Science In Space

Biology In Zero Gravity

DAVID MOORE

All living organisms function in gravity — it's a fact of life! How would they function without its all-pervading force? The Juno Mission, due to blast off from the Soviet Space Centre in Spring 1991, carrying 26 experiments designed by British scientists, may reveal part of the answer. David Moore's article gives the background and describes the experiments.

AT 0607hrs (GMT) on the 12th of April 1961, Vostock 1 was launched to carry the first human beyond the pull of Earth's gravity. The flight lasted only 1hr 48 minutes but when Yuri Gagarin unstrapped his parachute after landing in the Saratov region of the USSR, his pioneer flight had proved that man could survive the rigours of a rocket launch, could live and work in orbit, and return to ground safe and well.

In Spring 1991 a very different pioneering flight will be launched from the Soviet space centre. Timed to commemorate Gagarin's triumphant first step, this will be the Juno Mission which will carry a range of experiments for British scientists.

From the very beginning the Juno mission was planned to provide British scientists with the opportunity to fly experiments exploiting the virtual absence of gravity on board an orbiting spacecraft. British scientists have had relatively few chances to do this in the past. Now, with funding from British and international companies with UK and Soviet links, the opportunity can be provided.

Another objective has been to show that good science can be done to a very tight schedule. Under normal conditions four years is the bare minimum time in which to select experiments and design, construct and test the hardware they require. The Juno mission team will do all this in about 15 months!

MISSION PROFILE

Juno is an eight-day mission in the Soviet orbital complex comprising the Mir space station, various research modules and the flight spacecraft (Soyuz).

Mir itself is not a laboratory, but essentially a habitat in which astronauts can, and have, lived for long periods. In this respect it is quite different from the American Spacelab, which is a laboratory, lined with racks which accommodate the experiments.

The mass which can actually travel on Soyuz is 20 kg, which means that most of the actual experimental hardware has to be transported to Mir by a Progress cargo-craft which may be launched up to three months earlier.

Juno's biological experiments will be contained in four or five incubators with internal fittings (including a miniature 1 g control centrifuge) tailored to each experiment. The design and construction of space hardware is very different from that which would be used in a terrestrial laboratory. This is because of the stringent safety regulations which must be met and the enormous stresses to which the equipment will be subjected during launch. The equipment will be designed and built at Brunel University and 'space qualified' by British Aerospace.

Juno astronauts trained at the Gagarin Training Centre near Moscow are working at the Brunel Institute of Bioengineering to perfect the most efficient way to carry out the experiments. Eventually they will carry out identical 'control' experiments on the ground to record the differences between weightless and earth-gravity conditions.

The keynote to the science experiments is that they all apply new methods, ask new questions or investigate new organisms. Experiments currently on the agenda have come from 12 universities, one semi-commercial research institute, a defence research establishment, a research council and a school. Six are concerned with human physiology and experimental psychology, five with liquid culture of cells and microorganisms, three with developmental biology, three with plant physiology; four are from the materials science and fluid physics; one multiple experiment is concerned with protein crystallisation, and there's one technology and three educational experiments.

JUNO — THE SCIENCE

Environmental stimuli influence the development and behaviour of organisms, and gravity is one such stimulus — but an unusual one. Responses to light, wind, temperature or chemicals can all be due to the effects of differential exposure (e.g. one side of the plant is relatively shaded from the incident light, wind or heat, or the animal is moving in a concentration gradient coming from a source of chemical, etc.). But gravity cannot be 'shaded' and over the scale of living organisms there is no gravitational gradient. The challenge is to understand how organisms — even individual cells — exposed to the same, uniform field can detect gravity and use it to organise their growth and behaviour.

Gravity is always with us. It's been present during the evolution of all living things. It's such an ordinary part of our common experience that it's given little serious thought or appreciation. A child who falls over is expected to stand up; a germinating seed is expected to produce a root growing downward and a shoot growing up; and a mushroom, we all know, grows up like an umbrella, protecting its spores from the rain. But, which way *is* up?

A means of detecting gravity may have been one of the first sensory systems to evolve. Some gravity perception mechanisms have been identified. In animals, the movement of mineral grains on sensory hairs triggers nerve impulses which cause muscle activity to compensate for change in orientation. In addition, the complex nerve and muscle systems of higher animals allow them to learn how to place their limbs and body by reference to the force of gravity.

You can usually find a light switch in the dark because you position your hand and arm by balancing their weight against the tension, compression and turning forces of muscles, tendons and joints. You're not aware of this. Learning not to fling your arms about wildly when reaching for your spoon is part of growing up!

This accumulated subconscious knowledge becomes useless to astronauts as soon as their vehicle enters orbit, but

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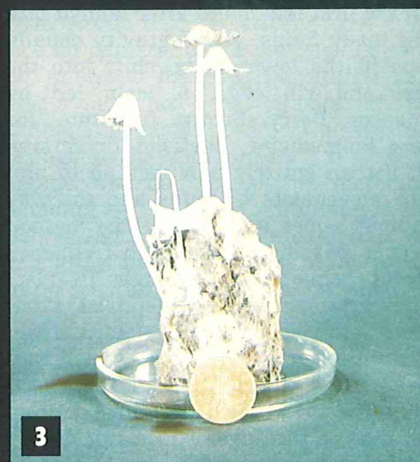

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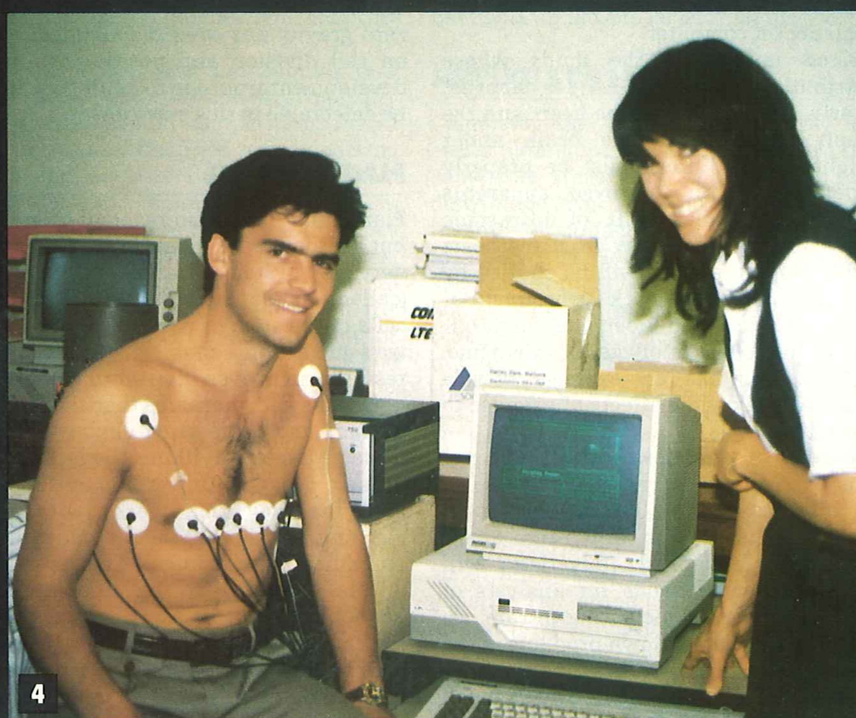
1 The view from Mir.

2 A microscope section of a very young Coprinus *fruit body. It is only 1 mm in height, yet is clearly differentiated into a mushroom.*

3 A mature culture of the inkcap fungus Coprinus cinereus*, one of the fungi which will be sent into space.*

4 Clive Smith, one of the backup astronauts, with Dr Liz Linley, one of the Sheffield team interested in measuring body fluid distributions during space flight.



THE JUNO MISSION

must be regained as soon as they return to Earth. Astronauts must adapt to the new conditions – and quickly, because their lives may depend on hitting the right switch at the right time. That humans (and other animals) can adapt rapidly to this abnormal situation is a tribute to the versatility and sophistication of their nervous systems. Understanding how the adaptation occurs will improve knowledge of the nervous system and how skills are learned.

An experiment to measure changes in manual coordination during adaptation to zero gravity and readaptation to normal gravity is being planned by Dr Helen Ross (Department of Psychology, Stirling University). It will require a blindfolded astronaut to move a hand or arm to positions for which he or she has been trained under terrestrial gravity, the results being recorded photographically and compared with observations before and after the flight.

In the first few hours after launch into orbit, body fluids, which gravity usually keeps in the lower body, shift into the chest and rib cage. A team led by Professor Barry Brown (Institute for Space Biomedicine, Sheffield University) will use an entirely new method to plot these movements of fluids and the way the body copes with them. The method involves passing a safe, high frequency current sequentially through 16 electrodes arranged around the chest. Computer analysis of the electric field distribution produces a map which represents fluid distribution in the chest. This experiment will be done on an astronaut in the Soyuz spacecraft during its journey from launch to the Mir space station, data being recorded on to a very small pocket computer.

Blood is one of the fluids whose distribution through the body is changed. Clearly, the function of the heart and the supply of blood to the brain under weightless conditions must be properly understood. With improved apparatus using the Doppler shift of ultrasonic sound waves, blood flow from the heart and through the brain will be studied by Professor John Woodcock (Department of Medical Physics and Bioengineering, University of Wales College of Medicine, Cardiff). Mir has an exercise bicycle which will allow the effects of exercise to be studied.

Another of the known effects of long-term exposure to microgravity is loss of calcium from the bones. Professor Graham Russell (Institute for Space Biomedicine, Sheffield Univeristy) will use some new methods for analysis of bone chemistry which concentrate on analysis of the breakdown products of the bone collagen matrix rather than the more usual calcium loss methods. This is much more sensitive than any of the techniques previously used, allowing bone changes to be monitored in days rather than weeks.

In all these experiments the astronaut is the experimental organism! Other experiments will use mammalian cell cultures to study production of interferon and other proteins, and to study the way weightlessness affects growth and division of animal cells immobilised in a gel matrix (Dr Nigel Jenkins, Biological Laboratory, University of Kent). Animal cell behaviour in gels is important for understanding embryology, wound healing, cancer and animal cell biotechnology. Professor Mark Ferguson and Dr Seth Schor (Department of Cell and Structural Biology, University of Manchester) will use fibroblasts growing in and on collagen gels to see if the absence of gravity affects the way cells interact with their gel matrix.

Gravity may be used as a sort of plumb line for the development of the shape and pattern of the embryo. Dr Laurie Haynes (Department of Zoology, Bristol University) will use eggs of the Japanese quail, which are small and tough, to study embryo development. Some of the eggs will have windows cut into the shells and fitted for observation by a miniature video camera, and others will be fitted with a transducer capable of detecting the heartbeat of the embryo.

The growth of a nematode in microgravity will be studied by Dr Jonathon Hodgkin, Dr John Sulston and Andrew Chisholm (MRC Laboratory of Molecular Biology, Cambridge). Aside from the nematode being a small (1 mm) easily-cultured organism, this experiment is significant because the adult worm has precisely 959 cells, the position and origin of each one being known in great detail. If zero gravity has even the slightest effect on cell division and positioning during development from egg to adult then it will be detectable in this experiment.

PLANTS IN SPACE

Plants and fungi also respond to gravity, but without the benefit of a complex nervous system. In plants, particles (called amyloplasts) inside particular cells of the stem or root fall to the 'lower' wall and set up a chain of reactions which result in an uneven distribution of growth hormones and guarantee that shoots grow upward and roots grow downward. Professor Malcolm Wilkins (Department of Botany, Glasgow University) will investigate the way this works with short (4–5 cm) lengths of wheat stem mounted on miniature centrifuges. The centrifuges will be controlled so that in one test the amyloplasts will be exerting pressure on the 'bottom' wall and in the other they will be beside the wall. The response of these two sets will show whether continuous pressure is needed for the gravitropic stimulus.

In another experiment, Dr Andrew Goldsworthy (Department of Pure and Applied Biology, Imperial College of Science and Technology) will find out whether weak magnetic fields can substitute for the gravity signal and organise proper root and shoot growth. This would be especially important for space missions of long duration when it may be necessary to cultivate crops under zero gravity conditions.

Another concern is whether zero gravity affects the way the plant cell wall is made. Dr Chris Brett (Department of Botany, Glasgow University) and Dr Keith Waldron (ARFC Food Research Institute, Norwich) will be germinating peas on Mir and then looking at the chemical composition and structure of the cell walls.

Desmids are single-celled algae; they contain barium sulphate crystals which are thought to act as gravity detectors. The shape and form of the crystals depend on desmid species and culture conditions. Dr Carole Perry (Department of Chemistry, Brunel University) will be growing desmid cultures on Mir to see what effect gravity has on crystal formation.

MUSHROOMS ON MIR

A mushroom produces spores which must fall vertically between the plates of tissue on which they form to be dispersed. So mushrooms are totally dependent on gravitational cues for their orientation. Turn a mushroom on its side and the growth of the stem is modified so that it bends upward and the alignment of the cap is restored. Yet fungi do not have nerves or sensory hairs and fungal cells certainly don't have any dense particles like amyloplasts. I will be examining mushrooms grown on Mir to find out how the outside world is perceived in these simple organisms and how that perception is used to control mushroom development. Related experiments will also investigate if zero gravity affects the production of biotechnologically important enzymes by fungi.

The Juno Mission is a truly pioneering mission for British science and the hopes of all the participating scientists will be metaphorically and, in their various experiments, literally, riding high for success in Spring 1991! ■

Dr David Moore is a Reader in Genetics in the Department of Cell and Structural Biology at the University of Manchester. His main research interest is the developmental biology of mushroom fungi. At present he is trying to understand how much of the mushroom structure is a consequence of response to mechanical effects experienced during development and how much is programmed genetically.