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Event 1: Balancing a Broom Handle

Author: Ethan Skyler
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Purpose

The first in a series of three articles, Balancing A Broom Handle is an investigation designed to sharpen our understanding of the roles played by acceleration/Action and acceleration/Reaction forces during balancing events. Since these same forces, including the same geometry of application, are equally present during more common and somewhat more complex bicycle, motorcycle and automotive cornering events, Balancing A Broom Handle is perhaps the least complex event within which we can begin this study.

Event 1

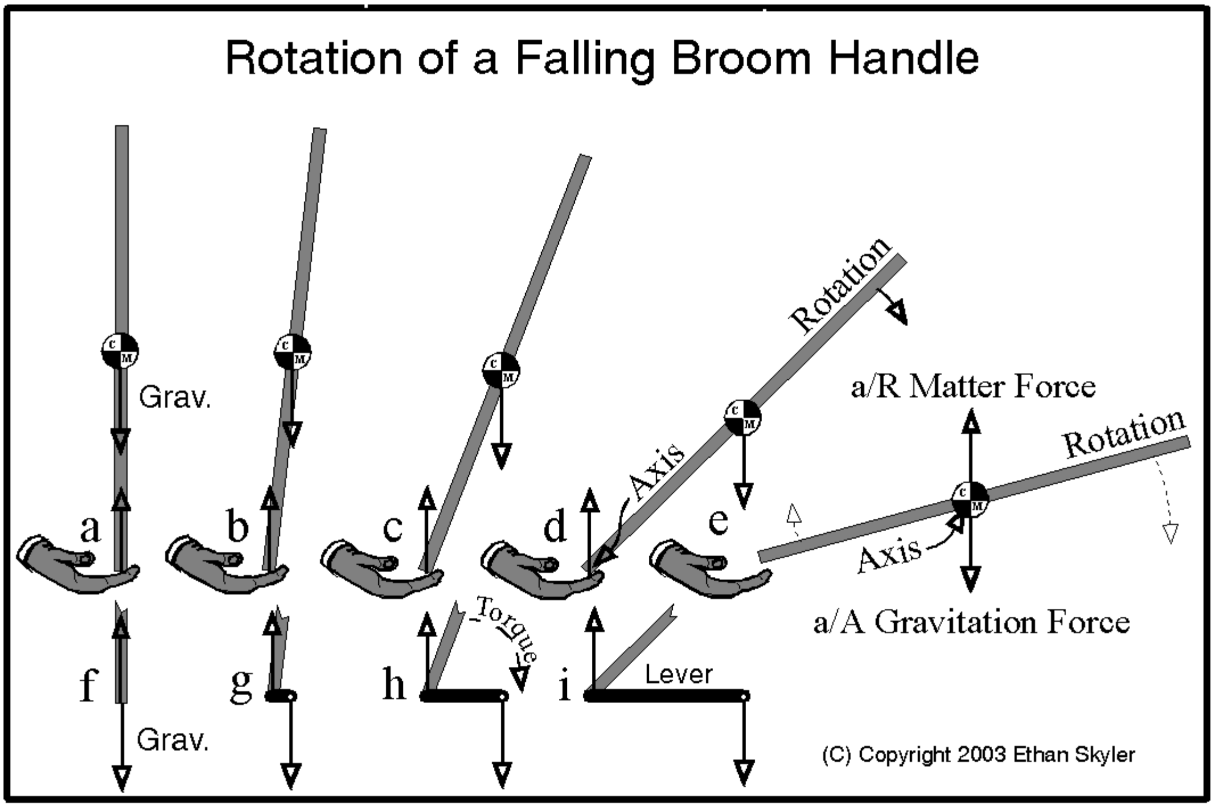
Obtaining a wooden handle of the type screwed into the wide head of a shop boom is a prerequisite to these considerations. I will wait right here for you to accomplished this task....

(2) In a level area, clear of moving or stationary obstacles, hold one hand out, palm up, at waist height. Place one end of the broom handle forward of your palm on the inside of the first joints of your first two fingers. Using your other hand, or other means if necessary, adjust the handle's shaft until it is vertical. As you release the shaft be prepared to adjust the position of your supporting hand to prevent the broom handle from falling away from vertical. While at first it may be difficult for you to shift your hand in the correct direction to the required degree to maintain the handle's vertical balance, in a few minutes of effort you will likely be able to acquire this skill. Performing this exercise inside an open room with a low ceiling will help for you can raise your supporting hand thereby trapping the top of the handle against the ceiling when things start to get out of control. Keep practicing until you are able to make and recover from minor adjustments in the position of the top of the handle.

(3) After maintaining the top of the handle in the vertical position for a few moments, I want you to pull your hand back just a bit so that the top of the handle begins to accelerate away from you in the forward direction. For the next few tries, do not attempt to prevent the handle's acceleration and rotational fall to the floor. Repeat this event several times, noting the acceleration and rotation of the handle prior to its leaving your hand. Also note the reduction in the force of the handle's weight against your open hand just prior to its departure. The handle does not drag off the edge of your hand with constant down-force but instead at the last moment lifts off your hand with little to no weight-force at all. This no-weight-force departure from your hand is an important clue to the forces and geometric rotation present in this event.

(4) For a closer look at the falling broom handle's no-weight-force departure from its support, try the same experiment as before only this time begin by balancing the handle on the arm of a chair

instead of on your open hand. During the handle's fall, after its release from vertical, you can move in for a good look at the moment of the rotating handle's lift-off from the chair's arm.



(5) Next let us look at the forces and geometrical motion present during this relaxed event where the broom handle is allowed to fall from vertical while being supported by your non-moving hand. In the drawing above, observe the five still frames "a" through "e" of the broom handle falling toward the floor. Notice in the middle of each broom handle I have inserted a C/M or center of matter icon. Note how the five downward-directed gravitational force vectors are drawn with their tails originating at the center of these five C/M icons. In every event where the action force of gravitation is involved, it is correct to draw the average of this myriad of internal forces as originating at the object's center of matter.

(6) As the event progresses from left to right, see how the downward-directed gravitation (Grav.) vectors become more and more misaligned with the upward-directed support force from your hand which, by the way, is also gravitationally based. Below each still frame, there is drawn an imaginary lever that represents this vector misalignment. The increasing length of this lever represents the increasing mechanical advantage the constant downward-directed action force of gravitation has upon generating the increasing torque force that is being applied to the broom handle as the handle's angle of lean departs from vertical at an increasing rate. This torque force is responsible for causing clockwise radial acceleration of the broom handle with the axis of this rotation located at the point where the broom handle is in contact with your hand. Once the handle is no longer in contact with your hand, as represented by still frame (e), the axis of the

handle's rotation naturally shifts to its center of matter. From this point on, the handle's downward-directed internal force of gravitation (Grav.) is almost exclusively an acceleration/Action force, on average centered at the C/M icon and responsible for both the handle's downward-directed acceleration and the reactive generation of the handle's supporting, internal acceleration/Reaction force. Here this pair of mutual forces are both internal and both equally present within the same object, the rotating and falling broom handle. Make no mistake, there exists no fabled "net force" here. Instead, within each component of the handle's matter there exists both a net internal acceleration/Action force of gravitation supported by a net internal acceleration/Reaction force in full agreement with Newton's LAW I, LAW III, the Universal Law of Mutual Forces, plus Rule 4b and Rule 7 of the Universal Rules for Force and Motion.

(7) In the Balancing A Broom Handle event we have established the following:

1) Misalignment between the downward-directed action force of gravitation (Grav.) and the opposing upward-directed action force provided by your hand causes the application of a torque force to the falling broom handle.
2) The magnitude of the torque force increases as the angle of the falling broom handle increases relative to vertical.
3) When the broom handle is supported by your hand, the axis of the torque force is located at the point of contact between your hand and the broom handle.

(8) Now that we have established that a gravitationally caused torque force is the cause of the broom handle's clockwise radial acceleration (from the perspective of the drawing) as it falls to the ground, let us figure a way to stop the handle's fall at about 5 degrees away from vertical. What do you think has to be done to halt the handle's rotational fall at this point? Grabbing the handle at its C/M with your free hand is one possible way. That will work fine since it causes a balancing counterclockwise torque to be applied to the broom handle. The vector of this balancing force will be represented by an arrow drawn from the handle's C/M icon horizontally to the left on my drawing which is straight back toward your person while being opposite to the direction of the handle's lean. The handle's fall will now come to a halt at about 5 degrees away from vertical. Increase the force applied by your free hand and the handle will begin to reduce its angle of lean. Decrease this force and the handle will begin to increase its angle of lean away from your person and away from vertical.

(9) Is there another way to halt the handle's angle of lean when it reaches 5 degrees? Say you are limited to finding a workable method using only horizontal changes in motion of the hand that is in contact with the base of the wooden handle. Consider that when the broom is balanced prior to any fall, the rate of acceleration of the handle's top is a match with the rate of acceleration of the handle's bottom. They are both equal to zero if you will allow me to ignore the minor orbital and rotational accelerations of Earth. Now consider that when balance is lost, the handle's top begins to accelerate away from you while the bottom remains relatively stationary. Here it should be no surprise that the position of the handle's top begins changing relative to the position of the handle's bottom, since the two ends are experiencing different rates of acceleration. Are you reaching the same conclusion as am I in that "freezing" the handle's angle of lean at 5 degrees when the handle's top is experiencing a certain rate of generally forward-directed acceleration is

logically possible only when the handle's bottom is experiencing the same rate and direction of acceleration?

(10) This equal-rates-of-acceleration conclusion means that first you balance the broom handle and then withdraw your supporting hand a bit to initiate the misalignment of vertical action forces that results in the gravitationally-based torque force causing radial acceleration of the handle's top away from your position. Then as the handle's top approaches 5 degrees of lean, you quickly begin accelerating the handle's bottom using the application of a forward-directed force from your supporting hand. If done correctly, the handle's angle of lean will "freeze" at a constant angle. Here the forward-directed horizontal acceleration rates of each end are a perfect match. The handle is now balanced at a constant 5 +/- degrees of lean, at least for as long a time as you are able to maintain the required rate of acceleration of the handle's lower end.

(11) But in reality, you can only maintain the required rate of linear acceleration for but a short time for there is a limit to how fast you can run. If you decide to perform this experiment while inside the enclosed cargo box of a large delivery van, it will be possible to "freeze" the falling handle at 5 degrees of lean for a longer period of time. But again there is a limit to how fast the van can travel. When the van reaches its speed limit, its declining rate of acceleration will be reduced to zero and the leaning broom handle will complete its fall to the deck. Clearly in order to keep the falling handle's angle of lean constant, a way of maintaining a constant rate of acceleration of the handle's bottom needs to be found.

(12) Before working on a solution for the constant-acceleration problem, let you and I give some thought to the forces present for the short time that you are able to keep the falling handle's angle of lean constant. From our first event we know that the downward-directed force of Earth gravitation that is being actively generated within every component of the handle's matter is causing the application of a torque force within the handle. This clockwise torque force is causing the radial and centripetal acceleration of the handle's top while the axis of the handle's rotation is located at the bottom where it is pivoting against your inactive, non-accelerating hand. What do you think is happening when you decide to cause an equal rate of acceleration for the handle's bottom which up to now has been the handle's pivot point or axis of rotation?

(13) If done correctly, the moment you begin accelerating the handle's bottom at a rate and direction equal to the acceleration occurring to the handle's top, all rotation of the handle will cease. As rotation comes to an end, one might think that the axis of this rotation can be abandoned. Yet this axis, located at the contact point between your hand and the broom handle, continues to be significant for it remains the site of the fulcrum or pivot point of the gravitational torque force as depicted on the drawing. Keep in mind that this clockwise gravitational torque force continues to be responsible for the forward-directed linear acceleration of the upper portion of the broom handle.

(14) What remains to be defined is the role of the action force of your hand. It is clear that this force is responsible for the forward-directed linear acceleration of the lower portion of the broom handle. What is not clear is how this force appears to provide balance for the clockwise

gravitational torque force. For certain this force is causing the linear acceleration of the fulcrum point for the gravitational torque force. Yet one wonders if this force from your hand is causing a counter-clockwise torque force on the broom handle and if so, where does its fulcrum point lie? I think some sort of counter-clockwise torque force has to be present to act as the balancing force for the clockwise gravitational torque force in order for the handle's angle of lean to continue to remain constant at 5 degrees during the handle's acceleration.

(15) In our first experiment where the broom handle is falling forward while being supported by your stationary hand, we are able to consider the action of the gravitational torque force when it is not being balanced by the action of an opposing torque force. Let's now consider an event where the accelerating push of your hand is directed at right angle to one end of the handle's shaft while no opposing gravitational action force is present. By isolating the accelerating push of your hand perhaps we can better understand the role of this balancing force.

(16) First let us imagine we are weightless in deep space wearing protective astronaut space suits. You position the broom handle "vertically" in front of you as you lightly grip its base between your thumb and index finger. When its position before you is generally the same as its position at the start of the event back on Earth, you withdraw your index finger releasing your grip on the handle and then using only your thumb, you quickly push the base of the "vertical" handle away from you in the forward, "horizontal" direction. I am positioned off to your right as observer to this event.

(17) What I observe is the base of the broom handle accelerating away from you as the force of your push initiates a counter-clockwise rotation for the broom handle. The axis for this sudden rotation appears to be about two-thirds of the way "up" the handle. During the push by your thumb, the handle's lower 2/3rds rotates away from your waist while the handle's upper 1/3rd rotates toward your head. Following your push in deep space, the handle naturally and automatically takes on a motion where it rotates about its center of matter at a constant rate as this new axis moves with a uniform motion away from you into space.

(18) Given the presence of the handle's counter-clockwise rotation I think we can safely conclude that during the force of your push against the handle's bottom your push produces a torque force whose lever pivots at and drops "vertically" down from the fulcrum point which is approximately 2/3rds the way "up" from the handle's bottom.

(19) In pondering this deep space event while sitting at my desk, I discovered that by placing a long pencil flat on the smooth surface of the desk and then flicking the pencil's end with my index finger, a perfect copy of the deep space event occurs. By placing my other index finger on the far side and at various points along the pencil's length, I am able to verify the 1/3rd - 2/3rds axis point during the pencil's rotational acceleration. Here at my desk gravitation is at right angle to the plane of this event so its role is a minimal one.

(20) Now I am imagining pushing or pulling horizontally and at right angle on the end of a yard stick that is being supported on a cushion of air while resting on an active air hockey table. With

the aid of an overhead movie camera, accurate verification of the 1/3rd - 2/3rd axis point during the push can be made. Then once the push or pull is over, verification of the natural shift of the 1/3rd - 2/3rd axis point to the yard-stick's 1/2 - 1/2 center of matter will also be possible. I should think overall this would make for a fine high-school science project. Especially considering that the air hockey table will need "warming up" prior to and "cooling down" following any such science experiment. (I will appreciate hearing the results of every such science project performed.)

(21) Let's return to our Earthly event where you are applying a constant acceleration force to the handle's bottom in order to maintain a constant 5 degree angle of lean. Now that we understand the role of this counter-clockwise, external (contact) torque force, with its fulcrum or pivot point 2/3rds of the way up the handle, let us consider the complete event including gravitation's role. Keep in mind that as the handle's angle of lean is changed, changes occur to each lever length of these two action forces. As their respective lever lengths change so changes the magnitude of their respective torque forces. I promise interesting combinations of torque forces will occur here that we can advance to Event 2 with its leaning and thereby cornering bicycle and motorcycle, and Event 3 with its cornering automobile, pickup and Sport Utility Vehicle.

(22) Next we will consider the range of these opposing torque forces. When you are successful in balancing the broom handle while holding your position, there is no misalignment of forces so the gravitational lever is at zero length. Here no gravitational torque force exists. Then when the handle is horizontal with one end supported by your hand, the gravitational lever is longest meaning the gravitational torque force is at its greatest value.

(23) Meanwhile, when the handle is vertically balanced, the "push" lever is longest which means that the torque force developed by any push you choose to make will be at its highest value. But when the handle is horizontal, with one end supported by your hand, the push lever is at zero length so no matter how great the force of your push, no torque force will occur.

(24) To recap their torque force capabilities, the downward-directed gravitational force will be least effective when the handle is vertical and most effective when the handle is horizontal. Conversely, your forward-directed push force will be most effective when the handle is vertical and least effective when the handle is horizontal. It should now be clear to you that only when conditions are perfect will these two torque-producing action forces provide perfect balance for each other. At all other times their imbalanced torques will cause an acceleration resulting in changes in the broom handle's angle of lean.

(25) Now let us have a look at solving the earlier problem of how to forcefully cause a constant rate of horizontal acceleration for the bottom of the handle so that a 5 degree forward-directed angle of lean can be maintained for considerably more than a few seconds of time. The key to the solution is to first recognize that the rate of acceleration for the top of the broom handle needs to match that of the bottom. Clearly no linear acceleration event will accomplish this task for long. That leaves an event where acceleration takes the form of changes in direction rather than changes in speed. Should you think changes in direction doesn't represent "real" acceleration, you are in for a real surprise. Climb aboard a playground turntable, begin balancing your broom handle and

hang on securely as I begin the turntable's rotation. As your rotation increases in frequency, you will find that for the first time you are able to maintain a steady angle of lean for the broom handle with it top leaning generally in the direction of the turntable's axis of rotation. The axis represents the horizontal direction of the centripetal acceleration/Action force. The top is also naturally leaning a bit into the "wind" to counter the entire handle's friction with air. This air friction can be eliminated if the handle is being balanced inside a tall, clear plastic box with no bottom. Then its lean will be directed precisely toward the turntable's axis of rotation.

(26) Here, as long as I keep the turntable's rotation constant, you are easily able to maintain a constant 5 degree inward-directed angle of lean. Now the reality of centripetal acceleration become clear. Viewing the leaning handle from your right side, I see the clockwise torque of downward-directed non-acceleration/Action force of Earth gravitation, with its axis located at your palm and its average located at the handle's center of matter, is a match for the counter-clockwise torque of the rotating turntable's inward-directed centripetal acceleration/Action force with its axis again located at your palm and its average located 2/3rds the way up the handle from your palm. Here gravitational torque force is a match for accelerational torque force brought to life through the action of constant centripetal acceleration caused by a constant external centripetal acceleration/Action force that in turn is causing the reactive generation of its own Newton LAW III required-to-be-present internal acceleration/Reaction force.

(27 This concludes our "Balancing A Broom Handle" event. I hope I did not lose your attention in this discussion regarding the action forces, axis of rotation, center of matter, and accelerational forces along with their directions. May I suggest you give Event 1 a quick review before moving on to Event 2 where we will use our newly found "broom handle" understandings as tools in exposing the same roles these forces and accelerations play in our upcoming "Cornering a Bicycle" event.

Ethan Skyler
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Author's Commentary

I apologize for taking so long to complete Event 1. Making a living for my wife and family is a huge distraction. It is helpful in this endeavor to receive contributions from viewers like you. I have many more articles planned. I hope I can find the time to complete this work prior to reaching my life's end. If you are enjoying this fresh new "Universal" look at some very old and entrenched problems and feel that here and only here real progress is being made, then please click Contacts below and consider supporting our efforts at UniversalPhysics.org.