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AUTO-SETTING LADDER INCLINATION

By William G. Switalski* and Ralph L. Barnett**

ABSTRACT

A straight or extension ladder maintains its equilibrium when placed against a wall or other structure by the friction resistance against sliding that is created between the side rail feet and the ground surface. When this friction force is not sufficient, the base of the ladder slides away from the wall dropping the climber.

In the United States, ladders are designed and tested using an angle of 75.52° which is also used as the limiting ladder set-up angle to avoid slide-out [1]. For the user to know that the ladder is properly set-up, a "rule-of-thumb" and on-product safety labels have been used. This safety strategy has room for improvement; over one-third of all ladder accidents are caused by ladder slide-out. A recent proposition involves a mechanical device using wheels attached at the bottom of the ladder at each side rail. This paper initially discusses the first generation of the proposed invention and its risks. Then, a second generation of the proposed invention is discussed and nine alternative designs are compared.

BACKGROUND

Proper Set-up Angle

The equations of equilibrium for straight or extension ladders indicate that the resistance against slide-out increases with the steepness of the ladder [2]. The steepness of the ladder is normally characterized by the acute angle formed between the ground surface and the centerline of the ladder. In the United States, ladders are designed and tested using an angle of 75.52°, which is also used as the limiting ladder set-up angle to avoid slide-out. The safety factor against ladder slide-out falls off very quickly as the ladder angle becomes shallower.

The various devices and techniques for achieving the 75.52° critical inclination of ladders includes a "rule-of-thumb" method, on-product safety labels, and an anthropometric method.

Rule-of-Thumb Method

The one-in-four method of setting the proper ladder angle involves arranging the geometry such that the base-to-wall distance is one-fourth of the active ladder length. This technique can be traced back to the first ladder safety standard and continues to be utilized in ladder safety standards in the United States today [3].

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No Charge

On-Product Labels

The "L" method involves mounting the letter "L" in label form on the side rail of a ladder. When correctly set-up, the L achieves a natural orientation with its legs in a vertical and horizontal position. A label of this type was required by American safety standards for non-self-supporting ladders manufactured from 1977 [4] until 1990.

Anthropometric Method

The anthropometric set-up method involves placement of an instructional label on the ladder with four steps to help the user achieve an angle of approximately 75°. These instructional steps are: 1) Place toes against bottom of ladder siderails; 2) Stand erect; 3) Extend arms straight out; 4) Palms of hands should touch top of rung at shoulder level. A label containing these four steps has been required on ladders built in compliance with United States safety standards since 1990 [5].

A NEW ANTI-SLIDE-OUT DEVICE INVENTION

A new device is proposed that involves the addition of inboard brackets at the bottom of the ladder that support two low friction wheels some twelve inches behind each side rail [6] as shown in Figure 1. When the side rail feet and the two wheels just touch a horizontal surface, the inclination angle is exactly 75.52°. At steeper angles, only the side rails contact the surface and an increased safety factor against ladder slide-out is achieved. At inclinations less than 75.52°, only the wheels are in contact with the horizontal support surface and the side rail feet are elevated. This state will not equilibrate the shallow ladder which will roll and accelerate away from the vertical support wall. This behavior will dramatically inform the user that the trial set-up angle is unsafe. There are many ramifications of this concept that are explored in this paper.

The First Generation of the Invention

If frictionless wheels were attached to the base of a ladder to act as its feet, the ladder would not support either itself or a live load. It would slide out and away from the vertical wall against which it was leaning. Figure 1 shows the bottom portion of a ladder equipped with a device for determining the proper set-up inclination angle. Three dispositions of the ladder are shown. In the center illustration, the wheels are located so that the ladder base and wheels simultaneously touch the horizontal surface when the desired set-up angle is achieved. When the ladder is set-up at a steeper angle, as shown in the right hand drawing, the wheels are lifted above the ground leaving the ladder base in contact with the support surface. Set-up angles steeper than the desired 75.52° increase the safety factor against a ladder slide-out occurrence. By contrast, the left sketch shows a ladder inclination that is less than the desired set-up angle. Here, the wheels remain in contact with the surface whereas the ladder base is above the surface. Consequently, the ladder will start falling, or sliding-out, as the ladder base propels itself away from the support wall. If the user does not oppose this motion, the ladder will fall against the ground.

An examination of the case where the user sets-up the ladder at too shallow an angle reveals three feedback mechanisms that indicate an improper inclination angle. First, the ladder base can be observed not touching the ground. Second, the ladder will push against the user who is standing in front of the ladder. Alternatively, if the user is not standing in front of the ladder, the ladder base will roll away from the wall as the top of the ladder drops. Finally, if the ladder is not too heavy, an attempt to mount the lowest rung(s) of the ladder will cause the top of the ladder to lift off of the vertical structure. The rollers at the bottom act as a fulcrum that gives rise to a seesaw action about the roller axle.

If the ladder were rigid, the climber would set the ladder to achieve simultaneous contact of the ladder base and the

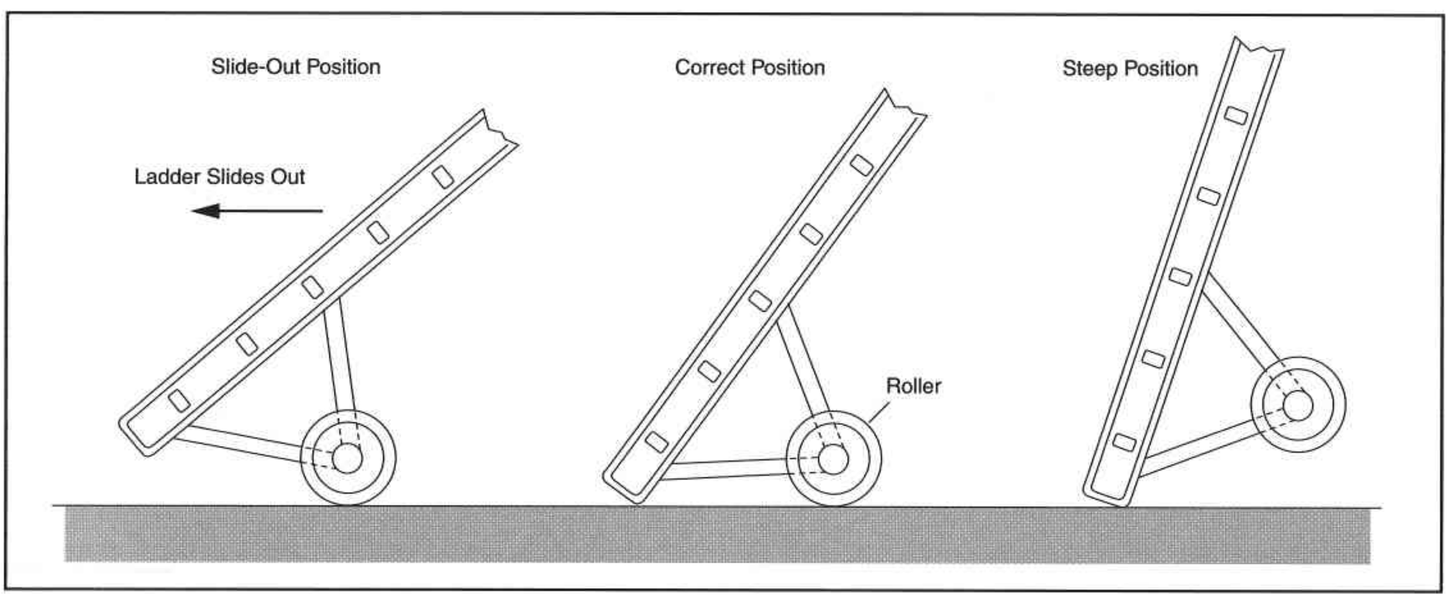

Figure 1 - First Generation of Proposed Invention

rollers. Then, a slight additional inward movement would elevate the rollers and allow climbing to proceed. However, the real world ladder is flexible and will sag when supporting a climber. This sag will rotate the ladder base in a direction which moves the rollers downward toward the ground. It is possible for this downward movement to cause the ladder base to leave the ground and reduce or remove the resistance to slide-out. Thus, a slide-out accident can result. This danger may be actively averted by instructing the user to leave a specified ground clearance beneath the rollers during set-up. On the other hand, a passive system may be used to prevent this phenomenon entirely.

The Second Generation of the Invention - Spring Loaded Rollers

Seven alternative means of automatic roller mechanism retraction are illustrated in Figures 2 through 8. Each concept will be evaluated with regard to the following concerns: Ease of use; Ease of Storage; Relative Safety; Cost; and Maintenance Issues. In general, all of the proposed anti-slide-out devices will add weight and cost to the basic ladder. They will make the ladder more difficult to store and/or transport due to the inability to "nest" ladders one on top of another. Although the safety of the ladder is improved with respect to reducing the potential for a slide-out accident, the ease with which the devices can be circumvented will be evaluated. Each of the anti-slide-out devices will eventually require parts replacement and lubrication. For example, the proper function of the roller device is dependent upon the proper diameter roller. Otherwise, the set-up angle will not be the desired 75.52°. Similarly, the springs utilized in several of the designs require pre-loading to very specific levels in order for the devices to function as intended. Hence, spring replacement with the proper spring is critical as is the pre-load adjustment of the spring.

Alternative 1

The system shown in Figure 2 has rollers that are spring loaded. At angles less than the desired set-up angle, the spring carries the weight of the ladder, plus a safety factor such as 1.5 times the weight, as shown in the left illustration. When in this state, the ladder base will accelerate away from the support wall. This action will provide both visual and tactile feedback relative to the improper set-up angle.

At any angle less than the desired set-up angle, the user may stabilize the ladder with his hands while mounting a rung. The weight of the user will overcome the pre-load in the spring and allow the ladder base to push against the ground with sufficient force to develop almost the full frictional resistance to slide-out associated with the specific ladder inclination. This situation is shown in the center illustration of Figure 2.

The right illustration of Figure 2 shows the ladder at the proper inclination angle, 75.52°. If the ladder sags under the weight of a user, the rollers do not cause the side rails to lift

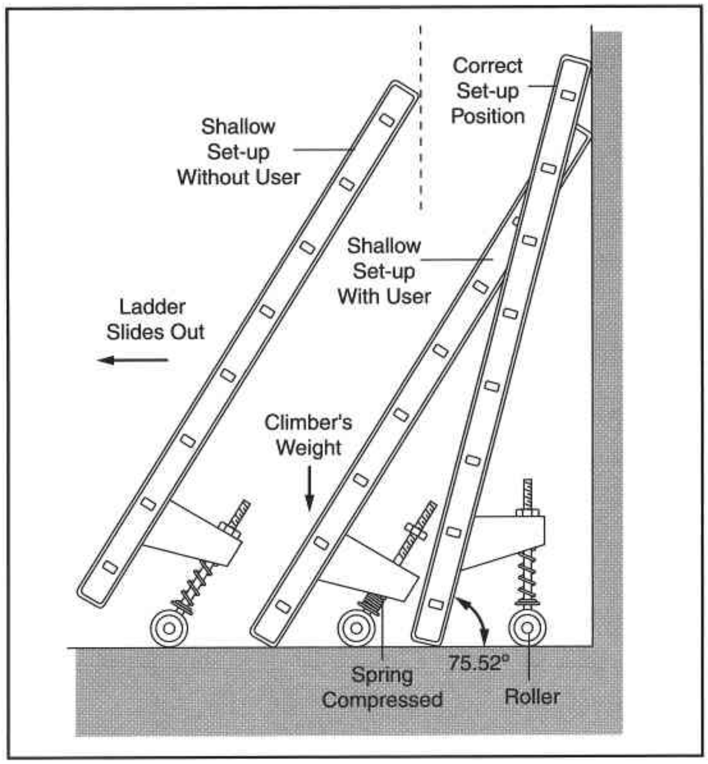

Figure 2 - Second Generation of Proposed Invention; Alternative 1

because the lifting capability is limited to the spring force. The spring force is small, but greater than the ladder dead weight. An additional benefit of the presence of the roller device is that the ladder can be easily moved without the user having to carry the full weight of the ladder. The ladder can be moved between locations in the same method as a wheelbarrow.

The Ease of Use of this device is good since no active user input is required to operate or reset it. The device compensates for sag created by the weight of the user, but compression of the springs reduces the frictional resistance against slide-out. The cost of the device is moderate compared to other concepts. There are sliding surfaces to lubricate, and the adjustment of the spring pre-load is critical to the proper function of the device.

Alternative 2

When the inclination of the ladder illustrated in Figure 3a is too shallow and a user places his weight on the ladder, the roller mechanism assumes the geometry shown in Figure 3b. In this configuration, almost no upward force is exerted on the ladder by the roller mechanism. Even when the user removes his weight, the ladder will not be lifted by the mechanism. To restore the original geometry of the mechanism shown in Figure 3a, the user must lift the ladder and allow the torsion spring to reset or reactivate the suspension system.

The eccentric mechanism shown in Figure 3 provides two additional safety features. First, when the climber misuses

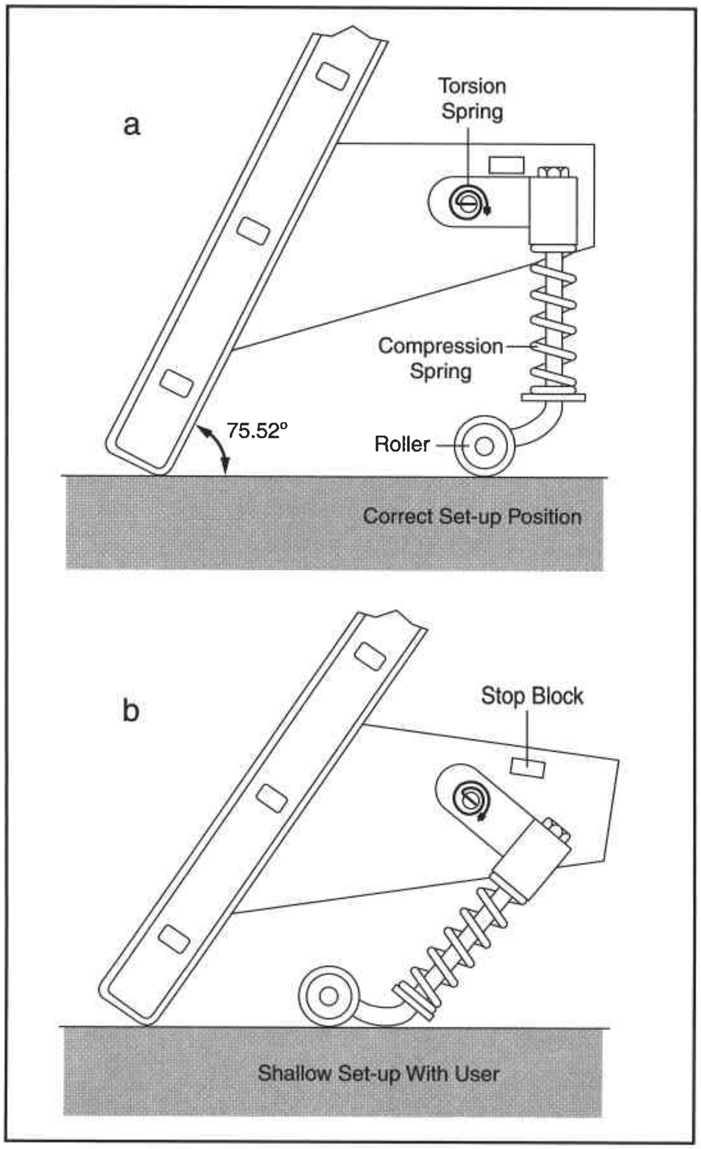

Figure 3 - Second Generation of Proposed Invention; Alternative 2

the ladder at too shallow an angle, the spring mechanism will not reduce the force of the side rail feet which might otherwise compromise the frictional resistance to slide-out. Second, when the user dismounts from the shallow set-up angle, the ladder will remain in equilibrium and not push back from the vertical support structure.

The Ease of Use of this device is good since no active user input is required to operate or reset it. The device compensates for sag created by the weight of the user, but compression of the springs in the correct set-up position reduces the frictional resistance against slide-out. The cost of the device is high compared to other concepts since there are four springs required along with two pivot connections and two sliding connections. There are both pivoting and sliding surfaces to lubricate, and the proper adjustment of the spring pre-load is critical to the proper function of the device.

Alternative 3

The system shown in Figures 4a through 4d has a detented cam and a spring-loaded roller mechanism that rests in the detent when in its activated position. At angles less than the desired set-up angle, the roller mechanism remains in the detent of the cam and carries the weight of the ladder, plus a safety factor, as shown in Figure 4c. When in this state, the ladder base will accelerate away from the support wall. This action will provide both visual and tactile feedback to the user relative to the improper set-up angle.

At any shallow angle less than the desired set-up angle, the user may stabilize the ladder with his hands while mounting a rung. The weight of the user will overcome the detented roller position, as shown in Figure 4d, and allow the ladder base to push against the ground. The position of the roller mechanism will provide the user with visual feedback relative to the improper set-up angle. The feet of the ladder side rails, now in contact with the ground, develop the full frictional resistance to slideout associated with the specific ladder inclination.

Figure 4a shows the ladder at the proper inclination angle, 75.52°. If the ladder sags under the live load of a user, the rollers do not cause the side rails to lift. Instead, the sag will act on the roller arm causing the detent pin to be pushed over the hump of the detent, moving the roller mechanism out of the way in a direction away from the ladder as illustrated in Figure 4b. Only the ladder feet will remain in contact with the ground to develop their full resistance to slideout. Here, the user is provided with visual feedback that the setup angle was proper in contrast to the roller position shown in 4d.

After using the ladder, the user can reset the roller position to its active position shown in Figure 4a or into a storage position shown in Figure 4d.

Just as with the previous design, an additional benefit of the presence of the roller device is that the ladder can be easily moved without the user having to carry the full weight of the ladder. The ladder can be moved between locations in the same method as a wheelbarrow.

The Ease of Use of this device is poor since user input is required to return it to the proper set-up angle position. The device compensates for ladder sag created by the weight of the user. The safety associated with the use of this design is enhanced since the rollers do not remain in contact with the ground when activated. Hence, there is no reduction in the frictional resistance against slide-out. The cost of the device is high compared to other concepts due to the cam surface. There are both pivoting and sliding surfaces to lubricate, but the adjustment of the spring pre-load is not as critical to the proper function of the device as with the previous designs.

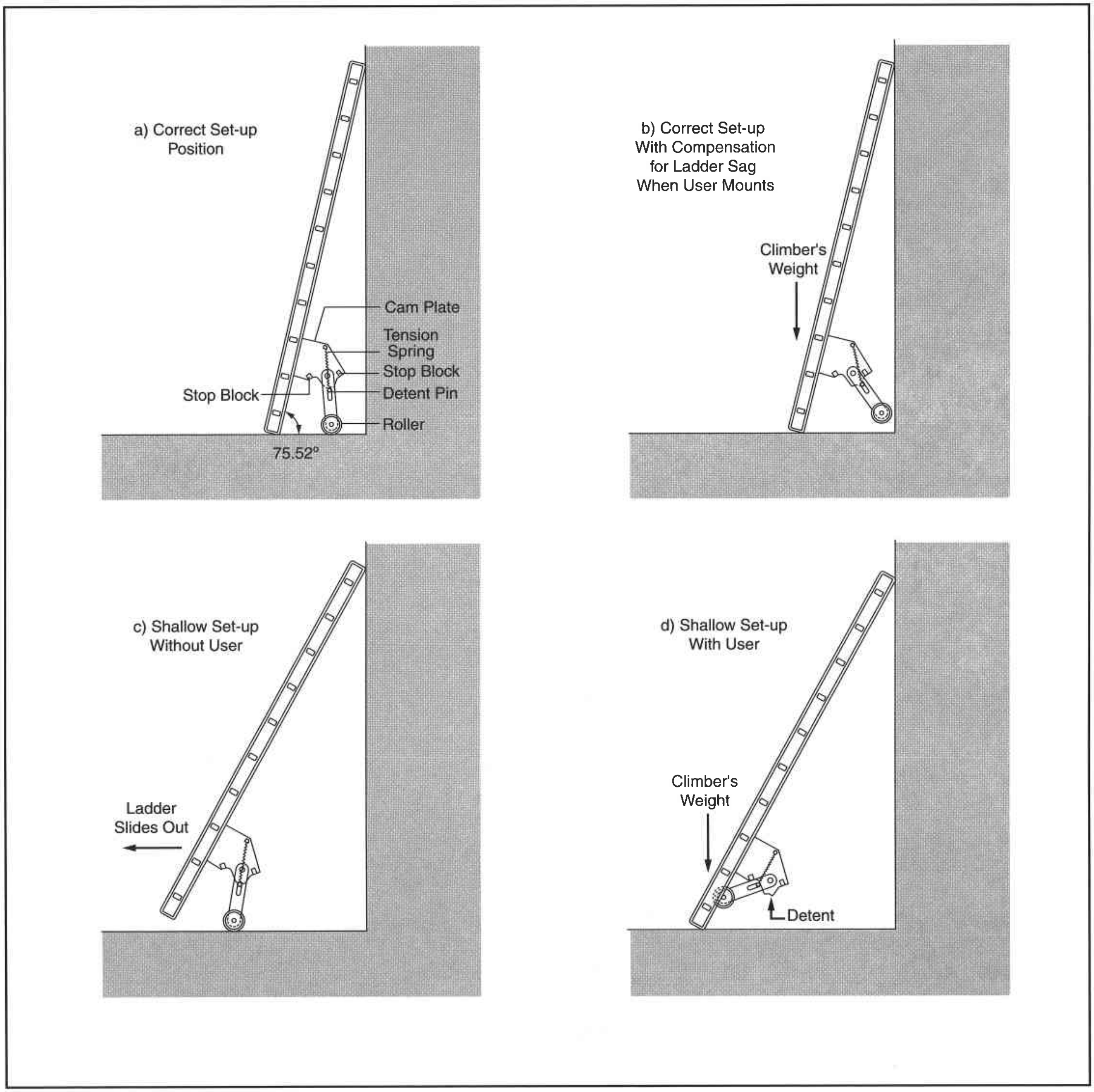

Figure 4 - Second Generation of Proposed Invention; Alternative 3

Alternative 4

By removing the hump of the detent cam closest to the ladder as described in Figure 4, repositioning the roller arm stop closest to the ladder, and repositioning the spring support pin, a transition from the mechanism described in Figure 4 to that of Figure 5a through 5c is accomplished.

When the ladder is positioned at the desired setup angle, 75.52°, there is no slide-out of the ladder under either the unloaded condition of Figure 5a or the loaded condition with sag shown in Figure 5b. The roller mechanism will not allow the ladder to be used when set up at a shallow angle as shown in Figure 5c since the user's weight will not remove the rollers from the surface. Just as with the previously described mechanism, the user can restore the roller mechanism by hand to its active position by moving the roller arm to the position shown in Figure 5a.

The Ease of Use of this device is poor since user input is required to return it to the proper set-up angle position. The device compensates for ladder sag created by the weight of the user. The safety associated with the use of this design is enhanced since the rollers do not remain in contact with the ground when activated. Hence, there is no reduction in the frictional resistance against slide-out. The cost of the

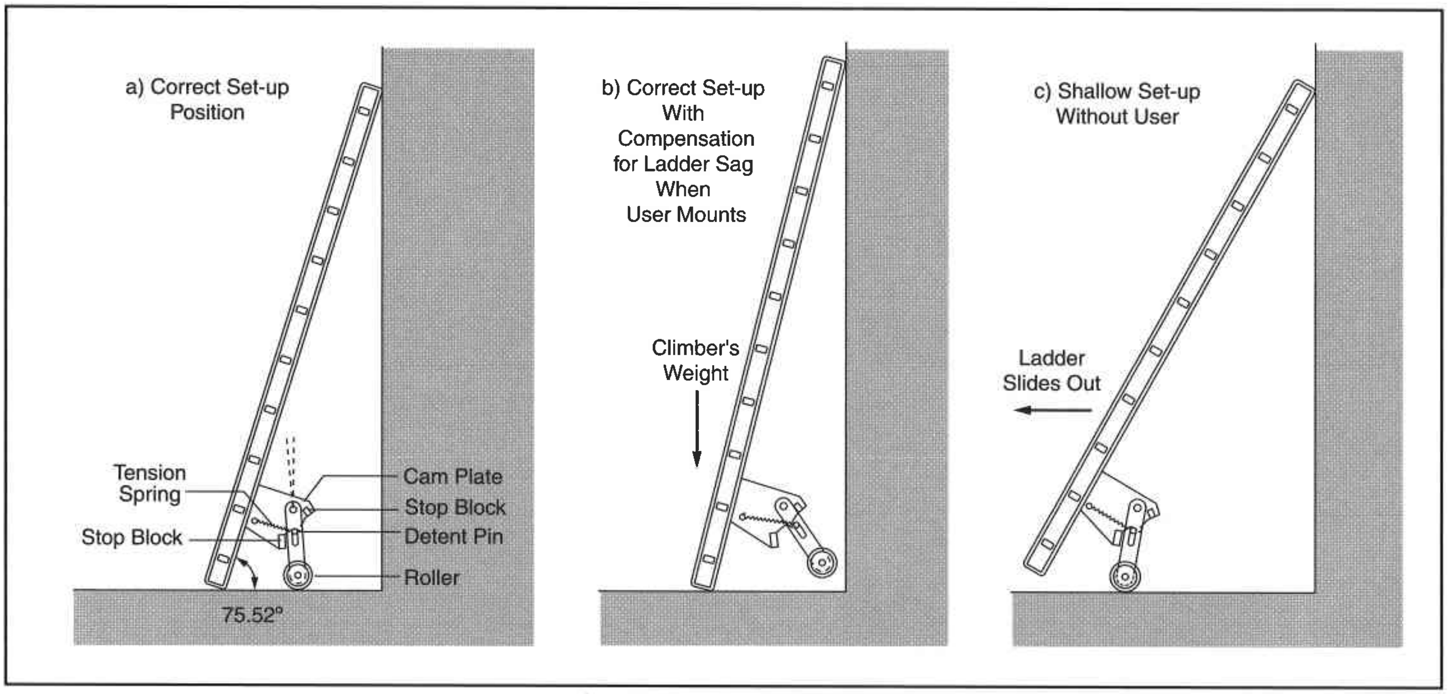

Figure 5 - Second Generation of Proposed Invention; Alternative 4

device is high compared to other concepts due to the cam surface. There are both pivoting and sliding surfaces to lubricate. There is no spring pre-load to adjust, but any replacement springs used must maintain the original spring constant.

Alternative 5

The roller device shown in Figure 6 is substantially similar to the mechanism shown in Figure 5a. By removing the cam hump and eliminating the detent slot, the snap-out retraction of the roller and roller arm is eliminated. This modification enables the roller mechanism to give way under sag due to the presence of a live load at the proper set-up angle. However, the roller does not retract to an out-of-the-way position as shown in Figure 5b. In this case, when the live load is removed from the ladder, or if the ladder is lifted up, the roller mechanism automatically returns to its active state as shown in Figure 6. The roller mechanism will not allow the ladder to be used when set up at a shallow angle as shown in Figure 5c since the user's weight will not remove the rollers from the surface.

The Ease of Use of this device is good since no user input is required to operate or reset it. The device compensates for ladder sag created by the weight of the user, but tension in the springs reduces the frictional resistance against slide-out. The cost of the device is moderate compared to the two previous concepts since the cam surface has been eliminated. Although there is a pivot point to lubricate, there is no spring pre-load to adjust. Any replacement springs used must maintain the original spring constant.

Alternative 6

The device illustrated in Figure 7a is similar to the design shown in Figure 2, utilizing a preloaded spring system. Here, the roller system will behave rigidly until a sufficient roller reaction force overcomes the preload. The weight of the ladder is not sufficient to overcome the preload of the compression springs so that the ladder will slide-out when set up at a shallow angle before a user attempts to mount.

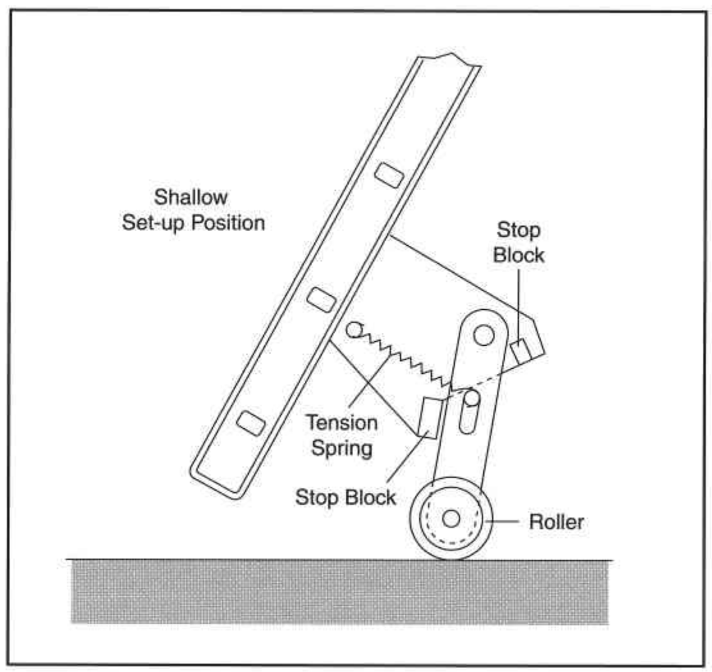

Figure 6 - Second Generation of Proposed Invention; Alternative 5

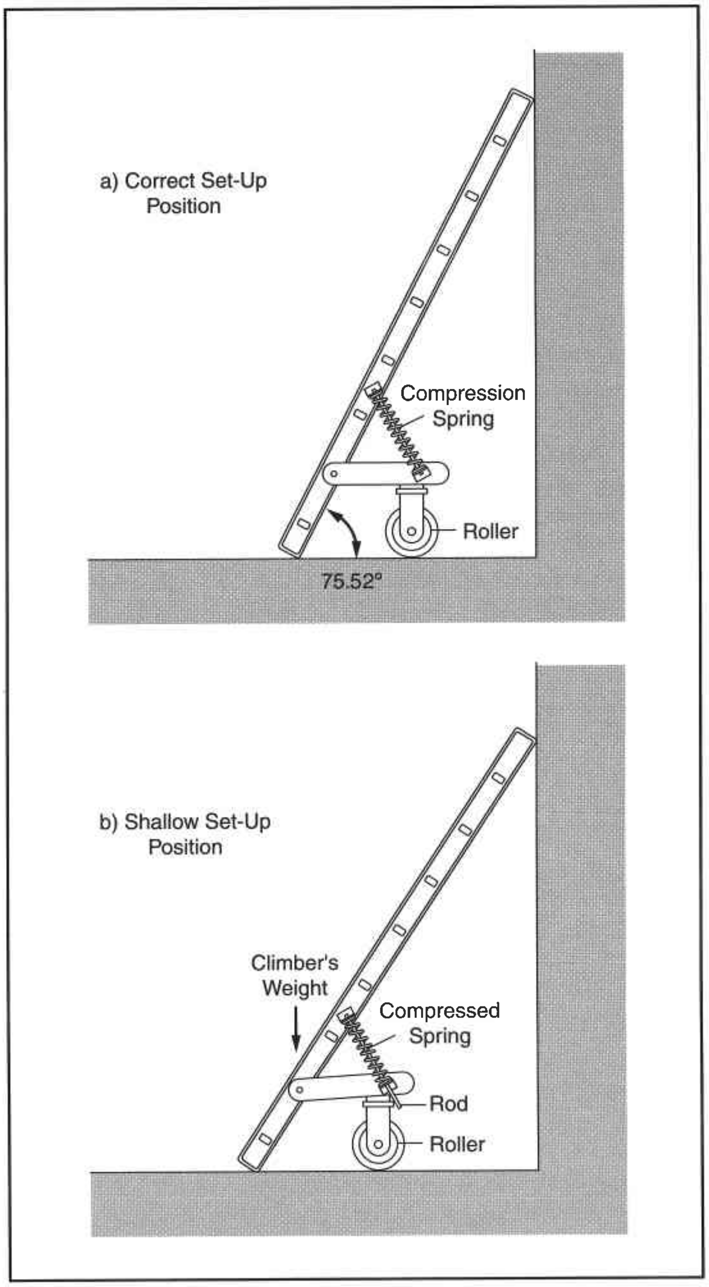

Figure 7 - Second Generation of Proposed Invention; Alternative 6

However, if a user mounts at a shallow angle, the springs will allow the roller mechanism to deflect as shown in Figure 7b.

The Ease of Use of this device is good since no active user input is required to operate or reset it. The device compensates for sag created by the weight of the user, but compression of the springs reduces the frictional resistance against slide-out in both shallow and correct set-up positions. The cost of the device is moderate compared to the other concepts. There are both pivoting and sliding surfaces to lubricate, and the adjustment of the spring pre-load is critical to the proper function of the device.

Alternative 7

The anti-slide-out device shown in Figure 8 incorporates a detent mechanism that acts as a mechanical fuse to unload the spring when the spring force reaches a preset level. This limits the parasitic effect of the compression spring reaction when a climber mounts at a shallow set-up angle. The detented slide block must be manually repositioned after it has acted to unload the spring by sliding downward.

The Ease of Use of this device is poor since user input is required to return it to the proper set-up angle position. The device compensates for sag created by the weight of the user, but compression of the springs reduces the frictional resistance against slide-out. The cost of the device is moderate to high compared to other concepts due to the presence of four springs. There are sliding surfaces to lubricate, and the adjustment of the spring pre-load is critical to the proper function of the device.

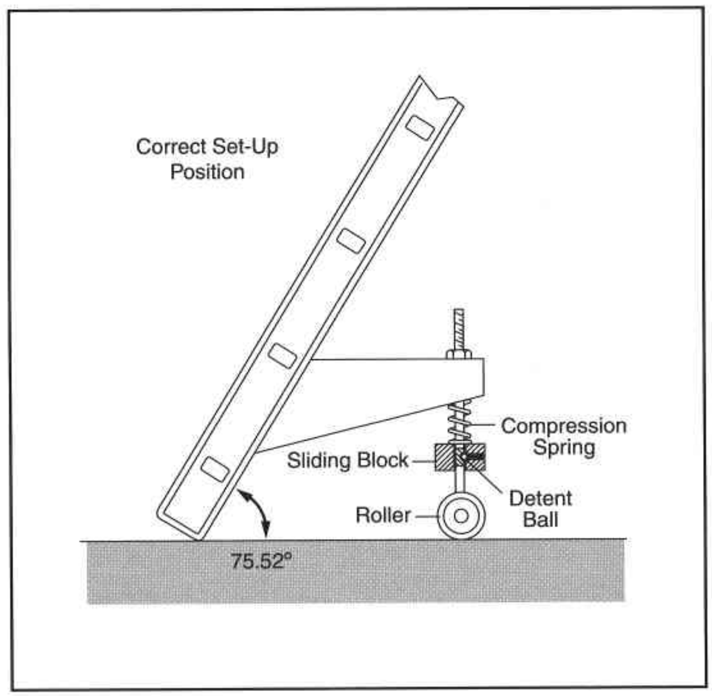

Figure 8 - Second Generation of Proposed Invention; Alternative 7

Alternative 8

A flat spring version of the anti-slide out device is shown in Figure 9. The spring is connected at one end to the ladder side rails and at the other end to a set of rollers. Due to the simplicity of this design, high reliability, and high robustness, the potential for minimum cost can be realized. In addition, this design can satisfy horizontal storage requirements by folding the device flat against the side rails when not in use.

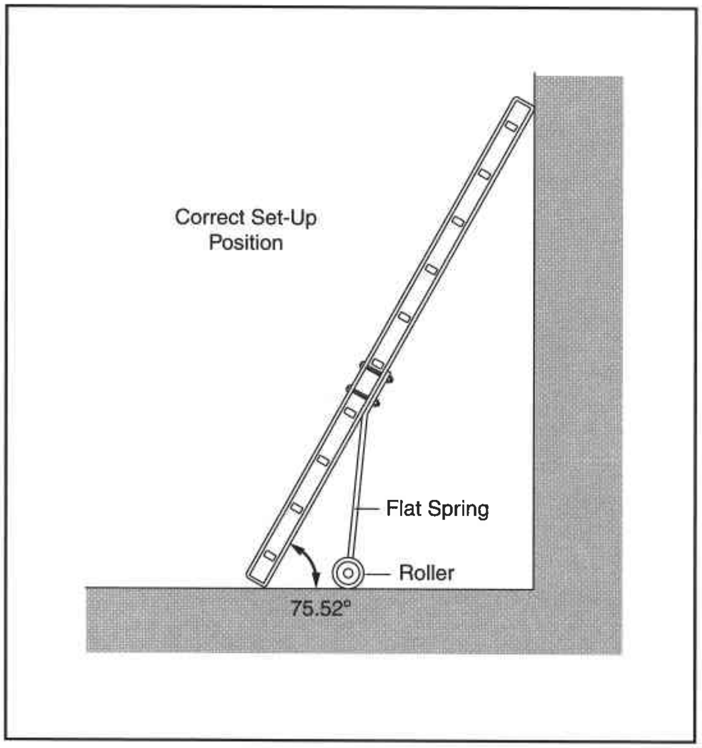

Figure 9 - Second Generation of Proposed Invention; Alternative 8

The Ease of Use of this device is good since no active user input is required to operate or reset it. The device compensates for sag created by the weight of the user, but deflection of the flat springs reduces the frictional resistance against slide-out. The cost of this device is the lowest among the concepts compared. There are no pivot points or sliding surfaces to lubricate or springs to adjust.

SUMMARY

Table 1 summarizes the features exhibited by each of the design proposals addressed in this paper.

Table 2 ranks the anti-slide-out devices in terms of desirability.

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Table 1 - Summary of Roller Mechanism Features

FEATURE	FIGURE NUMBER								
	1	2	3	4	5	6	7	8	9
Rollers fully retract when user mounts ladder at shallow angle				X					
Rollers retract, but remain in contact with ground when user mounts ladder at shallow angle		X	X				X	X	X
Roller mechanism compensates for sag when ladder is loaded with user's weight		X	X	X	X	X	X	X	X
Rollers can be utilized to move ladder like a wheelbarrow	X	X		X	X	X	X	X	X
Ladder rollers automatically reset	N/A	X	X			X	X		X
Ladder rollers must be manually reset	N/A			X	X			X	
Top of ladder moves away from wall when user mounts a light ladder at a shallow set-up angle	X				X	X			
Ladder will not push back from vertical support surface when user dismounts at shallow set-up angle			X	X				X	
Rollers fold for multiple ladder nesting/storage									X

Table 2 - Comparative Analysis of Roller Mechanism Designs

	FIGURE NUMBER								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Ease of Use	good	good	good	poor	poor	good	good	poor	good
Ease of Storage	poor	poor	poor	poor	poor	poor	poor	poor	good
Relative Safety	moderate	moderate	good	good	poor	good	moderate	moderate	moderate
Relative Cost	low	moderate	high	high	high	moderate	moderate	moderate	low
Maintenance Required	low	high	high	moderate	moderate	moderate	high	high	low

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