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Insects in Space: Experiments and Implications for Astrobiology

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Yet long before any human crossed the boundary of Earth's atmosphere, insects led the charge tiny, expendable bio astronauts whose journeys into the void would fundamentally shape our understanding of how life behaves beyond the cradle of our planet. From the V-2 launches of 1947 to ongoing experiments aboard the International Space Station (ISS), insects have served as indispensable research subjects, offering windows into genetics, physiology, behaviour, and the very nature of biological adaptation. Their stories are also deeply relevant to astrobiology — the scientific discipline concerned with the origin, evolution, and distribution of life in the universe **(Tsiara and Farsadaki, 2026)**.

This article surveys the history of insects in space, the key experiments conducted across eight decades of spaceflight, the biological findings those experiments have yielded, and the broader Astro biological implications that emerge from studying arthropod life under the extremes of the cosmos.

A Brief History — Insects as the First Space Farers

- **The 1947 V-2 Mission: The First Living Organisms in Space**

The story begins on February 20, 1947, at the White Sands Missile Range in New Mexico. A repurposed German V-2 rocket, one of hundreds captured after World War II, was loaded with a sealed capsule containing corn seeds and *Drosophila melanogaster* the common fruit fly. The rocket climbed to an altitude of 109 kilometres in just 3 minutes and 10 seconds, crossing both the U.S. Air Force's 80 km threshold and the international Kármán Line at 100 km, officially entering space. The Blossom capsule was ejected and descended by parachute; the fruit flies were recovered alive **(Beischer, 1962).** The primary purpose was not curiosity about insect behaviour but rather anxiety about cosmic radiation. Scientists in 1947 had no reliable data on the intensity of radiation beyond Earth's atmosphere or how much shielding would be needed to protect future human spacefarers. Fruit flies had already been established as a robust genetic model organism easy to breed, fast to develop, and widely used in radiation mutagenesis research since Hermann Muller's Nobel Prize-winning work in 1927. When the recovered flies were examined by Harvard biologists, the conclusion was definitive: no detectable changes were produced by the radiation **(DeVorkin, 1987).** The flies had proven that a brief passage through near-space radiation was survivable. This modest result reverberated through history. It paved the way for space-bound rhesus monkeys in 1949, dogs in 1951, and ultimately humans in 1961. The fruit fly had quietly opened the door to human spaceflight.

- **1953–1960s: Expanding the Insect Menagerie**

Following the success of 1947, the United States conducted additional unmanned balloon and rocket flights carrying fruit flies between 1953 and 1956, studying radiation effects at progressively higher altitudes. Simultaneously, research broadened to other insect species. Experiments in this era began exploring not just radiation tolerance but also the physiological effects of **microgravity** (often called weightlessness or zero-g) on development, reproduction, and morphology **(Harrington, 2014)**. Studies in the late 1950s and early 1960s found that some insects exhibited altered development when raised in simulated or actual microgravity conditions, prompting deeper questions about how gravity-dependent biological processes from fluid circulation to cellular orientation functioned in its absence.

- **1973: Arabella and Anita Spin Webs on Skylab**

Among the most memorable chapters in insect space history is the story of two spiders. In 1972, Judith Miles, a 17-year-old high school student from Lexington, Massachusetts, submitted an experiment proposal as part of NASA's initiative to include student experiments aboard Skylab the United States' first space station. NASA selected her proposal from more than 3,400 student submissions. Two female cross spiders (*Araneus diadematus*), named Arabella and Anita, were launched aboard Skylab 3 on July 28, 1973. Astronauts Alan Bean, Jack Lousma, and Owen Garriott managed the experiment over a mission lasting 59 days. The results were telling. Upon entering the microgravity environment, both spiders initially demonstrated erratic, disoriented behaviour described as erratic swimming motions. Arabella, however, adapted. Within two days, she had constructed a complete web. Anita was introduced mid-mission and also eventually spun webs. While these space webs were thinner and less geometrically regular than Earth-produced webs, the fundamental patterning of orb-web construction was preserved. Later analysis published in *The Journal of Arachnology* noted that observed irregularities were likely attributable to stress, starvation, and overall mission conditions rather than microgravity alone. The bodies of Arabella and Anita are preserved at the Smithsonian National Air and Space Museum's Steven F. Udvar-Hazy Centre — tiny, brittle pieces of biological history.

- **1970s–1980s: Radiation, Aging, and Developmental Anomalies**

Research through the 1970s brought increasingly complex findings. Experiments that combined radiation exposure with actual spaceflight conditions in fruit flies showed accelerated aging, genetic mutations, and damage to reproductive cells. In the early 1980s, flies born or raised in space exhibited shorter lifespans and wing damage, as well as reduced glycogen reserves in their wings though researchers noted that some of these effects may have been influenced by the mechanical stresses of launch and re-entry, complicating clean attribution to microgravity or radiation alone. These results, though methodologically complex, were pointing toward a crucial insight: space is not simply a neutral environment. It actively interferes with biological processes at the genetic level **(Taylor *et al.*, 2014)**.

Modern Experiments — International Space Station (ISS) and the Era of Precision Biology

The Fruit Fly Lab (FFL) on the ISS

The most sustained and systematic program of insect space biology has been NASA's Fruit Fly Lab (FFL) aboard the International Space Station, developed at NASA's Ames Research Center under the leadership of Dr. Sharmila Bhattacharya. The custom-designed habitat was a significant leap beyond earlier experiments: it featured NanoRacks centrifuges capable of exposing flies to variable gravity conditions ranging from 1 g (Earth-equivalent) to fractional g (simulating lunar or Martian gravity) to 0 g (weightlessness). This allowed researchers to disentangle the effects of different gravitational levels for the first time **(Leandro *et al.*, 2007)**. The FFL-01 mission launched approximately 200 fruit flies to the ISS; after 30 days of reproduction in the microgravity environment, roughly 10,000 insects returned to Earth — a dramatic demonstration of successful multi-generational reproduction in space. *Drosophila melanogaster* shares approximately 77% of known human disease-related genes **(Reiter *et***

***al.*, 2001**), making them powerful proxies for human physiological research. Their life cycle from fertilisation to reproductive adult in roughly 10 days at room temperature means that three weeks in space on the ISS is, biologically speaking, roughly equivalent to three decades of human life in terms of generational exposure. This compression of biological time makes them extraordinarily efficient research subjects for long-duration spaceflight biology.

Immune System Suppression: A Critical Finding

One of the most important discoveries from insect space research concern's immune function. When fruit flies were sent to Earth orbit aboard Space Shuttle Discovery in 2006 on a 13-day mission, researchers documented a measurable decrement in immune function across the board. This is directly relevant to human spaceflight. It has long been observed that astronauts' ability to resist infection is weakened during and after spaceflights a phenomenon that poses serious risks for long-duration missions to the Moon, Mars, or beyond. The fly data provide a model system for understanding the molecular basis of this suppression. As Dr. Siddhita Mhatre, a senior scientist at NASA's Ames Research Center, has stated: it is imperative that we understand the impacts of altered gravity on neurological function, and flies in space, alongside the astronauts, will help to further efforts in keeping astronauts healthy (NASA, 2022). Later ISS experiments found that spaceflight exacerbates immune gene activity and promotes tumour-like growths in flies, reinforcing the relevance of this model system for studying how long-duration cosmic exposure may affect cancer risk and immunological integrity in humans.

Artificial Gravity as a Countermeasure

A particularly significant result from the FFL experiments concerns artificial gravity. Studies have shown that flies exposed to centrifuge-generated artificial gravity during space missions aged differently upon return to Earth — experiencing less severe challenges during re-adaptation to terrestrial gravity compared to flies that experienced only microgravity throughout the mission **(NASA, 2022).** This finding directly supports the hypothesis that rotating spacecraft — long proposed theoretically could meaningfully protect biological organisms during multi-year missions.

Ants in Space: Collective Intelligence Under Zero-G

In 2014, a colony of pavement ants (*Tetramorium caespitum*) was sent to the ISS as part of the Ants in Space project, a collaboration developed in part through the University of Colorado Boulder. The experiment examined whether ants could perform their collective search behaviours specifically the systematic, distributed exploration of new territories in the microgravity environment. The findings, published in *Frontiers in Ecology and Evolution* **(Countryman *et* al., 2015)**, were illuminating. Ants demonstrated a remarkable ability to cling to surfaces and to collectively explore their enclosed habitat even in microgravity. However, when ants lost contact with a surface and became airborne, they entered a disoriented state. The colony-level search patterns observed in space were less efficient than on Earth but still functioned the colony adapted its behaviour in real time.

Silkworms and Honeybees: Reproduction and Development

Silkworm (*Bombyx mori*) eggs have been flown on multiple Chinese space missions, most notably aboard the Shenzhou spacecraft. Chinese space biology programs have used silkworm eggs to study embryonic development in microgravity, examining whether the orientation-dependent processes of early insect development are disrupted without gravity. Results indicated that silkworm development is broadly viable in microgravity, though certain developmental rates were altered, and the moths that emerged showed some behavioural differences. Honeybees (*Apis mellifera*) have also featured in space research. Experiments studied the bees' ability to build comb, thermoregulate as a colony, and orient themselves in microgravity. Honeybees rely heavily on gravity for multiple aspects of their biology, including the famous waggle dance — the directional communication system by which forager bees inform nestmates of food source locations. Unsurprisingly, dance orientation was disrupted in microgravity, though bees showed some degree of compensatory behaviour.

Stick Insects and Houseflies: Negative Results Matter Too

Not all insects have adapted gracefully. Stick insects (*Phasmatodea*) have reportedly struggled significantly with movement, radiation, and reproduction in space conditions. These negative results are scientifically valuable: they help map the boundaries of insect adaptability to the space environment and inform our understanding of which physiological systems are most gravity-dependent. Houseflies (*Musca domestica*) have also been studied in microgravity, primarily in the context of their development and orientation. Their flight mechanics — adapted for a constant 1 g environment — were predictably disrupted, though basic locomotion and reproduction remained possible.

Edible Insects for Space — A New Frontier

The Nutritional Case

One of the most practically urgent dimensions of insect space research concerns food production for long-duration missions. The European Space Agency's PINS project (Potential of Insects as Nutritional Food in Spaceflight) brings together food scientists, biologists, and aerospace engineers from across Europe to evaluate whether insects can form a viable protein source for astronauts on multi-year missions to Mars or beyond. The nutritional case is compelling. House crickets (*Acheta domesticus*) provide high-quality complete protein at levels comparable to or exceeding conventional meat, along with significant iron, zinc, and B vitamins. Yellow mealworms (*Tenebrio molitor*) are similarly nutritious and have been approved for human consumption by the European Food Safety Authority (EFSA) since 2023 **(Jensen *et al.*, 2025).** In 2022, ESA astronaut Samantha Cristoforetti carried cricket flour cereal bars to the ISS, marking a symbolic step toward practical entomophagy in orbit. Led by Professor Åsa Berggren of the Swedish University of Agricultural Sciences, the PINS team has found that insects seem to cope quite well in space environments, showing a good ability to withstand physical stresses **(Countryman *et al.*, 2015)**.

Astrobiological Implications

The study of insects in space contributes to both not by suggesting that insects themselves could colonise other planets, but by illuminating the mechanisms and limits of biological adaptation to conditions radically different from those in which life on Earth evolved.

- **Gravity as a developmental signal.** The fact that many insects can complete their life cycles — from egg to reproducing adult — in microgravity reveals that gravity, while integrated deeply into insect physiology, is not strictly required for the fundamental processes of development, reproduction, and metabolism. This is astrobiologically significant: it suggests that eukaryotic multicellular organisms could, in principle, develop and reproduce in reduced-gravity environments. Planetary bodies like Mars (0.38 g) or the Moon (0.17 g) might not be as biologically hostile to complex metazoan life as simple gravity arguments suggest.
- **Radiation tolerance as a model for panspermia.** The 1947 experiment demonstrated that brief radiation exposure at the edge of space did not detectably mutate fruit fly genetics. While insects are not radiation extremophiles in the way that *Deinococcus radiodurans* bacteria are (which can withstand over 5,000 Gy of ionising radiation, vs. roughly 64 Gy lethal to humans), the general principle — that life can survive interplanetary or interstellar radiation fluxes under appropriate shielding — underpins the **panspermia hypothesis**.
- **Immune suppression and the astrobiology of multicellular life.** The finding that spaceflight suppresses immune function in *Drosophila* mirrors findings in human astronauts and mouse models. This convergent vulnerability across vastly different organisms suggests that immune suppression in microgravity may be a fundamental biological phenomenon, not a quirk of any particular taxon.
- **Collective behaviour and the evolution of social complexity.** The ant experiments on the ISS demonstrated that emergent collective intelligence one of the most sophisticated phenomena in the animal kingdom remains partially functional under microgravity.

Tardigrades: The Context for Insect Space Research

Tardigrades are microscopic invertebrates, loosely related to insects within the superphylum Ecdysozoa, that have become icons of extreme survival. In ESA's 2007 *Tardigrades in Space* (TARDIS) experiment, tardigrades were exposed to the naked vacuum and full solar radiation of low Earth orbit for 10 days. Most survived and resumed normal functioning within 30 minutes of rehydration upon return **(Jönsson *et al.*, 2008)**. This experiment sent shockwaves through the astrobiology community by demonstrating that multicellular organisms could, at least in cryptobiotic form, survive direct exposure to open space.

Current Knowledge Gaps and Future Directions

Despite eight decades of insect space research, the field remains characterised by fragmented and incomplete data. As a 2025 review in *Frontiers in Space Technologies* **(Guidetti *et* al., 2025)** documented, information on the effects of microgravity on insects remains scattered across species and experiments, without systematic comparison across taxa or life stages. Many classic experiments lasted only minutes in parabolic flights providing only a snapshot of physiological response rather than sustained biological change.

Critical gaps include:

Long-duration life-cycle studies. We need multi-generational experiments (5+ generations) in true orbital microgravity to understand whether insects can maintain population viability over the timescales relevant to Mars missions (18+ months) or permanent off-world habitats.

Radiation biology at Mars-equivalent doses. The radiation environment inside a transit vehicle to Mars — primarily from galactic cosmic rays, with periodic solar particle events — differs substantially from low Earth orbit conditions aboard the ISS. Dedicated deep-space insect biology experiments are needed.

Gut microbiome interactions. Insects like crickets and mealworms harbour complex gut microbiomes essential for digestion and nutrition. How microgravity and radiation alter these microbiomes and consequently the nutritional value of edible insects is almost entirely unexplored.

Genetic and epigenetic adaptation. Whether insects can undergo heritable adaptation to space conditions over multiple generations and whether such adaptation could be beneficial or harmful remains an open question with profound implications for both space agriculture and evolutionary theory.

Closed-loop ecosystem testing. ESA's PINS project and similar initiatives are moving toward testing whether insects can form stable, productive components of bioregenerative life support systems closed ecological loops in which insect colonies process organic waste and produce protein, while also contributing to nutrient cycling. Initial results are promising, but full system-level testing in actual space conditions has not yet been achieved.

Conclusion

From the fruit flies of 1947 that proved cosmic radiation was survivable, to the spiders of 1973 who wove webs in weightlessness, to the modern Fruit Fly Lab experiments illuminating the genetic basis of immune suppression, insects have served as extraordinarily productive subjects for understanding how life complex, gravity-dependent, ecologically embedded life behaves under the cosmos's most challenging conditions. For astrobiology, the implications are significant. Insect research contributes to our understanding of gravity as a developmental signal, the radiation tolerance of complex organisms, the robustness of collective biological behaviours, and the feasibility of complex multicellular life in non-terrestrial environments. They remind us that life beyond Earth, if it exists, need not be microbial. Evolution under different physical regimes might produce complexity; understanding how our own complex organisms respond to those regimes is a prerequisite for reasoning clearly about what alien complexity might look like.

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