Centrifugal force essay sample

Centrifugal force (from Latin centrum, meaning “ center”, and fugere, meaning “ to flee”) is the apparent outward force that draws a rotating body away from the center of rotation. It is caused by the inertia of the body as the body’s path is continually redirected. In Newtonian mechanics, the term centrifugal force is used to refer to one of two distinct concepts: an inertial force (also called a “ fictitious” force) observed in a non-inertial reference frame, and a reaction force corresponding to a centripetal force.

The term is also sometimes used in Lagrangian mechanics to describe certain terms in the generalized force that depend on the choice of generalized coordinates.

The concept of centrifugal force is applied in rotating devices such as centrifuges, centrifugal pumps, centrifugal governors, centrifugal clutches, etc., as well as in centrifugal railways, planetary orbits, banked curves, etc. These devices and situations can be analyzed either in terms of the fictitious force in the rotating coordinate system of the motion relative to a center, or in terms of the centripetal and reactive centrifugal forces seen from a non-rotating frame of reference; these different forces are equal in magnitude, but centrifugal and reactive centrifugal forces are opposite in direction to the centripetal force.

History of conceptions of centrifugal and centripetal forces

The conception of centrifugal force has evolved since the time of Huygens, Newton, Leibniz, and Hooke who expressed early conceptions of it. Its modern conception as a fictitious force arising in a rotating reference frame evolved in the eighteenth and nineteenth centuries

Centrifugal force has also played a role in debates in classical mechanics about detection of absolute motion. Newton suggested two arguments to answer the question of whether absolute rotation can be detected: the rotating bucket argument, and the rotating spheres argument. According to Newton, in each scenario the centrifugal force would be observed in the object's local frame (the frame where the object is stationary) only if the frame were rotating with respect to absolute space. Nearly two centuries later, Mach's principle was proposed where, instead of absolute rotation, the motion of the distant stars relative to the local inertial frame gives rise through some (hypothetical) physical law to the centrifugal force and other inertia effects. Today's view is based upon the idea of an inertial frame of reference, which privileges observers for which the laws of physics take on their simplest form, and in particular, frames that do not use centrifugal forces in their equations of motion in order to describe motions correctly.

The analogy between centrifugal force (sometimes used to create artificial gravity) and gravitational forces led to the equivalence principle of general relativity.

Fictitious centrifugal force

Centrifugal force is often confused with centripetal force. Centrifugal force is most commonly introduced as an outward force apparent in a rotating frame of reference. It is apparent (fictitious) in the sense that it is not part of an interaction but is a result of rotation – with no reaction-force counterpart. This type of force is associated with describing motion in a non-inertial reference frame, and referred to as a fictitious or inertial force (a description that must be understood as a technical usage of these words that means only that the force is not present in a stationary or inertial frame)

There are three contexts in which the concept of fictitious centrifugal force arises when describing motion using classical mechanics:

In the first context, the motion is described relative to a rotating reference frame about a fixed axis at the origin of the coordinate system. For observations made in the rotating frame, all objects appear to be under the influence of a radially outward force that is proportional to the distance from the axis of rotation and to the square of the rate of rotation (angular velocity) of the frame.

The second context is similar, and describes the motion using an accelerated local reference frame attached to a moving body, for example, the frame of passengers in a car as it rounds a corner. In this case, rotation is again involved, this time about the center of curvature of the path of the moving body. In both these contexts, the centrifugal force is zero when the rate of rotation of the reference frame is zero, independent of the motions of objects in the frame.

The third context arises in Lagrangian mechanics, and refers to a subset of generalized forces that often are not equivalent to the vector forces of Newtonian mechanics. The generalized forces are called “ generalized centrifugal forces” in this context (the word generalized is sometimes forgotten). They are related to the square of the rate of change of generalized coordinates (for example, polar coordinates, used in the

Lagrangian formulation of mechanics. This topic is explored in more detail below.

If objects are seen as moving from a rotating frame, this movement results in another fictitious force, the Coriolis force; and if the rate of rotation of the frame is changing, a third fictitious force, the Euler force is experienced. Together, these three fictitious forces are necessary for the formulation of correct equations of motion in a rotating reference frame.

Reactive centrifugal force

A reactive centrifugal force is the reaction force to a centripetal force. A mass undergoing curved motion, such as circular motion, constantly accelerates toward the axis of rotation. This centripetal acceleration is provided by a centripetal force, which is exerted on the mass by some other object. In accordance with Newton's Third Law of Motion, the mass exerts an equal and opposite force on the object. This is the reactive centrifugal force. It is directed away from the center of rotation, and is exerted by the rotating mass on the object that originates the centripetal acceleration.

This conception of centrifugal force is very different from the fictitious force. As they both are given the same name, they may be easily conflated. Whereas the ' fictitious force' acts on the body moving in a circular path, the ' reactive force' is exerted by the body moving in a circular path onto some other object. The former is useful in analyzing the motion of the body in a rotating reference frame; the latter is useful for finding forces on other objects, in an inertial frame.

This reaction force is sometimes described as a centrifugal inertial reaction, that is, a force that is centrifugally directed, which is a reactive force equal and opposite to the centripetal force that is curving the path of the mass.

The concept of the reactive centrifugal force is sometimes used in mechanics and engineering. It is sometimes referred to as just centrifugal force rather than as reactive centrifugal force.

Example

Free body diagram showing the forces on a ball and a string keeping it in circular motion. Left: inertial frame where the ball is seen to rotate. Right: co-rotating frame where the ball appears stationary. All the forces have the same magnitude, but their directions may be opposite.

The properties of the two forces in the above Table are illustrated by an example shown in the figure. The figure shows a ball in circular motion, tied to a post by a string. The post is fixed in the ground, and the string is considered too light-weight to affect the forces. The figure is an example of a free body diagram, an " exploded" engineering depiction of the different parts with the forces on each shown separately.

The forces in the inertial frame where the ball is seen to move are shown in the left column, the co-rotating frame where the ball appears not to move is shown in the right column.

The center picture of the inertial frame (left) shows the ball rotating. This circular motion departs from a straight line because the ball is subject to the centripetal radially inward force provided by the string tension. As described in the article uniform circular motion, in the case where the speed of the ball is constant, the centripetal acceleration is: with a the acceleration, v the constant speed, and r the radius of the path. The force is, of course, this acceleration multiplied by the mass of the ball.

The center picture of the co-rotating frame (right) shows the ball sitting still in a rotating frame of reference. The force on the ball due to the tension in the string is balanced by the centrifugal force introduced by the rotation of the co-rotating frame, so when the centrifugal force is included in Newton's laws of motion there is zero net force upon the ball. The appearance of a centrifugal force in this non-inertial frame is indicated in the Table, and its properties agree with those in the Table.

The lower figures show the forces upon the string, which are the same in both frames: the two ends of the string are subject to equal but oppositely directed forces. At the end of the string attached to the ball, the force is the reactive centrifugal force, the outward force exerted by the ball upon the string in reaction to the force exerted upon the ball by the tension in the string, as predicted by Newton's " action and reaction" third law of motion. As indicated in the Table, this force appears in all frames of reference, and its properties agree with those listed in the Table. This force is transmitted to the center post, where the string pulls upon the post.

At the post-end of the string, the post reacts to the pull by the string and exerts an inward directed force upon the string, labeled post reaction. The force upon the string exerted by the post balances the outward reactive centrifugal force at the other end, resulting in zeronet force upon the string.

However, the two forces pulling opposite ends of the string in opposite directions place the string under tension. Detection of the non-zero tension in the string alerts the observers in the co-rotating frame that they are in fact rotating, and the ball only appears to be stationary because they are turning with it. This observation was used by Newton in his rotating spheresdiscussion of ways to detect absolute rotation.

Use of the term in Lagrangian mechanics

See also: Lagrangian and Mechanics of planar particle motion

Lagrangian mechanics formulates mechanics in terms of generalized coordinates {qk}, which can be as simple as the usual polar coordinates [pic] or a much more extensive list of variables.[19][20] Within this formulation the motion is described in terms of generalized forces, using in place of Newton's laws the Euler–Lagrange equations. Among the generalized forces, those involving the square of the time derivatives {(dqk ⁄dt)2} are sometimes called centrifugal forces.

The Lagrangian approach to polar coordinates that treats [pic] as generalized coordinates, [pic] as generalized velocities and [pic] as generalized accelerations, is outlined in another article, and found in many sources. For the particular case of single-body motion found using the generalized coordinates [pic] in a central force, the Euler–Lagrange equations are the same equations found using Newton's second law in a co-rotating frame. For example, the radial equation is: where [pic] is the central force potential and μ is the mass of the object. The left side is a " generalized force" and the first term on the right is the " generalized centrifugal force”. However, the left side is not comparable to a Newtonian force, as it does not contain the complete acceleration, and likewise, therefore, the terms on the right-hand side are “ generalized forces” and cannot be interpreted as Newtonian forces.

The Lagrangian centrifugal force is derived
without explicit use of a rotating frame of reference, but in the case of motion in a central potential the result is the same as the fictitious centrifugal force derived in a co-rotating frame The Lagrangian use of “ centrifugal force” in other, more general cases, however, has only a limited connection to the Newtonian definition.