Center of Excellence

Triodyne Inc.

Consulting Engineers & Scientists – Safety Philosophy & Technology

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LADDERS

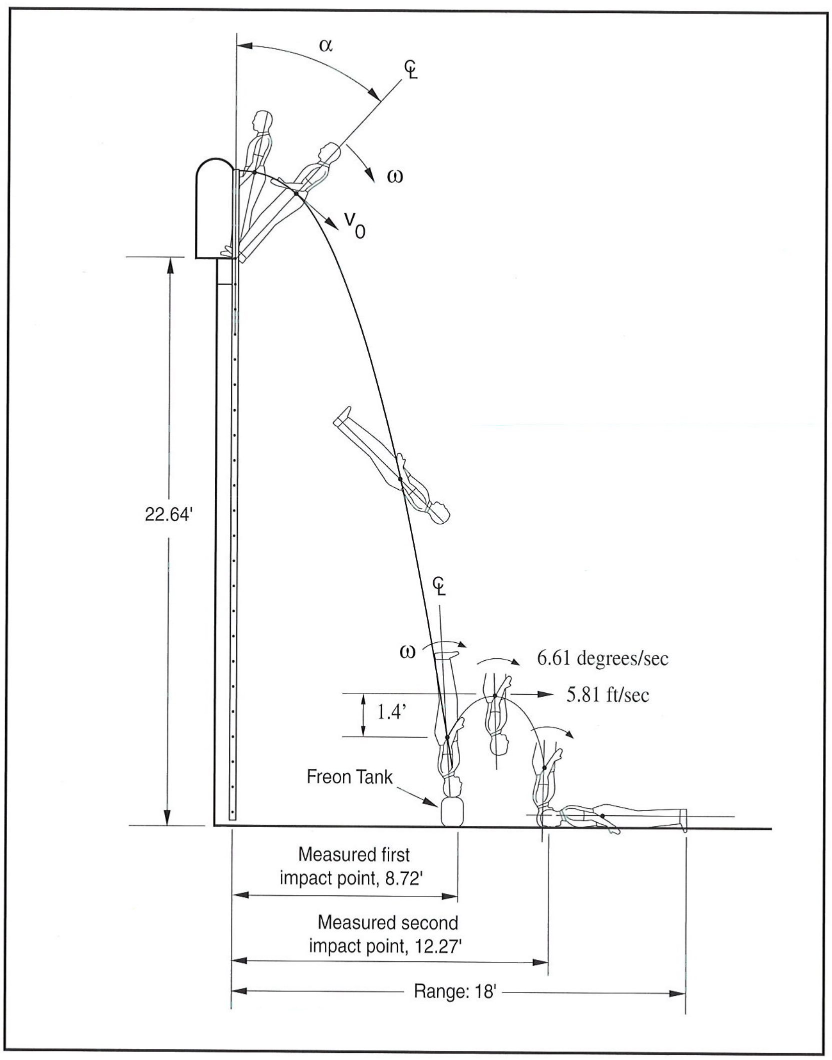


Figure 1 - Accident Reconstruction: Fall onto Freon Tank

PROBLEM STATEMENT

Discovered by monkeys, the ubiquitous ladder is used by all segments of the population – small children, housewives, maintenance workers, emergency crews, military personnel, librarians, retail salespeople, stagehands and circus performers. Furthermore, everyone uses many kinds of ladders including monkey bars, pool and step ladders, extension and bunkbed ladders, A-frame and rope ladders, fixed and aerial ladders, attic and combination ladders. Ladders are convenient, low cost, and multifunctional. Unfortunately, they are all gravity defying. In addition, everyone thinks s/he knows how to climb and use every ladder.

Born in antiquity, surely all the design problems associated with ladders have been resolved: the optimum shapes of siderails and rungs, the best material for ladder feet, the optimum rung spacing, anti-telescoping features, optimum methods for setting the angles on straight and telescoping ladders, the correct set of warning labels and instructions, the proper criteria for torsional and flexural stiffness, and the optimum width of A-frame ladders. Not true!

STANDARDS

For over two decades Triodyne Inc. has served in various capacities, including Technical Co-Secretariat, on the American National Standards Institute A14 Committee for ladder safety.

ACCIDENT INVESTIGATIONS

Triodyne has conducted hundreds of safety studies in conjunction with forensic services for defendants and injured parties. These include accident reconstructions of the type depicted in Fig. 1 for an unwitnessed fall from a fixed ladder onto a Freon tank.

SCIENTIFIC PAPERS

To help defeat "Daubert" challenges, it is desirable to include peer reviewed papers in an expert's background. Very few refereed papers have been written on the subject of ladders. In recent years, most of these have been prepared by Triodyne, e.g.:

1. Ladder Slide Out – First Order Analysis, by Ralph L. Barnett DETC99/RSAFP-8865, Proceedings of the Design Engineering Technical Conferences, American Society of Mechanical Engineers, September 1999. [Also available as Safety Brief, Vol. 12, No. 1, November 1996.]

2. Ladder Rung vs. Siderail Hand Grip Strategies, by Ralph L. Barnett and Peter J. Poczynok, Safety Engineering and Risk Analysis, SERA – Vol. 11, American Society of Mechanical Engineers, November 2001. [Also available as Safety Brief, Vol. 16, No. 4, April 2000.]

3. Auto Setting Ladder Inclination, by William G. Switalski and Ralph L. Barnett, DETC 2003/SERA-48689, Proceedings of the Design Engineering Technical Conferences, American Society of Mechanical Engineers, September 2003. [Also available as Safety Brief, Vol. 24, No. 1, July 2003.]

4. Sloped Surfaces – Ladder Slide Out, by Ralph L. Barnett and Theodore Liber, accepted for presentation at the 19th Annual International Occupational Ergonomics and Safety Conference, June 2005. [Also available as Safety Brief, Vol. 25, No. 1, January 2004.]

5. Ladder Cages, by Ralph L. Barnett and Christopher W. Ferrone, accepted for presentation at the American Society of Mechanical Engineers 2005 ASME International Mechanical Engineering Congress and Exposition, November 2005. [Also available as Safety Brief, Vol. 25, No. 4, April 2004.]

Triodyne publications on ladders include:

1. Extension Ladders – Going Out on a Limb, by Ralph L. Barnett and Andrew H. Tudor, Safety Bulletin, Vol. 3, No. 1, February 1996.

2. Truck Mounted Ladder Racks, by William Switalski and Ralph L. Barnett, Safety Bulletin, Vol. 6, No. 2, December 1997.

3. How to Climb an Unsafe Ladder, by Ralph L. Barnett, Safety Bulletin, Vol. 9, No. 4, January 2001.

Figure 2 - Beth Hamilton Safety Library

LIBRARY SERVICES

Triodyne's Beth Hamilton Safety Library maintains a specialty collection of ladder documents which can be characterized as follows:

- **Fixed Ladders and Fixed Industrial Stairs**, No. 0215 [70 references]
- **Portable Wood Ladders,** No. 0339 [60 references]
- **Access System Requirements (Including Ladders) Slip and Fall from Truck Cabs**, No. 0643 [35 references]
- **Ground and Aerial Fire Fighting Ladders**, No. 0843 [25 references]
- **Metal Extension and Trestle Ladders**, No. 0082 [85 references]
- **Metal Step Ladders and Step Stools**, No. 0053 [65 references]
- **Platform Ladders and Ladder Stands**, No. 0034 [35 references]

FACILITIES

Our indoor ladder testing and development activities are conducted in our Safety Laboratory which will accommodate a 24-foot ladder. Our ladder inventory for four current research programs is shown in Fig. 3. This work is supported by a fully equipped metalworking shop, an extraordinary woodworking shop, a universal testing machine, a 25-foot manlift, a force-plate system, and standard instrumentation capability.

SEMINARS

Triodyne staff have conducted eight seminars dealing with ladder safety. The most recent, "*The World of Ladder Safety*," was presented to the American Ladder Institute on September 20, 2004.

PATENTS

Two patents have been granted to Triodyne staff on "Anti-Slide Out Devices for Straight and Extension Ladders."

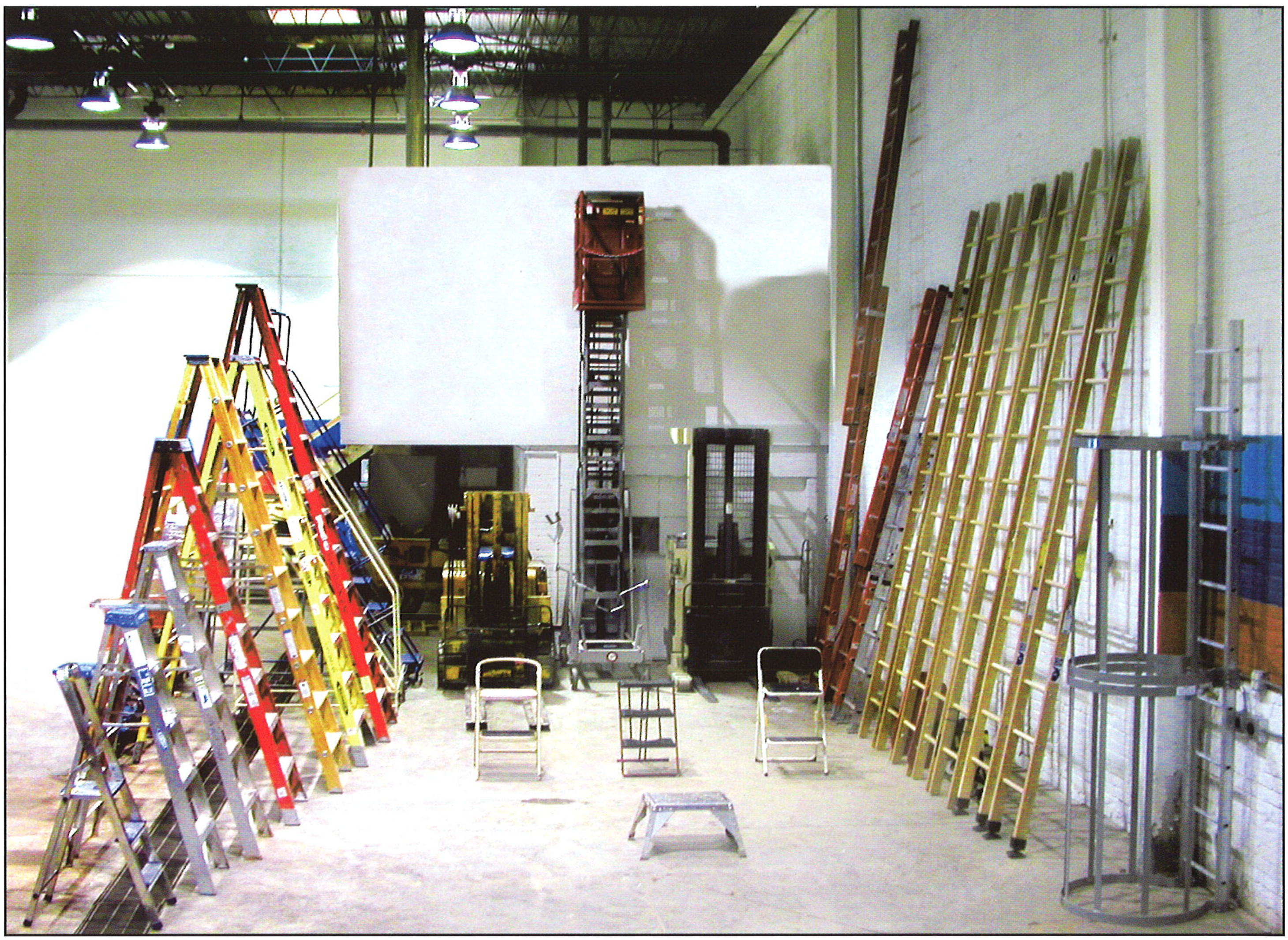
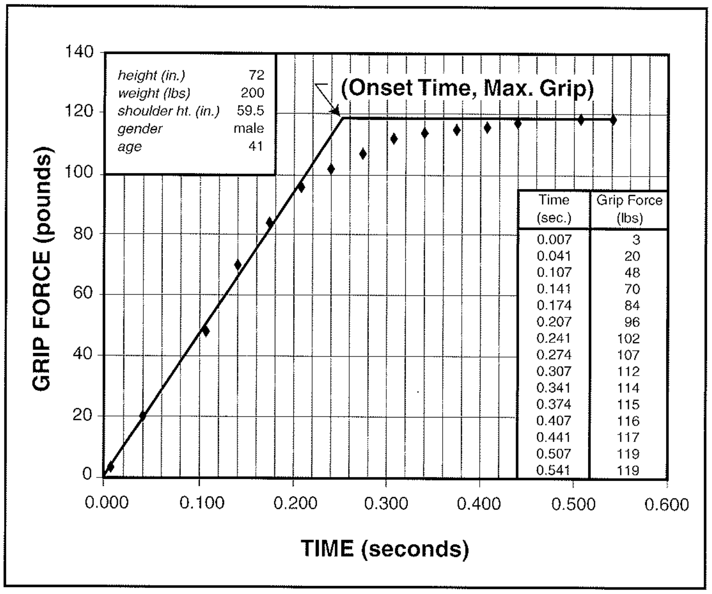


Figure 3 - Ladder Research Inventory

LADDER RESEARCH

Ladder Rung vs. Siderail Hand Grip

When a climber loses foothold on fixed, straight, or extension ladders, the incipient fall may potentially be arrested by gripping either the ladder rungs or siderails. The literature is equivocal on which strategy is better; Triodyne has established that it is more desirable to grasp the rungs. This demonstration required, among other things, the development of grip-time profiles of the type shown in Fig. 4. These were not available in the anthropometric literature.



Time (sec.)	Grip Force (lbs)
0.007	3
0.041	20
0.107	48
0.141	70
0.174	84
0.207	96
0.241	102
0.274	107
0.307	112
0.341	114
0.374	115
0.407	116
0.441	117
0.507	119
0.541	119

Figure 4 - Grip / Time Diagram - Test Subject 1

Ladder Slide-Out

One of the more important collapse modes for straight, combination, and extension ladders is base slide-out; the top of the ladder slides down the support wall as the base slips away from it. For the ladder geometry and general loading shown in Fig. 5a, the no-slip criterion for the base friction coefficient μ_b is shown in Fig. 5b. This inequality was used to establish the following observations.

i. The set-up integrity cannot be verified by standing on the bottom rungs. The higher the climb, the more critical the slide-out potential.

ii. Steeper ladders provide more slide-out resistance. The set-up angle is very critical.

iii. Ladder slide-out does not depend on the total loading or actual length; only the load distribution counts.

iv. An empty standing ladder can always be safely climbed halfway up.

v. Ladder slide-out testing may be drastically simplified.

vi. Wall friction plays almost no role in slide-out resistance.

vii. The current protocol for establishing the ladder set-up angle is not conservative, i.e., ladder shoes at climber's feet and arms horizontal while grasping the nearest rung.

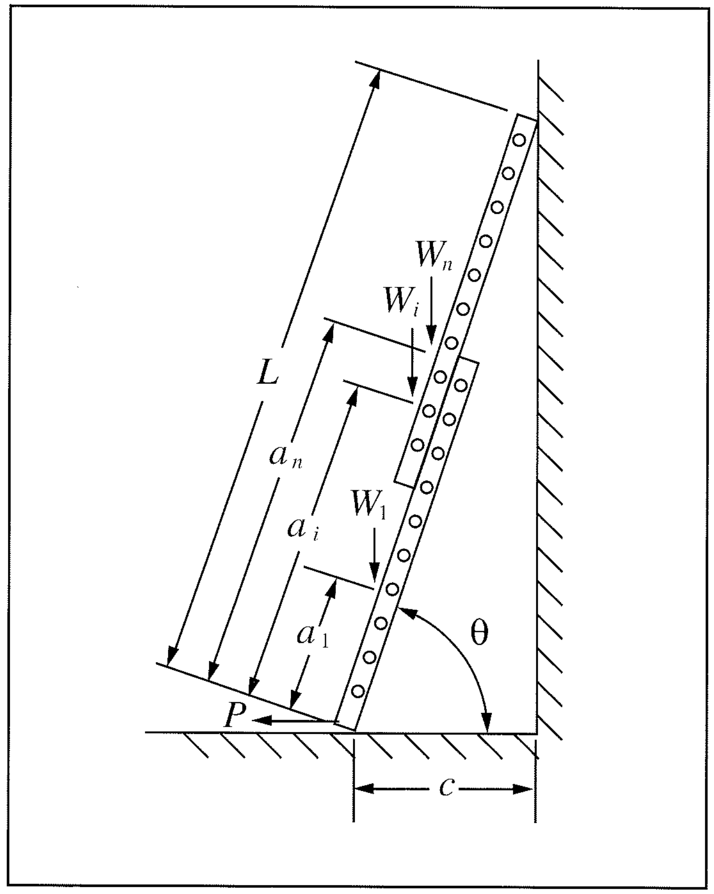


Figure 5a - Ladder Geometry and General Loading

$$\mu_b \geq \frac{(\mu_t + \tan\theta)\frac{P}{W} + \sum_{i=1}^{n}\left(\frac{W_i}{W}\right)\left(\frac{a_i}{L}\right)}{(\mu_t + \tan\theta) - \mu_t \sum_{i=1}^{n}\left(\frac{W_i}{W}\right)\left(\frac{a_i}{L}\right)}$$

Figure 5b - Non-Slip Criterion

Rung Spacing

In the U.S., the 12-inch spacing between rungs on portable ladders is specified by standards. This is not an optimum spacing; this is one third the arm length of King Henry I of England (1120 A.D.). According to the Principle of Uniform Safety, safety derives from the universality of this spacing because every ladder trains the user for other ladders.

A-Frame Stability

Excessive side loads on A-Frame ladders cause them to overturn. Ladders are not appropriate for certain rigorous tasks. Our current research seeks to quantify this notion by measuring the reaction forces applied to ladders during various construction activities. The force-plate used in this research is depicted in Fig. 7. This instrumentation is normally found in gait laboratories.

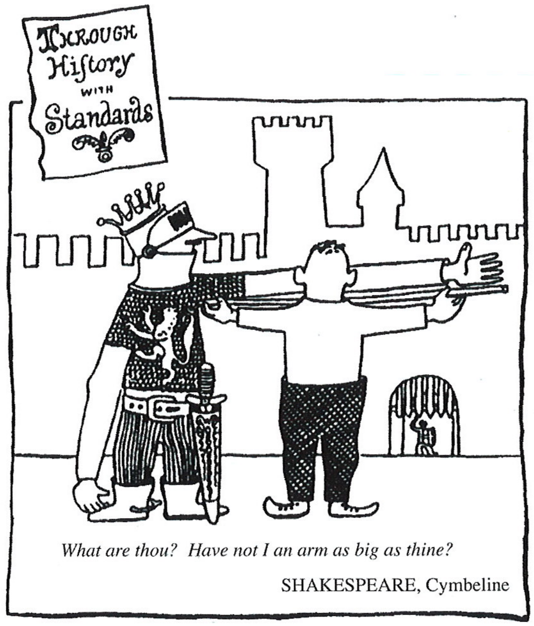


Figure 6 - The Definition of a Yard

Figure 7- Force Plate Study - Side Loading of A-Frame Ladders

Ladder Climbing Techniques

Weaknesses in a ladder's structure are not always self revealing. Furthermore, a momentary loss of foot or hand control or even a patch of ice or grease may compromise a climber's safety. Under such conditions the climbing method illustrated in Fig. 8 optimizes the safety profile.

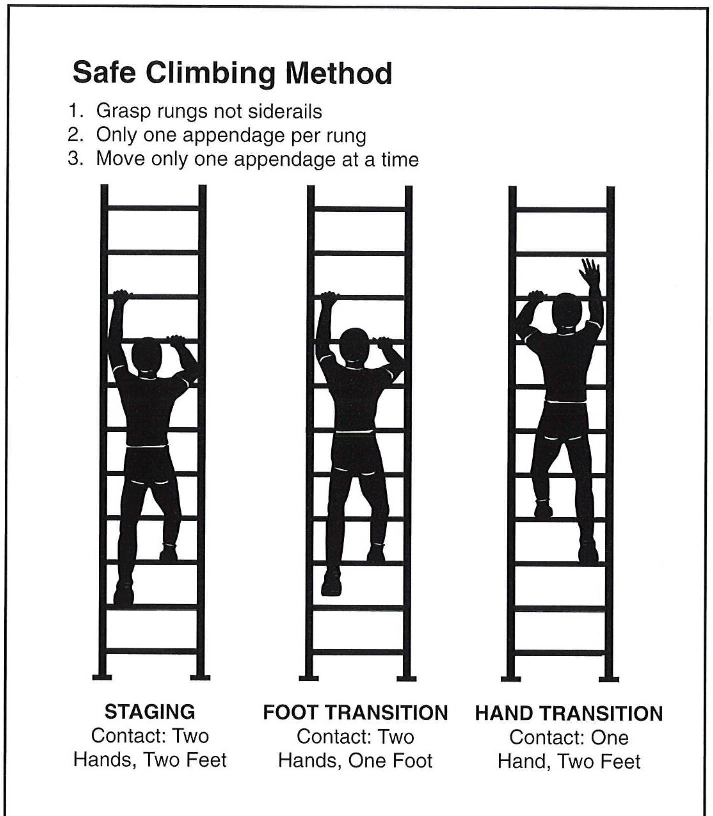


Figure 8 - Optimum Ascension Technique

Figure 9a - Rest Capability

Figure 9b - Dual Hand Release

Ladder Cages

It is inexplicable that the literature on fixed ladders is silent on the topic of ladder cage function in spite of ubiquitous codes and standards that have specified their use for eight decades. Cages enable a climber to rest at any level by leaning backward against the cage structure. Fall protection is provided whenever a climber loses both hand grips while retaining a foothold. These two functions of ladder cages are illustrated in Figs. 9a and 9b respectively.

Sloped Surfaces

All ladder testing and all set-up protocols are based on erecting straight, combination, and extension ladders on firm level ground. When the support surface slopes away from the support structure through an angle θ, Triodyne has shown that equal friction resistance is achieved by increasing the normal set-up angle from 75.52 degrees to (θ + 0.75.52) degrees.

Auto-Setting Ladder Inclination

Unaided, most users will set up a straight ladder at an inclination that is shallower than the recommended 75.52 degrees. These shallow angles compromise the slide-out resistance of the ladder. Many methods have been proposed for setting the optimum ladder inclination. Triodyne has developed an automatic system for setting the ladder slope on either level or sloped surfaces; the principle is illustrated in Fig. 10.

Anti-Telescoping Safety Systems

Long extension ladders are extended by pulling on a rope pulley that deploys the telescoping fly section. As the fly section extends, ladder locks automatically and intermittently grasp the base section rungs. This action is so aggressive that releasing the rope causes the fly section to lock up within one rung space of free-fall. To enable a climber to deliberately lower the fly section for storage, a tongue has been added to the left and right rung locks that bypasses the normal locking action.

When an extension ladder has been locked in working position, any lifting of the fly section over four inches will bypass the rung locks and cause the ladder to collapse by telescoping closed. Thus, the very tongue that conveniently allows for controlled rope lowering also gives rise to a dangerous collapse mode. The tree trimming scenario shown in Fig. 11 leads to an accident when the trimmed support branch springs upward after it has been cut. By removing the conventional tongue and re-rigging the pulley, Triodyne has produced an anti-collapse system with a controlled lowering capability. A version of this system is currently being used in Europe.

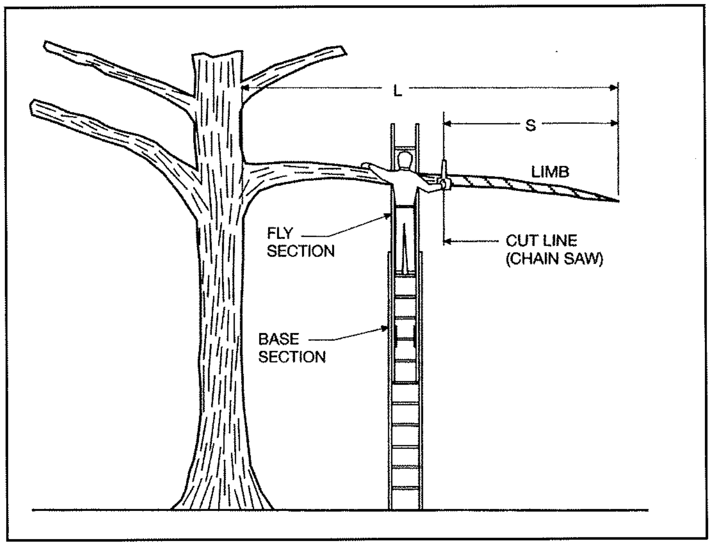


Figure 11 - Tree Trimming Set-Up

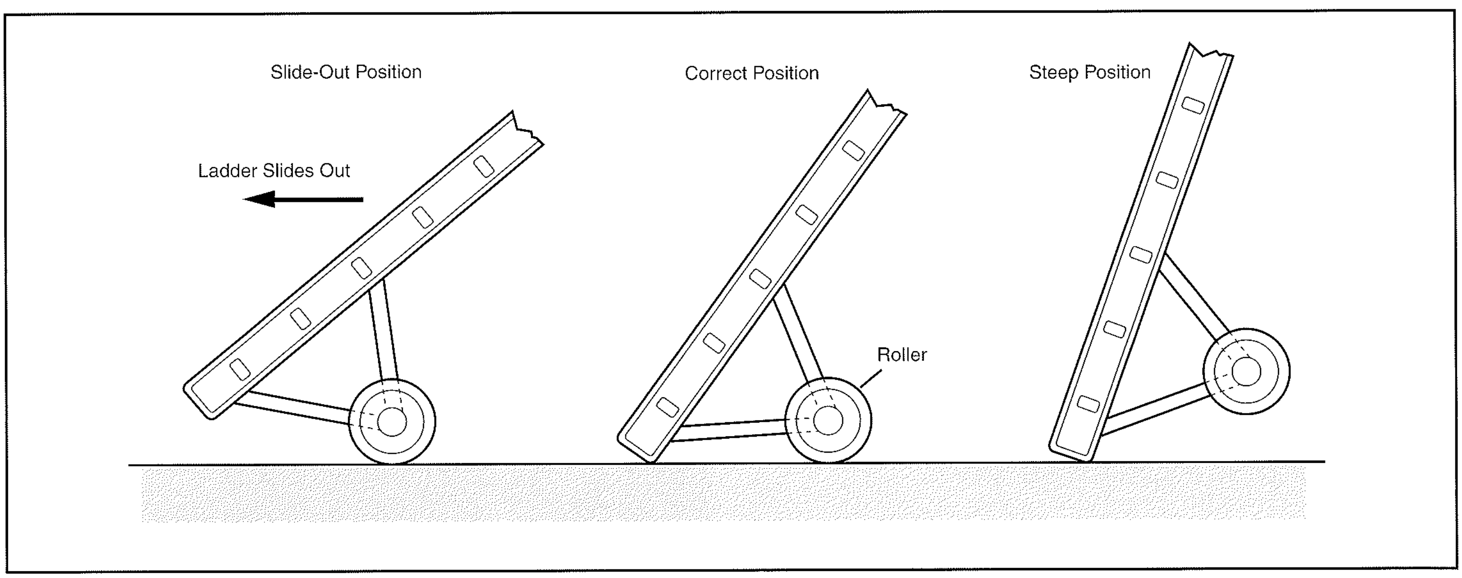


Figure 10 - First Generation of Proposed Invention