data to the rescue ship, sensors to control the air drag force and the quality of the microgravity, a solid state flight data recorder and a radio beacon. A telemetry radio system is not included as remote controlling is to be avoided for security reasons.

For reasons of symmetry of the mass load and necessary redundancy, 4 parachute containers (9) and 4 inflatable floaters containers (8) are placed above the large vertical gyro. Parachutes and inflatable floaters are released and deployed by lifting and rotating their own hatches in the airframe (12).

2 GPS, 2 satellite phone, 2 radio beacon and 2 radar transponder antennas (15) are in the external surface of the nozzle.

### THE PROBE

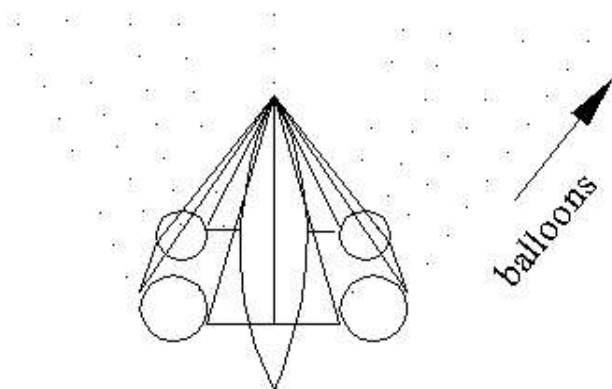


Fig. 2: Sketch of the probe carrying the laboratory

The frame of the probe is made of high torsion stress resistant alloys to carry the mass of the

laboratory safely. The legs are attached to the balloons by special cables designed to resist high tension in a wide temperature range.

The probe has an electrically independent experiments compartment, 2 parachutes, 2 inflatable floaters and a computer compartment with GPS, radar transponder and radio beacon.

### FLIGHT MODES

There are three possible modes of operation for the laboratory:

- 1) One short subsonic flight period, starting at a relatively low altitude,
- 2) Multiple successive subsonic periods, starting from a high altitude.
- 3) One long flight period, during which the laboratory will reach supersonic velocities, starting from a high altitude.

The first mode of operation will be the simplest and most cost effective way to perform microgravity experiments with the laboratory. In this mode the maximum velocity will be limited (to Mach 0.95 in the simulation, see FLIGHT SIMULATION) to avoid partially supersonic airflow around the laboratory's fuselage, which would probably cause strong turbulences and vibrations. The laboratory is released from an altitude of 10 km. This will give the a microgravity duration of 32 seconds and a total drop of about 5 km, after which the landing parachutes will be opened.

The second mode of operation can be performed as multiple successive drop phases, each similar to mode 1, from a much higher starting altitude. This mode will require using a set of disposable parachutes, one for each microgravity interval, to slow down the laboratory to parachute descent velocity each time it reaches the critical Mach number. This method would be especially interesting to perform multiple identical measurements within a short time, but its technical realization could prove difficult. A possible improvement would be finding an efficient and, if possible, reusable braking system that could slow down the laboratory to a near stop, even at high altitudes.

These two modes of operation will both need a relatively weak additional propulsion unit to compensate for the subsonic air drag. To achieve this, water vapor from the laboratory's cooling system could be expelled. This kind of propulsion could be regulated directly either by the heat generated by air friction, or alternatively by a Prandtl tube measuring the dynamic air pressure, which is proportional to the subsonic air drag. If necessary, vapour pressure could be increased by pressure tanks (see also THE LABORATORY). In any case, the additional thrust will have to be fine-tuned by the avionics system with the help of accelerometers to achieve high quality microgravity.

The third, and most interesting, mode of operation can generate a long period of microgravity by keeping the vertical acceleration equal to the gravitational acceleration at all times, which requires a strong propulsion system to compensate supersonic air drag, including the wave drag component. During the critical transonic phase vibrations, shock waves and turbulence, while limited by the external shape of the laboratory, would probably disturb any microgravity experiments and possibly damage instruments. To avoid this, an active vibration control system will have to be developed to compensate induced shocks and vibrations to the experiment container in real-time. This active shock insulation will be probably provided to the cooling liquid container too.

Passing through the transonic flight phase smoothly is one of the major difficulties for this mode of operation, as it will require a more powerful rocket engine than that using just vapour and compressed gas which was suggested for the subsonic modes. In addition, it is essential to design an efficient braking system (probably a succession of parachutes, each with several backup ones) able to slow down the laboratory safely from supersonic speeds so it does not pose a threat upon landing. The insufficient thrust problem could be solved by designing a chemically driven propulsion system which, when required, adds a reactant to the stream of expelled vapour in a suitable reaction

chamber to trigger a strongly exothermic chemical reaction that increases thrust. If an alkali metal is used as a reactant, the reaction would also produce hydrogen gas which could be burned for even more thrust. However, this propulsion system will need thorough development and testing before it can be employed.

## FLIGHT SIMULATION

As the project is still in an early stage, experiments on the laboratory's exact behaviour, especially at supersonic velocities and during the transonic phase, could not yet be performed.

Therefore, only some first estimations exist at the present time. All values were calculated using the U.S. Standard Atmosphere from 1976<sup>4</sup>.

### Flight Mode 1:

This simulation shows one single subsonic microgravity drop with a starting altitude of 10 km. The laboratory's vertical acceleration was assumed equal to the gravitational acceleration at any time during the flight, which would mean ideal microgravity conditions. With these flight parameters, the assumed critical velocity of approximately Mach 0.95 was reached at slightly below 5 km of altitude, which would provide a reasonable safety margin to deploy the landing parachutes. You can see the altitude profile and the vertical velocity profile for this flight mode in the following diagrams:

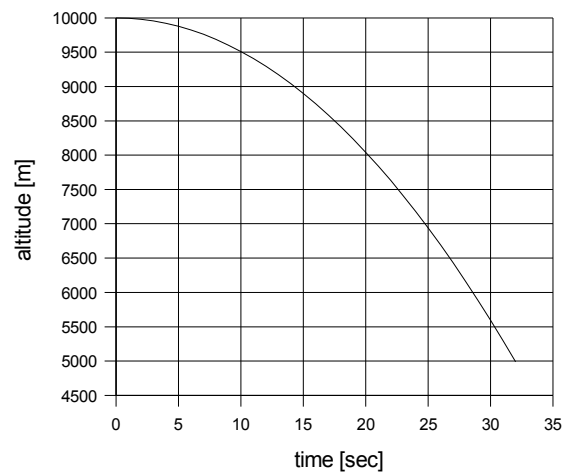


Fig. 3: Altitude profile for a single microgravity drop

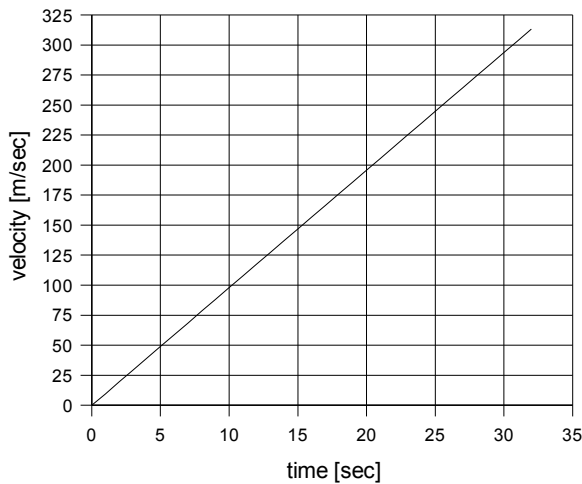


Fig. 4: Vertical velocity profile for a single microgravity drop

### Flight Mode 2:

The microgravity drops were calculated as in Mode 1, that is, acceleration was set equal to the gravitational acceleration.

Parachute deceleration was estimated by assuming a domed parachute (drag coefficient  $c_D = 1.5$ ) with a diameter of  $d = 30$  m. This leads to a parachute drag force of

$$F_D(h) = \frac{1}{2} \cdot c_D \cdot \left(\frac{d}{2}\right)^2 \cdot \pi \cdot \rho(h) \cdot v^2(h)$$

whereas  $\rho$  is the air density and  $v$  is the laboratory's velocity, both in dependence of the current altitude. At the current point, we were not able to model the parachute drag for near sonic velocities, which is, due to transonic wave drag, probably a lot higher than the value calculated with this formula. This might require a smaller parachute to decelerate the laboratory to a speed where the larger parachute can be opened without being damaged. Also, the equipment in the experiment container will have to be protected from the shock of deceleration when the parachute opens.

Additionally, a short period of constant velocity will be necessary to let any swinging and tumbling of the laboratory die away.

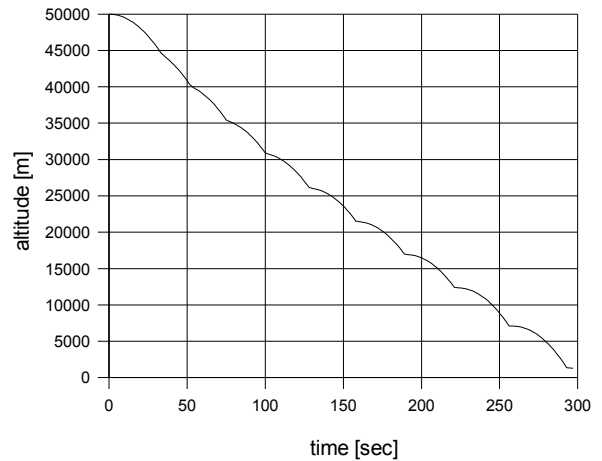


Fig. 5: Altitude profile for multiple successive microgravity periods

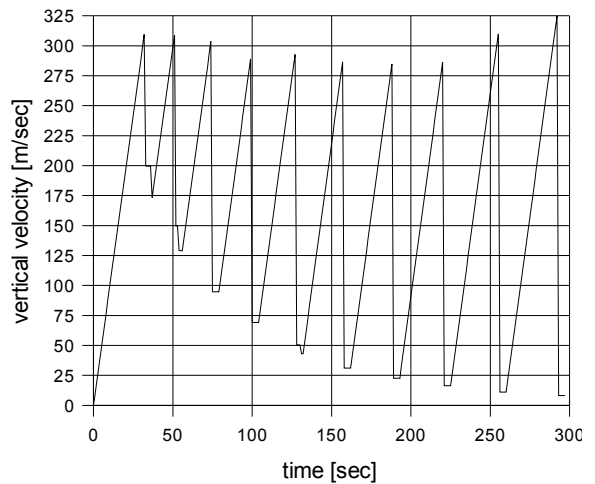


Fig. 6: Vertical velocity profile for multiple successive microgravity periods

Note that the microgravity intervals become longer and the parachute's deceleration efficiency increases as altitude decreases. This is due to the increasing air density for lower altitudes.

In this example simulation, we assumed the laboratory to have a mass of 5000 kg. As you can see, the parachute's deceleration capability is rather unsatisfactory at higher altitudes, which leads to very short microgravity times (less than 15 seconds for the drop after the first deceleration). Possible solutions are to make the laboratory as lightweight as possible, which would, on the other hand, limit payload capacity, or to start from a lower altitude, which would decrease the number of possible microgravity

periods.

### Flight mode 3:

The third simulation shows a flight with the laboratory's acceleration equal to the gravitational acceleration at all times. Opposed to flight mode 1, velocity was not limited to Mach 0.95. Instead, the starting altitude was set to 50 km and a critical altitude of 14 km was assumed where the simulation was stopped, i.e. the additional propulsion would be stopped at this point and the deceleration procedure would have to be started. You can see the altitude profile and the Mach number profile in these diagrams:

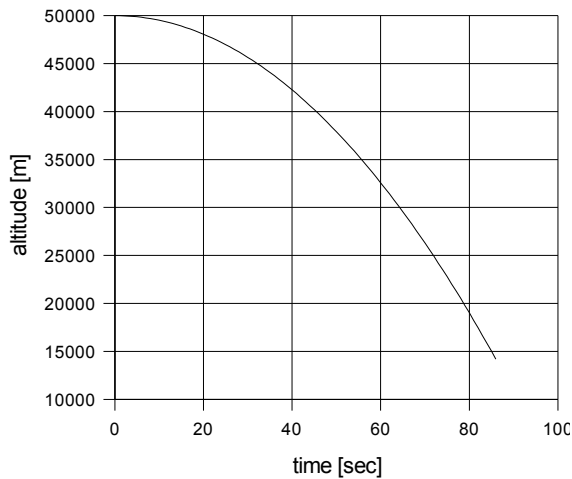


Fig. 7: Altitude profile for a supersonic microgravity drop

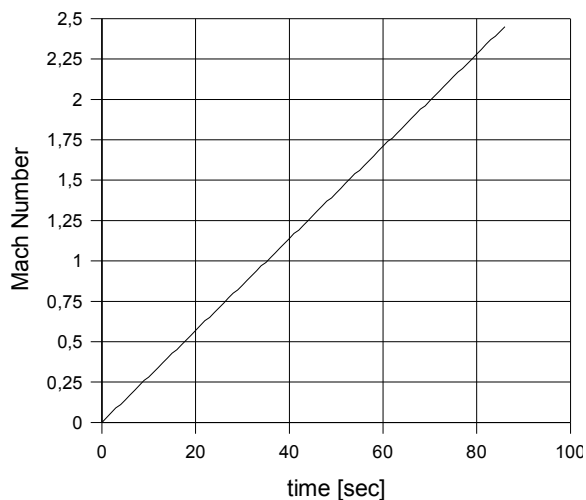


Fig. 8: Mach profile for one supersonic microgravity drop

As you can see, the laboratory reaches the speed of sound after approximately 35 seconds at an altitude of 44.1 km and travels in the transonic regime (generally assumed between Mach 0.75 and Mach 1.2) for approximately 15 seconds. The vertical velocity at the end of the simulation is Mach 2.45, which equals 834.4 m/sec at the final altitude of 14 km.

## PROBE FLIGHT

After lifting the laboratory to its release altitude, the lifting cradle can optionally serve as a high altitude atmospheric probe. For this purpose, lifting balloons that have a low leakage rate and can withstand intense UV radiation for a long period of time have to be developed.

For landing the probe, we suggest to reduce altitude slowly at first by carefully reducing balloon pressure. As the probe drops lower, environment pressure increases and compresses the lifting balloons, which produce less lift in turn. Therefore, the drop velocity will increase steadily.

As the probee, unlike the laboratory, will not be designed for high drop velocities, we suggest dropping it as far as possible with slightly deflated ballons. Before the drop velocity rises to a level that would damage the cradle or the lifting balloons, parachutes will be deployed to safely land the probe. Depending on the laboratory's release altitude, multiple sets of parachutes of increasing sizes might be necessary in order to minimize wind drifting.

## PURPOSED USAGE

Traditional technologies like drop towers, parabolic flights, suborbital rockets and satellites are already established and effective in their respective fields of application, but none of them can provide approximately 30 to 90 seconds of high quality microgravity at a low operating cost to be used in a wide range of basic and applied research.

The best applications of the system will be in fundamental physics and fundamental biology

investigations.

### SECURITY

The laboratory lacks all possible manoeuvring capabilities so it cannot control its own flight during both microgravity and parachute flight.

The probe navigation will be totally passive as its track will be determined by existing winds only. This is to make non-peaceful usage or otherwise unauthorised external control over the system impossible. The laboratory will always be dropped above the open sea. To ascertain this, it will be immediately dropped if the GPS indicates that the probe is approaching the ocean shores nearer than a specified safety distance.

Telemetry is not provided to the launch and rescue ship and any remote controlling will be technically impossible. The only kind of communication to the ship will be SMSs via the satellite phone, and its content will be only GPS data.

The laboratory has a main parachute and 3 back-ups. If all parachutes fail, a self destruction system will be automatically activated.

The probe has 2 parachutes and a self destruction system.

### OPEN SOURCE DEVELOPMENT

As our group ("Nanogravity Labs") is a small private organization of students, engineers and scientists, it is unable to carry out the full scale development of this technology. Therefore, and to make sure this technology is available to all organizations who intend peaceful scientific usage, we would like to develop it as an open international collaboration. This will also enable interested people who would otherwise be excluded from this project to contribute their ideas.

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