2.1: Floating to Moon

> *At that moment there came to me the happiest thought of my life . . . for an observer falling freely from the roof of a house no gravitational field exists during his fall . . .*
>
> *Albert Einstein*

will the astronaut stand on the floor—or float?

Less than a month after the surrender at Appomattox ended the American Civil War (1861-1865), the French author Jules Verne began writing *A Trip From the Earth to the Moon* and *A Trip Around the Moon*. Eminent American cannon designers, so the story goes, cast a great cannon in a pit, with cannon muzzle pointing skyward. From this cannon they fire a ten-ton projectile containing three men and several animals (Figure 2.1.1).

Jules Verne: Passenger stands on floor

As the projectile coasts outward in unpowered flight toward Moon, Verne says, its passengers walk normally inside the projectile on the end nearer Earth (Figure 2.1.2).[1] As the trip continues, passengers find themselves pressed less and less against the floor of the spaceship until finally, at the point where Earth and Moon exert equal but opposite gravitational attraction, passengers float free of the floor. Later, as the ship nears Moon, they walk around once again — according to Verne — but now against the end of the spaceship nearer Moon.

Early in the coasting portion of the trip a dog on the ship dies from injuries sustained at takeoff. Passengers dispose of its remains through a door in the spaceship, only to find the body floating outside the window during the entire trip (Figure 2.1.1).

Paradox of passenger and dog

This story leads to a paradox whose resolution is of crucial importance to relativity.[2] Verne thought it reasonable that Earth's gravitational attraction would keep a passenger pressed against the Earth end of the spaceship during the early part of the trip. He also thought it reasonable that the dog should remain next to the ship, since both ship and dog independently follow the same path through space. But since the dog floats outside the spaceship during the entire trip, why doesn't the passenger float around inside the spaceship? If the ship were sawed in half would the passenger, now "outside," float free of the floor?

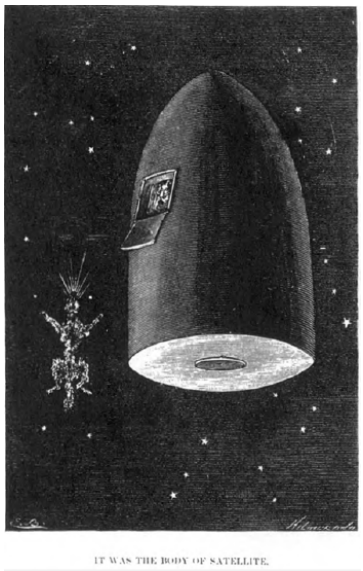

Figure 2.1.1: **Illustration from an early edition of *A Trip Around the Moon*.** Satellite is the name of the unfortunate dog.

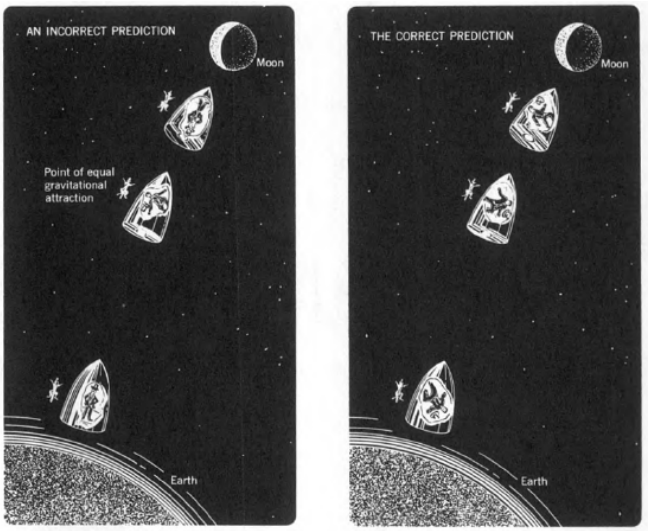

Figure 2.1.2: **Incorrect prediction**: Jules Verne believed that a passenger inside a free projectile would stand against the end of the projectile nearest Earth or Moon, whichever bad greater gravitational attraction-but that the dog would float along beside the projectile for the entire trip. **Correct prediction**: Verne was right about the dog, but a passenger also floats with respect to the free projectile during the entire trip.

Our experience with actual space flights enables us to resolve this paradox (Figure 2.1.2). Jules Verne was wrong about the passenger's motion inside the unpowered spaceship.[3] Like the dog outside, the passenger inside independently follows the same path through space as the spaceship itself. Therefore he floats freely relative to the ship during the entire trip (after the initial boost inside the cannon barrel). True: Earth's gravity acts on the passenger. But it also acts on the spaceship. In fact, with respect to Earth, gravitational acceleration of the spaceship just equals gravitational acceleration of the passenger. Because of this equality, there is no *relative* acceleration between passenger and spaceship. Thus the spaceship serves as a **reference frame** relative to which the passenger does not experience any acceleration.

To say that acceleration of the passenger relative to the unpowered spaceship equals zero is *not* to say that his velocity relative to it necessarily also equals zero. He may jump from the floor or spring from the side - in which case he hurtles across the spaceship and strikes the opposite wall. However, when he floats with zero initial velocity relative to the ship the situation is particularly interesting, for he will also float with zero velocity relative to it at all later times. He and the ship follow identical paths through space. How remarkable that the passenger, who cannot see outside, nevertheless moves on this deterministic orbit! Without a way to control his motion and even with his eyes closed he will not touch the wall. How could one do better at eliminating detectable gravitational influences?

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1 Jules Verne: Passenger stands on floor

2 Paradox of passenger and dog

3 Reality: Passenger floats in spaceship
