It All Started with Gaspard Gustave de Coriolis

Gaspard-Gustave de Coriolis (1792–1843) was a French mathematician, physicist, and engineer best known for describing the inertial forces in rotating frames of reference, now called the Coriolis effect. His work bridged theoretical mechanics and practical engineering, laying the foundation for many modern applications in meteorology, oceanography, and fluid dynamics.

Gaspard-Gustave de Coriolis

Born: May 21, 1792, in Paris, France; Died: September 19, 1843 (age 51)
Education:

- Ecole Polytechnique (1808)
- Ecole des Ponts et Chaussees (engineering training)

Career:

- Engineer and instructor at Ecole des Ponts et Chaussees
- Lecturer and later Director of Studies at Ecole Polytechnique
- Elected to the French Academie des Sciences in 1836

Scientific Legacy

- The Coriolis effect explains the deflection of moving objects in rotating systems, most famously the rotation of storms on Earth.
- His equations help describe fluid motion on rotating planets, critical in meteorology, ballistics, and engineering.
- Although his work was originally focused on rotating machinery, it now underpins large-scale systems from wind patterns to ocean currents.

Contributions to Mechanics

- Coriolis extended Newtonian mechanics to rotating frames, developed the mathematical description of fictitious forces, and helped formalize the energy concepts used in industrial mechanics. His legacy continues in physics, engineering, and Earth sciences.

Major Contributions

1. Mechanical Work (1829)

- Earlier paper: "Du calcul de l'effet des machines"
- Formalized the definition of work as force x distance
- Helped establish early energy-based analysis in mechanical systems

2. Coriolis Force (1835)

- Paper: "Sur les equations du mouvement relatif des systemes de corps"

Legacy:

- Widely known today for the Coriolis effect in physics and meteorology
- Namesake of Coriolis mass flowmeters, used in modern instrumentation
- Influential in multiple fields: fluid mechanics, geophysics, and engineering

Interesting Fact

- Although often associated with waterwheels, Coriolis' 1835 paper makes no mention of them. The connection came later through reinterpretation of his work.

Summary

- Coriolis was a foundational thinker in rotating-frame mechanics whose mathematical insights still power modern technologies, from weather forecasting to precision flow measurement.

Gustave de Coriolis’ 1835 Article: "Sur les equations du mouvement relatif des systemes de corps"

This is Coriolis’ seminal work in which he attempts to account for movement in a rotating frame of reference. This article is often referred to in discussions of the Coriolis principle. Coriolis wrote this article in French, but as far as we know, it has never been translated into English. For the purposes of research for this book, Flow Research has translated this article into English. The article is quoted from in this chapter.

In his 1835 article, Coriolis says that in order to account for the motion of an object in a rotating frame of reference, it is necessary to add two supplementary forces. He calls these supplementary forces *compound centrifugal forces*:

> “I give this general proposition, namely: that to establish any equation of relative motion of any system of bodies or of any machine, it is sufficient to add to the existing forces two species of supplementary forces; the first ones are always those which must be taken into account for the equation of the living forces, that is to say, they are forces opposed to those which are capable of maintaining the material points invariably linked to the moving planes: the second ones are directed perpendicularly to the relative velocities and to the axis of rotation of the moving planes; they are equal to the double of the product of the angular velocity of the moving planes multiplied by the quantity of relative motion projected on a plane perpendicular to this axis.
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> These latter forces have the greatest analogy with the ordinary centrifugal forces. To highlight this analogy, it is sufficient to note that the centrifugal force is equal to the momentum multiplied by the angular velocity of the tangent to the curve described, and that it is directed perpendicularly to the velocity and in the osculating plane, i.e., also perpendicularly to the axis of rotation of the tangent. Thus, in order to pass from these ordinary centrifugal forces to the second forces whose doubles enter into the preceding statement; one has only to replace the angular velocity of the tangent by that of the moving planes, and to substitute for the direction of the axis of rotation of this tangent, the direction of the axis of rotation of these same

moving planes. In other words, it is sufficient to substitute for everything that relates in magnitude and direction to the rotation of the tangent, that which relates to that of the moving planes, and to take the double of the forces thus obtained.
It is because of this analogy that I thought I should give these new forces the name of *compound centrifugal forces*: they participate in relative motion by the quantity of motion, and in the motion of moving planes by the use of their axis of rotation and their angular velocity.

We will therefore say that in order to pose an equation of relative motion, which is not that of the living forces, it is necessary to introduce, in addition to this equation, the doubles of *the compound centrifugal forces*." (see Appendix B for the full text).

Here Coriolis argues that in order to account for the motion of an object in a rotating frame of reference, it is necessary to add two additional fictional forces. These are called *compound centrifugal forces* and they are what later become known as the Coriolis force.

Historical and Modern Terms: Centrifugal and Coriolis Forces

In his 1835 article, Gaspard-Gustave de Coriolis introduced terms and concepts that would eventually form the foundation of modern rotating-frame mechanics. While he did not use the term 'Coriolis force,' he described it mathematically as part of what he called 'compound centrifugal force' (force centrifuge composée).

Key Concepts

- The 'simple' centrifugal force applies to stationary objects in a rotating frame.
- The 'compound' centrifugal force (now Coriolis force) acts only on moving objects in that frame.
- The term 'double' refers to the factor of 2 required for correctly expressing the Coriolis force.
- Coriolis was focused on rotating machinery, not Earth systems—but the math applies universally.

Modern Physics Summary

In a rotating frame with angular velocity Ω, the two key fictitious forces are:

Centrifugal: $F = m\Omega \times (\Omega \times r)$

Coriolis: $F = -2m\Omega \times v'$

These terms ensure that Newton's laws remain valid when observed from non-inertial rotating frames.

Coriolis' use of the term "living forces" may seem confusing, and understanding this requires placing the use of the term in the context of the time that Coriolis was writing.

From Force Vive to Kinetic Energy

1. Historical Evolution of 'Force Vive'

In early classical mechanics, the term 'force vive' (French for 'living force') was used to describe the quantity of motion associated with an object's velocity. Introduced by Leibniz in the 17th century, it challenged Descartes' idea that momentum (mv) was the true measure of motion. Leibniz proposed that mv^2, not mv, better represented a body's capacity to do work, especially in collisions and dynamic systems. This idea was widely used in continental Europe and became central to mechanical engineering during the 18th and early 19th centuries.

2. Coriolis and 'Force Vive'

Gaspard-Gustave de Coriolis used the term 'force vive' in his 1835 paper to describe the energy associated with bodies moving in rotating systems. His work clarified how this energy transformed in non-inertial frames. He also helped define the concept of mechanical work ('travail') and connected it to force vive.

Over time, the understanding of force vive matured into the modern concept of kinetic energy:

Kinetic Energy = $(1/2)mv^2$

3. The Work-Energy Theorem

Coriolis' work on rotating systems contributed to formalizing the relationship between work and motion. The work-energy theorem states:

The net work done on an object is equal to the change in its kinetic energy.
This theorem bridges the concepts of force (from Newton's second law) and energy (from force vive), and it underpins much of modern physics and engineering mechanics.

It is important to understand that Coriolis was talking about the motion of mechanical objects within a rotating frame of reference. While this would apply to waterwheels, nowhere in this paper does Coriolis mention waterwheels. The idea that Coriolis' article was about the motion of waterwheels came many years later in an effort to explain the intent of the article. Also, the idea that it applies to the rotation of the earth and to meteorological systems came quite a while after Coriolis' paper was published.

The first person to seriously apply Coriolis' equations to large-scale geophysical phenomena like atmospheric motion was William Ferrel, an American meteorologist, in the 1850s. The following is a historical timeline that shows the broader application of the term to meteorological applications after Coriolis' paper was published in 1835.

From Coriolis' 1835 Paper to Meteorology

This chronicle illustrates the historical development of the concept now known as the Coriolis force, from its mathematical origin in 1835 to its application in meteorology and planetary science.

- 1835 – Gaspard-Gustave de Coriolis publishes his foundational paper on motion in rotating systems, focusing on rotating machinery. He introduces what he calls 'compound centrifugal force'—later known as the Coriolis force.
- 1856 – William Ferrel becomes the first to apply Coriolis' equations to atmospheric motion, explaining why winds and air currents deflect in different hemispheres due to Earth's rotation.
- 1877 – Félix Tisserand incorporates Coriolis terms in celestial mechanics, helping formalize their role in planetary motion.
- 1901 – The term 'Coriolis effect' appears widely in meteorological literature, especially in studies of cyclones, ocean currents, and global circulation patterns.

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