5. Concept of Apparent Forces

By

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Apparent Force

(Also fictitious force, inertial force, transport force.) A force (mass times an acceleration) introduced on the side of an equation on which all supposedly real forces appear.

• In an inertial reference frame, a body at rest or in uniform motion has no net forces acting on it.

• A body at rest or in uniform motion relative to the rotating earth is not at rest or in uniform motion relative to a coordinate system fixed in space.

• To reconcile Newton's laws with the noninertial reference frame of the rotating earth, two apparent forces must be introduced.

• These are the centrifugal force and the Coriolis force.

For Newton's dynamical law of motion for a body of mass *m* acted on by a force **F**,

$$\mathbf{F} = m\mathbf{a},$$

to be valid requires that the acceleration **a** be specified relative to an inertial reference frame. If the acceleration in a noninertial reference frame (e.g., a rotating reference frame) is **a***, then

$$\mathbf{a} = \mathbf{a}^* + \mathbf{a}_i$$

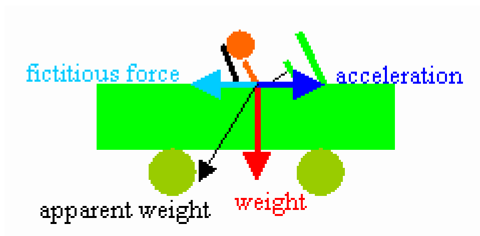
and the previous dynamical equation may be written

$$\mathbf{F} - m\mathbf{a}_i = m\mathbf{a}^*,$$

where the quantity $-m\mathbf{a}_i$ is the inertial or apparent force and $\mathbf{a}_i$ is the inertial acceleration. Examples of apparent forces are the centrifugal force and the Coriolis force. Within classical (Newtonian) mechanics inertial forces are fictitious, merely masses times accelerations. But in general relativity, inertial forces are equivalent to real forces resulting from interactions between bodies because it is impossible to distinguish between inertial and gravitational accelerations; both are independent of the mass of the body.

Fictitious Forces

Newton's first law, also called the law of inertia, defines a special class of reference frames, called **inertial frames**. It states that, when viewed in an inertial reference frame, an object at rest remains at rest and an object in motion continues in motion with constant velocity unless it is acted on by an external net force. Newton's second law and Newton's third law correctly describe the motion of objects as viewed by observers in inertial reference frames. In an inertial frame $\mathbf{F} = m\mathbf{a}$, where the net force $\mathbf{F}$ is the vector sum of all the real known forces acting on an object of mass m. If observers at rest in an accelerating frame want to use $\mathbf{F} = m\mathbf{a}$ to predict the motion of an objet in their reference frame, then $\mathbf{F}$ has to include not only the vector sum of all the real known forces acting on the object but also a **fictitious force**. Fictitious forces appear in accelerating frames.



You just got your new car. You want to experience it. You want to "feel" its power. You floor the gas pedal, and you experience a force pressing you back into your seat. Where does this force come from?

This force is a fictitious force. Fictitious forces appear in accelerating reference frames. Such frames are NOT inertial reference frames. The accelerating reference frame in the above example is accelerating with your car. In this frame your car and you are at rest. But you are feeling a force pushing you against the back of your seat. To your friend observing you from the sidewalk things look different. The motor is responsible for the forward acceleration of the car. Because of your mass, you have inertia. Without a force acting on you, you would remain at rest with respect to the sidewalk. To keep you accelerating forward, the back of the seat has to push on you. (You will be pushing on the seat with a force equal in magnitude, but opposite in direction.) The fictitious force appearing in the accelerating frame is the negative of the the real force responsible for maintaining your acceleration and keeping you at rest in the accelerating frame. The real force acting on you is in the forward direction, while the fictitious force experienced in the accelerating frame is in the backward direction.

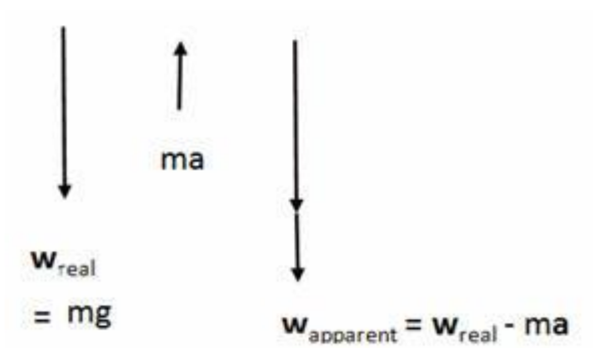
In the accelerating frame of the car, you experience the fictitious force in the backward direction and your weight, pointing down. The net force experienced is the vector sum of these two forces. This force becomes your **apparent weight**, which points in a direction backward and down.

The apparent weight of an accelerating object is the vector sum of its real weight and the negative of all the forces that produce the object's acceleration $\mathbf{a} = d\mathbf{v}/dt$.

$\mathbf{w}_{apparent} = \mathbf{w}_{real} - m\mathbf{a}$.

When you stand on a bathroom scale in an inertial frame, such as in your bathroom, the scale reading is proportional to your real weight. When you stand on a bathroom scale in an accelerating frame, such as an elevator accelerating upward, its reading is proportional to your apparent weight.

For the elevator accelerating upward:

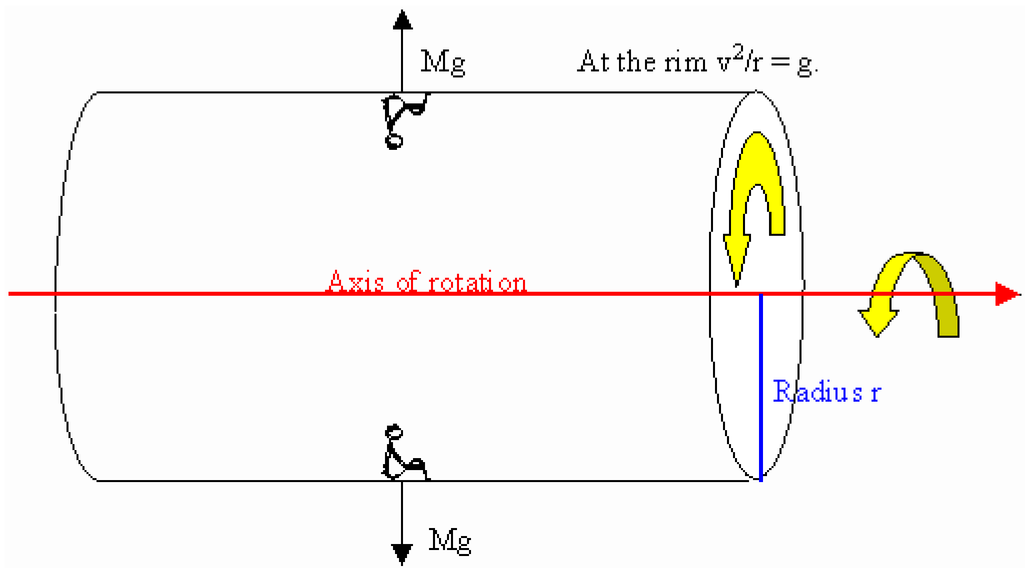


In every accelerating frame we have $\mathbf{w}_{apparent} = \mathbf{w}_{real} - m\mathbf{a}$. The apparent weight of a mass m is its real weight minus its mass times the acceleration of the frame (vector addition).

Assume you are riding on a merry-go-round. A reference frame in which you are stationary, i.e. a frame that is moving with you as you are moving along a circular path, is also an accelerating frame. This frame is moving with constant speed, but the direction of its velocity is constantly changing. You are sitting still on your seat while the merry-go-round is turning. But something seems to be pulling you towards the outside, away from the center. You experience a fictitious force. To your friend on the ground things again look different. You are moving in a circle. The direction of your velocity is constantly changing. You are accelerating. The direction of your acceleration is towards the center of the circle, so there must be a force pushing or pulling you toward the center. If you are sitting in a seat, the wall of the seat will be pushing against you, pushing you towards the center.

In many Science Fiction books, humans live in space in a space station that is rotating about a central axis. Their real weight is close to zero. The acceleration of a person with mass M at rest with respect to the space station near the rim is $a = v^2/r$ directed towards the axis. The apparent weight of the person is $\mathbf{w}_{apparent} = \mathbf{w}_{real} - M\mathbf{a} = Mv^2/r$ directed towards the rim.

If the rim is the floor of some room without windows, and the rotation speed and the radius of the station are adjusted so that $a = v^2/r = g$, then there is no way a human or a scientific instrument in the room can distinguish between the apparent weight and the force of gravity. If the human steps on a scale, the scale will read the same "weight" as it does on the surface on earth. If the human throws a ball near the "surface", the ball will follow the same trajectory it would on earth.



Problem:

Engineers are trying to create artificial gravity in a ring-shaped space station by spinning it like a centrifuge. The ring is 100 m in radius. How quickly must the space station turn in order to give the astronauts inside it apparent weights equal to their real weights at the earth's surface

Solution:

- Reasoning:
- We want $a = v^2/r = g$, or $v^2 = gr$.
- Details of the calculation:
- $v^2 = gr = (9.8\ m/s^2)(100\ m) = 980\ (m/s)^2$. Therefore $v = 31.3\ m/s$.
- The circumference of the space station is $2\pi r = 628$ m.

The space station therefore must completes a turn in (628 m)/(31.3 m/s) = 20