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# Overturning File Cabinet

**by Ralph L. Barnett[1]**

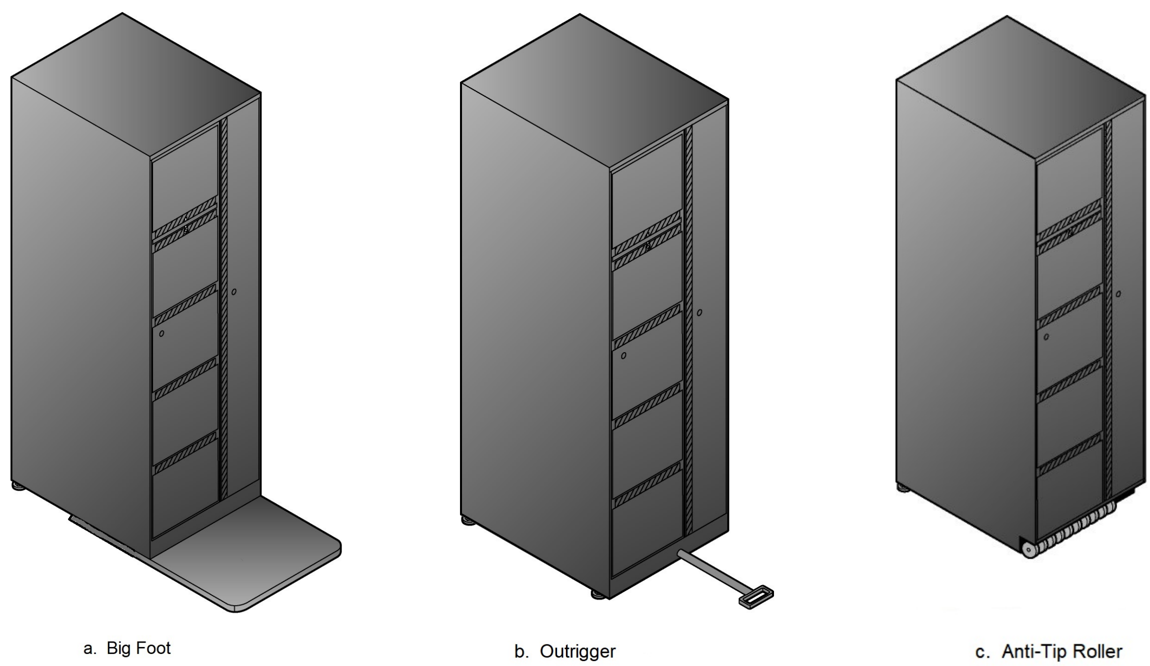


Figure 1: Proposed Anti-Tip Concepts

## Abstract

It is deceiving that an otherwise super-stable file cabinet can become critically unstable when it is unloaded or lightly loaded. This may expose office workers to the specter of a 200 lb. file cabinet striking the floor at 13 mph. File cabinet design is guided by standards that do not reflect "worst case scenarios," do not specify realistic safety loads, do not include snagging forces, and do not account for the effects of carpeting that may lower the tip resistance by 40%. This paper introduces three well known anti-tip concepts that radically improve the stability of file cabinets; elastic footprint extender, passively deployed outriggers, and rollers that trade off rotation for translation. These traditional concepts are added to the current arsenal of safety tip-over devices that include wall and floor bolting, ganging, under-mounting, counter-weighting, and single drawer deployment interlocks. The stability principles discussed are also applicable to such things as furniture, appliances, and tool cabinets.

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## INTRODUCTION

The primary purpose of a file cabinet is to store and protect paper products that can be very heavy in their aggregate (e.g. 200 pounds). These gravity loads are easily and safely accommodated within the closed configuration of the cabinets where stability is enhanced by the very weight of the lading. On the other hand, lightly loaded file cabinets without the benefit of lading are relatively easy to overturn under reasonably foreseeable circumstances, to wit,

- Concurrent extension of multiple drawers.
- Overloading of extended drawers.
- Hanging or climbing on extended drawers.
- People pulling horizontally on open or closed drawer hardware or cabinet structure.
- People ensnared on the cabinet structure while walking away from the unit.
- Impacting or pushing forward on the vertical backside of the file cabinet by human contact or with vehicles such as forklifts.
- Mounting file cabinets on non-level support surfaces.
- Impact resulting from rapidly opening drawers against stops.

The conventional methods of increasing the stability resistance of file cabinets include the following concepts:

1. Bolting the file cabinet to the floor.
2. Bolting the file cabinet to the wall.
3. Adding counterweights.
4. Gang bolting contiguous cabinets side-to-side or back-to-back.
5. Locating the file cabinet beneath a horizontal shelf-like surface that blocks its ability to tilt (under-mounting).
6. Interlock systems that permit only "one drawer at a time" operation. Concurrent drawer extension is precluded.

Bolting, ganging and under-mounting almost completely eliminate tipping; however, they immobilize the file cabinets by inhibiting their relocation within the office environment. The freestanding character of file cabinets is unaffected by counterweights and interlocks which do not eliminate tip over. They do however provide a modest improvement in overturning resistance. At present there are no practical methods for counter- weighting or interlocking the vast number of traditional file cabinets that all have multi-decade life spans.

Three concepts suggested by technology transfer are explored in this paper for increasing the stability of file cabinets. The three renderings shown in Fig. 1 describe the elastic footprint extender (Big Foot) [Ref. 1], the passively deployed outrigger, [Ref. 2], and the anti-tip roller, [Ref. 3].

Each of these devices may be used with freestanding cabinets where they easily provide a fourfold increase in the resistance to forward horizontal loads. The “Big Foot” and the outrigger also dramatically increase the resistance to gravity loads; the anti-tip roller has little effect. The cost of the various devices is equivalent to that of a counterweight system.

## STABILITY

There are many independent ways to tip a file cabinet. A constant horizontal force of sufficient magnitude will overturn them. A sufficiently large horizontal displacement of a pull handle will upset the cabinet. Bumping the unit forward with sufficient energy transfer will destabilize the file cabinet. Gravity loads of sufficient magnitude acting on extended drawers will dump the cabinets. Supporting the cabinet on a sufficiently steep ramp can cause tipping. The furniture industry through their trade association, Business and Institutional Furniture Manufacturers Association (BIFMA), has developed consensus standards that specify the minimum stability for file cabinet operations.

### A. Stability Analysis

The hazard associated with the forward tipping of a lightly loaded file cabinet may be deadly. This stability problem may be divided into three distinct physical phases that reflect the behavior of a file cabinet. Phase I considers the stationary cabinet under external force systems that may bring the bottom trailing edge of the unit to incipient lift-off. In Phase II, the external forces cause the cabinet to tip over its bottom leading edge. The file cabinet may continue to rotate forward until it reaches its balance point whereupon it may roll backwards, teeter, or continue to roll forward. If the external forces maintain their direction the file cabinet will accelerate into Phase III, forward of the balance point. Here, the gravity forces will join the external force system to increase the speed of the rotating file cabinet until it collapses.

#### 1. Phase I

Consider the side elevation of the file cabinet illustrated in Fig. 2 using heavy lines. Its center of gravity is located at coordinates ($\bar{x}$ , $\bar{y}$); its tilt axis on the bottom leading edge is labeled “0"; and its height is specified as h. A statically applied horizontal force F acts as an independent variable on the top rear edge of the cabinet giving rise to an applied tipping moment Fh. The total cabinet weight W acts at the center of gravity to provide a restoring moment W$\bar{x}$. When the applied tipping moment becomes equal to the restoring moment, the file cabinet’s bottom rear edge is at incipient lift-off,

$$F_{max} = \frac{W\bar{x}}{h} \qquad \text{Eq. 1}$$

where, $F_{max}$ represents the maximum F that can be achieved. Notice that $\bar{x}$ decreases as the cabinet tilts forward which decreases the required equilibrium force $F_{max}$. Maintaining the height of the horizontal force is not physically trivial; one might push the cabinet with a forklift set at h. If the horizontal force stays in contact with the top rear edge of the tilting cabinet, the height h must increase. Once again Eq. 1 indicates that F would decrease. So, as it turns out, $F_{max}$ is a special force for characterizing stability.

In Phase I, β = 0. Observe the following:

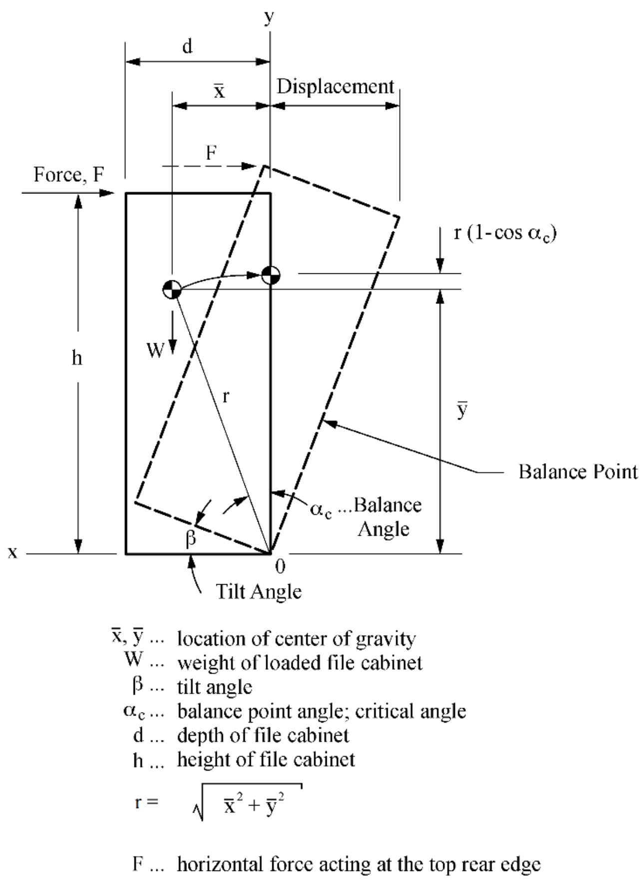



**Figure 2: Rectangular Parallelepiped**

a. $F_{max}$ may be determined using a rope and dynamometer; the test is inexpensive, rapid, and non-destructive.
b. For an unloaded file cabinet, $F_{max}$ has a unique value. A safe level can be specified by consensus.
c. $F_{max}$ is the maximum horizontal snagging force created by draping a garment over the top of a file cabinet and dragging it off.
d. To insert the blade of a hand truck underneath the rear of a file cabinet, the maximum horizontal push force $F_{max}$ is applied to the top rear edge.
e. There are an infinite number of external force systems that may act on a file cabinet to produce a moment about "0" of $hF_{max}$. Additionally, there are an unbounded number of gravity loads that can be placed in closed and extended drawers to produce a restoring moment $W\bar{x}$. This moment depends on $\bar{x}$ whose analytical determination is straightforward albeit super tedious. Whereas the restoring moment $W\bar{x}$ may be preferred by technologists for characterizing stability, laymen will infrequently comprehend this abstraction. The pull force $F_{max}$ is easily understood.

2. Phase II

The balance point of a file cabinet is achieved when its center of gravity is directly over its tilt axis "0." Here, $\bar{x}$ = 0 and the tilt angle β is equal to the critical angle $\alpha_c$ ,

$$\beta = \alpha_c = sin^{-1}\left[\bar{x}/\sqrt{\bar{x}^2+\bar{y}^2}\right] \qquad \text{Eq. 2}$$

In Phase II, $0 < \beta \leq \alpha_c$ .

The most straightforward procedure for balancing a file cabinet about "0" is to adopt the displacement of the top forward edge as an independent variable and set it at

$$\text{Displacement} = h \sin \alpha_c \qquad \text{Eq. 3}$$

Clearly, when the file cabinet is balanced, any slight resultant force to the right will cause collapse and any slight resultant force to the left will restore the unit to its upright position.

In a snag/unsnag event, the external force F can act as an independent variable to place the file cabinet into balance about "0." Rotating the cabinet raises its center of gravity resulting in an increase in its potential energy δ P.E.,

$$\delta\, P.E. = Wr\ (\ 1 - \cos\alpha_c\ ) \qquad \text{Eq. 4}$$

where $r = \sqrt{\bar{x}^2 + \bar{y}^2}$ . The work required to pull the cabinet into its critical displacement given by Eq. 3 is simply,

$$\text{Work} = \text{F (Displacement)} \qquad \text{Eq. 5}$$

To balance the file cabinet, the work expended by F must exactly equal the increase in potential energy together with the removal (unsnagging) of F at the critical displacement, i.e., F (h sin $\alpha_c$) = Work = δ P.E. = Wr (1 – cos $\alpha_c$),

$$F_s = \frac{W\left(\sqrt{\bar{x}^2+\bar{y}^2}\right)(1-\cos\alpha_c)}{h\sin\alpha_c} \qquad \text{Eq. 6}$$

where the horizontal snag force $F_s$ is applied at a height h.

In a forward overturn, the rear top edge of a file cabinet raises as much as Δ where

$$\Delta = \sqrt{d^2 + h^2} - h \qquad \text{Eq. 7}$$

3. Phase III

When the tilt angle becomes larger than the "balance angle" (β > $\alpha_c$), the file cabinet has entered its third and final phase. Here the restoring moment $W\bar{x}$ becomes clockwise about "0" and it accelerates the rotation of the unit.

Without a counteracting force system, the file cabinet will crash into the support surface in Phase III. The associated hazard may be measured by the magnitude of either the angular velocity ($\dot{\beta}$) or the kinetic energy at β = π/2. The Kinetic Energy K.E. is given by

$$K.E. = I\ (\dot{\beta})^2\ /2 \qquad \text{Eq. 8}$$

where I is the mass moment of inertia of the file cabinet about its axis of rotation "0."

Several tipping examples are presented to reveal the virulence of the hazard, the likelihood of escaping it, and the robustness of the cabinet to snagging scenarios.

Example 1: Topple From Balance Point

Assume that the file cabinet shown in Fig. 2 is a homogeneous rectangular parallelepiped that falls from a stationary position at its balance point ( $\beta = \alpha_c$ ) onto the support surface ($\beta = \pi/2$). The cabinet will be characterized by the following data:

d = 24 in $\bar{x}$ = 12 in.
h = 66 in. $\bar{y}$ = 33 in.
W = 188 lb. g = 386.4 in/sec…gravitational acceleration

The mass moment of inertia of the unit about its axis of rotation 0-0 is,

$$I_{0-0} = \frac{W}{g}\left(\frac{d^2+h^2}{3}\right) \quad \text{Eq. 9}$$

Specifically,

$$I_{0-0} = \left(\frac{188}{386.4}\right)\left(\frac{24^2+66^2}{3}\right) = 799.88\ in-lb \quad \text{Eq. 10}$$

The stationary cabinet has a potential energy at $\beta = \alpha_c$ of $W\sqrt{\left(\frac{d}{2}\right)^2 + \left(\frac{h}{2}\right)^2}$; at $\beta = \pi/2$, W(d/2).

The change in Potential Energy $\delta$ P.E. is

$$\delta\ P.E. = 188\left[\sqrt{12^2+33^2} - 12\right] = 4{,}345.45\ in-lb \quad \text{Eq. 11}$$

The Conservation of Energy Requires that the change in Potential Energy be transformed into Kinetic Energy (K.E.) of motion,

$$\begin{aligned} K.E. &= I_{0-0}\dot{\beta}^2\ /\ 2 \\ &= (799.88/2)(\dot{\beta})^2 = 399.94\ (\dot{\beta})^2 \end{aligned} \quad \text{Eq. 12}$$

Thus, K.E. = $\delta$ P.E.

$$\begin{aligned} 399.94\ (\dot{\beta})^2 &= K.E. = \delta P.E. = 4345.45 \\ \dot{\beta} &= 3.30\ rad/sec \end{aligned} \quad \text{Eq. 13}$$

The top leading edge of the cabinet attains an impact speed of,

$$\begin{aligned} v &= radius\ x\ \dot{\beta} \\ &= (66\ in)(3.30\ rad/\text{sec}) \\ &= 217.8\ in/\text{sec} = 12.38\ mph \end{aligned} \quad \text{Eq. 14}$$

The kinetic energy at impact is 4,345.45 in-lb. or 362.12 ft-lb. This is equivalent to dropping a 5 lb. hammer from a seven story building.

Example 2: Falling Time

The ability to escape a falling file cabinet depends in part on the "falling time" $t_f$. To determine the time required to tip from the upright to the prone position, one can integrate the equation of motion of a rigid body about the tipping axis "0", i.e.,

$$I\ddot{\beta} = M(\beta) \quad \text{Eq. 15}$$

where M ($\beta$) is the moment of the gravity forces and the external forces trying to rotate the file cabinet. Because M($\beta$) is generally non-linear, a closed form solution of Eq. 15 for $\beta$(t) is usually unobtainable. For purposes of this example, we have overcome this problem by assuming a cabinet subject to external forces that provide a constant overturning moment M about the axis of rotation "0-0". Now, integration of Eq. 15 is straightforward.

$\ddot{\beta}$ = (M/I) … (M/I) … constant
$\dot{\beta}$ = (M/I) t + k
$\beta$ = (M/I) $t^2$ / 2 + kt + p

where the two arbitrary constants, k and p, are determined from the boundary conditions,

t = 0, $\dot{\beta}$ = 0 => k = 0 (initially stationary)
t = 0, $\beta$ = 0 => p = 0 (initially erect)
Hence,

$$\beta(t) = (M/I)t^2\ /\ 2 \quad \text{Eq. 16}$$

When the cabinet is about to strike the support surface, $\beta$ ($t_f$) = $\pi/2$. From Eq. 16

$$t_f = \sqrt{\frac{\pi}{(M/I)}} \quad \text{Eq. 17}$$

Taking M as n multiples of the incipient lift-off moment W$\bar{x}$, (M = n W$\bar{x}$), and using the data from Example 1,

$$\begin{aligned} t_f &= \sqrt{\pi/nW\bar{x}\left[\frac{W}{g}\left(\frac{d^2+h^2}{3}\right)\right]} \\ &= \sqrt{\frac{\pi}{n(188)12}(799.88)} \end{aligned} \quad \text{Eq. 18}$$

n = 1 $t_f$ = 1.055 sec …fall time at one lift-off moment
n = 2 $t_f$ = 0.746 sec
n = 3 $t_f$ = 0.609 sec
n = 4 $t_f$ = 0.528 sec

Observe the following:

- The falling or escape times are shorter than human reaction times.
- The escape times are inversely proportional to the square root of the overturning forces.

- Solving the equation of motion, Eq. 15, provides the angular accelerations, angular velocities, and rotations of the file cabinet.
- When the lift-off moment is applied to a balanced cabinet, its angular velocity at full tip is given by,

$$\dot{\beta} = (M/I)t_f = W\bar{x}t_f \; / \; I_{0-0}$$
$$= 188(12)(1.055)/799.88 = 2.98\,rad/sec \qquad \text{Eq. 19}$$

Example 3: Body Tilt

When the center of gravity of a file cabinet is almost over the axis rotation even minor snagging can overturn the unit. Improving the stability not only helps to mitigate this tipping, it causes the snagged workers to increase their lean angles as a warning that overturning is approaching.

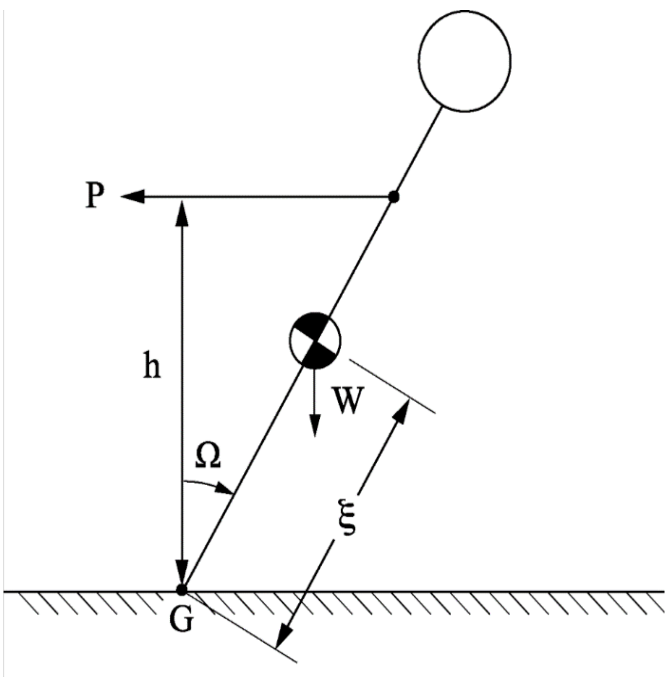



**Figure 3: Pull Force v. Lean Angle Ω**

Figure 3 represents a mathematical model of a human pulling scenario. The lean angle Ω is determined by taking the moment about the tilt axis G,

$$Ph = W(\xi \sin \Omega) \qquad \text{Eq. 20}$$

where ξ locates the center of gravity of the worker. Thus,

$$\Omega = sin^{-1}(Ph/W\xi) \qquad \text{Eq. 21}$$

Here, P represents the snagging force and W is the weight of the worker. As an example, consider a 50%-tile male whose weight is W = 161.9 lb located at his center of gravity ξ = 38.2 in. At a snag height h = 50 in, the lean angle Ω is,

$\Omega = \sin^{-1}$ (P x 50 / 161.9 x 38.6)
= 4.59° at P = 10 lb
= 9.21° at P = 20 lb
= 13.89° at P = 30 lb
= 18.66° at P = 40 lb
= 23.58° at P = 50 lb

Observe that the larger lean angles act as a precursor to overturning.

B. Test Equipment

All of the stability tests were conducted using a single Universal Vertical drawer Tower (Basic 4799) manufactured by Steelcase. The unit has four drawers, one lift-up drawer, and one wardrobe; its empty weight is 188 lb. Figure 4 provides the basic dimensions of the file cabinet.

Throughout this paper, all test drawer loading was taken from ANSI/BIFMA X5.9-2004 [Ref. 4]; 0.017 lb/in$^3$ in the clear space. This clear volume was measured as 20.125 x 9.5 x 13.5. The corresponding drawer loading is 43.88 lb.

The tip-over forces were created by manual pull with a calibrated digital dynamometer,

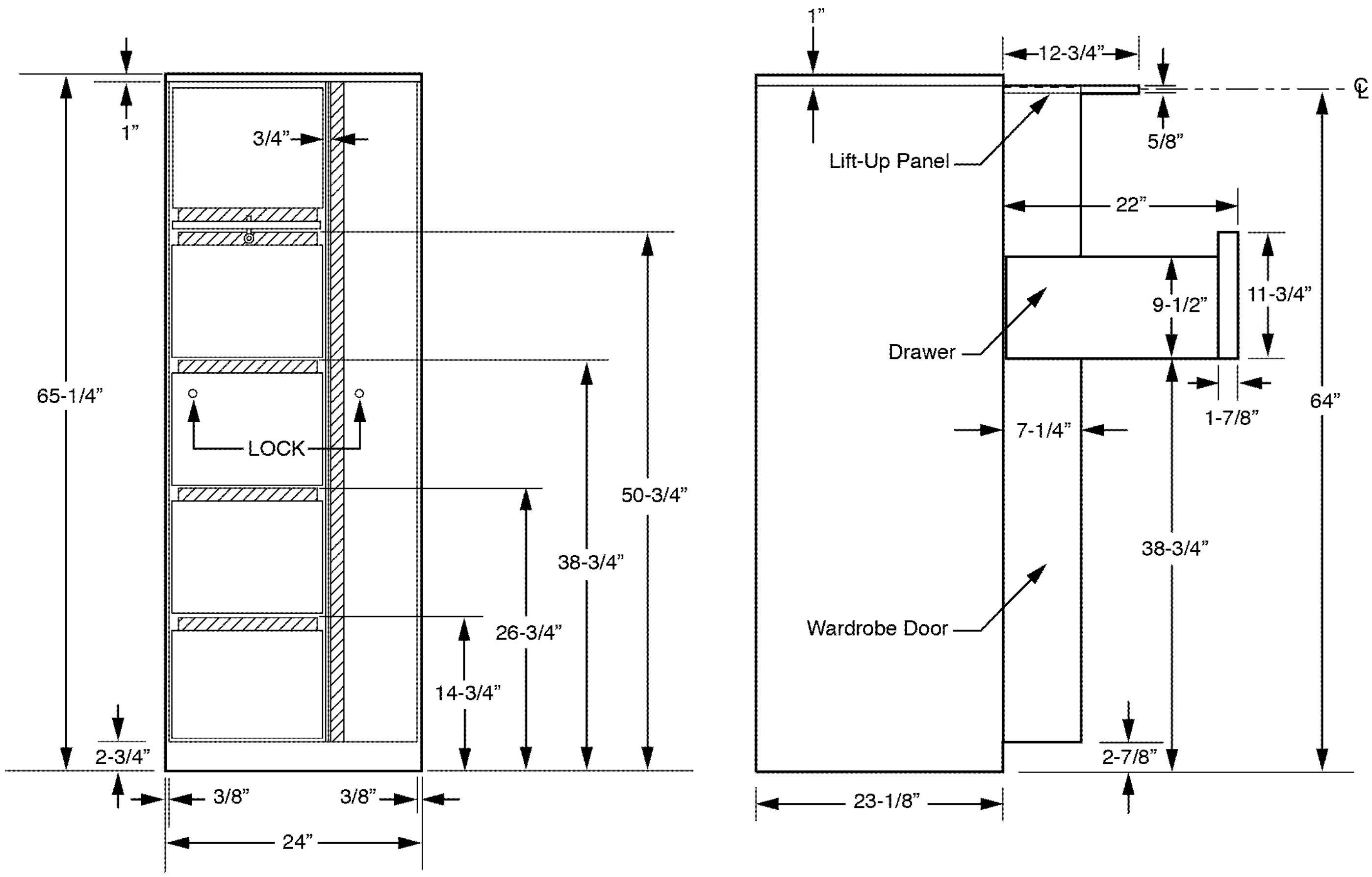
Mfg: Mark 10
Model: MG100; Serial: 57878
Range: 100 lb/0.1 lb Digital
Calibration Date: 03/19/2014

The stability tests were performed on various surfaces,

- Concrete
- Vinyl Tile
- In-Door/Out-Door Carpeting – Thickness: ¼ in., Mounted on Wood Platform
- Brown Pile Carpet – Thickness: 1-5/8 in., Mounted on Small Wood Platform

C. ANSI/BIFMA X5.9-2004

Office furniture, which includes storage units such as file cabinets, is designed to reflect the safety, durability, and structural performance levels established by BIFMA. With respect to the subject file cabinet, the ANSI/BIFMA stability standard X5.9-2004 has been summarized in Exhibit 1. The text of Section 9.3, Stability Test for Type 1 Units with At Least One Extendible Element, requires that the test setup locate the storage unit on a test platform.




a) Front View b) Lift-Up Panel and Wardrobe Drawer Open

**Figure 4: Universal Vertical Drawer Tower (Basic 4799); Mfg. Steelcase**

The test set up shown in Exhibit 1 differs radically from a “worst case scenario.” The propensity to tip is maximized by unloading the lower drawer and by relocating the 44N (10 lb.) force to the top of the cabinet. For example, when retrieving a coat stored on top of the file cabinet, a snag creates a force along the top. BIFMA has not addressed the snagging problem in their 2004 standard.

The most influential parameter on the stability of lightly filled file cabinets is the 44N (10 lbf) force shown in Exhibit 1. Departure from this minimal force level will profoundly affect the design of these storage units. The 10 lbf magnitude does not appear to have a scientific basis. Female children, ages 2 – 5, have a one-handed pull strength on a horizontal cylindrical bar in the range [Ref. 5], 78.09N (17.56 lbf) to 237.99N (53.50 lbf).

Large horizontal forces may be applied to drawers that are stuck, locked, interlocked, or fully extended. Indeed, such forces may act on other cabinet elements.

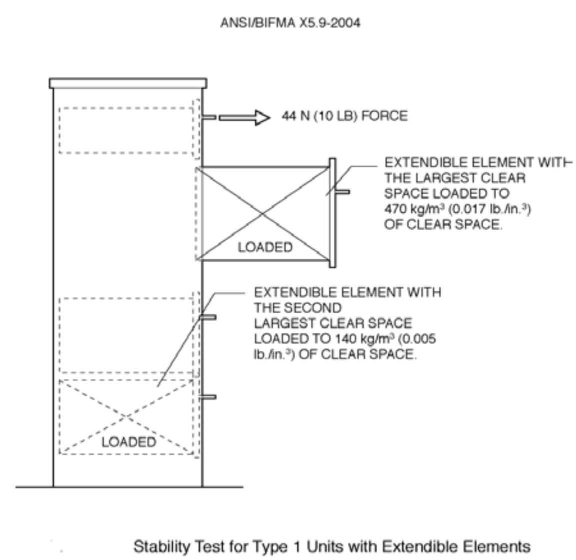
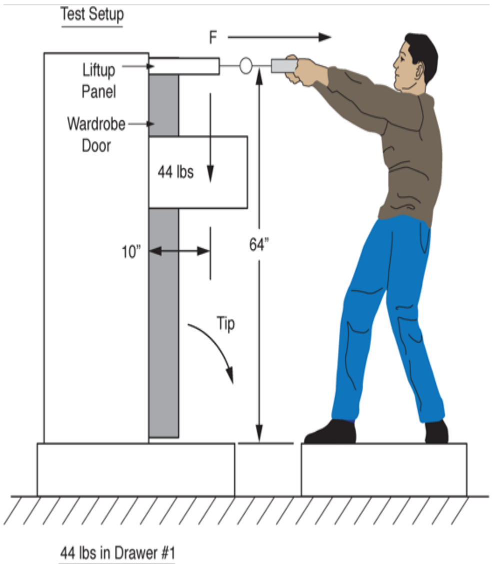
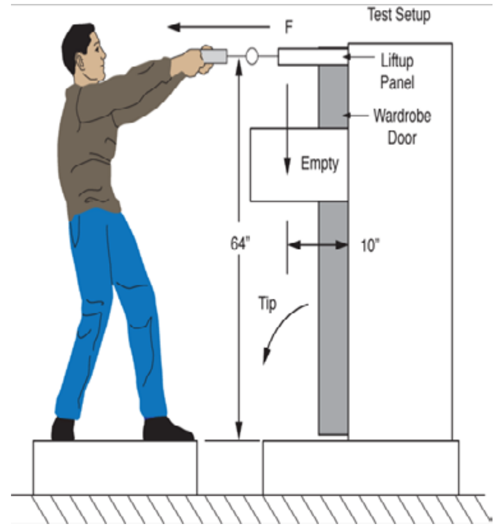



**Exhibit 1 - BIFMA Stability Criterion for the Steelcase Vertical Driver Tower**




a) Worst Case Scenario

| Total | Brown Pile Carpet on Platform | Indoor/Outdoor Carpet on Concrete | Tile Floor on Concrete | Concrete |
|---|---|---|---|---|
| 1 | 10.4 lb. | 12.4 lb. | 17.1 lb. | 15.3 lb. |
| 2 | 9.6 lb. | 12.1 lb. | 16.7 lb. | 16.3 lb. |
| 3 | 9.2 lb. | 11.8 lb. | 16.7 lb. | 16.0 lb. |
| 4 | 10.3 lb. | 12.4 lb. | 16.1 lb. | 16.2 lb. |
| 5 | 10.7 lb. | 11.6 lb. | 16.0 lb. | 15.5 lb. |
| 6 | 8.7 lb. | 11.5 lb. | 16.6 lb. | 16.2 lb. |
| 7 | 10.2 lb. | 11.1 lb. | 15.7 lb. | 16.3 lb. |
| 8 | 10.6 lb. | 11.3 lb. | 15.1 lb. | 15.6 lb. |
| 9 | 9.8 lb. | 12.4 lb. | 16.1 lb. | 16.4 lb. |
| 10 | 9.3 lb. | 12.2 lb. | 15.9 lb. | 15.8 lb. |
| Average | 9.88 | 11.88 | 16.20 | 15.96 |
| Standard Deviation | 0.668 | 0.487 | 0.585 | 0.386 |
| Coefficient Variation | 6.76% | 4.10% | 3.60% | 2.42% |




b) Loading Empty Cabinet – Onset

| Total | Brown Pile Carpet on Platform | Indoor/Outdoor Carpet on Concrete | Tile Floor on Concrete | Concrete |
|---|---|---|---|---|
| 1 | 17.4 lb. | 23.1 lb. | 25.3 lb. | 25.0 lb. |
| 2 | 17.0 lb. | 21.7 lb. | 23.3 lb. | 24.6 lb. |
| 3 | 17.1 lb. | 21.4 lb. | 23.4 lb. | 25.6 lb. |
| 4 | 17.2 lb. | 21.9 lb. | 24.8 lb. | 24.4 lb. |
| 5 | 17.1 lb. | 22.3 lb. | 24.7 lb. | 25.5 lb. |
| 6 | 17.0 lb. | 21.7 lb. | 24.9 lb. | 24.0 lb. |
| 7 | 17.6 lb. | 21.3 lb. | 24.9 lb. | 24.8 lb. |
| 8 | 17.9 lb. | 22.9 lb. | 24.1 lb. | 24.8 lb. |
| 9 | 17.4 lb. | 22.2 lb. | 24.8 lb. | 24.5 lb. |
| 10 | 17.8 lb. | 21.7 lb. | 25.2 lb. | 24.4 lb. |
| Average | 17.35 | 22.02 | 24.54 | 24.76 |
| Standard Deviation | 3.275 | 0.6033 | 0.7042 | 0.4993 |
| Coefficient Variation | 1.89% | 2.74% | 2.87% | 2.02% |

## D. Baseline Stability

The baseline stability of the vertical tower storage unit chosen for our study is established in this section for various support surfaces. As it turns out, the support surfaces exert a significant influence on stability that is not recognized in the ANSI/BIFMA standard. The baseline provides an important element for judging the efficacy of the various candidate retrofit designs for improving stability.

Two configurations of the vertical tower are addressed in this paper; the "worst case scenario" and the onset of loading an empty cabinet. The "worst case scenario" is characterized by,

- One fully extended drawer with a standard load (44 lb.) acting at the centroid. Note that the drawer interlock only allows a single extended drawer.
- Open wardrobe door.
- A horizontal load F is applied almost at the top of the cabinet (center of extended lift-up panel).
- No loads in closed drawers, compartments, or wardrobe.
- Tower is supported on a test platform covered with a brown pile carpet.

The measured balance angle $\alpha_c = 9°$.

Under the above stated conditions, the horizontal load P was gradually increased until it reached its maximum. This corresponded to incipient lift-off of the bottom rear edge. The test results are tabulated in Table 1a where the unit tipped under loads as small as 8.7 lb. when supported on the pile carpet. Overturning of a 232 lb. cabinet that is almost 5-1/2 feet tall represents a life-threatening hazard. The indoor/outdoor carpet tests were conducted on a concrete slab. The "elastic foundation effect" is not as prevalent on such a stiff surface which provided a 20% increase in stability compared with the pile carpet covered platform. The concrete slab and the vinyl tile over concrete surfaces provide the identical stability which is 63% greater than the pile carpet.

The test program was repeated without placing a load in the extended drawer. The corresponding test loads are tabulated in Table 1b. Without the destabilizing effect of the 44 lb. lading, the tip resistance is increased in every category. Once again, stiffer support surfaces favor stability. The higher stability resistance for the empty drawer is almost twice that for the loaded drawer. What starts out as a reasonably safe enterprise when one begins to load a file cabinet, quickly degenerates into a critical stability situation as the drawer becomes full. It must be emphasized that only lightly loaded file cabinets have stability issues. On the other hand, lightly loaded cabinets are reasonably foreseeable. Storage unit manufacturers admonish users to empty the cabinets before relocating them. Functional office demands may temporarily deplete the contents of the unit. The original sale and each resale of the cabinets give rise to the restocking of an empty unit.

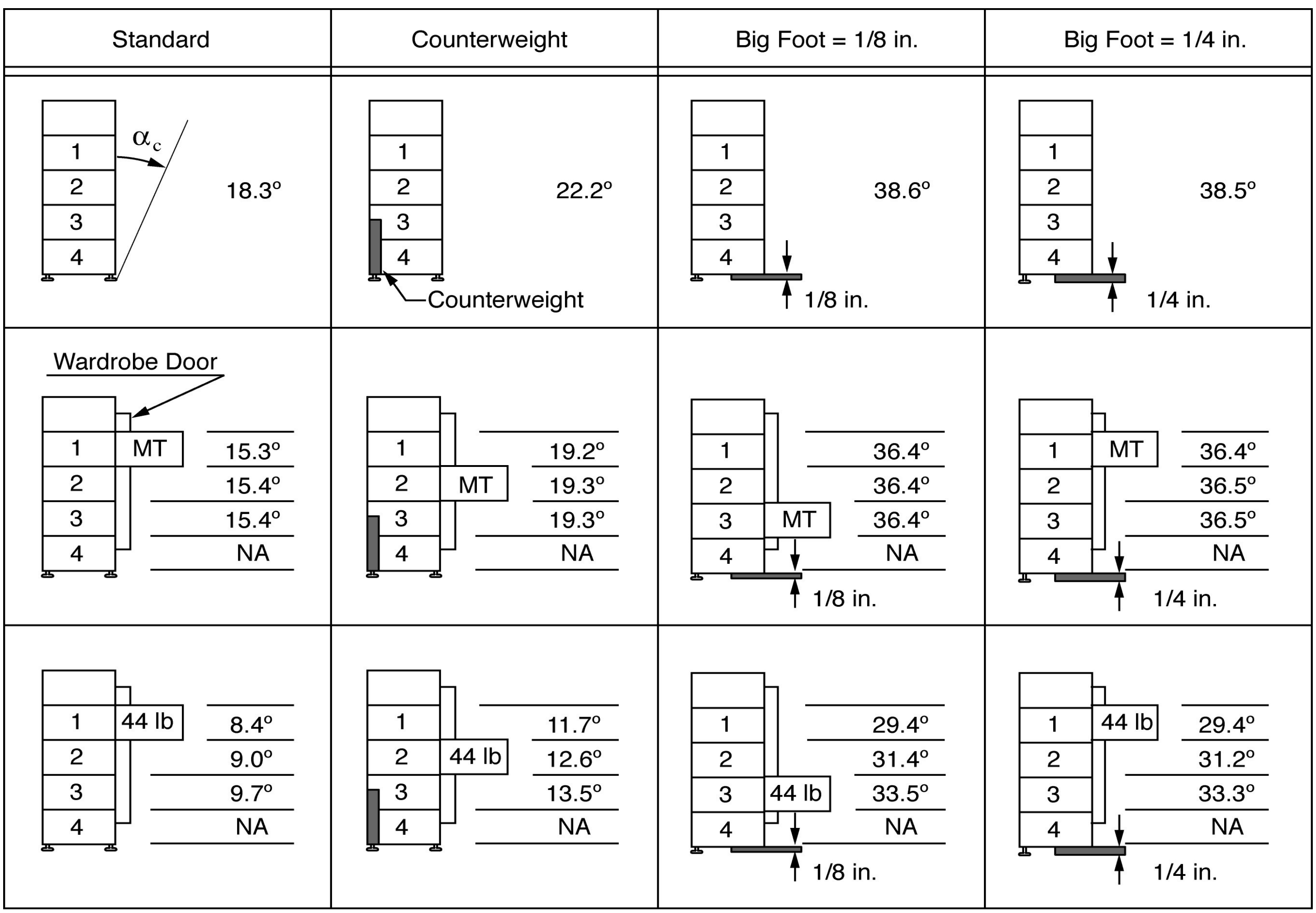
E. Counterweights

As previously mentioned, the counterweight is one of the conventional anti-tip concepts that is compatible with freestanding storage units. For the subject vertical tower, the counterweights weigh 21.5 lb. and are mounted on the inside of the rear panel. Adopting the same test protocol used to establish the baseline, the counterweighted file cabinet was tested on a vinyl tile floor mounted on a concrete slab with its wardrobe door open. The following results in Table 2 were obtained for the upsetting force P:

**Table 2: Counterweight Stability Tests**

| | | |
|---|---|---|
| **Empty Extended Drawer** | | |
| Mean P: | 31.62 lb | |
| Standard Deviation: | 0.839 lb | (10 tests) |
| Coefficient Variation: | 2.65% | |
| Range: | 30.03 to 32.9 lb | |
| **Loaded Extended Drawer (44 lb)** | | |
| Mean P: | 23.5 lb | |
| Standard Deviation: | 0.540 lb | (10 tests) |
| Coefficient Variation: | 2.3% | |
| Range: | 22.4 to 24.3 lb | |

Comparing the mean overturning resistance for the tile floor in Table 1b and Table 2 indicates that for the loaded and counterweighted unit P = 23.5 lb. and for the unloaded standard unit P = 24.54 lb. It is clear that the counterweight just about counterbalances a 44 lb. drawer load.




MT... empty; NA... not applicable; unless indicated all drawers are empty.

**Table 3 Forward Balance Angle; $\alpha_c$**

F. Balance Point Angle (Critical Angle $\alpha_c$)

If a file cabinet is tipped forward it will eventually overturn, i.e. if the critical tilt or balance angle $\alpha_c$ is exceeded. A large balance angle provides a timely feedback to an office worker who can either escape injury or reverse the impetus causing the tilt.

An array of balance angles $\alpha_c$ are presented in Table 3 for the standard file cabinet with or without counterweights and for the "Big Foot" with both 1/8 inch thickness and ¼ inch thickness. The angles were reported for a concrete support surface. Because the contact of the balance point is an edge, the various surfaces provide identical $\alpha_c$'s. The following observations are noteworthy:

1. As the top drawer of an empty standard cabinet is loaded, the critical angle becomes dangerously small, $\alpha_c$ = 8.4°. Such cabinets are not robust; they are displacement sensitive.
2. Closed drawers provide greater balance angles.
3. Any extended drawer in an empty file cabinet leads to the same critical angle.
4. The bottom drawer contacts the surface before the balance angle is achieved.
5. Compared to the standard cabinet the "Big Foot" retrofit provides a 20° increase in $\alpha_c$ which ranges between 29.4° and 38.6°.
6. The smallest critical angles are found in top-heavy units; but, not by much.

With respect to the anti-tip roller concept, balance angles are not delineated in Table 3. Without artificially constraining the rollers in the way a hand truck is used, the cabinet will not tilt. Excessive tilt forces manifest themselves as translations. Table 3 also omits balance angles for the single outrigger concept which does not rotate forward around the bottom front edge. The unit tilts about a skewed axis aligned with a front lower corner of the cabinet and the outboard end of the deployed outrigger. This causes the unit to tilt forward and to the side which provides sufficient feedback to an office worker that mischief is afoot.

G. Stability Under Vertical Loads

Office workers have no realistic way of estimating how much weight they have inserted into a file cabinet drawer. Further, there is no stated load limit on a drawer. Consequently, the occasional drawer loading destabilizes the cabinet. One of the approaches used by the furniture industry to mitigate the danger associated with this hazard is to warn and instruct users to load an empty cabinet from the bottom up and unload a full cabinet from the top down. To examine the basis for this recommendation we first observe that identical loading placed in any drawer produces the same overturning moment about the tip axis "O." Thus, the bottom drawer has equal propensity for tipping the cabinet. What then is so special about loading the bottom drawer first? Not much, unless displacement is the independent variable. One answer to this question is contained in the ANSI/BIFMA X5.9-2004 standard in paragraph 9.4.4 which defines the acceptance criteria for Type 1 units with at least one extendible element,

> *9.4.4 Acceptance Level*
> *The storage unit shall not tip over and the interlock system, if present, shall have no loss of serviceability. If open extendible elements prevent the unit from tipping over due to contact with the test platform, the unit does not meet the acceptance criteria.*
> *Note: The use of devices such as casters on a bottom extendible element is an acceptable method of preventing tipping.*

Accordingly, the bottom drawer will catch an overturning file cabinet and limit its tilt angle.

Consider the following typical file cabinet warning label:

> *To avoid tipping your file, always load the bottom drawer first, and when full, fill in the next drawer above.*

The warning is incorrect; however, it does have limited value in snagging and other displacement sensitive scenarios. It has been established by J. Paul Frantz, et al [Ref. 5] that very few users read or comply with this warning even when they noticed it. Furthermore, the sequence for loading an empty file cabinet is dictated by functional considerations not stability, e.g., alphabetizing usually proceeds with A in the top drawer and Z in the bottom drawer.

Multiple drawer extensions is the leading cause of overturning of file cabinets, machinist tool cabinets, chest of drawers and the like. The introduction of the "one drawer at a time" interlock system has all be eliminated tip-over caused by gravity loading of file cabinets.

Three devices for improving the stability of free-standing storage units are explored in the following sections. The associated safety concepts find wide applicability to other objects that threaten our safety with overturning such as bookcases, wardrobes, grandfather clocks, and display furniture.

## BIG FOOT – ELASTIC FOOTPRINT EXTENDER

A. Description

The footprint of a file cabinet may be enlarged by fastening a thin elastic plate to the bottom of the cabinet which extends or protrudes forward as shown in Fig. 1a. The axis of rotation of the file cabinet, which is normally the bottom front edge, is now shifted forward in front of the file cabinet. This increases the restoring moment and improves the forward stability limit.

A second significant safety property is associated with the elastic footprint extender. The elastic behavior of the plate provides a precursor of impending instability. Normally, when a file cabinet begins to tip, its maximum resistance is achieved at incipient lift-off of the lower back edge. After lift-off, the restoring moment continually decreases as the tip angle increases. Sometimes the overturning moment increases. One experiences a rapid loss of stability after lift-off. When the elastic footprint extender is retrofitted to the cabinet, tip-over does not commence with lift-off. The elastic (deflection) behavior of the cantilevered footplate gives rise to considerable rotation before the balance point is reached as shown in Figure 5. The precursor to tip-over enables an actor to take precautionary measures, e.g., stop pushing, start catching the file cabinet, unsnag garments, or move away.

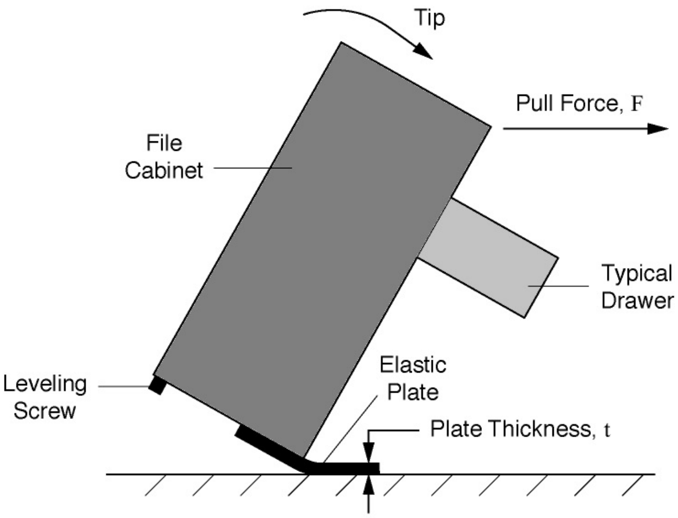
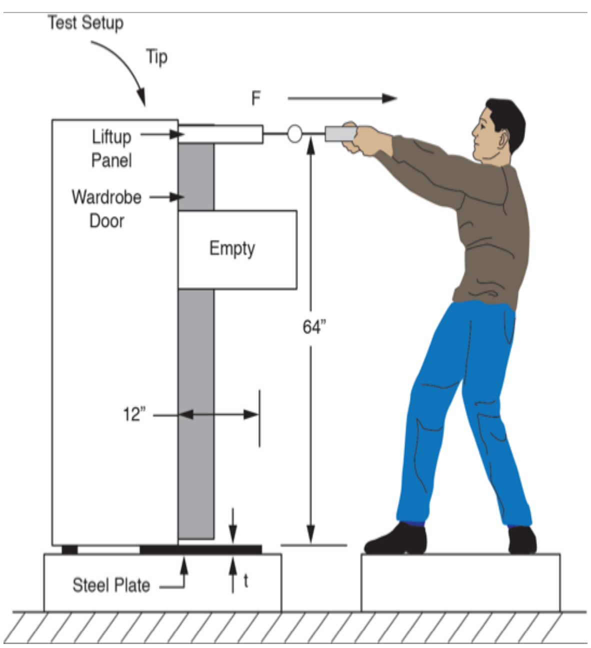



**Figure 5: Elastic Behavior of the Extended Plate**

**Table 4: Stability of "Big Foot" Retrofitted Cabinet Without Loading**



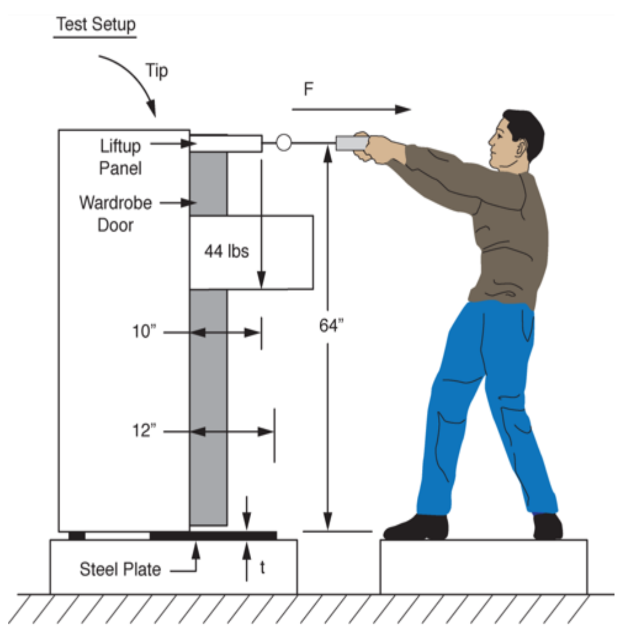

| | Original File Cabinet | Big Foot: t = 1/8 in. Retrofit | Big Foot: t = ¼ in. Retrofit |
|---|---|---|---|
| Mean F | 18.72 lb | 43.92 lb | 53.74 lb |
| St'd Deviation | 0.432 lb | 0.764 lb | 1.53 lb |
| Coef. Variation | 2.30% | 1.74% | 2.86% |
| Range | 18.0 – 19.5 lb | 42.7 – 45.2 lb | 51.7 – 57.5 lb |
| Balance Angle | 15.5° | 36.33° | 36.65° |
| Trials, n | 10 | 10 | 10 |

B. Testing

To compare the stability of the "Big Foot" to that of the original file cabinet, a test program was undertaken using a large platform covered with a white shag carpeting. Using an empty extended top drawer and the test set up depicted in Table 4, the maximum horizontal forces F were recorded in ten trials for the original cabinet and for the 1/8 in. And ¼ in. "Big Foot" retrofits. Observe that the tip force of the 1/8 in. "Big Foot" is over double that of the original cabinet and the ¼ in. "Big Foot" is almost triple the stability. Also, the critical angle (balance angle) of the retrofits is about 2 ½ times that of the original storage unit.

The testing program was repeated using the test set up illustrated in Table 5 with 44 lb. in the drawer. Here, we observe that a force F equal to 9 lb. destabilized the original storage unit and that the mean resistance was only 9.39 lb. The stability of the 1/8 in. "Big Foot" is almost four times that of the original file cabinet; the ¼ in. "Big Foot" retrofit is over five times greater. The critical angle was not recorded for the loaded drawer tests because the height of the 44 lb. load C.G. was not properly represented for a tilting cabinet.

**Table 5: Stability of "Big Foot" Retrofitted Cabinet with Drawer Loading**




| | Original File Cabinet | Big Foot: t = 1/8 in. Retrofit | Big Foot: t = ¼ in. Retrofit |
|---|---|---|---|
| Mean F | 9.39 lb | 35.21 lb | 48.64 lb |
| St'd Deviation | 0.281 lb | 0.461 lb | 1.85 lb |
| Coef. Variation | 2.99% | 1.31% | 3.80% |
| Range | 9.0 – 9.7 lb | 34.5 – 36.1 lb | 44.8 – 51.3 lb |
| Trials, n | 10 | 10 | 10 |

Because the "Big Foot" concept involves a plate extending 12 inches in front of the cabinet, safety considerations must account for this potential trip hazard. This topic is addressed by the following safety organizations under the caption, "Change in Level:"

- ASTM, American Society for Testing and Materials [Ref. 6]
- NFPA, National Fire Protection Association [Ref. 7]
- ANSI, American National Standards Institute [Ref. 8]
- ICC, International Code Council [Ref. 9]
- ADA, Department of Justice [Ref. 10]

Their regulations are all identical; to wit,

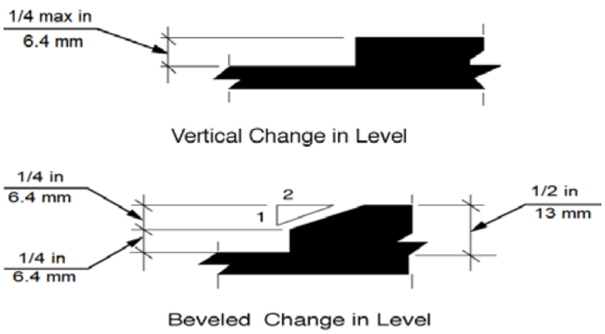



**Exhibit 2: Change in Level**

The two "Big Foot" plates used for our retrofits are 1/8 and ¼ inches thick; both satisfy the standards. Furthermore, the exposed edges can be tapered for additional safety. When the plates are located over carpeting, they sink into the nap. Also, they may be placed below the carpet.

Our final observation deals with the strength of the "Big Foot" plate. Continual tipping of the cabinet will eventually cause the entire storage unit to support itself on the leading edge of "Big Foot;" this edge must equilibrate the weight of the entire cabinet and its contents. To design the plate it is conservative to treat it as a horizontal cantilever under a vertical tip load equal to the weight of the cabinet with all of the drawers fully loaded (approx.. 400 lb.).

## OUTRIGGER

A. Description

One of the classic control devices is the outrigger found in most cranes, aerial lifts, many boats, and cannon trails. When deployed, outriggers enlarge the footprint of a contrivance which improves its overturning resistance.

To prevent a freestanding file cabinet from tipping forward, a retractable outrigger can be deployed that extends outward from its base as shown in Fig. 1b. The essential components of an outrigger system consist of the following:

1. The outrigger's cantilever structure may reflect any cross-sectional shape such as circular, rectangular, I-beam, or U-shaped. It may be prismatic or tapered.
2. The outrigger may be extended as a telescope, on a roller-tracks, or by a scissor mechanism.
3. The force required to extend the outrigger structure may be developed by extension springs, compression springs, gas springs, or electromagnetically.
4. Lifting the rear base of the file cabinet off of the support surface shall trigger or signal the outrigger to deploy.
5. The outrigger structure may incorporate some device that will positively prevent its retraction after deployment. This device may be a lock, a dog, or a detent; it must be manually released to retract the outrigger. Our testing has shown that friction alone will prevent retraction; only an extension limiting stop is required.
6. One or more outriggers may be used.

To demonstrate the feasibility of the outrigger concept and establish its efficacy, the subject vertical tower was retrofitted with a compression spring deployed plunger that became an outrigger. This pipe-like plunger telescoped out of a support tube affixed to the cabinet frame. The plunger was held within the confines of the cabinet until a forward tipping motion raised the rear end of the storage unit. A circular groove in the plunger was engaged by a spring-loaded detent pin that was <u>spring removed/held closed</u>.

Figure 6 is a schematic of the outrigger retrofitted to the subject file cabinet. Several observations may be relevant,

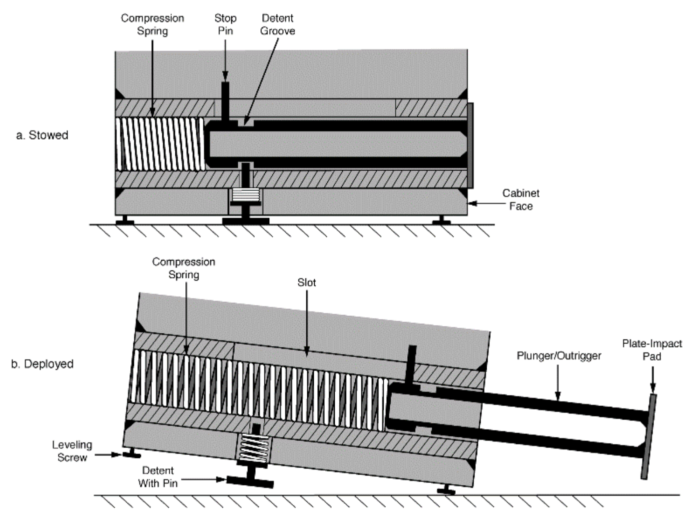



**Figure 6: Telescoping Outrigger**

- The simple telescoping mechanism that was adopted literally has dozens of counterparts.
- The outrigger reliably deployed on hard surfaces and indoor/outdoor carpet.
- Friction prevented the functional retraction of the outrigger even at the balance angle. Simple devices can be used to lock the deployed plunger in place if required.

- The deployed outrigger is reset by tilting the cabinet rearward while manually retracting plunger and allowing the unit to settle back normally.
- The plunger was allowed to repeatedly impact the foot of a technician wearing tennis shoes without distress. The leading edge of the outrigger can, of course, be padded.
- At large tilt angles the unit tips forward and to the side; the tipping axis becomes the line between a front leveling screw and the end of the deployed outrigger.

B. Testing

Using the test setup shown in Table 6, the retrofitted tower cabinet was subjected to a tilt load F with the extended outrigger on a vinyl tile over concrete surface and on an indoor/outdoor carpet. The open top drawer was tested when empty and filled with a 44 lb. weight. The overturning resistance F is tabulated in Table 6 for a 14 in. extended outrigger; all values are in the neighborhood of 50 lb. It is very difficult to apply such a force at 64 in. from the floor. Note that the carpeted floor gives rise to a slightly lower stability than the tile floor.

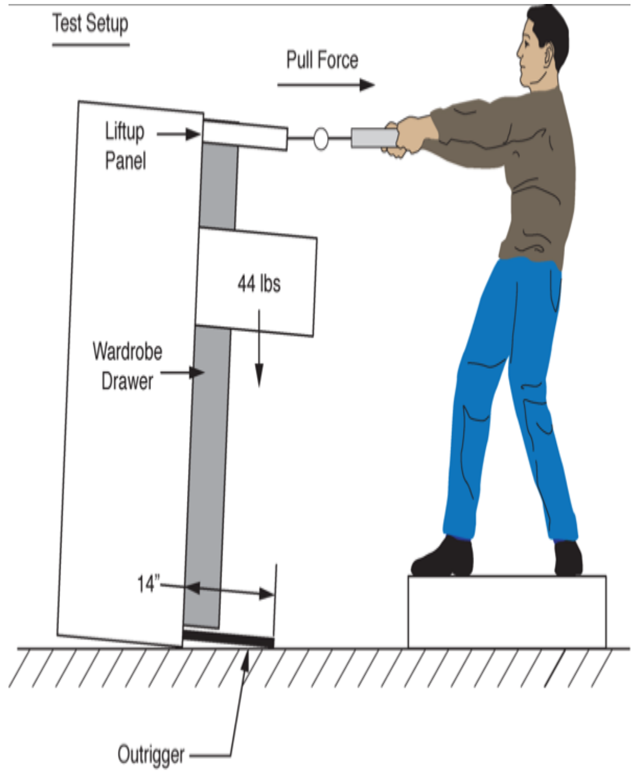



**Table 6: Stability of 14" Outrigger Retrofitted File Cabinet**

| | Empty Top Drawer | | 44 lb – Top Drawer Loaded | |
|---|---|---|---|---|
| | Tile Over Concrete | Indoor/Outdoor Carpet | Tile Over Concrete | Indoor/Outdoor Carpet |
| Mean F | 56.30 lb. | 54.64 lb. | 47.58 lb. | 46.80 lb. |
| St'd Deviation | 1.24 lb. | 2.98 lb. | 1.57 lb. | 0.935 lb. |
| Coef. Variation | 2.21% | 5.46% | 3.29% | 2.00% |
| Range | 54.5 – 57.7 lb. | 51.8 – 59.7 lb. | 44.9 – 49.0 lb. | 45.8 – 48.3 lb. |
| Trials, n | 5 | 5 | 5 | 5 |

C. Lowest Drawer Outrigger

Figure 7 illustrates the use of the bottom drawer as an outrigger. The bottom drawer may be automatically opened during a forward pitch of the file cabinet. The drawer structure is extended on a roller-track system. The fully deployed drawer must support the weight of the file cabinet plus its lading. It must also carry any specified downward design forces. Note that the interlock placed on modern file cabinets to prevent concurrent drawer deployment must be overridden when the rear base is elevated; interlocking the bottom drawer may be unnecessary.

The notion of using the lowest drawer as an outrigger is contained in the previously cited paragraph 9.4.4 of the ANSI/BIFMA X5.9-2004.

**ANTI-TIP ROLLER**

A. Description

When solid objects are freestanding on a plane surface, forces can translate, rotate, or leave the objects unaffected. These events are mutually exclusive and jointly exhaustive, i.e., one and only one will occur. To eliminate the dangerous tip-over

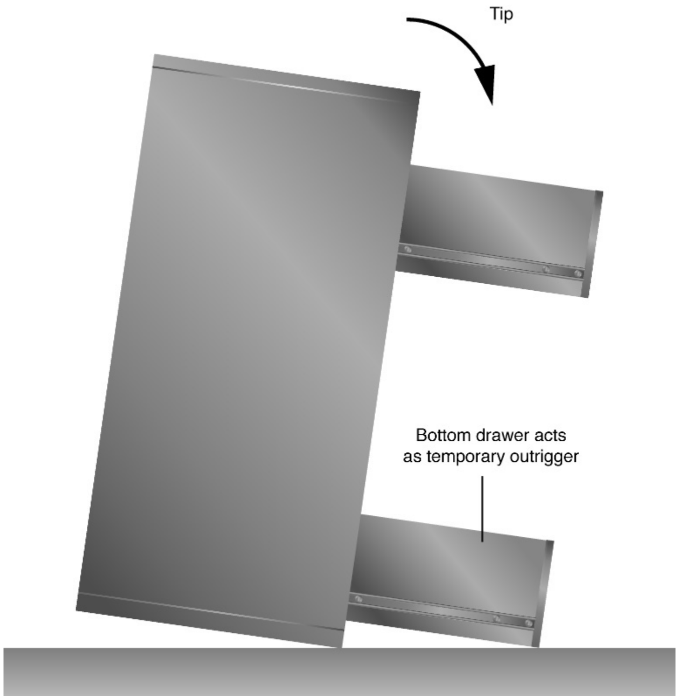



**Figure 7: Lower Drawer Deployed as Outrigger**

of a file cabinet one can impose a translation by inserting a "low drag" roller at the front lower edge of the cabinet shown in Fig. 1c. When a forward acting load causes the lower rear edge of the cabinet to lift-off or drag along the surface, the entire file cabinet will translate forward without tipping. The front lower edge will ride along the surface on the roller.

The file cabinet, when pulled, impacted, or pushed forward may rock fore and aft while moving frontwards. It will never tip-over when snagged, pulled or pushed; on the other hand, the front edge roller will not improve the stability of the file cabinet under gravity loads such as weights in the extended drawers.

A second feature of the proposed anti-tip concept is the ability to move the file cabinet as a wheelbarrow. This concept is illustrated below in Figure 8.

The use of casters on storage units is known to inhibit overturning and promote skidding. ANSI/BIFMA X5.9-2004 admonishes testing personnel to block the leading edge casters in order to perform their specified stability tests. In paragraphs (9.3.2), (9.4.2), (9.5.2), (9.6.2), and (9.7.2), the following statement can be found:

> *"if equipped with casters, each front caster shall be blocked with an obstruction or other restraining device 13 mm (0.5 in) in height affixed to the test platform. The device shall prevent sliding but not restrict the unit from tipping."*

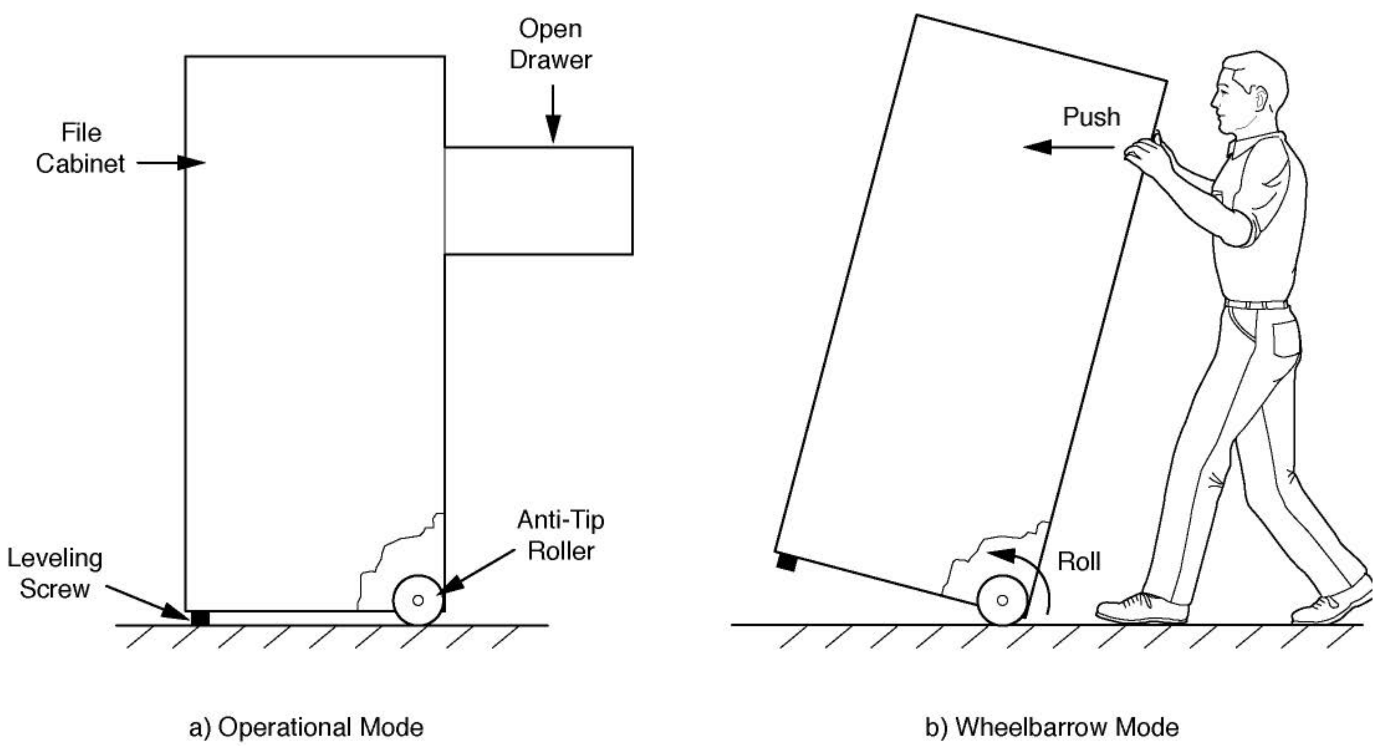



**Figure 8: Retrofitted Cabinet with Anti-Tip Roller**

It should be noted that casters give rise to planar motions in all directions with minimal drag resistance whereas the proposed cylinder device is unidirectional with half the loaded cabinet weight dragging on the rear level screws or the flat bottom of the unit.

B. Testing

The roller used to retrofit the Universal Vertical Drawer Tower is normally used in a roller conveyor; its 2.5 inches in diameter and 12.5 inches in width. The roller was mounted beneath the drawer section of the tower as shown in Figure 1c. A proof-of-concept test program was undertaken to establish the validity of the anti-tip roller safety device.

Using a vinyl tile over concrete surface, three configurations of the tower unit were studied; closed and empty, top drawer extended and empty, and top drawer extended with 44 lb. of lading. A horizontal force was applied to the file cabinet at 64.5 inches above the surface. Twenty-four trials were conducted in each of four directions. The rearward and the left and right directions resulted in tipping without translation. In the forward direction, the force caused the storage unit to roll on the front edge and skid on the rear edge. No overturning occurred.

The proof-of-concept tests were all executed with the anti-tip roller located within the confines of the cabinet which shortened and compromised the restoring moment arm. On the other hand, an outboard retrofit roller assembly was bolted to the front edge of the cabinet which expanded the footprint. This enhanced the stability with respect to downward acting loads on extended drawers.

The anti-tip roller assembly adopted for the tower retrofit extended the roller ½ inch below the bottom of the cabinet. This allowed the file cabinet to be moved in the wheelbarrow mode depicted in Figure 8b. It should be pointed out that the practicality of the anti-tip roller concept on deep pile carpets has not been established.

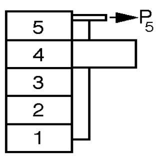
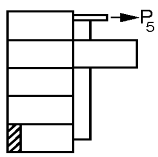
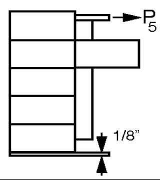
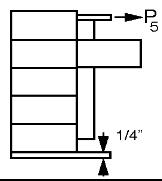
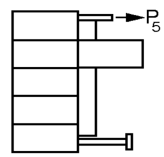
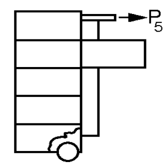
## OBSERVATIONS

Each of the three proposed safety devices for freestanding file cabinets provided a four to five fold increase in their stability resistance; 45 lbf. Instead of 10 lbf. The "Big Foot" concept permanently increased the footprint and provided a large balance point angle to warn users of impending tip-over. By contrast, the outrigger device increased the footprint only after the onset of tipping. Persistent overturning forces caused the tower to tip forward and to the side as a precursor to total collapse. The anti-tip roller concept substitutes sliding for overturning. This translation is accompanied by drag forces acting on the bottom rear of the cabinet that preclude runaway.

There are realistic settings that give rise to high pile carpeting, forty pound horizontal forces applied at the top of the storage unit with an open wardrobe door, and an extended fully loaded drawer in an otherwise empty cabinet. This worst-case scenario is not approximated by the ANSI/BIFMA standard for storage units. It is silent on the significant influence of the support surface on stability. Snagging is not addressed nor is the justification for the "10 lbf." The same standard calls for a minimum horizontal load resistance of 40 lbf. applied at six locations at a height of 54 inches for tall storage units without extendible elements.

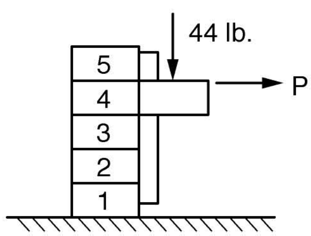
The results of our testing programs are summarized in Tables 7 and 8.

**Table 7:** Average Pull Resistance Against Tipping - Worst Case Scenario

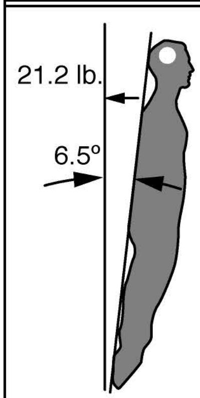
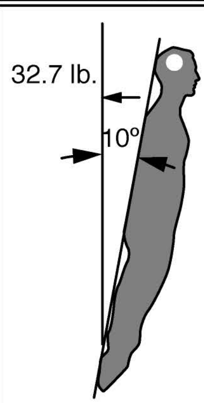
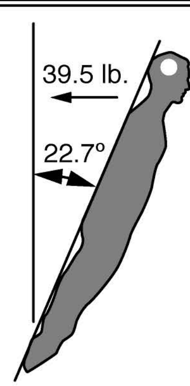
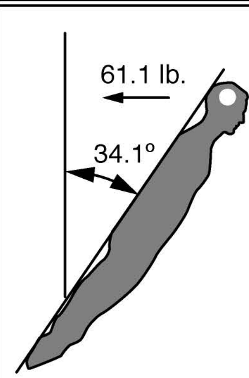
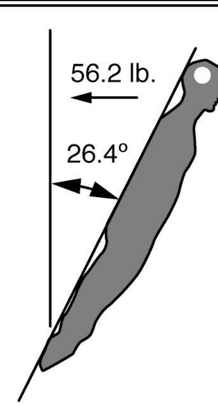
| Loading Condition | Original Cabinet | Retrofit | | | | |
|---|---|---|---|---|---|---|
| | | Original - Plus Counterweight (21.5 lb.) | Big Foot Thickness 1/8” | Big Foot Thickness 1/4” | Outrigger | Anti-Tip Roller |
| Drawers 1, 2, 3, 5 Empty<br>Wardrobe Door-Open |  |  |  |  |  |  |
| Drawer No. 4 Empty | $P_5$ = 18.72” lb. | $P_5$ = 31.62” lb. | $P_5$ = 43.92” lb. | $P_5$ = 53.74” lb. | $P_5$ = 55.47” lb. | $P_5 = \infty$ |
| | $P_4$ = 23.61” lb.<br>$P_3$ = 30.92” lb.<br>$P_2$ = 44.79” lb.<br>$P_1$ = 81.23” lb. | $P_4$ = 39.88” lb.<br>$P_3$ = 55.22” lb.<br>$P_2$ = 75.65” lb.<br>$P_1$ = 137.20” lb. | $P_4$ = 55.39” lb.<br>$P_3$ = 72.54” lb.<br>$P_2$ = 105.08” lb.<br>$P_1$ = 190.57” lb. | $P_4$ = 67.77” lb.<br>$P_3$ = 88.76” lb.<br>$P_2$ = 128.57” lb.<br>$P_1$ = 233.18” lb. | $P_4$ = 69.95” lb.<br>$P_3$ = 91.61” lb.<br>$P_2$ = 132.71” lb.<br>$P_1$ = 240.68” lb. | $P_4 = \infty$<br>$P_3 = \infty$<br>$P_2 = \infty$<br>$P_1 = \infty$ |
| Drawer No. 4 44 lb. | $P_5$ = 9.39” lb. | $P_5$ = 23.50” lb. | $P_5$ = 35.21” lb. | $P_5$ = 48.64” lb. | $P_5$ = 47.19” lb. | $P_5 = \infty$ |
| | $P_4$ = 11.84” lb.<br>$P_3$ = 15.51” lb.<br>$P_2$ = 22.47” lb.<br>$P_1$ = 40.74” lb. | $P_4$ = 29.64” lb.<br>$P_3$ = 38.81” lb.<br>$P_2$ = 56.22” lb.<br>$P_1$ = 101.97” lb. | $P_4$ = 44.40” lb.<br>$P_3$ = 58.15” lb.<br>$P_2$ = 84.24” lb.<br>$P_1$ = 152.78” lb. | $P_4$ = 61.34” lb.<br>$P_3$ = 80.33” lb.<br>$P_2$ = 116.37” lb.<br>$P_1$ = 211.05” lb. | $P_4$ = 59.51” lb.<br>$P_3$ = 77.94” lb.<br>$P_2$ = 112.90” lb.<br>$P_1$ = 204.76” lb. | $P_4 = \infty$<br>$P_3 = \infty$<br>$P_2 = \infty$<br>$P_1 = \infty$ |

$P_5$ ... Average of Ten Tests; $P_{1,2,3,4}$ ... Derived

**Table 8:** Lean Angle Required to Tip Cabinet




Wardrobe Door Open
Drawers 1,2,3,5...Empty
Drawer 4 ... 44 lb.

| | Retrofit | | | |
|---|---|---|---|---|
| Original Cabinet | Original - Plus Counterweight (21.5 lb.) | Big Foot Thickness: 1/8” | Big Foot Thickness: 1/4” | Outrigger |
|  |  |  |  |  |

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