

1. Introduction

When preparing for long-duration space missions beyond the 3 to 6 months range, the medical and psychological aspects of the mission crew become an issue of major importance. The isolated and confined nature of spaceflight, in particular when considering missions beyond LEO to the Moon and Mars, along with its potential hazards, poses challenges and great risks related to human performance. However, research in the near-Earth orbit is severely constrained by the limited number of flight opportunities. Ground-based simulators of microgravity are valuable tools for preparing spaceflight experiments, but they also facilitate stand-alone studies and thus provide additional and cost-efficient platforms for gravitational research. Of all the possible ways of simulating microgravity or zero-gravity conditions on Earth, i.e. parabolic flights that allow utmost a few seconds of free-fall, sounding rockets, drop-towers that would have to be of sky-scraping heights to provide enough time to collect any data, buoyancy tanks, etc., the clinostat and its variants are the most practical and economical means within the reach of any experimentalist.

2. Microgravity Simulation

The simulation of microgravity depends on a variety of factors, the response time, external factors such as buoyancy, temperature, light, etc. Since space is eliminating the gravity vector by freefalling continuously, one is able to inhibit gravitropic responses by continually changing the direction of the gravity vector. Therefore, simulating microgravity under normal ground conditions by using devices such as clinostats or the Random Positioning Machine that rotate and change the gravity vector of a given sample are based on the hypothesis that sensing no weight would have similar effects as being weightless. Perfect weightlessness is difficult to achieve even within a spacecraft since in practice, the spacecraft follows an elliptical path and not a circular path around the Earth. Therefore, acceleration of the order of 10^{-4} - $10^{-6}g$ is more typically experienced in today's spacecraft and is usually referred to as microgravity.

3. Specifications for the microgravity simulator

SimulTek has proposed to design and manufacture an experimental prototype of a microweight ("microgravity") simulator based on the principle of "gravity vector-averaging". This system may be compared with a classic clinostat, although the clinostat has only a 2D averaging, while the proposed Microgravity Simulator provides a functional volume which is "exposed" to simulated microweight (see technical specifications in Table 1). The Microgravity Simulator may be used to generate low partial gravity accelerations ($\sim 10^{-3}g$ to $0.9g$).

Table 1. Technical parameters of the Microgravity Simulator

Parameter	Description	
Functional experiment accommodation volume (m^3)	1	5
Simulated gravity conditions	$\sim 10^{-3}g$ to $1.0g^*$	$\sim 10^{-3}g$ to $1.0g^*$
Maximum experiment mass to be accommodated (kg)	TBD**	TBD
Operational Frequencies of the Microgravity Simulator	TBD	
Operational modes	• Random • Centrifuge and clinostat • Freely programmable mode	
Experiment interfaces	• MEMS accelerometer sensors • DAQ system • Wi-Fi and Bluetooth data transfer	
Material	Coated aluminum and stainless steel*	
Supply voltage (V)	220-380, 3 Phase	
Supply current (A)	TBD	
Supply frequency (Hz)	50-60	
Weight (kg)	TBD	

* - Notes: All parameters marked with an asterisk in Table 1 will be specified more accurately during the actual design and are given for reference only.

** - TBD – To Be Determined

4. Design of the microgravity simulator

The preliminary design of the laboratory microgravity simulator proposed by SimulTek is presented in Fig. 1.

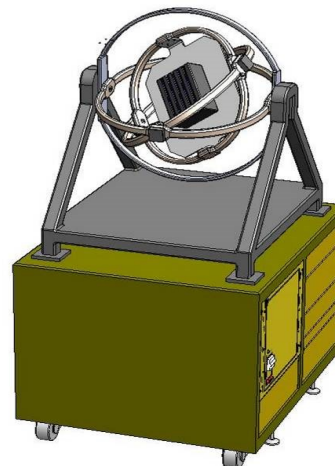


Fig. 1. Experimental prototype of the Microgravity Simulator with three independently driven rings

The lay-out of the Microgravity Simulator prototype consists of a sturdy base-frame, two (eventually, three) cardanic rings, and the experimental set-up platform mounted in the center of the inner ring. The rings are mounted one inside another, using bearings and are driven independently by means of separate drive mechanisms, including programmable electro-motors and motor controllers. The motors are controlled on the basis of feedback signals generated by encoders, mounted on the motor-axes, and by "null position" sensors built into the rings.

4.1 Gravity Sensors (Accelerometers)

The collection of microgravity acceleration data has cross-disciplinary utility to microgravity life and physical sciences, as well as to structural dynamics communities. The Micro-Electronic Mechanical (MEMS) acceleration sensor systems shown in Fig. 2 have been selected to be used on the platform of the laboratory scale microgravity facility prototype for the collection of microgravity acceleration data. This sensor represents a new design approach using MEMS accelerometers and state of the art analog to digital converters.



Fig. 2. Microgravity acceleration measurement system.
— external design



— internal design showing the microgravity sensor



These MEMS accelerometer sensors were developed for goals where the reduced size and weight offer inherent advantages over conventional mechanical devices. The resulting sensor has a sensitivity of less than $10^{-6}g$ or 1 micro-g, with a packaging size of under 8 cubic inches, weight under 0.25 pounds, and power consumption less than 1 Watt. The MEMS sensor combined with the prototype electronics has the performance to produce microgravity resolution in the general purpose 0.1 to 25 Hz range and can be extended to 1500 Hz.

The gravity conditions at the experiment platform can be provided by the triaxial acceleration sensor that will be mounted on the platform. This sensor measures the accelerations in 3 axes (Fig. 3).

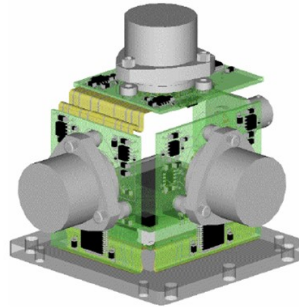


Fig. 3. Mounting of the microgravity triaxial sensor and electronic interface card

Experiment power supply, electrical connections, communication and sensor's feedback will be provided via the slip-rings feedthroughs accommodated in every single bearing. The output is displayed on-line in the user interface of the microgravity simulator. The average g level is calculated from the sensor output and indicates the symmetry in gravity nullification during an experiment run.

4.2 Electrical and Computer Interface

The overall control of the microgravity simulator will be performed by a modern computer-based system (Fig. 4). It includes: a) an experiment electrical and electronic interfacing; b) multifunctional Data Acquisition Board (DAQ); c) motor power supply and controller; and d) computer running the facility-dedicated control software.

Experiment power supply, electrical connections, communication and sensor's feedback will be provided via the slip-rings (Fig. 5). Collection of data during the experiments and monitoring of different parameters of simulated microgravity conditions at the experiment platform will be controlled by a modern DAQ system.

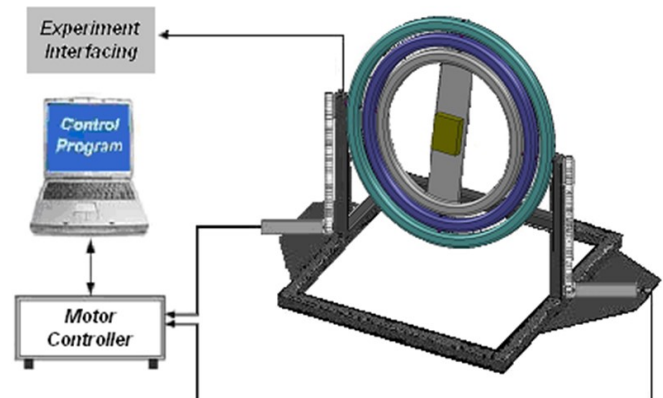
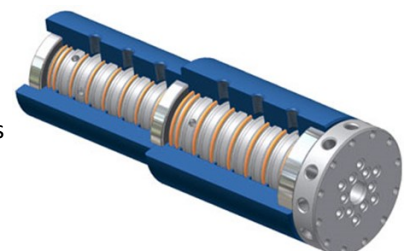


Fig. 4. Electrical and computer interface of the microgravity simulator prototype

Fig. 5. A 12 passage slip-ring feedthrough with radial & face connections for maximum mounting flexibility



4.3 Control Modes of the Microgravity Simulator

As far as the sample on the experiment platform of the proposed microgravity simulator is to be manipulated randomly to different orientations, the simulator has to be controlled in a way no dominant orientation prevails during an experiment run. This can be achieved in two ways. The walk pattern can be made regular with, as input parameter, the even distribution of orientations. Another approach is to use the random walk pattern. When the walk path is truly random, the path coverage over the sphere surface will become equally distributed after a long time. The control software of the microgravity simulator will provide different operational modes.

4.4 Data Acquisition Instrumentation and Software

The control software will incorporate the following main operational modes of the microgravity simulator: random control mode, clinostat, and freely programmable mode or programmable path. The value of ω can be selected independently either in "revolutions per minute" (rpm) or in Rad/sec for every of the rotating rings between 0 and 10,000 rpm before starting the experiment run. The duration of a simulated microgravity test can be selected by pushing the corresponding button above the chart (see Fig. 6). The measured gravity peak values in the directions X, Y and Z are shown on digital displays in the units of g. The gravity conditions measured in each of the three directions can be averaged over a given time period by pushing one of the buttons '1 sec', '10 sec', '30 sec', '1 min', '3 min', '5 min' located in the upper right corner of the interface.

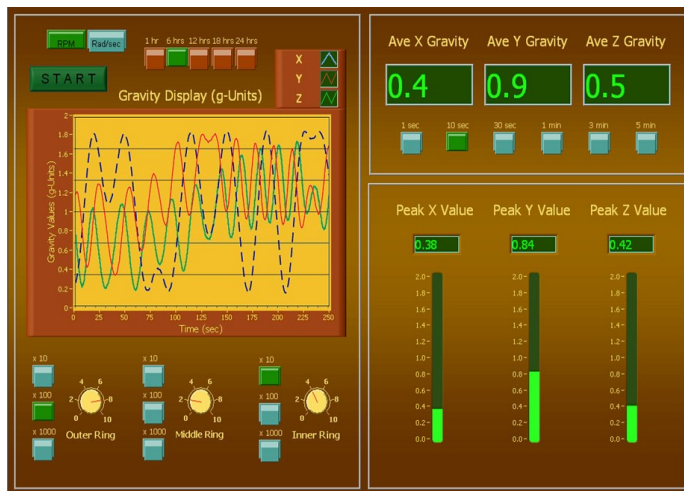


Fig. 6. Computer control software of the microgravity simulator

5. Integrated Environment Chamber

As the next stage, the created Microgravity Simulator prototype will be installed in the Integrated Environment Chamber shown in Fig. 8 for testing and investigation of the functional volume which is "exposed" to simulated microgravity and operational angular "walk speed" of the independently driven rings to achieve the acceptable levels of simulated microgravity.

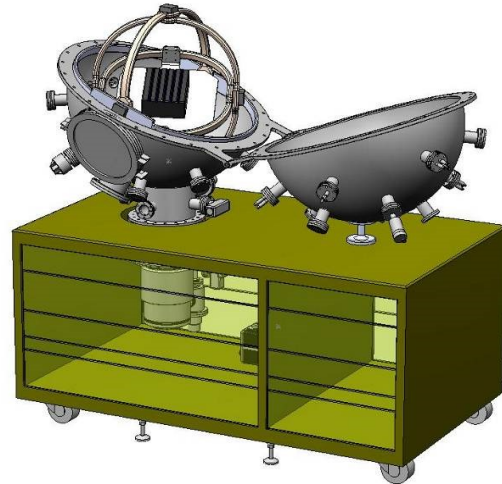


Fig. 8. Experimental prototype of the Microgravity Simulator inside the Integrated Environment Chamber

Based on the customer's requirements, the Integrated Environment Chamber can be developed and include some of the following factors:

- vacuum conditions;
- UV radiation;
- temperature and humidity; noise (<100 dB);
- gas (noxious);
- Darkness; and
- electromagnetism.

The chamber can be equipped with all necessary temperature and humidity sensors, pressure gauge controllers, flow meters and controllers, etc., to provide the required specifications of the Integrated Environment Chamber, such as the accuracy, sensitivity, uniformity (stability), controllability and monitoring of the parameters of the simulated integrated environment.

Further details of the technical design and performance parameters of the equipment to be created for life research on living objects can be discussed with the Customer.

6. Conclusion

The proposed project is concerned with the development of a high-tech Integrated Microgravity Simulation Equipment that can be used as a scientific platform for space and life research, to create the "zero gravity" and "lunar gravity" conditions, to simulate microgravity conditions, acceleration and displacement under specific integrated environment conditions. The technical proposal was prepared to specify the design, technical parameters, development and manufacturing stages, of a science platform for life research for living objects under microgravity conditions, also to support manned space programs, space exploration activities, space engineering and cosmonauts training, as well as ensuring human's safety in space.