Non-inertial Reference Frames & Fictitious Forces

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Non-inertial Reference Frames

A non-inertial reference frame is a frame of reference that undergoes acceleration with respect to an inertial frame. An accelerometer at rest in a non-inertial frame will, in general, detect a non-zero acceleration. While the laws of motion are the same in all inertial frames, in non-inertial frames, they vary from frame to frame depending on the acceleration.

In classical mechanics the motion of bodies in non-inertial reference frames is modeled by introducing additional forces (d'Alembert forces) to inertial reference frames in order to account for the inertia effects that are appearing in this situation. Because in principle they don't belong to the modeling of an inertial frame in terms of Newton's second law such inertial effects are called fictitious forces. They might be called inertial forces or pseudo forces, too. Common examples of this include the Coriolis force and the centrifugal force.

In general, the expression for any fictitious force can be derived from the acceleration of the non-inertial frame.

As stated by Goodman and Warner, "One might say that F = ma holds in any coordinate system provided the term 'force' is redefined to include the so-called 'reversed effective forces' or 'inertia forces'."

In the theory of general relativity, the curvature of spacetime causes frames to be locally inertial, but globally non-inertial. Due to the non-Euclidean geometry of curved space-time, there are no global inertial reference frames in general relativity. More specifically, the fictitious force which appears in general relativity is the force of gravity.

Fictitious Forces

A fictitious force is a force that appears to act on a mass whose motion is described using a non-inertial frame of reference, such as a linearly accelerating or rotating reference frame. It is related to Newton's second law of motion, which treats forces for just one object.

Passengers in a vehicle accelerating in the forward direction may perceive they are acted upon by a force moving them into the direction of the backrest of their seats for example. An example in a rotating reference frame may be the impression that it is a force which seems to move objects outward toward the rim of a centrifuge or carousel. The most commonly observed example is the turning of a car. While the contact force of the side door (inward or centripetal) is ‘real’, the passenger thinks that there must be an outward (or centrifugal) force pushing him against the door.

The fictitious force called a pseudo force might also be referred to as a body force. It is due to an object's inertia when the reference frame does not move inertially any more but begins to accelerate relative to the free object. In terms of the example of the passenger vehicle, a pseudo force seems to be active just before the body touches the backrest of the seat in the car. A person in the car leaning forward first moves a bit backward in relation to the already accelerating car, before touching the backrest. The motion in this short period just seems to be the result of a force on the person, it's a pseudo force. A pseudo force does not arise from any physical interaction between two objects, such as electromagnetism or contact forces. It's just a consequence of the acceleration ‘a’ of the physical object that the non-inertial reference frame is connected to, i.e. the vehicle in this case. From the viewpoint of the respective accelerating frame, an acceleration of the inert object appears to be present, apparently requiring a "force" for this to have happened. Another way of saying this is that in the accelerated reference frame of the car, the passenger sees himself as at rest. If Newton’s laws are to continue to apply here, then the contact (Normal) force of the backrest ‘must be’ canceled by an equal (in magnitude) but opposite (in direction) to keep $F_{net} = 0$.

Such an additional force due to nonuniform relative motion of two reference frames is called a pseudo-force.

The pseudo force on an object arises as an imaginary influence when the frame of reference used to describe the object's motion is accelerating compared to a non-accelerating frame. The pseudo force "explains," using Newton's second law mechanics, why an object does not follow Newton's second law and "floats freely" as if weightless. As a frame may accelerate in any arbitrary way, so may pseudo forces also be as arbitrary (but only in direct response to the acceleration of the frame). An example of a pseudo force is the Coriolis force, maybe better to be called: the Coriolis effect. The gravitational force would also be a fictitious force (pseudo force), based upon a field model in which particles distort spacetime due to their mass, such as in the theory of general relativity. (*I’m not understanding this last statement!*)

Assuming Newton's second law in the form F = ma, fictitious forces are always proportional to the mass m.

Four fictitious forces have been defined for frames accelerated in commonly occurring ways:

1. caused by any acceleration relative to the origin in a straight line (rectilinear acceleration)
2. involving rotation: centrifugal force
3. involving rotation: Coriolis effect
4. involving a variable rate of rotation: Euler force