# Microgravity research platforms – A study

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**Materials processing in space, based on the research undertaken during the past three decades by the leading space-faring nations is on the verge of becoming a commercial venture. Indian Space Research Organization (ISRO) is planning to promote microgravity research in the country by providing a suitable platform for scientists to conduct experiments in various fields. This paper presents the details of a comprehensive study undertaken at ISRO Satellite Centre, Bangalore and suggests the following two options: to develop a recoverable and reusable satellite as a long-term goal and to make use of stratospheric balloon-drop tests for immediate use by scientists to gain hands-on experience in designing and conducting microgravity experiments.**

## Introduction

ALTHOUGH gravity is an universal force, there are times when it is desirable to conduct scientific research to understand various physical, chemical and biological processes which are masked by gravity. For example, the phenomena such as convection, sedimentation and hydrostatic pressure are absent under microgravity and one can observe an interestingly different behaviour in solids, liquids, gases and their interfaces.

Most of the contemporary scientific theories and physical phenomena to our experience are all related to earth gravity environment. With the advent of space vehicles and space travel, physical designs need to confirm to a gravity-free environment and condition. With the growth of space technology and applications, it was found that gravity influences many physical phenomena as experienced by us and the behaviour could be much different to our expectations in the absence of phenomena such as convection, sedimentation and hydrostatic pressure. Studies in many areas have exposed that the gravity-free environment may be exploited to improve many industrial processes to get better results. There is a lot of scientific interest to explore this in greater details.

The microgravity research being conducted around the world is already proving its usefulness in challenging and validating contemporary scientific theories as a result of unexpected or unexplained discoveries. Since 1981, on an average approximately $ 100 million is being spent annually towards microgravity research by space agencies in America, Europe, Germany and Japan. Some areas of research have already culminated in commercial production: polystyrene spheres of 20 to 40 micron size are being produced, with high degree of perfection for applications such as instrument calibration, encapsulating anti-tumour drugs, etc. Gallium–arsenide semiconductor crystals produced in space with high electron mobility are finding applications in high-speed super-computers and telecommunication appliances.

The contemporary microgravity research pertains mainly to the following areas: materials science, fluid physics and combustion, and biology and biotechnology.

The material science research is aiming at identifying and understanding the cause and effect relationship between the processing, properties and structure of materials under microgravity environment. The investigations include study of directional solidification, semiconductor and zeolite crystal growth, diffusion in liquid metals, container-less processing of corrosive materials, formation of metal foams, special alloys, composites, special glasses, ceramics and polymers.

Microgravity research in fluid physics is focused on a comprehensive study of fluid dynamics and transport phenomenon, where fundamental behaviour is limited or affected by gravity. These include study of two phase flows, diffusion of liquids and gases, surface tension-induced convection, capillary flow, critical point wetting and how particles and gas bubbles suspended in a fluid interact with and change the properties of the fluid. The universal nature of these phenomena make their study fundamental to other areas of microgravity research by providing new tools for ground-based research in science and engineering.

The research in combustion is centred on improving the understanding of the process of ignition, propagation, spreading and extinction of flames under microgravity conditions in space. The research includes the study of droplet combustion and establishing flammability limits for various combustible materials.

The biology and biotechnology[1] research is focusing on understanding the fundamental processes controlling protein crystal growth and cell/tissue culture. Research in this area involves growth of large protein crystals under microgravity to study its structure, understanding mammalian and plant cell division and growth, electrophoretic separation and purification of cells, encapsulation of anti-tumour drugs and study of human biology and physiology

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and to understand the role of gravity in the growth, form, function and behaviour of various organisms.

In future, high strength alloys with high temperature resistance for applications such as turbine blades, cutting tools and high performance magnets as well as glasses with special optical properties for making high sensitive optical equipment would come from space. Important life-saving drugs and pharmaceuticals could be produced in space. These include beta cells (for diabetes), pituitary cells (for dwarfism), urokinase (for blood clots), interferon (for certain cancers) and protease inhibitors (for AIDS).

This paper tries to explain the various platforms that are available currently to provide microgravity environment and the proposed national initiatives.

## Microgravity platforms

There are different means of achieving microgravity conditions for conducting experiments and different platforms are being used depending on the type of studies and the level of microgravity and duration of experiment. In the beginning few microgravity experiments were carried out on-board *Apollo* and space lab missions. Today a number of microgravity platforms are being used, as explained below, that may be selectively utilized meeting the needs of investigating scientists.

### *Drop tower*

Drop towers were built with varying heights by different countries so that microgravity experiments can be conducted without necessarily going into space. A drop tower is a vertical shaft which provides microgravity condition during the free fall of the experimental package for a duration that depends on the height of the tower. A microgravity level of $10^{-3}$ *g* could be achieved with drop towers, which was later improved to $10^{-5}$ *g* by adopting different techniques to counter the effect of acceleration due to gravity. One common method is to evacuate the tube and the other methods are to drive air flow downwards at an acceleration of 1 *g* or by providing a thrusting device essentially to counter air drag. It costs about Rs 150 lakhs to construct a drop tower of height 150 m.

USA has two drop towers built at Lewis Research Center, Cleveland, with 24 m and 142 m height, offering microgravity level of $10^{-5}$ *g* for 2.2 sec and 5.2 sec, respectively. Germany has built at the University of Bremen, in 1990, a drop tower with a height of 146 m and the shaft can accommodate a payload module weighing 250 kg and measuring 800 mm in diameter and 1200 mm in length. This facility offers microgravity level of $10^{-5}$ *g* for 9 sec duration. Recently a 490 m free drop facility[2] with 10 sec duration and microgravity level of $10^{-5}$ *g* has been commissioned at a mine shaft at Japan Microgravity Center in Kami-Sunagwa, Hokkaido, Japan.

A major disadvantage in the drop towers is the short duration of microgravity condition and the cost of building a tower is high with evacuation facilities.

### *Parabolic flights*

Aircrafts executing manoeuvers along a parabolic flight path at approximately 45 degree inclination and at an altitude of 3 km and above can offer microgravity for durations up to 25 sec. National Aeronautics and Space Administration (NASA) and European Space Agency (ESA) have converted jet aircrafts offering microgravity research facility for the scientists. A number of flight tests can be carried out in a single day. Even today NASA has been using the aircraft *KC-135* while ESA has been using *Caravelle* aircraft.

Parabolic flights offer microgravity level of $10^{-2}$ *g*, and are in use since 1989 and more than 300 experiments were conducted till date. The major advantages of parabolic flights are their short turn-around time, typically two months between reception of payload and conduction of experiments and secondly the investigators can directly modify or adjust the experimental set-up either on-board or between flights. The major disadvantage is that a dedicated aircraft is needed and the level of microgravity achieved is low, apart from the fact that durations are limited. It costs about $ 3000/kg (Rs 1,20,000/kg) of payload to conduct microgravity experiments using a parabolic flight.

### *Balloon-drop*

Modern stratospheric balloons can reach peak altitudes of 39 to 41 km and are being used regularly for a variety of missions, including space science missions. Such balloon missions are being used for microgravity research as reported by Germany and Japan. Germany has developed a microgravity test-bed named MIKROBA – a microgravity payload module[3] that can be released from a balloon at the peak altitude and can be recovered by a parachute. This facility which was made operational (MIKROBA-4) in 1990 can offer a microgravity level of $10^{-3}$ *g* with a free fall duration of 55 sec. Japan has been conducting microgravity experiments using balloon-drop tests since 1983. Their payload free-fall altitude is around 32 km and can offer microgravity for a duration of 20 sec. The MIKROBA[4] facility is offered to the user agencies for conducting microgravity experiments at a cost of DM 10,000/kg (Rs 2,40,000/kg) of payload. Balloon-drop tests offer advantages compared to parabolic flights in terms of duration and level of microgravity, keeping the turn-around time short.

## *Sounding rockets*

A two-stage sounding rocket can reach a peak altitude of more than 400 km and during its parabolic flight path it can attain a microgravity level of $10^{-4}\,g$ for durations of 5 to 6 min. Germany, Japan, China, France and USA have used sounding rockets for conducting microgravity experiments in the past. The only disadvantage is the recovery of experimental module from distances that extend beyond the peak altitude and the costs involved. The sounding rocket RH-560 developed at ISRO can provide the above microgravity environment, but each costs around Rs 50 lakhs, i.e. approximately about Rs 40,000/kg of payload (excluding payload recovery cost).

## *Recoverable satellite*

Satellites provide an on-orbit laboratory for conducting research in microgravity as well as for materials processing and production. A satellite is launched into low earth orbit typically 500 km above earth and can provide microgravity level of $10^{-5}\,g$ and vacuum condition of $10^{-6}$ torr for few months compared to other facilities like drop towers, parabolic flights and sounding rockets which offer poorer microgravity levels and duration ranges from few seconds to few minutes. Some of the materials processing experiments involving heating and cooling may require few hours of operation and can only be conducted in space. Also, some of the experiments such as plant biology would require microgravity environment up to 30 days or more.

A satellite meets all these requirements and after experiments are completed the satellite can be recovered safely through deorbit, reentry and recovery manoeuvres. Since the space shuttle, international space station may not be accessible to many countries, the recoverable satellite becomes an attractive proposition.

China has developed a satellite recovery technology, code named 'FSW' series, and has successfully used it for conducting many microgravity experiments. Similarly, Russia developed 'PHOTON', while Germany has developed 'EXPRESS'. USA has developed 'COMET' and 'RRS' (Reentry Reusable Satellite) exclusively for conducting microgravity experiments.

A team at ISRO Satellite Centre has conducted a study during 1995 and submitted a detailed report on 'Microgravity Applications Recoverable Satellite' (MARS)[5]. This satellite weighing 900 kg operates at 500 km orbit for a few months with all the provisions like independent power, telemetry, telecommand and attitude on-orbit control. It provides a volume of 0.5 $m^3$ and could accommodate up to 250 kg for microgravity payload modules. The satellite will be deorbited and after reentry it will be recovered on land with minimum dispersion by deploying parachute systems and employing state-of-the-art inertial guidance and GPS systems. MARS can be developed indigenously in about 42 months and can be launched onboard *PSLV* or any commercial launch vehicle. Major specifications are presented in Table 1, and the mission schematic of MARS is shown in Figure 1. It is estimated to cost around Rs 3 lakhs/kg of payload using PSLV launch vehicle and $ 10,000/kg using foreign vehicles. The important feature of this satellite is that it can be reused for up to 10 missions, bringing down the costs further.

*Space shuttle* – The space shuttle is a typical recoverable spacecraft that is put into orbit around 300 km above the

**Table 1.** Specifications of microgravity applications recoverable satellite (MARS)

| |
|---|
| Orbit: Circular 500 km, 45–55 degree inclination |
| Mass: 900 kg |
| Payload mass and volume: 200 kg, 0.5 $m^3$ |
| Mission duration: 90 days (typical) |
| Microgravity level: $10^{-5}\,g$ |
| Power: 500 Watts (300 W for payload) |
| TTC: S-band, 512 bps, on-off commands 704 |
| Data handling: S-band, 500 bps, 2.1 Gb memory |
| Recovery: Ballistic reentry, parachute recovery on land; CEP < 10 km |
| Launch vehicle: *PSLV*/commercial launch vehicle |
| Development schedule: 42 months |
| Attitude control: 3-axis stabilized, monopropellant RCS/11N thrusters/ momentum wheel/torque (on-orbit) |
| Experiments: Multiple |

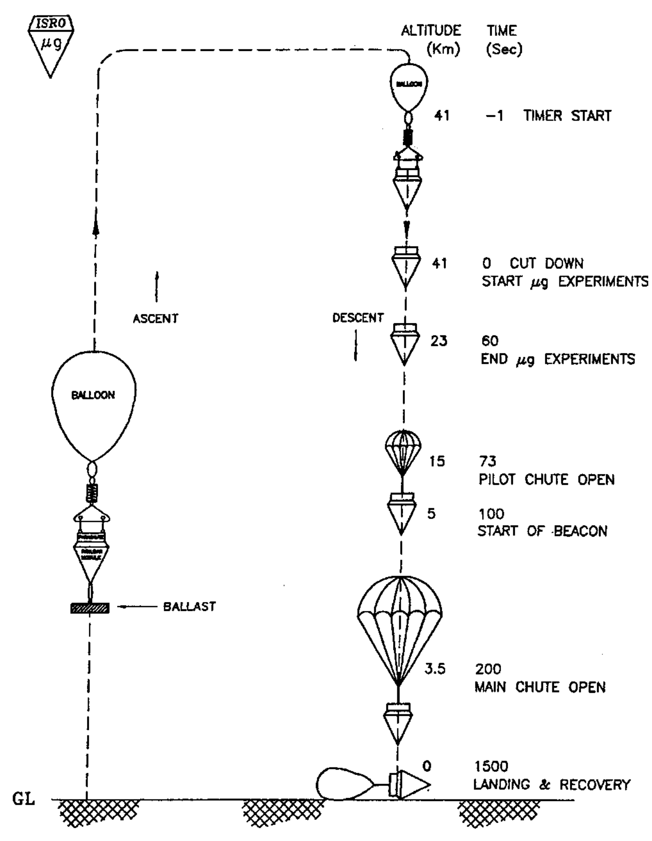


**Figure 1.** Balloon drop – Mission sequence.

earth and can provide services up to 11 days. NASA has not only been using the space shuttle for carrying out its own microgravity experiments, but also offering the facility to other nations. The space shuttle offers microgravity level of $10^{-4}$ $g$ when it flies in the gravity gradient mode for the duration of the experiments. The major disadvantage is the fact that this facility is not accessible to all countries and the experiment microgravity payload module has to meet the man-rated safety requirements. Also the cost is around $ 30,000/kg (Rs 12,00,000/kg) of the payload module.

*Eureca platform* – ESA has developed a microgravity platform called 'Eureca', specifically for producing gallium–arsenide semiconductor crystals on a commercial scale as well as for conducting experiments in other areas. The Eureca platform was flown aboard the space shuttle and was released into space and with its own propulsion system; its orbit was raised to 500 km in view of reduced drag where the microgravity experiments are carried out. It will be brought back by a subsequent space shuttle flight. This facility can provide microgravity level of $10^{-5}$ $g$ for durations extending to a few months. Two missions have been carried out till now. ESA is planning to develop its own recoverable spacecraft that can be put into orbit by Ariane-5 rocket.

*Wake shield* – The wake shield is a disc-shaped spacecraft measuring 4 m in diameter, designed exclusively for producing gallium–arsenide semiconductor crystals by NASA. This, like Eureca, is carried aboard the space shuttle and released into space and will be picked up during the next space shuttle mission. As the name implies, the disc is rotated at an inclination and a wake is created around the experimental module providing a typical vacuum level of $10^{-13}$ torr in space. The purpose is to achieve high purity level during materials processing, so that high quality homogeneous materials properties can be obtained.

## *International space station*

Though few microgravity experiments were conducted aboard the Russian *MIR* space station, its life has come to an end and NASA is launching an International Space Station Alpha (ISSA) with the participation of European countries (ESA), Russia, Canada and Japan. This space station is expected to become operational by the year 2004 and carries a separate module called Columbus Orbital Facility (COF) for microgravity experiments[6], developed by ESA. This facility orbiting around 400 km above the earth will offer a microgravity level of $10^{-6}$ $g$ for long periods with isolation techniques and controlling all the perturbations.

NASA is offering the facilities on the ISSA to the prospective user-countries. India is also considering various ways and means of utilizing the facilities on-board ISSA even though the cost implications are not yet clear.

## *Balloon-drop tests*

In the Indian context, the National Balloon Facility (NBF) operated by TIFR at Hyderabad has been regularly launching stratospheric balloons to an altitude of 41 km for conducting various space science experiments and also recovering important and costly payloads without damage using parachutes. NBF has all the facilities from fabrication of balloons, assembly and integration of payloads as well as for launching, tracking and recovery. The balloon-drop facility at NBF is a quicker and cheaper access for scientists to gain hands-on experience in designing and conducting microgravity experiments. It is also required to update certain facilities like telemetry, telecommand, GPS and data communication systems. The specifications for the balloon-drop facility are presented in Table 2.

A payload module, capable of carrying multiple experiments in the area of materials science, fluids physics and biotechnology in a single mission, is being designed for suitable aerodynamic configuration, taking its reusability into account to minimize the mission cost. This module also uses a cold gas thruster system for compensating the acceleration due to drag as well as attitude correction. A schematic of the balloon-drop mission is shown in Figure 2. A typical balloon mission which can lift 500 kg payload module to an altitude of 41 km for conducting microgravity experiments is estimated to cost around Rs 15 lakhs (Rs 3000/kg).

A comparison of the important microgravity platforms is presented in Table 3.

**Table 2.** National balloon facility[7]: Available balloon specifications

| Volume ($m^3$) | Weight (kg) | Payload (kg) | Accessories (kg) | Ballast (kg) | Float altitude (km) |
|---|---|---|---|---|---|
| 414906 | 625 | 470 | 130 | 120 | 41 |
| 203886 | 383 | 310 | 120 | 100 | 39 |
| 140347 | 539 | 860 | 180 | 225 | 31 |

Specifications

| *Hydrogen balloon* | *Microgravity payload module* |
|---|---|
| Volume: 414,906 $m^3$ | Maximum size: 1.3 m dia × 5.5 m length |
| Peak altitude: 41 km | Volume: 0.5 $m^3$ |
| Payload: 500 kg | Weight: 200 kg |
| Free fall height: 18 km | No. of experiments: Up to 3 |
| Free fall duration: 60 sec | Recovery: By parachute |
| Microgravity level: $10^{-3}$ $g$ | Reusability: 10 missions |

*Facilities*

Assembly and integration: 18 × 6 × 5.8 m ht.
Telemetry: PCM-FSK-AM (VHF) (To be updated to S-band)
Tracking: Navy-SYMM-XR5M-6 channel GPS + airport radar + beacon
Recovery: 100 ft dia. parachute

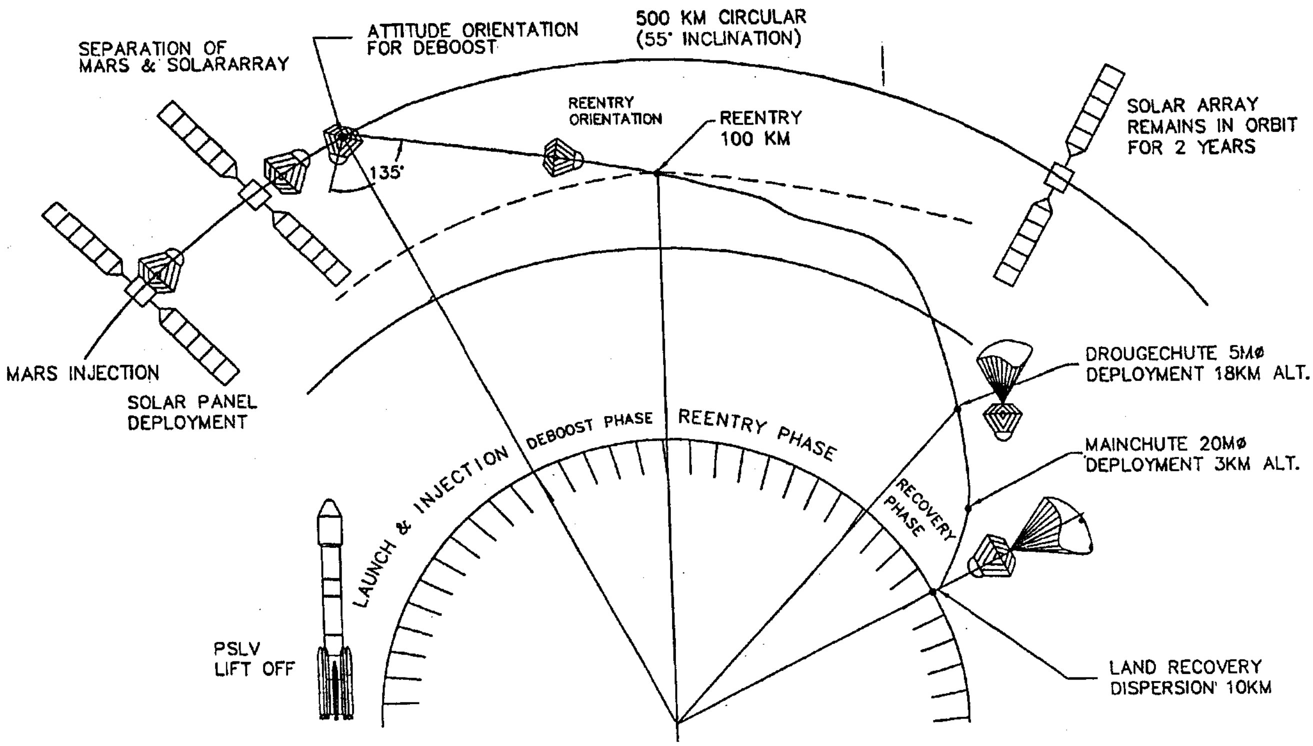


**Figure 2.** Mission schematic for recoverable satellite.

**Table 3.** Comparison of the available microgravity research platforms

| Microgravity platform | Duration | Gravity level |
|---|---|---|
| Drop tower/shafts | 2–9 sec | $10^{-2}$–$10^{-5}$ $g$ |
| Parabolic flights (aircraft) | 25 sec | $10^{-2}$–$10^{-3}$ $g$ |
| Balloon-drop | 60 sec | $10^{-2}$–$10^{-3}$ $g$ |
| Sounding rocket | 6 min | $10^{-3}$–$10^{-4}$ $g$ |
| Space shuttle | > 9–11 days | $10^{-3}$–$10^{-5}$ $g$ |
| Space station/recoverable satellite | > months | $10^{-5}$–$10^{-6}$ $g$ |

## Conclusion

A comparison of various platforms for microgravity missions is made and the relative merits are identified. For promoting microgravity research in the country, it is opined, based on the relative merits and associated cost, that the following options may be pursued.

(i) To develop a recoverable and reusable satellite platform as a long-term goal;
(ii) For the immediate needs of scientists to get hands-on experience in designing and conducting microgravity experiments, the balloon-drop option could be taken-up as it is the most economical and provides a quicker access.


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