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The Space Environment

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The Space Gravity Environment

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It is generally thought that gravity is zero on an object travelling at constant velocity in space. This is not exactly so. We detail in the following those causes that make space gravity not strictly zero.

1.1 Open Space

An object (spacecraft or celestial bodies in general) travelling in the open space is obviously subjected to acceleration forces coming from the spacecraft itself (see below in Section 1.2). The spacecraft is also submitted to gravity forces resulting from the other massive objects, planets, stars, etc. To give an example, Earth's gravity is reduced by a factor 10^6 at a distance of 6×10^6 km from Earth. The Sun's gravity is reduced by the same amount at a distance of 3.7×10^9 km [1].

In addition to these gravity effects, at least in the solar system, a phenomenon of friction due to the solar wind and radiation pressure induces deceleration in the direction of Sun. Basically, absolutely zero gravity does not exist within the universe. All solar systems, nebulas, and galaxies are all under the influence of gravitational fields generated by the mass present and acting over astronomical distances.

1.2 Satellites and Rockets

The means to go into space, that is, going into weightlessness, are classically (sounding) rockets, which follow a parabolic trajectory to generate a free fall or for low-orbit satellites going around Earth where the centrifugal force compensates the gravity attraction. Such spacecrafts are submitted to the above open space effects (Section 1.1). However, there are also effects due to gravity interactions between objects. A mass of 1,000 kg generates 0.007 μg at a 1 m distance. At low orbital altitudes from 185 to 1,000 km, for example, for the International Space Station (ISS), friction effects due to the very sparse molecules in the thermo- and exosphere orbiting the day or night part of an Earth's orbit influence the ISS (Figure 1.1). This atmosphere causes

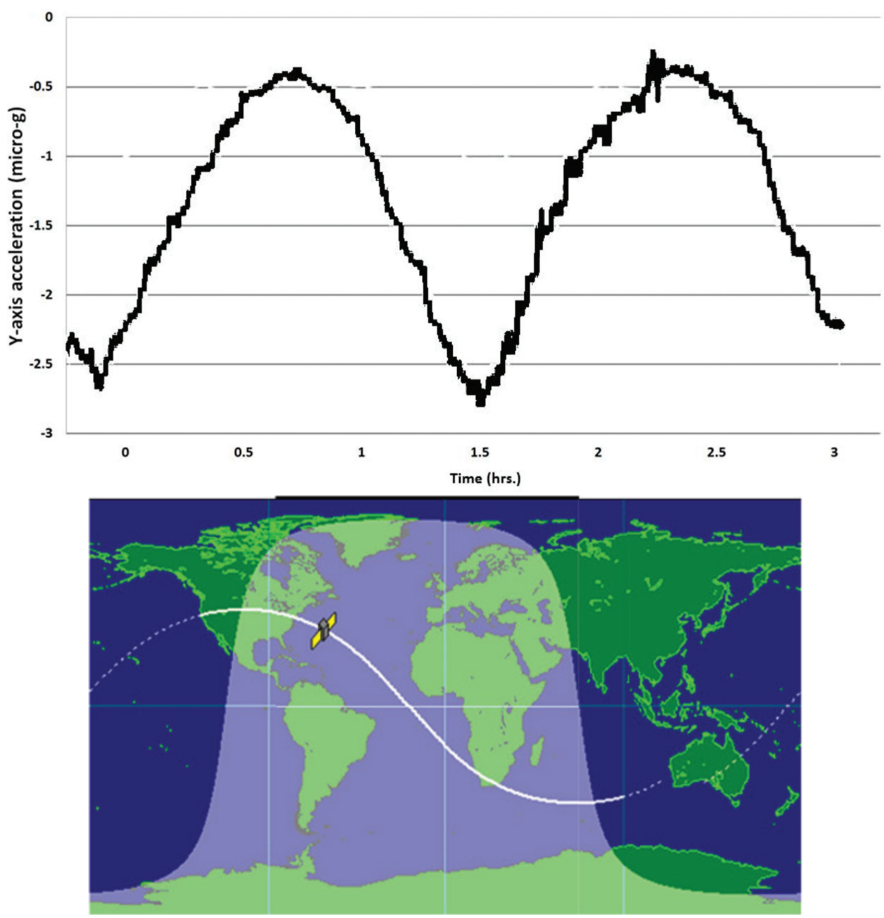

Figure 1.1 The quasi-steady microgravity environment on the orbiter Columbia shows the effects of variations in Earth's atmospheric density. The primary contribution to the variation is the day/night difference in atmospheric density. The *plot* shows that the drag on the orbiter varies over a ninety-minute orbit (Courtesy NASA, 1997 [2]).

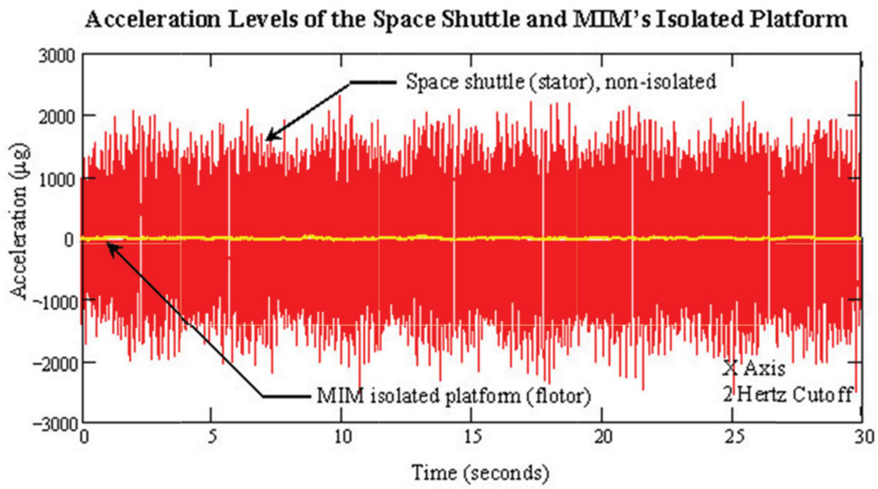

Figure 1.2 Example of the accelerations measured by the accelerometers of the 2nd version of the Microgravity Vibration Isolation Mount (MIM-2) stator (non-isolated) and of the MIM-2 flotor (isolated) during the STS-85 shuttle mission. The accelerations were filtered by a 100-Hz low-pass filter and sampled at 1,000 samples per second. The time traces thus have frequency content up to 100 Hz. The MIM-2 controller was set to isolate above a cutoff frequency of 2 Hz for this run (data courtesy CSA). See also [3].

deceleration, which can be compensated by a small continuous thrust, but in practice, the deceleration is only compensated from time to time, so the small g-force of this effect is not eliminated.

Other effects increase the level of gravity. Even at rest, all the spacecrafts are subjected to vibrations coming from the inboard instrumentation, re-ignition of thrusters, human movement within the module, etc (g-jitter). The vibration frequency spectrum depends on the mechanical architecture of the spacecraft. For instance, in the ISS, the frequency spectrum of vibration in the 10^{-2}–10^{3} Hz range varies from 1 to 10^{3} μg (g = 9.81 ms^{-2} is Earth's acceleration constant).

In satellites, the weight compensation is located only at the center of mass. At a distance d from it, gravity rises in the ratio d/z, where z is the distance between the spacecraft and Earth's center of mass. To give an example, at d = 1 m from the spacecraft mass center, the residual gravity is steady and equal to 0.17 μg. In addition, in low Earth orbit, the force of gravity decreases upward (by 0.33 μg/m), which can make a variation of about 0.5 μg/m.

Free floating objects in the spacecraft can also be submitted to gravity effects. Such objects orbit Earth in different orbital planes and their distance

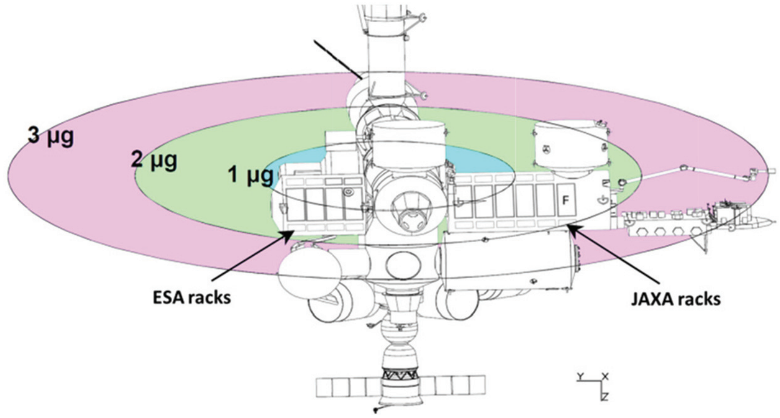

Figure 1.3 Self-gravitation in the International Space Station (*ISS*). Depending on the location with the ISS mass perceives a gravitational pull ranging from 0 to 3×10^{-6} g from the total mass of the ISS itself [4] (Image courtesy NASA).

oscillates, with the same period as the orbit, corresponding to an inward acceleration of 0.17 μg/m. One has also to consider the effects of the solar wind and radiation pressure whose effect is similar to air, but directed away from Sun.

1.3 Typical Gravity at Some Celestial Objects

Gravity amplitude at the surface of some, nearby, celestial objects as asteroids, moons, and planets are listed in Table 1.1, together with their radii. See also Chapter 5 for more information.

Table 1.1 Gravity in units of g on some celestial objects

Name	Radius (km)	Gravity (in g)
Earth	6,370	1.0
Moon	1,740	0.165
Mars	3,396	0.371
Europa	1,561	0.134
Callisto	2,410	0.126
Io	1,822	0.183
Enceladus	252	0.011
433 Eros[a]	34–11	6.0×10^{-4}
ISS	$\sim 0.07 \times 0.10$	$0–3 \times 10^{-6}$[b]

[a] 433 Eros is a near Earth stony asteroid by some mentioned as a possible source for asteroid mining. Estimated mass of the object is 6.7×10^{15} kg (Wikipedia)
[b] Mass of the ISS is around 420,000 kg (date: June 2014)

1.4 Conclusion

The situation of pure weightlessness is thus never encountered in space. What is rather met is a mean low gravity showing at best values expressed in ppm (microgravity), with gravity peaks due to spacecraft maneuvers and human activity. Over the years, various vibration isolation systems have been developed, improving the level of weightlessness, with, however, limitations on (long) times and (small) frequency.

For a typical low Earth orbit, like for the ISS, the altitude is some 350 km. However, the level of gravity is still 9.04 m/s^2 at this height. This is only 8 % less than the gravitational field on Earth's surface.

In this publication, as in many others, the term "microgravity" (μg) is used. Strictly speaking, this term is wrong since, seen the example above, objects are still in a gravitational field, but are in free fall. It is better to use the term weightlessness, or even better, near weightlessness. However, seen the broad use of the term microgravity, we will also apply it in this book.

References

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[4] ISS Design Analysis Cycle & Environment Predictions: Section18. NASA Glenn Research Center, March 5–7, 2002.