2.2: The Inertial (Free-float) Frame

goodbye to the "force of gravity"

It is easy to talk about the simplicity of motion in a spaceship. It is hard to think of conditions being equally simple on the surface of Earth (Figure 2.2.1). The reason for concern is not far to seek. We experience it every day, every minute, every second. We call it gravity. It shows in the arc of a ball tossed across the room (Figure 2.2.2, left). How can anyone confront a mathematical curve like that arc and not be trapped again in that tortuous trail of thought that led from ancient Greeks to Galileo to Newton? They thought of gravity as a force acting through space, as something mysterious, as something that had to be "explained."

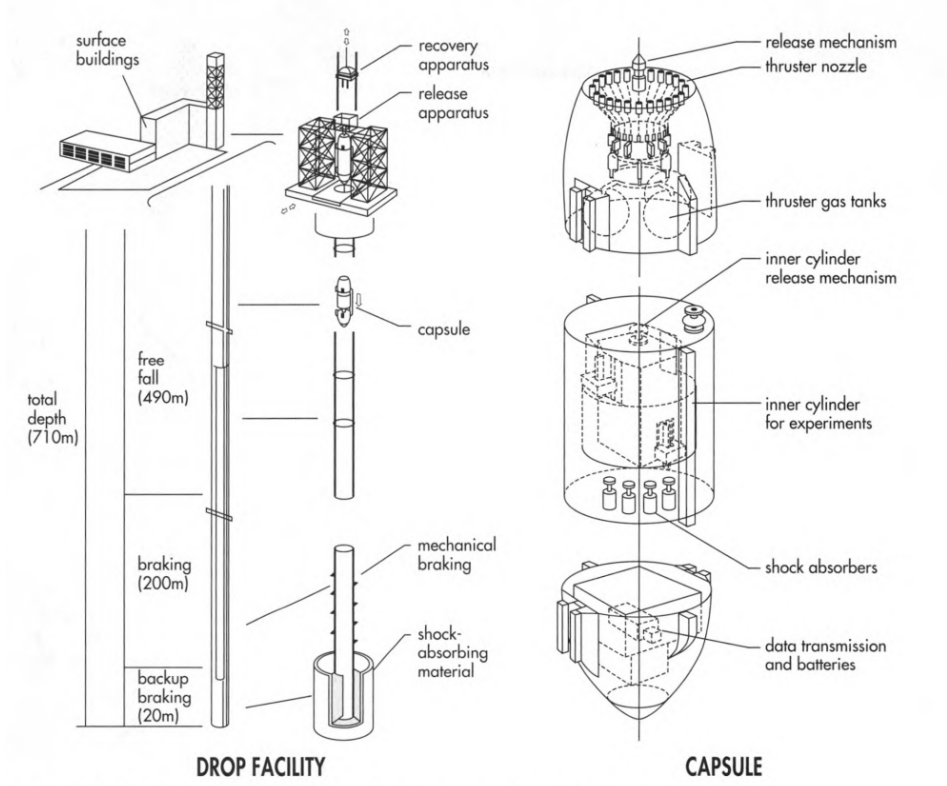

Figure 2.2.1: **The Japan Microgravity Center (JAMIC) installed in an abandoned coal mine 710 meters deep in the small town of Kamisunagawa on the northern island of Hokkaido, Japan.** The capsule carrying the experimental apparatus provides a free-float frame for 10 seconds as it falls 490 meters through a vertical tube, achieving a maximum velocity of nearly 100 meters/second. It is guided by two contact-free magnetic suspensions along the tube. The vertical tube is not evacuated; downward-thrusting gas jets on the capsule compensate for air drag as the capsule drops. The capsule is slowed down in an additional distance of 200 meters near the bottom of the tube by air resistance after thrusters are turned off, followed by mechanical braking. Twenty meters of cushioning material at the very bottom of the tube provide emergency stopping. The falling capsule is nearly 8 meters long and nearly 2 meters in diameter with a mass of 5000 kilograms, including 1000 kilograms of experimental equipment contained in an inner cylinder 1.3 meters in diameter and 1.8 meters long. The space between capsule and experimental cylinder is evacuated. The inner experimental cylinder is released just before the outer capsule itself. Optical monitoring of the vertical position of the inner cylinder triggers downward-pushing thrusters as needed to overcome air resistance. Thus the experimental cylinder itself acts as an internal "conscience," ensuring that the capsule takes the same course that it would have taken bad both resistance and thrust been absent. The result? A nearly free-float frame, with a maximum acceleration of 1.0×10^{-4} g in the experimental capsule, where g is the acceleration of gravity at Earth's surface. Experiments carried out in this facility benefit from conditions of "no air pressure, no beat convection, no floating or sinking buoyancy, no resistance to motion," as well as much lower cost and less environmental damage than those involved in launching and monitoring an Earth satellite. The facility is designed to carry out 400 drops per year, with experiments such as forming large superconducting crystals, creating alloys of materials that do not normally mix, studying transitions between gas and liquid phases, and burning under zero-g. (See also Figure 9-2.)

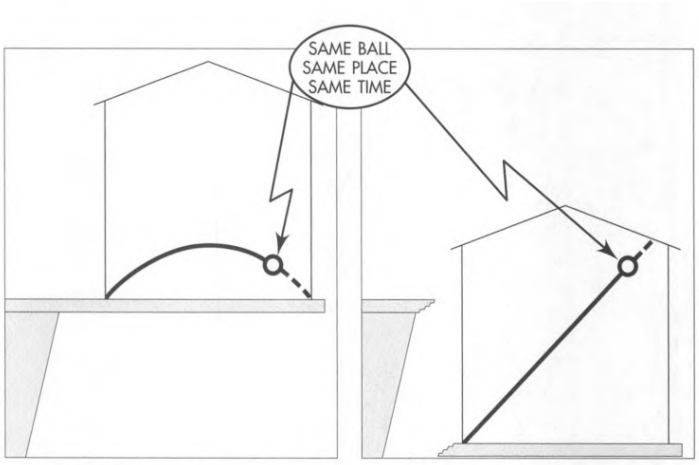

Figure 2.2.2: **Illusion and Reality.** The same ball thrown from the same corner of the same room in the same direction with the same speed is seen to undergo very different motions depending on whether it is recorded by an observer with a floor pushing up against his feet or by an observer in "free fall" ("free float") in a house sawed free from the cliff. In both descriptions the ball arrives at the same place-relative to Mother Earth - at the same instant. Let each ball squirt a jet of ink on the wall we are looking at. The resulting record is as crisp for the arc as for the straight line. Is the arc real and the straight line illusion? Or is the straight line real and the arc illusion? Einstein tells us that the two ink trails are equally valid. We have only to be honest and say whether the house, the wall, and the describer of the motion are in free float or whether the describer is continually being driven away from a condition of free float by a push against his feet. Einstein also tells us that physics always looks simplest in a free-float frame. Finally, be tells us that every truly local manifestation of "gravity" can be eliminated by observing motion from a frame of reference that is in free float.

Einstein put forward a revolutionary new idea. Eliminate gravity!

Concept of free-float frame

Where lies the cause of the curved path of the ball? Is it the ball? Is it some mysterious "force of gravity"? Neither, Einstein tells us. It is the fault of the viewers - and the fault of the floor that forces us away from the natural state of motion: the state of **free fall**, or better put, **free float**. Remove the floor and our motion immediately becomes natural, effortless, free from gravitational effects.

Let the room be cut loose at the moment we throw the ball slantwise upward from the west side at floor level (Figure 2.2.2, right). The ball has the same motion as it did before. However, the motion looks different. It looks different because we who look at it are in a different frame of reference. We are in a free-float frame. In this **free-float frame** the ball has straight-line motion. What could be simpler?

Even when the room was not cut away from the cliff, the floor did not affect the midair flight of the ball. But the floor did affect us who watched the flight. The floor forced us away from our natural motion, the motion of free fall (free float). We blamed the curved path of the ball on the "force of gravity" acting on the *ball*. Instead we should have blamed the floor for its force acting on *us*. Better yet, get rid of the floor by cutting the house away from the cliff. Then our point of view becomes the natural one: We enter a free-float frame. In our free-float frame the ball flies straight.

> *What's the fault of the force on my feet?*
> *What pushes my feet down on the floor?*
> *Says Newton, the fault's at Earth's core.*
> *Einstein says, the fault's with the floor;*
> *Remove that and gravity's beat!*
>
> *— Frances Towne Ruml*

How could humankind have lived so many centuries without realizing that the "arc" is an unnecessary distraction, that the idea of local "gravity" is superfluous — fault of the observer for not arranging to look at matters from a condition of free float?

Even today we recoil instinctively from the experience of free float. We and a companion ride in the falling room, which does not crash on the ground but drops into a long vertical tunnel dug for that purpose along the north - south axis of Earth. Our companion

is so filled with consternation that he takes no interest in our experimental findings about free float. He grips the door jamb in terror. "We're falling!" he cries out. His fear turns to astonishment when we tell him not to worry.

"A shaft has been sunk through Earth," we tell him. "It's not the fall that hurts anyone but what stops the fall. All obstacles have been removed from our way, including air. Free fall," we assure him, "is the safest condition there is. That's why we call it free float."

"You may call it float," he says, "but I still call it fall."

Free-float through Earth

"Right now that way of speaking may seem reasonable," we reply, "but after we pass the center of Earth and start approaching the opposite surface, won't the word 'fall' seem rather out of place? Might you not then prefer the word 'float'?" And with "float" our companion at last is happy.[1]

What do we both see? Weightlessness. Free float. Motion in a straight line and at uniform speed for marbles, pennies, keys, and balls in free motion in any direction within our traveling home. No jolts. No shudders. No shakes at any point in all the long journey from one side of Earth to the other.

For our ancestors, travel into space was a dream beyond realization. Equally beyond our reach today is the dream of a house floating along a tunnel through Earth, but this dream nonetheless illuminates the simplicity of motion in a free-float frame. Given the necessary conditions, nothing that we observe inside our traveling room gives us the slightest possibility of discriminating among different free-float frames: one just above Earth's surface, a second passing through Earth's interior, a third in the uttermost reaches of space. Floating inside any of them we find no evidence whatever for the presence of "gravity."

✔ Question and Answer

Wait a minute! If the idea of local "gravity" is unnecessary, why does my pencil begin to fall when I hold it in the air and let go? If there is no gravity, my pencil should remain at rest.

Answer

And so it does remain at rest — as observed from a free-float frame! The natural motion of your pencil is to remain at rest or to move with constant velocity in a free-float frame. So it is not helpful to ask: "Why does the pencil begin to fall when I let go?" A more helpful question: "Before I let go, why must I apply an upward force to keep the pencil at rest?" Answer: Because you are making observations from an unnatural frame: one held fixed at the surface of Earth. Remove that fixed hold by dropping your room off a cliff. Then for you "gravity" disappears. For you, no force is required to keep the pencil at rest in your free-float frame.

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1 Free-float through Earth
