University of Southern Queensland

Faculty of Engineering and Surveying

The Development of a New Multi-Directional Fall arrest Device

A dissertation submitted by

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In fulfillment of the requirements of

Courses ENG4111 and ENG4112 Research Project

towards the degree of

Bachelor of Engineering (Mechanical Engineering)

Submitted: 25th October, 2004

University of Southern Queensland

Faculty of Engineering and Surveying

Abstract

This research project has been undertaken to develop a mechanical solution that will automatically arrest the fall of a person working at height in any attitude while allowing unrestricted movement in normal use and to simplify the device set up.

Current fall arrest equipment used in industry are of a cumbersome design with limited application that can lead to potentially serious injury to the user.

Following a review of fall arrest systems used in industrial and recreational applications, a methodology for the design, prototype construction and testing procedures was established.

This dissertation documents the process used to produce a working back up fall arrest device in the following areas:

- Conceptual design.
- Construction of a prototype.
- Testing of the prototype.
- Evaluation of the design and testing.

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I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

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Date

Acknowledgements

I would like to acknowledge the generous assistance, guidance and support given to me whilst undertaking the research project without which many of the tasks would have been difficult to achieve in the limited time I have had to complete the project.

Firstly to the research project supervisor,

Dr Selvan Pather

Of the University of Southern Queensland Engineering and Surveying Faculty,
for his valued guidance and suggestions throughout the whole period taken to complete the project.

Secondly,

Mr Boris Rogelja

Of Single Rope Technique Equipment, Padstow, New South Wales, for the generous use of his time, suggestions and use of his testing equipment to conduct the static testing on the prototype device.

Lastly,

My wife Christine and daughters, Tia Rana and Natasja Raine

For their patience and support during my two month absence while constructing and testing the device in Sydney, and the time taken to produce the project dissertation.

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Glossary of Terms

Abseiling:
Controlled method of descending a fixed rope.

Belay:
Method used by recreational climbers to protect a lead/seconding climber and limit a free fall.

Descender:
Mechanical device attached to single or double rope to allow a person to abseil at a controlled rate and in a controlled manner.

Dynamic Rope:
High elongation synthetic fibre rope used by climbers to reduce deceleration forces imposed on a falling climber sustained by a sudden arrest, generally in 50metre lengths of 8.8 to 11mm diameter with up to 18% elongation under load.

Energy Absorber:
Device designed to reduce the deceleration force imposed by a sudden arrest to less than 6kN of force.

Harness:
Synthetic fabric webbing fabricated to be worn by a user to allow connection to safety point/descender/ascender

Jumar:
Generic name now given to hand held mechanical rope ascent device. Originally designed and manufactured by the Swiss Walter Marte in 1958. Variation still in current production

Karabiner:
Metal ring with a spring loaded close gate used for attaching equipment together - capable of being opened /closed, locked by hand and able to be loaded to 24kN in the primary axis.

Limited Free Fall:
A free fall not greater than 600mm.

Lanyard:
A line used to connect a fall – arrest harness to a safety point/line.

Protection:
Method by climbers used to provide rapid/portable anchor points

Prussiking:
Controlled method of ascending a single fixed rope using two or more mechanical ascender devices in an alternate progressive motion.

Rope Grab:
Mechanical device designed to firmly grip a working line when loaded in one direction, free to move in the other direction. Ascender rope grab types allow for positioning a worker on the work line. Back Up rope grab can be made to freely slide along a safety line whose purpose is to arrest a limited free fall.

Safety Line:

A synthetic fibre rope used as a back up to arrest a limited free fall in the failure of the working line.

Static Rope:

Low elongation synthetic rope used for working and safety lines in industrial applications. Rope lengths can be up to 100 metres of 9 to 13mm with elongation of less than 5%. Kernmantle construction with abrasion resistant outer sheath, Australian/New Zealand Standard 4142.3 refers. An energy absorber must be incorporated if used as a safety line.

Working Line:

A synthetic fibre rope use for the primary support in industrial applications including ascent and descent of an operator.

Type 1 Fall Arrest Device:

Classification under Australian/New Zealand Standard 1891 pertaining to a fall arrest device that can travel along an anchorage line, locks to the line when loaded and can only be loaded in the direction of the line.

Type 2 Fall Arrest Device:

Classification under Australian/New Zealand Standard 1891 pertaining to a fall arrest device that contains a spring retracted anchorage line that pays out, the mechanism locks when loaded and retracts when the load is released.

Type 3 Fall arrest Device

Classification under Australian/New Zealand Standard 1891 pertaining to a fall arrest device that contains a spring retracted anchorage line that pays out, the mechanism locks when loaded but may be manually wound back as a winch after loading and locking.

Chapter 1. Introduction

1.1. Introduction.

1.2. The Need for Research.

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Chapter 1. Introduction

1.1. Introduction

While the contrasts of working at heights and enjoying a height related outdoor activity might seem so different the way fall prevention is approached, eliminating or minimizing the potential for death or serious injury from a fall is paramount in both areas.

In Australia, falls from heights that cause serious injuries or death in many industry sectors are estimated to contribute to over 20% of all workplace fatalities annually.

Falls can occur in almost every workplace environment or on any height related outdoor activity where there is a potential fall hazard, the contributing factor of height can magnify the severity of injuries sustained in fall.

Several fall prevent methods are used in both workplace and recreation areas where the risk of a fall is present. The methods include preventative and pro-active measures to eliminate the risk of a fall or to minimize the fall distance to an acceptable level of risk to a person.

1.2. The Need for Research

Current fall prevention methods used in the workplace are cumbersome and of limited in application that can hinder their operating effectiveness in the advent of a fall. These deficiencies can potentially lead to serious injury or death to the user if the equipment is incorrectly set up or fails during a fall.

Equipment used for recreation is generally both well designed and adaptable for use in many different areas of application. While the equipment is generally designed for lower margins of safety in order to reduce weight and manufacturing costs, the equipment is sufficiently strong enough to withstand the fall forces generated in the advent of a fall.

Research into workplace and recreational fall prevention methods may identify limitations and positive features that could lead to improvements in design and application to eliminate these deficiencies, making the devices safer for the equipment user.

1.3. Dissertation Overview

This dissertation has used a methodology of:

- Design conceptualization was formulated using a review of:

    - State Government Occupational Health and Safety legislation pertaining to work related fall prevention methods.
    - Workplace and recreational fall related accident statistics.
    - Workplace and recreational fall prevention methods.
    - Australia/New Zealand and European Standards required for fall arrest systems and equipment.
    - Critical evaluation of several current fall arrest devices.

- Prototype modeling

    - Device construction.

- Device testing criteria using the Australia/New Zealand Standards and a test proposal for evaluating components outside of the Australia/New Zealand Standards
- Evaluation of prototype test results
- A review of prototype test results

1.4. Project Objectives

To establish the design concepts for the Research Project, the review of background literature and evaluation of several current fall arrest devices identified four key objectives to be met:

- Simplify device connection to the safety rope.
- To design a device that is intuitive to use and eliminate incorrect safety rope attachment.
- Operate without any user inputs.
- Adaptable for several different fall arrest methods.

1.5. Chapter Conclusion

The Introduction Chapter has identified the key areas that have been explored and developed in this dissertation to produce a tested working prototype model based on the dissertation overview to satisfy the project objectives.

Chapter 2 describes the extent of the background research and literature review carried out for fall prevention measures in both the workplace and recreational areas.

Chapter 2. Background Literature Review of Fall Arrest Methods

Chapter 2. Background Literature Review of Fall Arrest Methods

2.1. Introduction

This chapter explores areas of fall arrest method literature identified in Chapter 1 to establish a basis for the design criteria that has been used for the research project. These specific areas reviewed for the fall arrest methods include:

- Government Occupational Health and Safety legislation for workplace and recreation fall arrest prevention.
- Workplace fall related accident statistics.
- Recreation fall related accident statistics.
- Australia/New Zealand and international standards for fall arrest methods and equipment.
- Fall prevention Methods used in the workplace.
- Fall prevention Methods used in recreation activities.

An overview of Risk Assessments for Fall Hazards identified in the literature review of Occupational Health and Safety legislation for the workplace can be viewed in Appendix D.

Background Literature Review

2.2. Government Legislation for Workplace and Recreation Fall Prevention

- Occupational Health and Safety Act And Regulations For Workplace Fall Prevention.

An increase in the number of fatal accidents and severity of injuries sustained from fall related workplace accidents has meant that all Australian state governments have had to impose legislative controls to prevent workplace falls.
Each Australian state and territory has enacted Occupational Health and Safety Act legislation (OH & S Act) to provide a framework of Occupational Health and Safety Regulations (OH & S Regulations) for identifying, eliminating or controlling work related risks. This is accomplished by implementing mandatory risk control measures in the areas of lighting, noise, atmosphere, electricity, confined spaces, heights and man-handling. (New South Wales Occupational Health and Safety Regulation Chapter 4 2001).

The stated objective of the Victorian State Governments Occupational Health and Safety Regulation 2003 legislation is:

> "To eliminate accidents at a workplace involving falls – specifically falls from over 2 metres or to reduce the potential for injuries from a fall"

- Industry Codes of Practice For Specific Workplace Areas

Industry "Codes of Practice" have been adopted to provide practical advice for implementing the regulatory requirements. The NSW WorkCover Authority Code of Practice Safe Work on Roofs, Part 1 – Commercial and Industrial Buildings says:

> "The codes of practice have been developed by a tri-partite working party and has involved extensive consultation with industry and other special interest groups"

The codes give practical guidance on how to comply for any person placed under the obligation of the OH &S Act and its regulations but are not mandatory as the person may

choose to comply with the regulations in another way that fulfils the requirements. The codes of practice have been drafted for specific types of workplace environments by use of a “check list” approach to ensure work is done safely by conducting a risk assessment, work system preparation check and then to implement the control measures that will prevent falls during the work process. Specific topics covered by the codes describe the work areas where the codes are to be used, preferred methods to be considered for fall prevention, other control methods with their inherent risks, personal protective equipment provisions, training and instruction, and legal requirements.
The codes have incorporated Australia/New Zealand Standards publications to be used as additional guidance for complying with the OH & S regulations. Australian/New Zealand Standards are prepared by a technical committee comprising state government statutory departments, employer bodies, unions and interested parties that specify requirements for selecting, using, maintaining and testing industrial fall prevention systems and devices. (Australia/New Zealand Standard AS/NZ 4488.2:1997 Industrial rope access systems)

- Recreational Activity Legislation For Fall Prevention

Private recreational height related activities are specifically excempted from each state OH &S legislative act but are covered under several state regulations for National Parks and Local Government acts that only seek to impose restrictions not to regulate such activities. (Victorian Occupational Health and Safety, Prevention of Falls Regulations p.5 2003).

2.3. Workplace fall related accident statistics

Each Australian state and territory has a regulatory authority body, WorkCover/ WorkSafe, that oversees and enforces each the OH & S legislative acts and regulations required for plant designers, plant manufacturers, employers and employees to be implemented for preventing accidents due to falls from height at the workplace. One function of the body is to collect accident reports for statistical analysis of accident trends across industry groups to provide feed back of regulatory effectiveness.

The bodies provide yearly reports that present accurate information on accidents by type, severity, lost man-hours and cost to the community for overall and by industry groupings. Accident trends for previous years for comparisons are also reported.

- Over a three-year period, 23 people were killed in workplace falls in Victoria alone, while many more were seriously injured in falls. (Victorian WorkCover Authority WorkSafe Online viewed 5 March 2004).

- In New South Wales, for the nine-year period 1991/1992 to 2000/2001 78 people were killed in falls from heights at the work place. (WorkCover NSW Worker Compensation Statistical Bulletin Section 2 Table 2.3.1 2000/2001).

- Workplace and recreational related falls from plant or building sites, cliffs or caves, or falls into pits or shafts, have the potential for causing serious injury or death but also cause great cost to community and business. While the gross cost of workplace injuries was more than $804,000,000 AUD to the community in New South Wales for the 292,157 weeks of lost time, 9.4% of this total were caused by falls from height. (WorkCover NSW Worker Compensation Statistical Bulletin Section 3 200/2001).

2.4. Recreation Fall Related Accident Statistics

Statistics related to recreation fall related accidents have been collated by recreational sporting bodies for use as an accident preventative measure in several countries around the world.

The Australian Climbing Accident Data operated by members of the Victorian Climbing Club has collected records of 300 climbing accidents for the fifty year period to 2004 of Australians undertaking recreational activities for the specific areas of abseiling, rockclimbing, gymnasium climbing and mountaineering. The database provides an overview for accident type, severity, activity, age and experience of the participants and gives selected findings into several of the accidents.

The ACAD report, Climbing Accidents in Australia 1955-2004, reports that of the 83 deaths to Australians in climbing related activities in Australia and internationally, 40 people were killed in fall related accidents. The report's author states that specific analysis of the statistics breakdown is yet to be conducted. However he provides selected findings that highlights the need for several preventative measures that could potentially reduce the severity of climbing related accidents. (Climbing Accidents in Australia 1955 –2004. Ian B Sedgman).

2.5. Australia/New Zealand Standards For Workplace Fall Arrest Methods

The Australia/New Zealand Standard AS/NZ 1891.4:200 Industrial fall-arrest systems and devices Part 4: Selection, use and maintenance 31 July 2000 recommends for:

- Total restraint – using a restraint belt and fixed restraint lanyard attached to an anchor of 6kN ultimate tensile strength.

- Restrained falls – either a body belt or work positioning harness should be used with a fixed length restraint lanyard of 6kN ultimate tensile strength.

- Limited free fall **-** a fixed lanyard and work positioning harness should be used with an anchorage of ultimate tensile strength 12kN or horizontal lifeline/rail system to limit a free fall of less than 600 mm.

- Free falls **-** the fall arrest system used with a fall arrest harness lanyard or fall arrest device connected to a 15kN ultimate strength anchor or horizontal lifeline/rail system should limit a free fall to 2 metres maximum.

Selection for determining the most appropriate types of system components for the envisaged use is based on:

- Risk assessment of hazard.

- Work type.

- Mobility requirements were the degree of lateral and vertical movement needed to perform a task while connected to system.

- Effects on wearer regardless of the system type if there is a potential for a free fall of more than 600 mm a fall arrest harness is to be worn.

- System components should be compatible with each other to ensure maximum degree of safety, comfort, freedom of movement and security against injury in the advent of a fall. Potential and severity of the fall risk.
  (Australia/New Zealand Standard AS/NZ 1891.4:200 Industrial fall-arrest systems and devices Part 4: Selection, use and maintenance 31 July 2000).

Safe use relating to practices to be followed for the selected system:

- Fall arrest equipment should be used in accordance with the manufacturer's instructions.

- The equipment should be carefully handled to preclude damage. Defective equipment should be destroyed or marked "defective" to prevent it being reused.

- Particular fall arrest equipment should be used only if there is sufficient fall clearance for the system to operate.

- Rescue provisions are in place to quickly remove a person from a suspended position. The provisions should reflect an awareness that a person can only be suspended in a harness for a short time after sustaining a fall as they may suffer suspension trauma from blood pooling in their legs which can lead to loss of consciousness and eventually death.

- Inspection, maintenance and storage.

- All equipment items in regular use are subject to scheduled periodic inspection and servicing at either manufactures recommendation or the guidelines listed in the standard.

- Accurate equipment records for each piece of equipment should be kept for documenting the service and maintenance history.

- Equipment should be stored dry and away from excessive heat, humidity or moisture.

Equipment types used for Fall-arrest devices are described in Australia/New Zealand Standard AS/NZ 1891.3 Industrial fall-arrest systems and devices Part 3: Fall-arrest devices:

- Lanyards made of synthetic webbing may be required to make the connection between the workers harness and a safety anchor or back up rope grab. The lanyard length should be as short as practicable to prevent a free fall longer than 600 mm. A short lanyard of 300mm is recommended if a worker is to incorporate a personal energy absorber when a back up rope grab is used.

- Fall arrest devices may utilize grab cams or inertial elements to lock and arrest a worker in the advent of a fall.

  Australia/New Zealand Standard AS/NZ 1891.3 Industrial fall-arrest systems and devices Part 3: Fall-arrest devices classifies the devices as;

  > "Type 1 - a fall-arrest device which travels along an anchorage line, locks to the line when loaded and can only be loaded in the direction of the line."

> "Type 2 – a fall-arrest device from which a spring loaded anchorage line pays out, and which locks when loaded and releases when the load is removed, e.g. an inertia-reel device"
>
> "Type 3 – a fall arrest device from which a spring-loaded anchorage line pays out, which locks when loaded, but may be wound back as a winch after loading and locking."

2.6. International Standards for Recreational Fall Arrest Methods

Standards for commercially available recreational equipment have mainly been European in origin, the two main standards in use are:

- Union Internationale de Association d' Alpinisme (UIAA).
  The first requirements for climbing ropes where adopted in 1951 by the UIAA over concerns with rope quality particularly with the then recently introduced nylon 66 ropes (UIAA website 2001).
  The UIAA is an international representative body of international and national mountaineering and climbing bodies and guides associations from over 70 countries from around the world including Australia and New Zealand that actively promote mountain recreation.

  The UIAA website's official history says for mountaineering equipment:

  > " (the) UIAA role is to promote reliable equipment suited to the needs of the terrain"

  UIAA Safety Standards and quality control committees have been long established to ensure equipment manufactures that seek UIAA endorsement comply with the UIAA standards. The UIAA label is marked onto equipment that is recognized by these UIAA committees. Many of the UIAA standards for recreation equipment have been referred to for European Standards (EN) which have been produced to cover recreational equipment compliance for industrial applications in the 18 European Economic Area countries.

- CE Marking System
  Many international manufactures of personal protective recreational equipment (PPRE) have begun adopting European Economic Area (EEA) conformance procedures and regulations that require them to comply with design and manufacturing requirements for their products. The CE Marking system has become a defacto standard for a majority of PPRE manufacturers around the world as all PPRE products that are intended to be sold in the European market are obliged to carry the CE marking before they can be freely traded in the 18 member countries of the EEA.
  The CE Marking system indicates that the product conforms to set European health, safety and environmental protection legislation subject to conformity assessment procedures.

  The CE Marking website comments:

  > "There is only one set of requirements and procedures to comply with in design and manufacturing a product for the entire EEA. The various and conflicting national regulations are eliminated. As a result the product no longer needs to be adapted to the specific requirements of the different member states of the EEA."

The benefit of implementing the CE marking requirements for the manufacturer has been of greater user acceptance now that the PPRE products are now designed and manufactured to a safer and consistent standard than previously.
However equipment and systems used in the workplace in EEA members countries are still required to conform to European Standards. (CE Marking Website 2001)

- From Recreational Use to Industry Standards:
  The cross over from recreational to industrial use has been accomplished through the European and Australia/New Zealand Standards system of using technical committees to specify the standards requirements. In compiling several of the EN standards for a particular industrial fall arrest device the UIAA standard for the device has been used as a reference. Several of the Australian Standards for industrial fall arrest devices have in turn referred to the relevant EN standard for compiling the Australia/New Zealand standards requirements. (AS/NZ 1891 4:2000).
  UIAA members: the New Zealand Alpine Club and the New Zealand Mountain Guides Association have had representation on the Joint Technical Committees that have formulated the standards requirements for certain Australia/New Zealand standards. This has led to increased awareness of risk assessment and alternate fall prevention techniques and has allowed scope for flexibility while reducing risk and overall cost of complying with the government regulations for working at heights. For specific Australia/New Zealand Standards, specific EN standards are accepted under the requirements of the Australian system. (AS/NZ 1891.3:1997 p.5) A number of recreational fall arrest items that are commercially available in Australia can in fact have several international standards labels; the UIAA label, a CE Mark, an EN number and an AS/NZ standards number. (Petzl Rescucender brochure 2001).

2.7. Fall Prevention Measures Used in the Workplace

Work-site control measures are developed using the risk assessment and the hierarchical system approach to rank the order of fall control measures required. Practicable measures for controlling fall risk are selected according to how appropriate they are in performing the task and the severity of the risk involved.

2.7.1 Work on Ground

By eliminating the requirement for a task to be performed at height, the risk due to a fall may be effectively nullified. Methods can include using prefabrication of components at ground level and erection on site or the use of tools with extended handles. (WorkCover Victoria Code of Practice – (No.28) – Prevention of Falls in General Construction p.8 31 March 2004).

2.7.2. Work from a Solid Surface

By utilizing areas of a work-site to act as a solid surface that can support people, equipment and material loads, the fall risk can be eliminated by:

- Ensuring that the surface is of sufficient structural strength that will safely carry the expected loads. A structural engineer may need to determine the safe load capacity.
- Providing perimeter protection around all exposed openings and edges from or through which a worker could fall.
- Providing an even, slope free surface. WorkCover Victoria Code of Practice – (No.28) Prevention of Falls in General Construction 2004 recommends maximum slope gradients for smooth or grated surfaces and to for the surface to be free of trip hazards.

- Providing a safe means of access and egress to the solid surface. Permanently fixed platforms are required to comply with Australia/New Zealand Standard AS/NZ 1657 Fixed platforms, walkways, stairways and ladders – Design construction and installation

2.7.2 Passive Fall Prevention Measures

Passive fall measures are a combination of material and equipment designed and installed with the intention to prevent a worker falling that does not require any on going adjustment, alteration or operation by any person to ensure the integrity of the system to provide that function.

2.7.3.1 Temporary Work Platforms – Scaffolding

Scaffolding is used for many applications where a temporary stable and safe work platform is required for work at height. Depending on anticipated loads, scaffolding is rated as light, medium, heavy or special duty for the safe loading limitations. State government regulations require that scaffolding where a person or object could fall more than 4 metres must be erected by certified rigger and the scaffolding must comply with Australia/New Zealand Standard AS/NZ 4576 Guidelines for scaffolding.
Scaffolding can introduce additional hazards and risks during erection and use:

- Falls from height during erection and use by ensuring full platform decks, handrails and access ladders are progressively installed.
- Use toe boards and platform trapdoors to prevent objects from falling.
- Surface conditions are vital for the strength and stability of the scaffolding.
- Weather conditions strong winds during erection.
  (WorkCover Victoria Code of Practice – (No.28) – Prevention of Falls in General Construction pp. 9-11 31 March 2004)

2.7.3.2 Elevated Work Platforms

There are many types of elevated work platforms (EWP) available for use in industry to provide mechanized access for work at heights that provide a stable ground based level work platform. The platforms are considered plant and are subject to State plant regulations for design, installation, use and maintenance. Australia /New Zealand Standard AS/NZ 2550.10 Cranes - Safe use - Elevating work platforms refers to specific measures for safe use:

- Safe working load limits should be clearly marked on the unit.
- Operators working above 11 metres in boom lifts, cherry pickers or travel towers are required to wear a safety harness anchored to a secure point in the work platform area that will arrest a fall from the work platform. All operators are required under state regulation to hold an EWP operator certificate to ensure competency.
- EWP should only be used on a solid level surface unless specifically designed for operation on rough terrain. The surface should be inspected for obstruction hazards that could cause the unit to overturn.
- Check weather condition – particularly high winds, which could overturn the EWP. EWP can be powered either by internal combustion engines or storage battery electric-hydraulic units that include;
  (i) Scissor lift units available in wide selection of work platform areas and reach – generally self driveable, but are required to be stabilized before being operated at height, operation is generally restricted to vertical movement only.
  (ii) Boom lifts – generally self-driveable aerial units that can be moved in three axes and can be repositioned while the boom is extended. The units are designed to be

operated throughout their full range of movement with out the need for stabilization if used on a level surface. Required to be positioned and stabilized before operating the boom.

(iv) Travel platforms – these include mast/ tower climbing platforms and horizontal travel platforms. Travel platforms may be of a portable design that can be towed into position and stabilized for use or are erected at the work-site for use.

2.7.3.3 Fabricated Work Platforms

Fabricated work platforms (FWP) are designed for specific tasks that can be permanently fixed, portable or mobile to provide a stable work area for work at height. FWP incorporate perimeter guard-railing, toe boards, barriers, safe access/ egress to the work platform, and safety anchor attach points complying to Australian/New Zealand Standard AS/NZ 1891 Industrial fall-arrest systems and device for platforms, for heights above 2m.

Portable/ mobile FWP are designed to form a permanent moveable "solid work surface" that can be positioned around a work-site for a specific task:

- Construction and building use for concrete column and ceiling fixture work.

- Aircraft maintenance access stairs for entry/ egress to aircraft or for fixed height work platforms used for aircraft servicing, some types incorporate hydraulic height adjustment. Docking systems used for aircraft maintenance work provide a multi-level "solid work surface" that are designed to provide safe access and eliminate fall hazards on fuselage, wings and empenage areas. Aircraft docking systems can be either roof suspended and/or floor mounted with levels linked by access stairways or ladders, Figure 1. Below shows how a combined floor mounted/roof suspended system is used to enclose a Boeing 747-400 aircraft. Several modules are used to encompass a whole aircraft. Ground mounted modules are towed/ pushed into position while roof suspended systems lower the dockings into position by electric motor or pneumatic driven jackscrews. Provisions are made for safety harness-attach points and lowerable perimeter guardrails for flight control operation checks and aircraft de-docking.

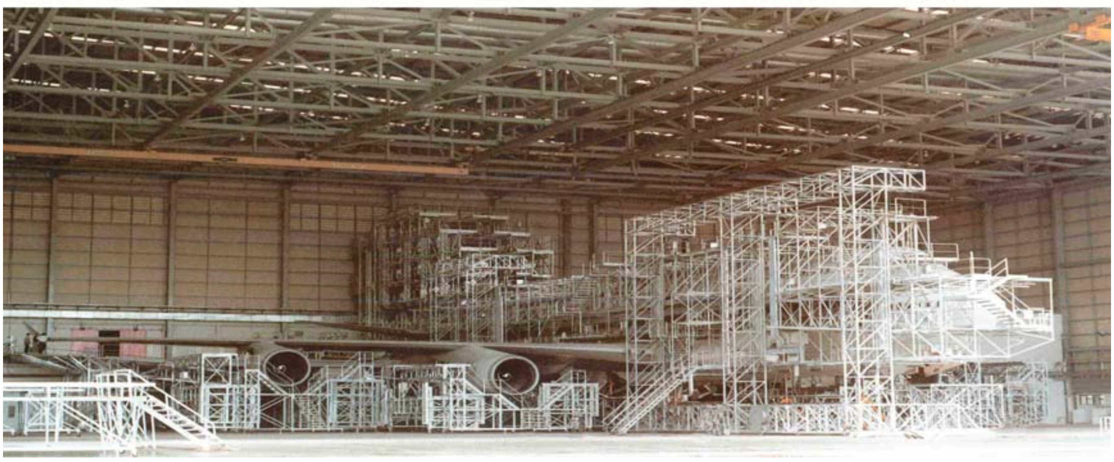

Figure 2.1. Fixed Working Platforms
Floor mounted wing and fuselage dockings, and roof suspended empenage dockings used on this Thai Airways Boeing 747-400 aircraft provide safe access to all areas for aircraft maintenance tasks.

Dockings decks are designed to support operation loads for specific maintenance tasks and to allow limited re-configuration of the docking sections due to different aircraft or engine types. (Airlines Support Industries Australia Pty Ltd Brochure March 2004)
Traverse /climbing platforms (T/CP) used for building maintenance.
T/CP types include cable climbing “window cleaner/ painter” platforms that are electric motor powered and purlin trolleys that traverse the length of a horizontal steel beam. For purlin trolleys roof structures are required to be capable of supporting the trolley and operational loads. The T/CP must be provided with holding brakes and mechanisms to prevent the platforms from inadvertent dislodgment from purlins. Fall protective guardrails on T/CP are required, if this is not practicable the user must wear a safety harness anchored to the platform.
To reduce hazards when using portable/ mobile FWP only use on level surfaces that can support the load safely. Lock the castors to prevent movement the FWP while anyone is on them.

2.7.3.4 Perimeter Protection Against Fall Hazards

Perimeter protection (PP) provides a high level of all of fall protection against a worker inadvertently falling from an unprotected edge or opening. State codes of practice recommend that PP provision be made if work is to be carried out within 2 metres of any edge where a person could fall 2 metres or more.
The NSW WorkCover Code of Practice Safe Work on Roofs Part 2 – Residential Buildings 1 March 1997 recommends that:

> “perimeter protection should be provided for all work irrespective of height if the risk assessment has identified an increased risk of falling from
> - slippery roofing materials
> - the pitch of a roof exceeds 25 degrees, or 15 degrees if it made from a brittle material
> - if a hazardous situation exists below the work surface onto which a person could fall if a worker is exposed to a risk of a 2 metre fall from a roof perimeter”

Methods of perimeter protection that are used are:

- Safety Meshing/ Netting. While not strictly part of PP, the mesh system is generally used in conjunction with edge and perimeter protection while performing roof work. Meshing/ netting can either be long term where a wire mesh is placed under a brittle or fragile roof or as a temporary protection measure were a flexible net is placed over a brittle or fragile roof. The mesh/ net system works by preventing a worker from an internal fall if the worker breaks through a brittle or fragile roof surface or when installing roofing materials. For brittle and fragile roofs permanent safety meshing consists of 2 millimetre diameter steel wire welded into a mesh of 150 mm by 300mm spacing that is secured to roof purlins by a qualified contractor in accordance with Australian Standard 2424-1981 *Plastic Building Sheets – General installation requirements and design of roofing systems.* Safety netting is applied as a fall prevention measure by placing cables over each roof bay and the roof perimeter, then the net is hung over each cable and is then secured are secured in position. The CP93British Standard Institution (BSI) Code of Practice for the Use of Safety Nets on Construction Works refers to net installation for use in New South Wales.
  Nets are required to be inspected after installation, repositioning or repair and require daily inspection for cuts, abrasion, heat/fire damage from welding or gas

cutting processes. Repairs are required to be carried out before work is resumed above the net.

- Exterior Perimeter Screens are used for building facades during construction or renovation work. Purpose built screens are either secured to the exterior of a building or secured to scaffolding that surrounds the building, screens are required to cover at least two levels of a work-site. The screens serve three main purposes by protecting people below the work-site from falling debris, to prevent workers from falling from the perimeter edge at the work site level and to provide fall protection while an upper level is being constructed.
  (WorkCover Victoria Code of Practice – (No.28) – Prevention of Falls in General Construction pp. 23-24, 31 March 2004)

- Perimeter Guardrails provide effective fall prevention at perimeter edges, skylights, on fragile roofs, openings in floor or roof areas, and at edges or shafts or excavated areas.
  The NSW WorkCover Code of Practice Safe Work on Roofs, Part 1- Commercial and Industrial Buildings November 1993 recommends that guardrails should be between 900 mm and 1 metre in height above the work surface, to incorporate a mid rail, have a toe board if the slope of the roof exceeds 15 degrees and be constructed to withstand a force of 0.445 kN at any point on the rail.
  The most appropriate type of guardrail system is dependent on the roof pitch angle, the roof structure that the guardrail will be attached to and the force applied by the momentum of a falling person.
  For a steep roof of 38 and up to 45 degrees, the NSW WorkCover Code of Practice Safe Work on Roofs, Part 2 – Residential Buildings 1 March 1997 recommends that a two plank 450 mm wide working "catcher" platform with an outer guardrail be constructed out from the roof perimeter. This is to minimize the likelihood of a worker falling onto, then over the guardrail

2.7.3.5 Work Positioning Systems

Work positioning systems (WPS) allow a worker to be positioned and safely supported while performing a task at an elevated work-site. WPS are requires a higher level of training and competency with close supervision required to ensure correct procedures are adhered to.

The Victorian WorkSafe Code of Practice for the Prevention of Falls in General Construction 31 March 2004 states;

> " according to the hierarchy of control they (WPS) should only be used where it is not practicable to use higher order controls"

For steep work areas that exceed 35 degrees, guardrails and catcher platforms are considered inappropriate by the Victorian WorkCover as standing is made difficult on steep roofs or parts of an aircraft structure.
WPS using travel restraints, industrial rope access equipment or scaffold platforms/ roof pitch laddering systems should be used to provide a safer alternative.

- Travel Restraint Systems. Travel restraint systems (TRS) prevent workers from approaching an unprotected edge on a work-site while carrying out work. Generally the system comprises of a safety harness worn by the worker attached by a lanyard to a safety attach point or a static line or rail system. When considering the positioning of safety attach points and static lines, the engineer must consider that the temporary or

permanent anchors and building or plant structure are suitable to support the anticipated loading, safe access and egress to the safety anchors/ static line points.
Careful consideration should be given for positioning the anchor points to limit a free fall and to prevent possible 'swing down' or 'swing back' falls where the worker is swung down onto a lower surface or back into an obstruction if the worker has been working at an angle away from the anchor. Damage to the lanyard can occur if the falling worker is allowed to swing back across a perimeter edge until directly below the anchor. To prevent this occurring, a second anchor or a sliding attachment on the static line may be required to allow the worker's attach lanyard to be positioned directly in line with the work area to prevent swing down and swing back types of falls.
(WorkCover Victoria Code of Practice – (No.28) – Prevention of Falls in General
Types of TRS include:

- Temporary and permanent building safety point anchors and static line systems. Safety point anchors are placed on the building structure to allow for site specific tasks to be carried out, while static cables/rails systems allow a worker both safety for specific tasks and also access/egress to those area while preventing the worker from approaching an unprotected edge.
  Plant such as aircraft docking systems have permanent safety attach anchor and permanent static lines set up to allow a worker wearing a safety harness and lanyard to quickly attach to if the task requires them to work in areas that are either steep or have a risk due an unprotected edge. Areas include crown areas of fuselages were a full travel static line and lanyard system built into a hanger roof allows a worker to walk on top of the fuselage and to be supported while working on the steeper fuselage sections. Some areas of a wide body transport aircraft have safety attach receptacles incorporated into their structure that allows for temporary static lines to be installed. One example is the Boeing B747 where safety anchor points are placed on the upper wing and horizontal stabilizer surfaces to allow work to be carried out near the unprotected leading and trailing edges and engine pylon areas. Either a static line system can be connected between the over-wing entry door and the wing surface receptacles which will allow the worker to traverse safely to a work area on the upper wing surface or a worker can be attached directly to the receptacle to allow a "circle of access". (Boeing 747–400 Aircraft Maintenance Manual 27-00-01 Page 22

- A recent approach for temporary safety anchors for wide body aircraft is the innovative use of a vacuum diaphragm device powered from a pneumatic source that can be used as a WPS anchor for use on aircraft upper wing surfaces. The WinGrip device shown in Figure 2. uses a pneumatic driven vacuum pump to attach a large diameter diaphragm to a smooth almost flat surface.

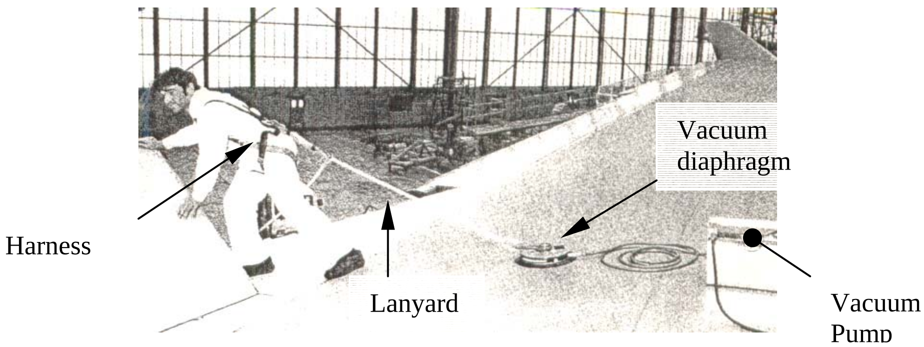

Figure 2.2. Work Positioning System; the WinGrip System uses an innovative vacuum pad solution for preventing falls from height while working on-top of aircraft structures near an exposed edge.

The equipment is intended for use by a single worker who can carry the 5.5.kg device and quickly set it up on the wing surface, then attach his harness/ lanyard for restraint while working. (WinGrip Rota Limited West Midlands England Revision 4, Jan 2000)

- Individual Fall Arrest Systems. Independent fall arrest systems (IFS) are used to arrest falls near unprotected edges, the systems differ from WPS in that IFS may not provide continuous support but becomes effective in the event of a fall. The state and territory OH & S regulations refer to Australian Standard 1891 Industrial fall-arrest systems and devices for setting out requirements and recommendations;
  A worker at risk of a potential injury producing fall is to be secured by an appropriate fall arrest system that will:
- Will not be subjected to an arresting force not exceeding 6 kN.
- Wear equipment that will distribute fall–arrest forces over the body in a way that will minimize the possibility of injury.
- Be connected to a system that will prevent the user reaching the ground or striking any other obstacle that could cause injury and will maintain a suitable post fall attitude for rescue.

2.7.3.6. Industrial Rope Access Systems

Industrial rope access systems (IRAS) give a worker access to an elevated worksite below an anchor using rope descent/ascent techniques that have been developed by a Joint Technical committee represented by employer bodies, state government OH & S departments, employee unions, Industrial Rope Access Associations and recreational clubs.
Australia/New Zealand Standard AS/NZ 4488.2:1997 Industrial rope access systems Part 2: Selection, use and maintenance Appendix A page 15 describes a typical method for IRAS that draws from the European Standard EN 567 Mountaineering equipment, rope clamp, safety requirements and test method.
The system utilizes two independently secured lines for ascent/descent procedures

- A working line is used to support the worker and his equipment load. The worker is connected to the working line by a descender attached to his harness for descending, refer to Figure 3(a). and by ascender rope grabs attached to his harness when ascending, refer to Figure 3(b).
- A safety line provides security in the event the working line or its anchor or attachment fails. The worker is connected to the safety line by a rope grab attached by a lanyard to his harness.

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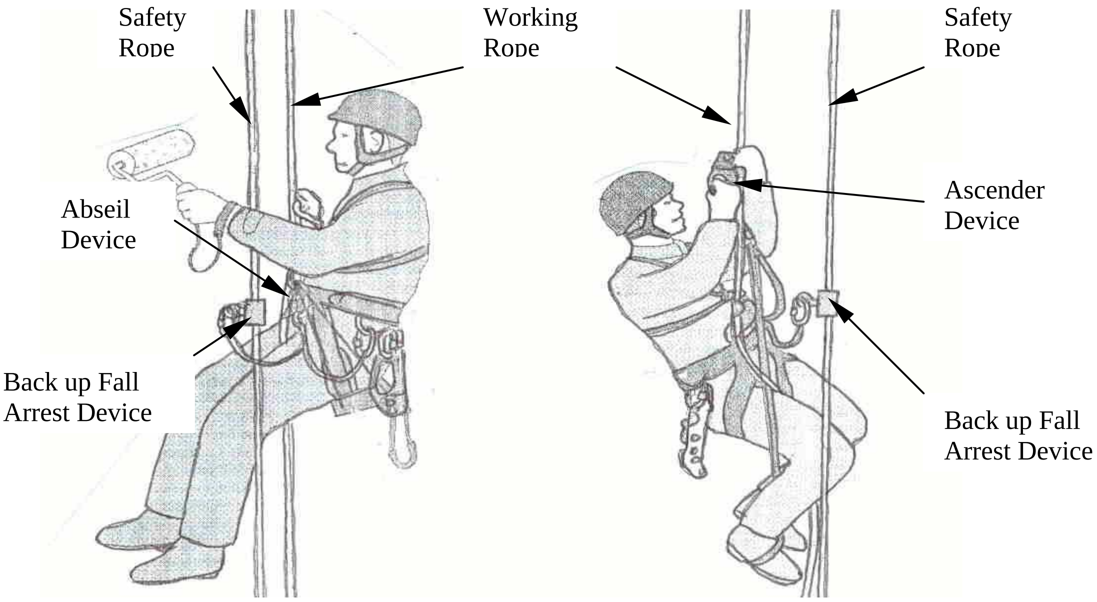

Figure 2.3.(a). Industrial Rope Access Descent. Descender device used on working rope, back-up rope grab used on safety rope.

Figure 2.3.(b). Industrial Rope Access Ascent. Ascender devices used on working rope, back-up rope grab used on safety rope.

The system allows for three operation modes:

- Descent only using a descender where the worker progressively controls his descent to a lower work-site in incremental stages as the back up rope grab on the safety line must be physically repositioned lower as the worker descends.
- Descent only using two ascenders the worker incrementally descends by climbing down the working rope alternately unweighting one ascender at a time and moving it down and repeating the process for the next ascender. The back up rope grab must be physically repositioned lower each time.
- Ascent using only the ascenders, the worker incrementally unweights one ascender and moves it up repeating the process to gain height with each The rope grab is also physically moved up each time.

Considerations for setting up of IRAS:

- Rope Access Systems give direct access to a an elevated work-site directly below an anchor
  point. Careful thought must be given on how to position anchors so that a worker is able to comfortably work within his reach. Redirection anchors may be required to allow the working and safety ropes to be positioned sideways to
  each the work-site.
- Rope protection at points where abrasion or other damage to the work and safety lines may be needed using protective sleeves or rollers systems.

- Energy absorber is required to be incorporated between the worker and the safety line so that the maximum force of an arrested fall does not exceed 6kN.This can be done by incorporating an energy absorber in the safety line or by using a personal energy absorber in the lanyard.

2.8. Fall Prevention Methods Used in Recreational Areas

In Australia, equipment and systems used in the outdoor recreation areas of rock climbing, abseiling and caving have evolved not from a strict regulatory frame work but from a sensible approach by users that has been greatly influenced by a number of very unique innovations in equipment design, manufacture and application.

Outdoor sports encompass many forms of fall arrest systems for use in either ground up or a top down approach that allows the user to identify and reduce the risk and hazard levels to a level that would be deemed unacceptable for industrial use.
The four main areas where forms of fall-arrest systems are used in recreational activities are:

2.8.1. Abseiling.

Abseiling is a controlled descent of a rope using friction between the abseil device and a fixed rope to control the rate of descent. By increasing the load on the free end of the rope, the abseiler will increase the friction between the rope and the abseil device, which slows the abseilers descent. Figure 4. Shows the basic equipment used by an abseiler.

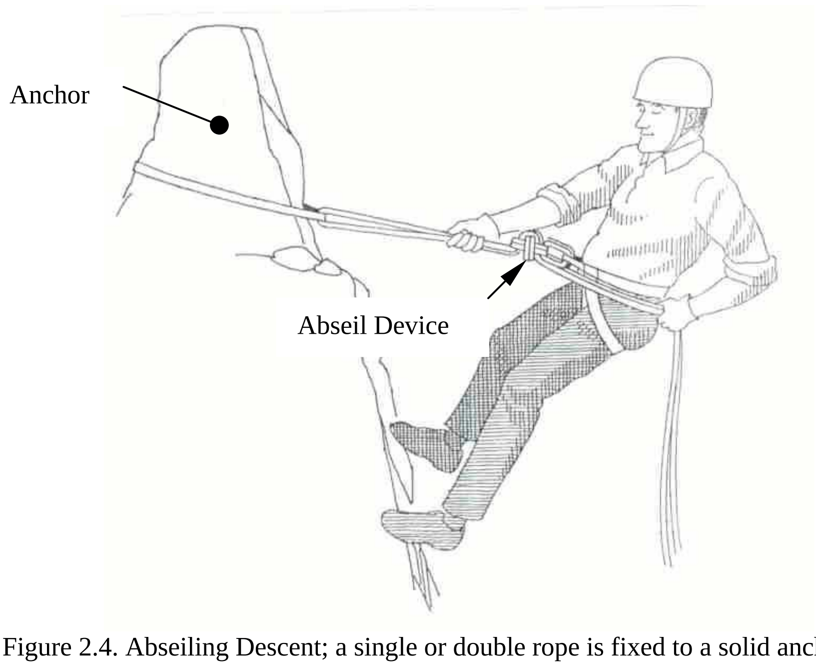

Figure 2.4. Abseiling Descent; a single or double rope is fixed to a solid anchor point, the abseiler is connected by a descender device to the rope and his harness. The abseiler can control his rate of descent by adjusting the friction through the systemby increasing the load with his left-hand grip.

Ropes generally used are 9 to 11 mm diameter low stretch “static” ropes of 50 metres long. The ropes can be rigged as a single strand by attaching the rope to anchors at the top of the pitch or the rope can be rigged for retrieval at the base of the pitch by looping the rope

around the anchor point and abseiling down the doubled rope, then pulling one end of the rope down afterwards.
At the top of a pitch fall protection using a lanyard is employed to prevent an abseiler reaching an unprotected edge while connecting to the abseil rope.
If an abseiler gets into difficulties during the descent, a person standing at the base of the pitch is able to lock/control the abseilers descent rate. By pulling on the free ends of the rope the person can effectively "brake" the abseilers fall, Figure 5. refers. (Montgomery N. Single Rope Techniques p.68 1977

Figure 2.5. Bottom Belay Braking; an abseilers descent can be stopped/controlled by increasing the friction through the descent device by a person pulling on the free ends of the rope.

2.8.2. Caving.

Systems used in caving allow a person to descend, traverse and ascent areas inside a cave where there is a height hazard or the risk of a fall. Abseiling systems are adapted for use in caves by using the same rope to for ascending if required, Figure 6 shows one method of using two ascender rope grabs to allow a caver to safely ascend a rope. Unlike IRAS, a back-up safety line is not used.

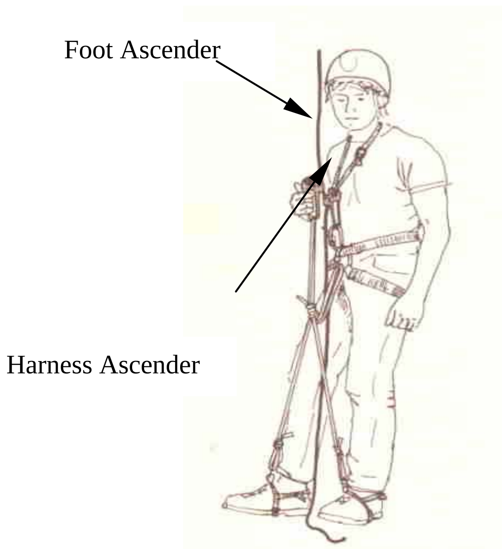

Figure 2.6. Frog Method of Ascender Rope Grab attachment; two ascenders are used – one directly attached to the cavers sit harness, the second to both feet by lanyards/cord. An alternating sit-stand position allows the caver to progressively ascend the rope.

While the risk may be increased by not using a safety line, it allows a large reduction in descent and ascent times. Low stretch static ropes are required to be used to avoid excessive rope bounce, which can lead to rope abrasion on the cave surfaces particularly during prussik ascents using ascenders. Dynamic ropes also suffer internal damage due to mud/dust particles from the cave environment penetrating the looser outer rope sheath of the rope where it can internally wear the rope core during use. The tighter sheath weave of a static rope prevents this. For safe passage through a cave, horizontal fixed safety ropes can be rigged to allow a person to traverse across hazardous areas, fall prevention two point lanyards allow the caver to remain connected to the safety line and bypass intermediate anchors safely. (Montgomery N., Single Rope Techniques p.37 1977)
Portable flexible cable ladders are also used for descent/ascent in some caves. The fall arrest method is by using a dynamic rope belay to arrest a caver if he falls from the ladder, refer Figure 7. below. A second caver is positioned at the top of the ladder connected to separate anchors to that of the ladder to control the dynamic rope by pulling in the rope as the caver ascends the ladder. If the caver falls the belayer can lock the belay rope to arrest the fall.

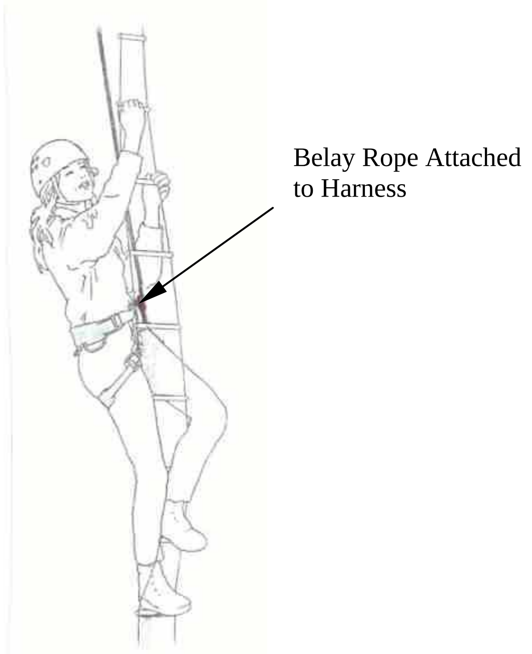

Figure 2.7. Dynamic Rope Belay of a Caver Climbing a Caving Ladder to Provide Fall Arrest.

2.8.3. Rock-Climbing.

Fall arrest methods used in rockclimbing are the most advanced of the recreational outdoor sports.
The systems using high energy absorbing "dynamic" ropes and innovative temporary friction anchors that have been developed from incremental improvements over many years in materials and equipment design that are able to withstand the large fall forces generated. The systems have allowed extreme forms of climbing to develop as the inherent risks have been significantly reduced:

- Lead Climbing. To reduce the risk of a fall a lead climber places intermediate anchors using the natural rock formation and a selection of mechanical friction devices placed at regular intervals on the pitch to allow the safety rope to be connected to. In the advent of a fall the lead climber will fall as far down as the last anchor plus the distance he was above the anchor while his second uses his belay device to lock and arrest the fall, Figure 8. below shows the lead climber/ second climber team during a climb.

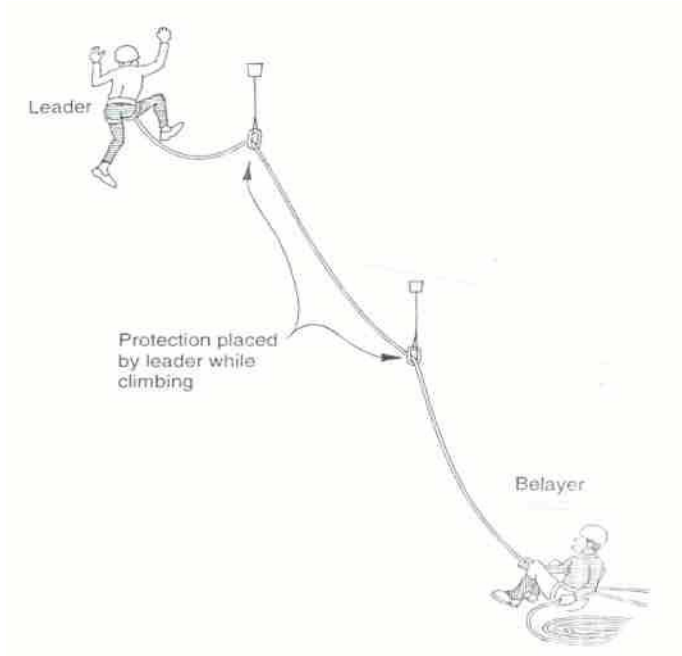

Figure 2.8. Rockclimbing Fall Arresting; climb leader being belayed by second climber

The impact fall force generated in the safety rope by the falling lead climber is absorbed by the safety rope, each anchor point and the belayer.
A fall factor of the ratio of rope distance between the belayer and climber verses the actual climber's fall distance can be used to find the severity of the impact fall force generated in the rope. The most severe fall is a "factor 2 fall" where the climber falls double the distance of the rope distance between him and the belayer, Figure 9(a). shows a "factor 2 fall". As a climber progressively climbs a pitch the fall factor reduces as more intermediate anchors are placed and the rope distance between the climber and belayer increases, Figure 9(b). shows the reduced fall factor as a climb is progressed.

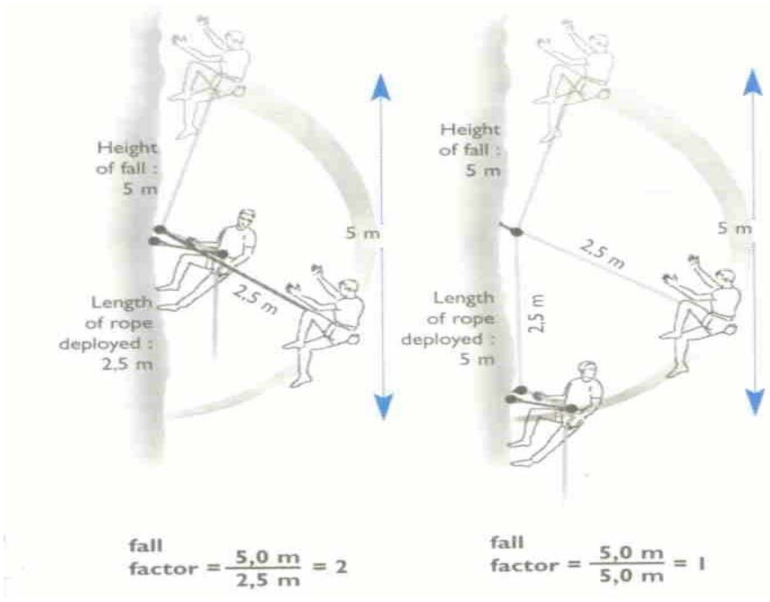

Figure 2.9.(a) The Most Severe Fall: A Factor 2 Fall

Figure 2.9.(b). Less Severe Fall: Less than a factor 2 fall

The resulting impact force generated in a rope is reduced as fall force are transferred to the intermediate anchors and absorbed by the greater length of rope between the climbers. (Grayson D. Ed Freedom of the Hills pp. 131-135 1992).

- Top Roping. This is similar to the belay method used for caving ladders. After the lead climber has set up an anchor system at the top of a pitch, the lead climber belays the second climber by pulling the safety rope through a belay device connected to the anchors. As the second climbs the rock-face removing the intermediate anchors as he ascends, the lead climber takes in the rope in case the second falls off the climb, Figure 10 below shows this fall prevention methods in use.

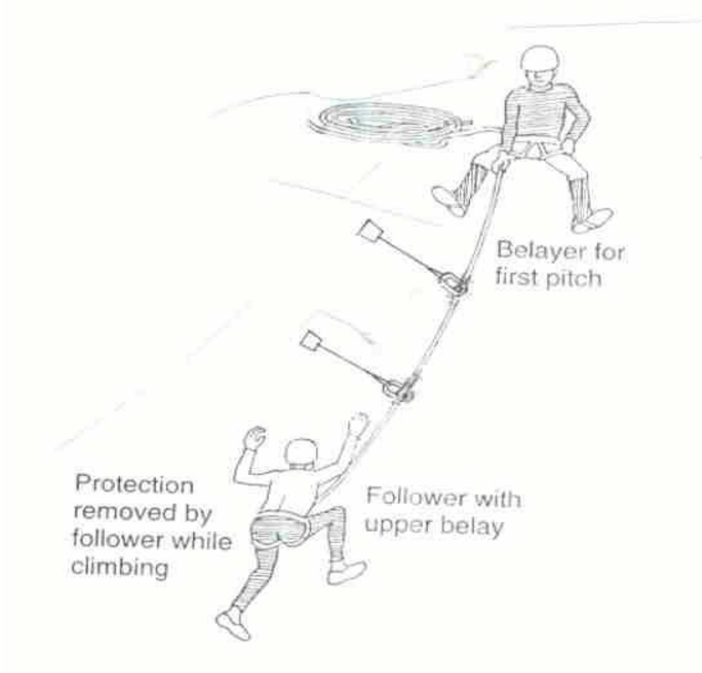

Figure 2.10. Top Rope Belay; fall protection for the second climber

- Solo Back Roped Rock Climbing: A solo climber attaches the belay rope to anchors at the base of the climb and connects the rope through a belay device attached to his harness. As the climber ascends the rock, the rope is either manually fed through the device or the rope automatically feeds through the device. The climber protects himself from falling by placing secondary anchors at convenient intervals in the rock face similar to normal climbing practice. In the advent of a fall the belay device locks onto the belay rope when the climber falls past the upper most secondary anchor. Figure 2.11 below shows the basic equipment set up.

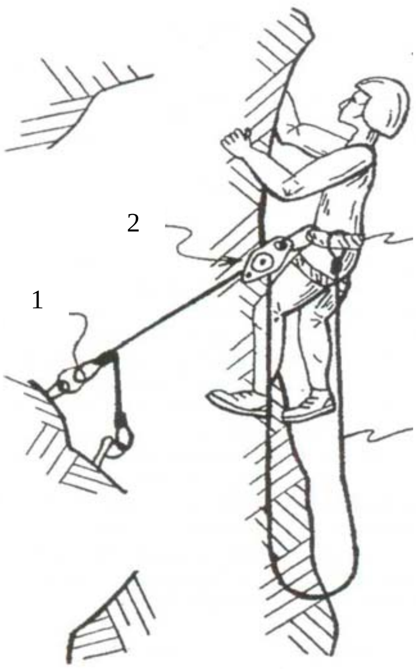

Figure 2.11 Solo Back Roped Rock Climb Showing: Anchor Point (1), Belay Device (2) Harness (3) and Belay Rope (4)

2.8.4. Mountaineering

The mountain environment's climatic conditions, altitude, rock/ice avalanche dangers and glacier crossings pose additional risks to the height hazards associated with mountaineering. Added to the fall prevention/arrest techniques for abseiling, caving and rockclimbing used in mountaineering are:

- Glacier Travel. Gaining access to and from climbs can involve crossing of glaciers where the risk of a fall into a crevasse can be quite high. A pair of climbers will "rope-up" using a 50-metre long 9mm-diameter dynamic rope for use as a safety line. The ends of the rope are directly tied into a climbers harness and the distance between the two climbers is shortened to 15- 20 metres by placing coils of rope over one shoulder and the rope is again tied into the climbers harness. Shortening the rope reduces the possible fall distance into a crevasse. The two climbers move together as a team over the glacier keeping the rope between them relatively taut and will have prussik slings connected to the rope with ice axes ready for action. In the advent of a fall into a crevasse, the belayer is required to act quickly and to use his ice axe to arrest the climbers fall. Once an anchor is made in the ice or snow surface above the crevasse and the rope to the fallen climber is secured to it, the belayer is required to assist or rescue the fallen climber from the crevasse.

(Grayson D. Ed Freedom of the Hills pp. 319-323 1992). Figure 2.12 shows the basic method for glacier travel.

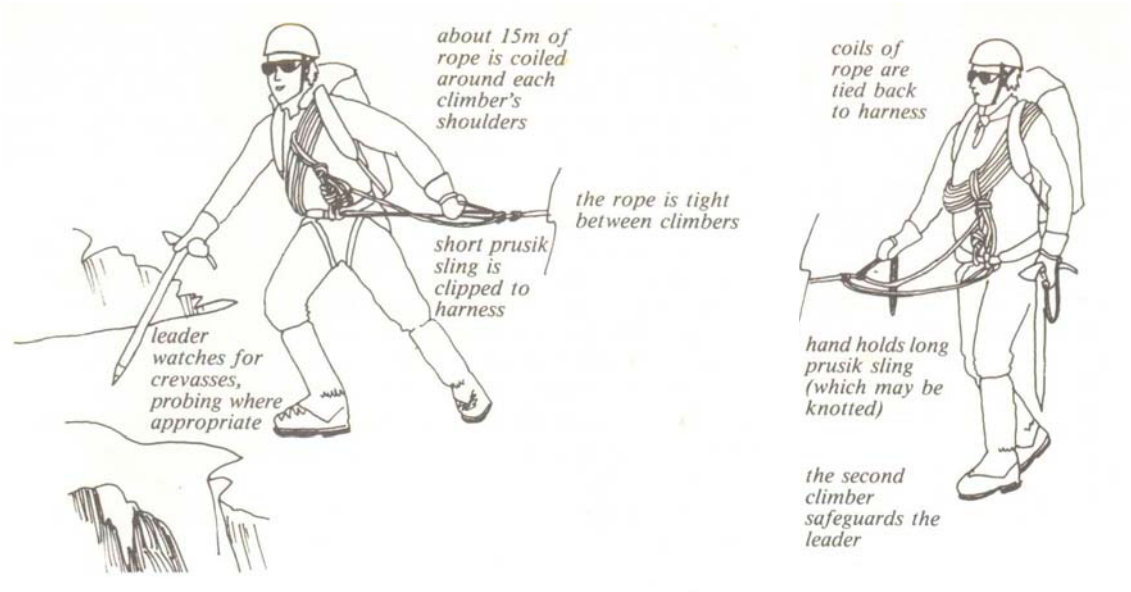

Figure 2.12. Method of Roping up for Glacier Travel

- Fixed Rope. Like the safety line system used in industrial applications, fixed ropes allow safe egress across high-risk areas on a mountain. Fixed lines are generally employed on high altitude mountaineering expeditions where a particular section of the route may be repeated several times during the climb and to allow a line for safe retreat. A single static rope of 7- 9mm diameter of up to 200 metres long may be attached to several intermediate anchors in the rock and ice. Long sections on a route may be set up this way to provide safe passage. The steep-ness of the sections fixed may range from flat crevassed areas to vertical sections of ridges and faces were the risk of a fall may be high. A climber is attached by lanyard connection from his harness to the fixed rope using two karabiners. For ascending the fixed line a climber may use a prussik sling or a handled ascender to provide a “hand –hold” that he moves up the rope as he climbs. For descending, the climber may use a simple descender to allow him to control the speed of descent, or he may elect to simply use a gloved hand to provide sufficient friction on the rope. (Grayson D. Ed Freedom of the Hills pp. 392 to 394 1992)

2.9. Chapter Conclusion

The literature review conducted in this Chapter has highlight several areas relating to fall arrest prevention by exploring the regulatory frame work setup by state government OH&S legislation, and supported by the relevant Australia/New Zealand Standards for use in the workplace. For recreation use, the fall prevention equipment used may be outside of the Australia/New Standard requirements, the equipment selected is generally of a higher quality design and construction.

The following chapters explore this area further by conducting a critique of current fall arrest equipment that will allow the evaluation of design features, operation and possible deficiencies to be acknowledged for incorporation into the project device design.

Chapter 3. Current Type 1 Fall Arrest Fall Arrest Device Evaluation

Chapter 3. Current Type 1 Fall Arrest Fall Arrest Device Evaluation

3.1. Introduction

From the Chapter 2 background literature review for fall prevention methods, Type 1 back up rope grabs where identified as the primary area for this research project.
In this Chapter, four backup rope grabs were selected for critical evaluation. The four devices were selected on the basis of being commercially available in Australia through outdoor recreation shops and industrial safety suppliers and have gained wide acceptance for their specific use.
While three of the four devices have been tested for Australia/New Zealand Standard AS/NZ 1891 compliance for use in industrial applications, one device, the Silent Partner is outside the scope of any Australian or international standard yet it performs equally as well as the other purpose designed devices.
The evaluation criteria used for determining the pro and cons of each of the four selected back-up Rope Grab was by an "in–use" approach in the following areas:

- Ease of rope connection by the user to a safety rope.
- Handling qualities of the device in both normal use and in a fall arrest situation.
- The back up rope grab's method of operation.
- Purchase price and weight of the device.

3.2. Current Fall Arrest Models Selected for A Critical Evaluation

3.2.1. Gibbs Ascender Evaluated Model: Type 2

Manufactured in Salt Lake City Utah USA by Gibbs Products. This cam operated device consists of an aluminium alloy U fabricated frame with a cast aluminium alloy cam, or a full stainless steel fabricated version, Each model uses a quick release pin to secure the cam inside the frame when in use, Figure 3.1. Shows a spring loaded Gibbs Model Type 2 ascender below

Figure 3.1. Gibbs Ascender Model "Type 2" Rope Grab

The device was initially designed for mountaineering use and has gained a reputation in both recreational caving and rescue applications for its rope holding abilities and durability. (Warild, Vertical p.91 1988)
Several modifications have been incorporated since the device was first commercially available in 1970 that have included spring closing of the cam and the inclusion of a single hand operated two action quick release ball-lock pin (*United States Patent* 4,253,218 March 3,1981) and adding a hinge on the U frame to allow the frame to swing open for ease of connecting to a working rope (United States Patent 5,146,655 September 15,1992).
There are two model sizes to allow use of 12 to 19mm diameter ropes. Each device is statically proof loaded to 454kg at the end of the manufacturing stage (Gibbs Products brochure 1979).
The basic design works on a first principle of lever method with a person's weight used to actuate the cam against the U frame and pinch the rope. (Storrick, Dr Gary Ascenders - Descender Collection 2001) The cam is profiled to provide an increase in radius as the cam lever is moved further downwards under the operating load, several large smooth teeth reduce rope slippage.
The spring-loaded model Type 2 aluminium version weighs about 200grams and retails for $96 AUD.
Montgomery (Single Rope Techniques, a guide for vertical cavers pp. 80,81 1978) describes the advantage of using body weight to give a more positive cam closure than a spring loaded cam but also says;

> "the worst feature of the Gibbs Ascender is its awkward three-piece construction. Compared to the Jumar, it requires a slow and fiddley process to get the rope in or out"

Figure 3.2(a). Shows the difficulty in aligning the components below, while Figure 3.2(b) shows the quick-release pin being inserted through the aligned frame and cam.

Figure 3.2.(a) Aligning the Components

Figure 3.2.(b). Inserting the Quick Release Pin.

This is due in part to the need to carefully hold the frame around the rope and align the am hole with the frame hole and then while pressing the quick release pin button to insert the pin through the cam and frame.
The Gibbs Ascender while relatively difficult to install on a rope, it performs well as back up rope grab. Unsprung units can slide up and down a safety line with out the need or the worker to manually reposition, and the unit is capable of withstanding a dynamic fall without damage to a rope outer sheath during AS 1891.3 dynamic testing.

Table 3.1 below shows the results of the Appendix B Current Device Evaluation Critique conducted on the Gibbs Industries Type 2 rope grab fall arrest device.

	Gibbs Model Type 2
Physical Attributes	Width: 57mm, Height: 100mm, Length: 80mm, Weight: 200 grams
Rope Connection	2 hands, 2 actions required to align components and insert quick release pin. Relatively difficult to align all components while connecting to rope. Can be attached to a user’s harness while connecting to the rope. Device is asymmetric - will lock in one direction only, requires a conscious effort to position the device for locking in the correct sense.
Design Features	No external handle, cam spring may be set to "on/off" by hooking key ring under spigot on frame.
Normal Operation	In spring "off" mode - must ensure cam positively engages rope or will not lock. In spring "on" mode - the device runs easily in the upward direction. Easy to release to allow the device to be lowered. Can be used for work positioning. If used on horizontal safety line device will only allow locking in one direction. Device must be released by hand to allow it to be manually repositioned down
Fall Operation	In spring "off" mode - possible not to lock onto rope if body falls downward without any outward load to activate the cam onto the rope. In spring "on" - the device locks onto the rope quickly without any downward sliding. Can be locked during a fall on a slope.
Release	Release after load is removed is very easy.
Rope Removal	Once load is removed, very easy to pull quick release pin out from frame and to remove rope.
Handling	Small size makes handling for connection difficult, Lack of external handle difficult to hold onto with a hand, however small size allows for use in "built-in" ascent systems.

Table 3.1 Gibbs Model Type 2 Rope Grab Fall Arrest Device Evaluation

3.2.2. Protecta. Evaluated Model “Cobra” AC202A

Manufactured in Carros cedex Nice, France by Proctecta International France.
The device is purely for industrial applications as a back up rope grab which is also cam operated on a similar principle to the Gibbs ascender using the first principles of lever method to actuate the profiled cam and pinch the safely rope against the frame. The whole unit is fabricated from a “high impact resistant” steel and either cadmium or zinc electroplated (Protecta International Technical Specifications “Cobra” Rope Grab AC202A, 2001). Figure 3.3. below,

shows the fabricated sheetmetal rope-grab. The cam is made from five pieces of sheet steel riveted together to provide the cam profile and eye for attaching the device to the workers harness, the cam is permanently attached to the frame body.

Figure 3.3. The Protector “Cobra” Model AC202A Rope Grab

Two distinct hand actions are required to open the hinged steel fabricated frame for attaching the device to a safety rope by unlatching and sliding the spring loaded bolt bar back and then pressing a back up release button, refer Figure 3.4(a) and Figure 3.4(b) shows the “Cobra” frame hinged open to connect to the rope
Storrick (Storrick, Dr Gary Ascenders - Descender Collection 2001) describes the cam profile as ‘unique’, the reason being that no other device commercially available uses the same oversized cam toothed profile or the upper location of the pivot in relation to the device frame
.

Figure 3.4.(a). Two Distinct Hand Actions Used to Unlock the “Cobra”.

Figure 3.4.(b). Frame is Hinged Open to Accept the Safety Rope.

The manufacturer specifies a certain type and diameter of rope for use with the device of white laid nylon in either automatic mode where a 12 mm to 16mm diameter rope can be used or in the manual mode where only a 16mm laid rope is recommended to be used. Selecting a spring-loaded pawl to act against the cam lever creates manual and automatic modes. In automatic mode the cam is spring loaded against the rope allowing the unit free to travel up but to grab and lock on the safety line when the unit is moved down. In manual the automatic lever can be stowed to allow the rope to run freely through the device in either direction. The large size of the unit allows it to be used in horizontal lifeline application, the unit may not necessarily lock into position on the lifeline but it is physically robust enough to preclude any frame distortion when used this way. The unit is considerably heavy weighing 805 grams and retails for $160 AUD. Each device has compliance markings for EN 353-2 and CE0086, and has a serial number and date of manufacture.

Table 3.2 below shows the results of the Appendix B Current Device Evaluation Critique conducted on the Protecta Cobra AC202A rope grab fall arrest device.

	Protecta : Model Cobra AC202A
Physical Attributes	Width: 60mm, Height: 90mm, Length: 130mm, Weight: 805 grams
Rope Connection	2 hands, 3 actions to open the device, very easy to close unit, but weight of unit requires the user to be careful not drop it. Can be attached to the user’s harness while connecting to the rope. Device is asymmetric - will lock in one direction only, requires a conscious effort to position the device to lock in the correct sense.
Design Features	No external handle, cam spring may be set to "automatic / manual" by hooking spring lever on frame.
Normal Operation	In spring "manual" mode - must ensure cam positively engages rope or will not lock. In spring "automatic" mode - the device runs with difficulty in the upward direction when using the manufactures recommended laid rope. Cam teeth can snag on rope - difficulty in releasing to allow the device to be lowered. Can be used for work positioning. If used on horizontal safety line device will only allow locking in one direction. Device must be released by hand to allow it to be repositioned down.
Fall Operation	In "manual" mode - possible not to lock onto rope if body falls downward without any outwards load to activate the cam onto the rope. In "automatic" - the device locks onto the rope quickly without any downward sliding. Can be locked during a fall on a slope.
Release	Cam teeth can snag onto rope, however once load is fully released- easy to move cam down onto stop.
Rope Removal	2 hands, 3 actions to open the device, slightly clumsy to open unit if still attached to the rope. but weight of unit requires the user not drop it.
Handling	Heavy, sharp edged construction makes the device awkward to handle, however, closing the device after placing the rope inside operates well.

Table 3.2 Protecta: Model Cobra AC202A Rope Grab Fall Arrest Device Evaluation

3.2.3. Petzl. Evaluated model "Ascension" B17 Right and Left Hand

Manufactured by Petzl International in Crolles France. The device has found wide acceptance in both industrial as a fall arrest rope grab back up and in recreational mountaineering, rock climbing and caving applications where the devise is primarily used an ascender. Each application present different environments that the device is subjected to, particularly the mountain environs where the device is used as a rope grab back up or an ascender for moving on fixed rope in freezing or icy conditions and in caves where the abrasive effects of ascending on muddy ropes can quickly wear components.
The Ascension is one of many similar devices that are based on invention, the Jumar, originally manufactured by Walter Marti in 1958 in Reichenbach Switzerland. Marti's original design was used to descend to birds nest on cliff faces and was quickly adopted for use in mountaineering and caving circles. (Peterson B., 'Canyon and Caves' Number 3 pp 9,10 1971). The original Jumar design allowed very quick attachment on and off a rope and used a second order of lever principle where the workers weight directly attached to the devices frame and the spring loaded cam was held in constant contact with the rope. A repositionable stop prevented the device from being released from the rope accidentally, a single-handed operation two action movement allows the device to be connected/removed to the work or safety rope.
The Petzl Ascension improves on Marti original design by incorporating two features that Marti also improved in his later models. The first is the change from a cast aluminium frame to a fabricated frame, Marti's original frame suffered several brittle fractures that marred the devices reputation such that he had to revise the alloy used for his later cast frames.
The Ascension's fabricated aluminium alloy frame has been manufactured to give sufficient stiffness for operating loads and to allow a large gloved hand to fit the handle, Figure 3.5. below shows the large handled Petzl "Ascension " right handed model.

Figure 3.5. Petzl "Ascension" Right Handed Rope-grab.

While the second is to include connection holes that are rated to 18 kN for the upper hole and 20kN for the lower hole, (Petzl Ascension Brochure Aug 2001). Marti argued that his original design was intended for a different method of attachment when supporting a worker that predated harnesses now used for climbing and industrial work. (Peterson B.,'Canyon and Caves' Number 3 pp 9,10 1971).

The handle and attach point align the device so that the workers load is placed between the cam pivot and the point where the rope is pinched by between the cam and frame. An investment cast chrome alloy steel eccentrically shaped cam contains several rows of conical spikes that provide additional purchase to grip the rope and the cam also incorporates a hold open and cam release stop. (Petzl Professional Catalogue p.56 2003)
The Ascension design allows a single hand/thumb movement to operate the cam and stop mechanism as shown in Figure 3.6(a) to (c) for connection and detachment to the rope.

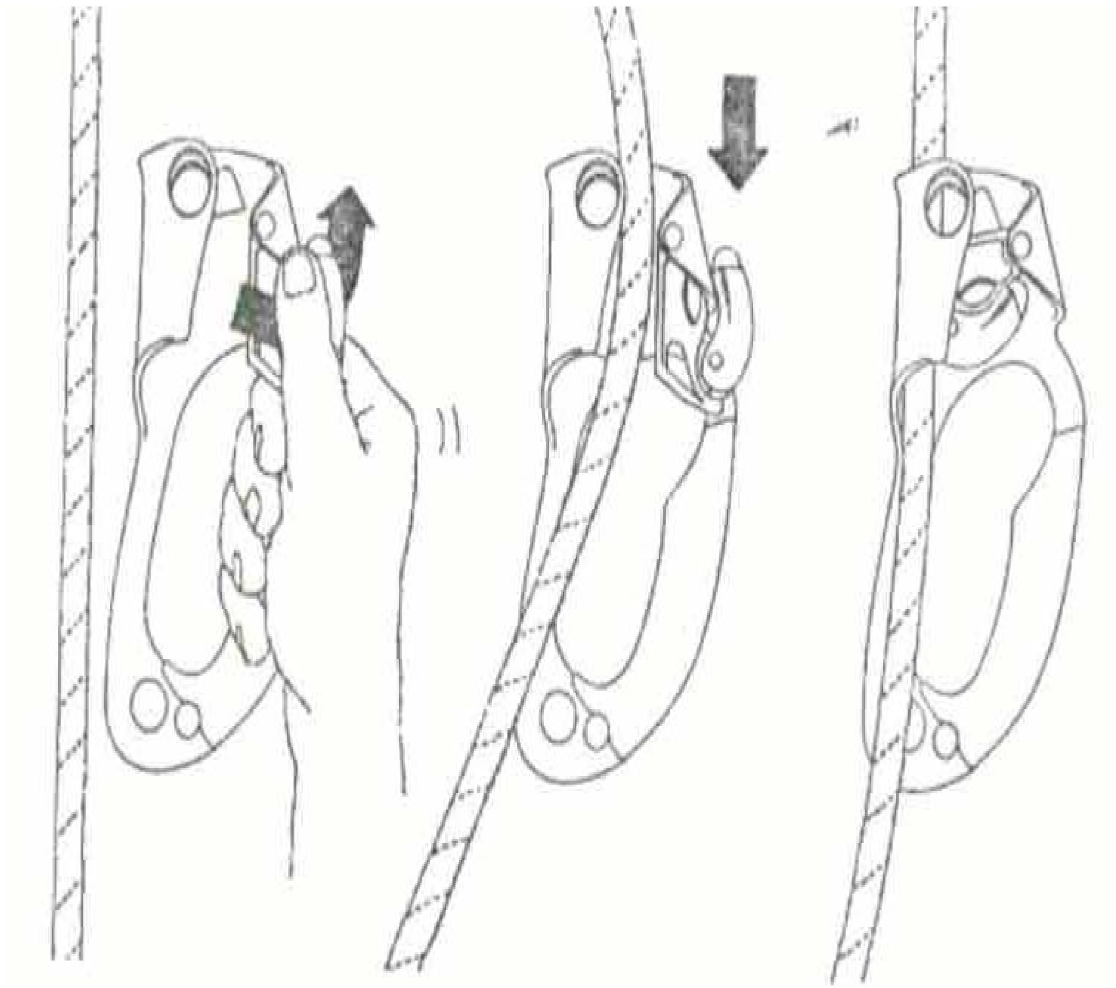

Figure 3.6.(a). Open Cam and Lock Stop on Frame Using Thumb

Figure 3.6.(b). Place Rope in Frame

Figure 3.6.(c). Release Stop to Secure Cam Against Rope

The Ascension can be used on work line diameters of 8 to 13 mm and each device is proof tested and identified stamped with European Standard EN 567 Mountaineering equipment, rope clamp, safety requirements and test method, the CE 0197 stamp and an identifying serial number that gives batch and date of manufacture.
Testing data is shown in the Ascension Aug 2001 brochure for dynamic loading of an Ascension device for different rope diameters where fall factors have been used with a test load of 80kg similar to the AS 1891.3 testing procedure. Each device weighs196 grams and retails for $80 AUD.
Table 3.3 below shows the results of the Appendix B Current Device Evaluation Critique conducted on the Petzl Ascension rope grab fall arrest device.

	Petzl Model Ascension B17
Physical Attributes	Width: 30mm, Height: 105mm, Length: 190mm, Weight: 196 grams
Rope Connection	1 hand, 2 thumb actions. Easiest of the models to connect to a rope. Can be attached to a user's harness while connecting to the rope. Device is asymmetric - will lock in one direction only, requires a conscious effort to position the device to lock in the correct sense.
Design Features	Large external handle. Cam stop and connection holes allow efficient use.
Normal Operation	Light cam spring forces allow the device to be pushed up rope easily. Once load is removed from rope, the device is easy to be moved down the rope. Can be used for work positioning. If used on a horizontal safety line a support karabiner must be installed through the device frame and attached to the safety rope to prevent the ascender from disconnecting. If used on horizontal safety line device will only allow locking in done direction. Device must be released by hand to allow it to be repositioned down
Fall Operation	Can be locked during a fall on a slope.
Release	Cam teeth can snag onto rope, however once load is fully released- easy to move cam down onto stop.
Rope Removal	Release after load is removed requires a very dexterous thumb in order to "park" the cam/stop onto the frame.
Handling	Good characteristics due to the external handle and size of device.

Table 3.3 Petzl Model Ascension Rope Grab
Fall Arrest Device Evaluation

3.2.4. Wren Industries. Evaluated model "Silent Partner"

The Silent Partner is manufactured under license by Wren Industries of Grand Junction Colorado U.S.A. according to a unique US patent, (United States Patent 4,941,548 July 17,1990). The device differs in several ways from that the normal rope grab devices in the way it is connected to a safety rope and the way the device is activated in a fall. The device is designed for recreational rockclimbing use but while it does not conform to any standards, the device eliminates a several of the shortcomings of normal back up rope grabs. Below, Figure 3.7. shows Wren Industries "Silent Partner".

Figure 3.7. Wren Industries “Silent Partner”

The device is CNC milled and turned from wrought aluminium stock to utilize a simple centrifugal clutch that will lock at a velocity preset by return springs acting against each of the two lock rollers inside the clutch. A safety rope is attached to the device by rotating the support frame open and carefully tying a clove hitch knot around the centrifugal clutch drum, then rotating the frame closed and connecting the device to the workers harness. Figure 3.8 (a) and (b) below shows how to connect the rope to the device. The middle section of the drum periphery has a wide rib that forces the clove hitch knot to separate which effectively loosens the knot allowing the device to be moved up or down.

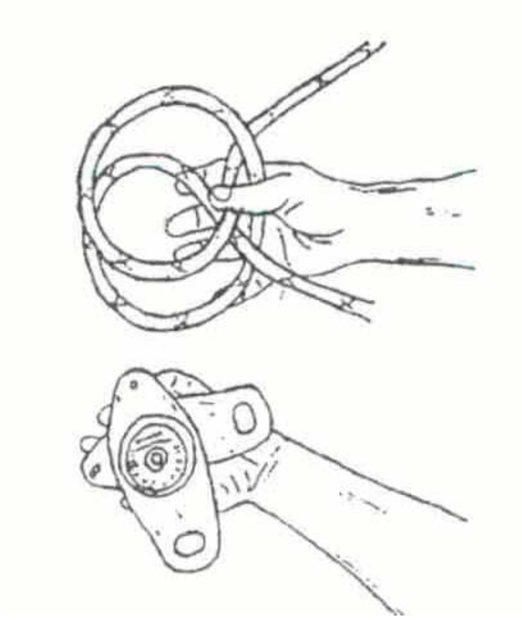

Figure 3.8.(a). Connecting the Safety Rope; a clove hitch is tied in the safety rope.

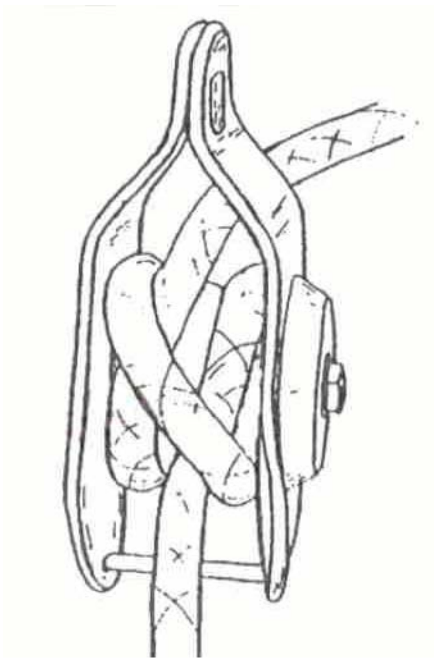

Figure 3.8.(b). The clove hitch is placed around the drum and the frame is rotated closed.

During a fall the drum is rotated by the fixed safety rope until the preset velocity is reached and the clutch rollers engage and lock the centrifugal clutch drum to the device frame, the resulting deceleration tightens the clove hitch knot and all is arrested. Once unloaded, the device unlocks easily. (Silent Partner User’s Manual Wren Industries 2000).

The Silent Partner operates in both directions of rope travel, something which normal rope grabs cannot do and so can be for both lead and top rope climbing. The device requires a certain fall distance before activating, and may release after locking if the load is removed, in both of these situations however the normal rope grab will perform better and still can be re-locked on without taking another reactivation fall. The weight of the rope can affect the devices operation if it becomes sufficient enough to increase the drum drag. Each device weighs 410 grams and retails for $360 AUD.

Table 3.4 below shows the results of the Appendix B Current Device Evaluation Critique conducted on the Wren Industries Silent Partner rope grab fall arrest device.

	Wren Industries Model: Silent Partner
Physical Attributes	Width: 70mm, Height: 167mm. Length: 72mm, Weight: 410 grams
Rope Connection	2 hands 3 actions required to tie open the device, tie and connect the clove hitch knot to the devices drum, then close the device. Must be disconnected from a users harness while connecting - possibility of dropping the device. Device operates symmetrically- can be connected inverted and will still operate normally.
Design Features	Device is locked closed by attaching a user’s harness attach karabiners.
Normal Operation	Device allows rope to run freely either up or down a rope, however the weight of the rope below causes drag and can tighten the clove hitch - manufacture requires a strict rope handling procedure to be followed to avoid this problem. Cannot be used for work positioning systems as unable to lock device onto rope in normal operation.
Fall Operation	Device centrifugal clutch operates very effectively to cause the clove hitch knot to arrest a fall - a preset fall distance of less then 200mm occurs, so user can expect to stop a distance below the point of fall. Device has difficulty in locking on slope less than 40º as critical operating speed to activate the device is not reached.
Release	Release is easy once the load is removed - the free rope end may need to be physically pushed back into the drum to allow the clove hitch knot to release. However the device lacks a secondary rope grab mechanism to block any further fall if the load is removed from the rope unintentionally immediately after a fall
Rope Removal	A struggle to remove the device from the rope, difficult to remove the device from the harness attach karabiners at the top of a climb, then possibility of dropping the device.
Handling	Operation is very good, however connection/removal is difficult.

Table 3.4 Wren Industries Model: Silent Partner Rope Grab Fall Arrest Device Evaluation

3.3. Issues Identified From the Critique Evaluation

- Specific Design Advantages:
    - Automatic multi direction fall arrest blocking is provided by the Silent Partner device.
    - A two-handed action sequence is required to open and close the Cobra device.
    - Simple and intuitive design of the Ascension device allows easy rope connection.
    - Cam profile of the Gibbs Type 2 device allows for good rope jamming and once the load is removed, the cam can be quickly released from the rope.
- Specific Design Deficiencies:
    - Rugged oversized steel construction of the Cobra limits the size and type of safety rope to uncommon rope types.
    - Thin frame sections of the Ascension and Gibbs devices may limit the anticipated fall forces generated in a fall as the frames may distort under the dynamic loads.
    - Difficult rope connection for the Silent Partner may allow the device to be

      dropped due to the user cannot clip the device to his harness during the device setup
    - No secondary rope blocking provided on the Silent partner – if the load is removed the locking knot can be quickly released and the device will allow a second fall/lock sequence to occur.

3.4. Chapter Conclusion

The evaluation critique has allowed direct in service comparisons between the four designs and has identified several advantages and disadvantages for each of the four devices when used as Type 1 back up rope grabs.
The critique tables developed for each of the four devices in this chapter have been grouped together as Appendix B which has been used to provide the objective basis for the design considerations for the fall arrest device.

Chapter 4. Design Criteria for the Research Project Back Up Fall Arrest Device

Chapter 4. Design Criteria for the Research Project Back Up Fall Arrest Device

4.1. Introduction

This chapter describes the criteria that was used as the basis for the Research Project Back Up Fall Arrest Device design using information gained from the literature review in Chapter 2 and the device evaluation critique in Chapter 3.

4.2. Design Considerations

By identifying limitations and positive features from the literature review and evaluation critique several specific issues can be improved in both design and application to eliminate these deficiencies and to combine the positive features for making the devices safer for the user. The specific areas are:

- Issues Arising from the Literature Review and Current Fall Arrest Device Evaluation Critique.
- Intended use of the device.
- Anticipated loads that will be placed on the device.
- Minimize human error in connection to the safety rope and operation of the device.
- Method of device actuation.
- Method of rope blocking that ensures the device remains blocked after the fall arrest load is removed.

4.2.1. Issues Arising from the Literature Review and Current Fall Arrest Device Evaluation Critique

Several ideas arising out of the literature review have been considered on how they will affect the specific areas listed above in the Design Consideration, these ideas include:

- Manageable size and weight for handling.
- To ensure rope connection is simplified.
- Allowing connection/removal while attached to a user’s harness to avoid dropping the device.
- Use of deliberate hand actions to open/close and latch the device.
- Visual conformation device is locked.
- Incorporate an automatic fall arrest function without user interaction, but allow for a user input to manually release the blocking cams for work positioning.

- To limit the fall distance to reduce fall forces.

- Allow “hands free” climbing by user with no input required by user to reposition device.

- Be capable of locking in either fall direction on a rope.

- Be capable of use on horizontal static lines and able to be locked in either direction on the static line to allow user positioning across the horizontal line span.

4.2.2. Intended Use of the Device

A back up rope grab type 1 fall arrest device was chosen for the research project as an area that would benefit from a detailed use analysis and design review with two key areas of use identified:

- Fall Arrest – Automatic and Manual Operation Control:
  The fall arrest method is illustrated in Figure 2.3 (a) and Figure 2.3 (b) specifically for a work place situation where the back up rope grab fall arrest device is attached to a safety rope that is separate from the user's work rope.
  In recreation used the device would be connected to the work rope, as a separate safety rope is not normally used.
  In the work place, the OH&S regulations and Australia/New Zealand Standards specify that a full body harness be worn by the user, this allows the back up fall arrest device to be either connected to the front of the harness where the device is in easy reach of the user or it may be attached to the back of the harness out of the reach of the user. This will directly affect the intended use of the device; the device will be expected to be fully automatic for the back attach point, while the front attachment will allow for manual work positioning.
  For recreational use, sit harnesses are normally used, so the device is attached to the front of the harness allowing the user full control of the device functions.
  The fall arrest device may be connected to the users harness either directly or by a short lanyard.

  - Automatic Operation:

  The automatic function of the device will allow a user to ascend/descend the working rope without having to physically reposition the backup fall arrest device on the safety rope. The fall arrest device will trail up and down the safety unless the user falls and the device in intended to automatically actuate and block the fall.
  The design criteria for this is to allow the user to have both hands free for climbing, this criteria is in direct opposition to the intent of the Australia/New Zealand Standard AS/NZ 4488.1:1997 Industrial rope access systems Part 1: Specifications were the Standard requires that the back up fall arrest device must be manually repositioned by the user. The evaluation critique of the current fall arrest devices has identified that the intent of the Standard in this aspect could be a contributing factor in creating a fall particularly in recreational activities where the user may fall off dubious hand/foot holds while having to physically reposition the fall arrest device – particularly when down climbing.

  - Manual Operation - Work Positioning:

  Work positioning allows the device to be manually locked on a vertical or horizontal working rope so that the user is restrained to allow work to be performed with a set area of reach.

4.2.3. Anticipated Loads That Will Be Placed on the Device

To facilitate the stress analysis and device design, the maximum static load of 4kN designated in the Australia/New Zealand Standard AS/NZ1891.3:1997 Industrial fall-arrest systems and devices Part 3 Fall-arrest devices has been adopted as a key design parameter. This load has a basis of being four times the expected working load of an 80kg user weight with 20kg of safety equipment and work equipment, then a safety factor of 2 is applied and the resulting mass total multiplied by the gravitational acceleration of $g = 9.81\ ms^2$.
The dynamic test also designated in the Australia/New Zealand Standard AS/NZ1891.3:1997 Industrial fall-arrest systems and devices Part 3 Fall-arrest devices has been adopted so that the device will limit the fall arrest distance to a maximum of 600 millimetres.

4.2.4. Minimize Human Error in Connecting to the Safety Rope and Operation of the Device

- Connecting the device to the safety rope:
  Consideration for allowing simple safety rope connection while ensuring that the design would allow the activation mechanism to operate and for the device to be structurally sound was made. Much effort has been done in this area to ensure the step for connecting the rope is both intuitive to the user and to eliminate any chance of incorrect rope connection occurs. This is accomplished by positioning the guide pullets and blocking cams so that it allows only one rope path to prevent the chance of any mis-rigging.
  When the frame is closed the guide pulleys, grab cams and frame have been located to encapsulate the rope to prevent the rope from being shifted out of the correct position
  In developing this, several different ideas were considered to allow for the ease of rope connection to the device. While the Silent Partner design of allowing the device frame halves to be rotated about the common shaft to give access for rope connection is a simple solution, other considerations have affected the design of the frame. Consideration for prevented the device being dropped meant that the key hinge open frame feature of the Cobra device would be a better alternative to ensure reduced human error in connecting the device to the rope and to allow the connection to the rope while still attached to the user's harness without the need for the device to be removed.

- How the device can be opened using two distinct hand actions:
  Consideration for this point was made so that two simple but independent sliding pin latches that lock the hinged frame half directly to the harness attach point/trigger link was made. The sliding pins were designed to be spring loaded in the closed position:
  and to be held in double shear through the trigger link shafts while allowing the user to visually confirm the device is locked. When closing the unit, the action for locking was designed so that the user has to make a deliberate action to lock the frame closed – this is to prevent a user from assuming that the device has automatically "snapped" closed.
  Consideration for visual confirmation was made so that the user can quickly ascertain that the device is closed and locked.

- Operation Considerations:
  Careful consideration was made to ensure that the device is symmetric so that the device will operate correctly if connected to the safety rope inverted - this feature creates a device that performs the multi-direction fall arrest function that only the Silent Partner is capable of doing.

4.2.5. Method of Device Actuation

For the device to operate as a multi-directional fall arrest unit consideration was given on how to sense a fall and then how to actuate the rope blocking mechanism. The fall speed sensing inertia mass concept used by the Wren Industries Silent Partner in activating the device was expanded to incorporate the variation in the friction forces generated by the safety rope sliding over the inertia activated clutch to trip the upper blocking cam and effectively block the user's fall.

- How will the activating mechanism operate?
  Reviewing the patent document for the Wren Industries Silent Partner, design considerations were made so that the clutch pulley mechanism would be sized to fit neatly into the clutch frame. Consideration for keeping the rope aligned as it travels through the device was made by designing the clutch drum as a vee pulley with a rubber coated surface and machining shallow vees in the two guide pulleys.
  In normal use the rope has some drag as it is moved along the rope due to rolling resistance from the rope riding over the clutch pulley and the two guide pulleys, the pulleys rotating on plain brass bushes, and the rope sliding against the blocking cam surfaces
  In a fall situation, the clutch mechanism uses the rate of change of angular momentum of the pulley to impart a force impulse onto the device when the pulley lock rollers reach a set angular velocity. This angular velocity is determined by the centrifugal force generated as the two clutch rollers overcomes the return spring forces.
  When the angular velocity set point is reached - a roller at the lower position inside the clutch pulley moves out of its indent and moves along the ramp surface of the clutch pulley. The movement of the lower roller moves the operating ring to force the upper roller out of its indent and along the ramp. The rollers become wedged between the ramp surfaces and the clutch frame to jam the clutch pulley to the clutch frame.

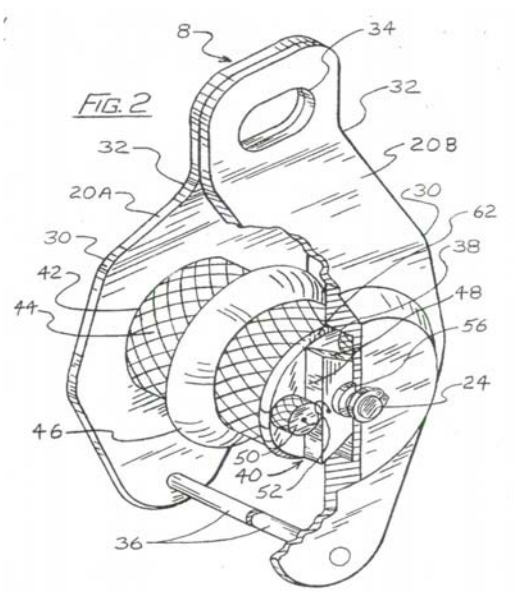

Figure 4.1. Wren Industries Silent Partner
US Patent 4,941,548 Document
Showing one of three operating
Rollers (50) and springs (52),
triangular roller ramps (48)
driven by the rope drum (46)

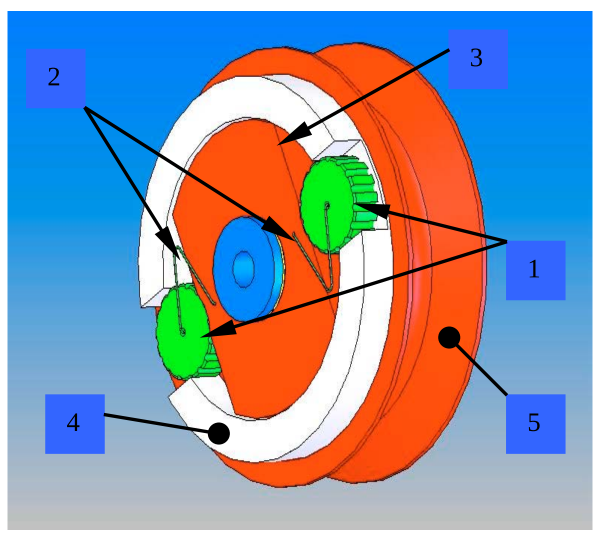

Figure 4.2. Proposed Clutch Mechanism
Showing the two operating rollers (1)
and springs (2) the two roller ramps (3)
the nylon actuating ring (4) all the
driven by the vee pulley (5)

The sudden locking of the clutch pulley causes the safety rope to drag over the rubber surface of the clutch pulley and to rapidly increase the retarding fall force experienced by the falling device frame. This is due to the friction force induced between the rope now sliding over the rubber surface is much larger than the rolling resistance experienced during by the rope winding through the clutch pulley and guide pulleys in the unlocked position.
The upper blocking cam is released by the trigger link that continues falling under gravitational acceleration relative to the frame. As the frame falls downwards at a slower rate of acceleration due to the retarding friction force, the trigger link trips the blocking cam release to allow the spring loaded cam to rotate upwards to force the rope against the guide pulley.
The cam wedge profile has been designed so that for a for each degree of rotation the contact surface of cam is set at a constant wedge angle to cause the cam to effectively block the rope against the guide pulley. The cam shafts were positioned so that for a certain range of intended rope diameters of 9 to 11 millimetres, would be blocked against the cam with some remaining cam travel. The cam was sized so that the cam could not be dragged all the way through and past the guide pulleys.

- Resetting of the device after activation:
  Design consideration was made to the grab cam wedge angle so that the cam would provide effective blocking, however too fine an angle and the cam becomes too difficult to release from the rope, conversely too coarse an angle the effective blocking is reduced. An effective wedge angle of 10° was selected as a trial for the prototype cams.
  The cam size and profile was designed to allow for the cam to be latched in the open position to allow for the rope to be connected. When the cam was either manually released or activated in a fall, the rotated cam profile protrudes from the device frame so the user can visually see confirm the device has been activated.
  The device is reset by removing the load from the device and then pushing the cam edge back to the open position – this is confirmed by a “click” as the cam is engaged by the release mechanism.
- Rope drag and locating the guide and clutch pulleys:
  To reduce the overall rope drag through the device and to ensure that the rope moving through the device would spin up the clutch pulley - a compromise was made to ensure an effective contact angle between the rope and the clutch pulley and reducing the amount of induced friction in the rope as it is fed over the guide pulleys/clutch pulley. The guide pulleys were also positioned to allow for the grab cams to swing clear of the clutch pulley when activated. The guide pulley location was positioned adjacent to the frame hinges so that the device would allow the rope to run on the pulleys only and clear of the cam surfaces – the advantage of this allows the device to be used as a runner on a horizontal safety rope.

4.2.6. Method of Rope Blocking That Ensures the Device Remains Blocked After the Fall Arrest Load Is Removed

One drawback of the Silent Partner design is its inability for the device to remain blocked after the fall arrest load is removed. Removing the fall load allows the clove hitch knot used to block a fall to quickly release. It is unfortunate that to re-block the device onto the rope again, a rapid manual pull on the safety rope must be done – or a second fall must occur to carry out the blocking.

The simpler fall arrest devices evaluated retain this ability of having the blocking cam engaged on the safety rope to prevent any further movement down the rope. In particular the Ascension blocking cam is spring loaded against the rope allowing rapid re-blocking, while the Gibbs and Cobra devices are quite easy to reset the cam back onto the safety rope.

4.2.7. Design Evaluation

Several ideas were trialed in order to establish what prototype layout could best accomplish each of the design criteria without adding constraints that may increase the device complexity or physical size.
Several of these ideas were explored using cardboard models and the software package SOLIDWorks to work out what features were feasible for use.

Figures 4.3 and 4.4 show the prototype evaluations explored using physical and virtual modeling techniques to determine:

- Component size, rope.
- Rope connection possibilities.
- Device actuation.
- Rope blocking.

In the case of this models shown below all ideas were rejected due to difficulty inserting the rope, possibility of dropping the device while connecting and limited manual control, however the device would have remained blocked after the load was removed.

Figure 4.3. Cardboard and Polystyrene Modeling of a Rotating Frame Idea with Integral Blocking Cams on the Inertia Pulley

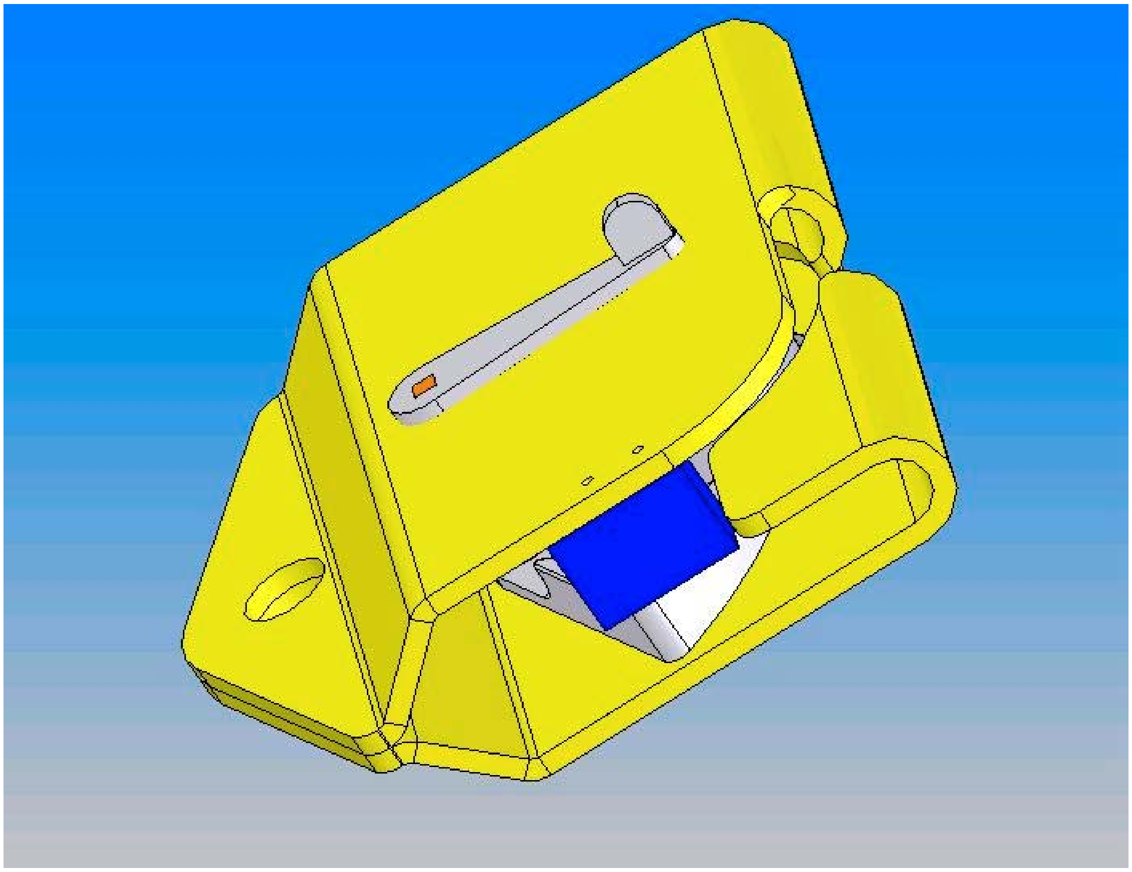

Figure 4.4 The SOLIDworks Virtual Model of the Initial Design Idea.
The blue block is a rope guide to prevent the rope from shifting.

4.3. Chapter Conclusion

This chapter has allowed a descriptive concept of the Back Up Type 1 Fall Arrest Device model to be developed using the information gained from the literature review of Chapter 2 and the Current Fall Arrest Device Evaluation Critique carried out in Chapter 3.
While the design concept appears to be a large brief, the next chapter shows that several of the ideas have accomplished the intent of several of the points simultaneously by using logical design techniques. The next chapter describes the process of converting the work of this chapter into a stress analyzed virtual prototype model ready for the manufacturing process.

Chapter 5. Prototype Design and Manufacture

Chapter 5. Prototype Design and Manufacture

5.1 Introduction

This chapter uses the proscriptive design that was developed in Chapter 4 to conduct stress analysis of key components for determining components sizes based on the materials selected for manufacture, then to construct a virtual model using to allow for sizing and component interaction.
Stress analysis of the design was conducted using both ANSYS 5.5 ED and COSMOSxpress finite element analysis software packages to help verify the manual “Back of the Envelope” calculations.
Virtual modeling was carried out using the Solidworks program package to put together workable component and assembly models of the design.
Production drawings were developed from the Solidworks models to allow the physical prototype components to be manufactured on non-CNC lathe and milling machines.

5.2 Material Selection

The materials used for manufacturing the prototype components from have been selected primarily due to availability. All the materials used are of commercial grade and are obtainable in the Singapore market. The reasoning for the material selection are based:

- Purchase cost price.

Material	Size	Cost (AUD)
Aluminium Alloy 6063-T6	Rod 75mm Ø x 300mm length Bar 20mm x 150mm x 300mm length	$15.00 (Singapore) $36.00 (Singapore)
Stainless Steel AISI 302	Rod 20mm Ø x 300mm length	$42.00 (Singapore)
Yellow Brass 60/40	Rod 20mm Ø x 100mm length	$6.00 (Singapore)
Nylon 66	Rod 50mm Ø x 100mm length	$12.00 (Sydney)

Table 5.1. Purchase Costs of Prototype Materials May 2004

- Commercially available materials.
  The engineering supply shops in Singapore supply a wide range of wrought aluminium alloys, however the for practical purposes the decision to cap the cost of prototyping has limited the material choice to either 6061-T6 or 6063-T6. 6063-T6 was selected due to better machineability and higher yield strength, improved corrosion resistance and higher material hardness than 6061-T6.
- Relative ease of machineability.
  This criteria is important for the AISI 302 stainless steel used as several of the machine tools used for the manufacture of components would experience some difficulty in performing the machining process due to the harness properties of other available grades of stainless steel.
  For the alumimiun alloy 6063-T6, the material free machines with much less chip welding to the cutting tools than 6061-T6.
  Known material properties for stress analysis using Appendix B, Mechanics of Materials, Beer & Johnston 2nd Edition 1992 and Juvinall R. and Marshek, K. ‘Fundamentals of Machine Component Design’, 2nd Edition, Wiley 1991, P.772.

Material	Yield Strength MPa	Density Kg	Modulus of Elasticity GPa	Poison Ratio
Aluminium Alloy 6063-T6 Wrought	260	2710	260	0.36
Stainless Steel AISI 302 Cold Worked	860	7920	190	0.3
Yellow Brass 65 % Copper/35 % Zinc	510	8470	105	Not Found
Nylon 66	45	1140	2.8	Not Found

Table 5.2. Material Properties For Selected Materials Used in Prototype Manufacturing

5.3. Hand Stress Analysis Calculations for Key Prototype Components

Several "back of the envelope" calculations were carried out on key fall arrest prototype components using the material yield strength values. Refer to Appendix E 'Back of Envelope' Stress Analysis Calculations.

5.4. SOLIDworks Prototype Modeling of a Fall Arrest Prototype

The time to produce the prototype design working drawings significantly reduced by using the software program SOLIDworks to create several virtual models of each component required to build up the prototype model. Figure 5.1 shows: below shows the virtual model assembly layout.

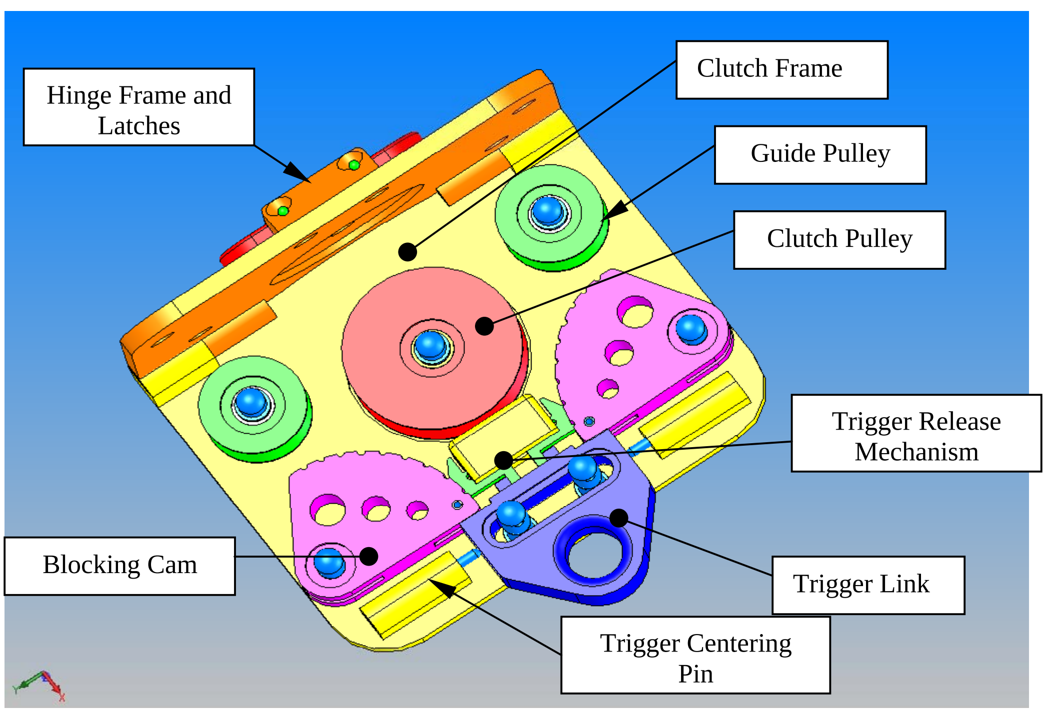

Figure 5.1. SOLIDworks Final Prototype Assembly Model of the Back Up Fall Arrest

The SOLIDworks virtual models allowed checking of component and assembly lay out in the following areas:

- Component dimensions.
- Critical geometric relationships between components.
- Fits and clearances of fixed and moving components and to highlight on areas of possible interference between components.
- Component mass.

By building up an assembly model – the inter-relationships between component could be checked for physical layout, fits, clearances and the problems of component interference. Figure 5.2 below highlights an exploded view of the 48 components used to make up the fall arrest device- each have been checked for correct clearance to the other components in the assembly. The SOLIDworks component model sketches and production drawings have been compiled as Appendix H.

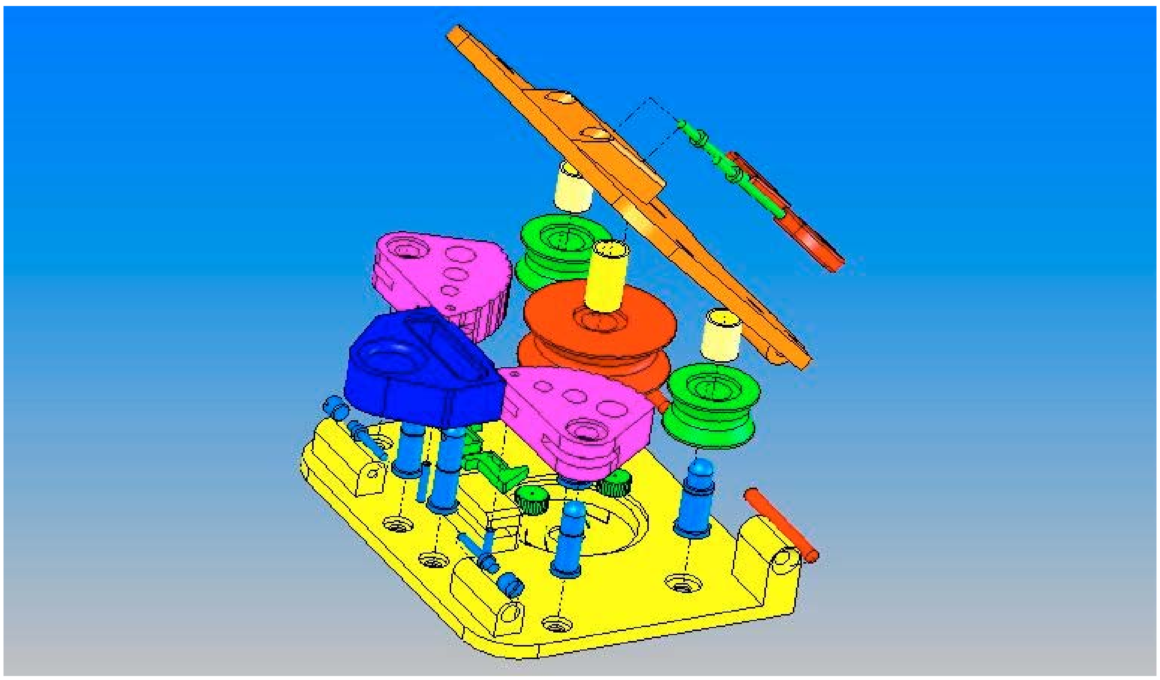

Figure 5.2. SOLIDworks Exploded View of the Back Up Fall Arrest Device Assembly

5.4.1 Clutch Frame, Hinge Frame and Latch Design Justification

- The clutch frame has been designed to be manufactured out of 6063-T6 aluminium alloy with overall dimensions of 142 mm long by 113 mm width in order to house all the components. The physical size of the whole device is directly proportional to the rope diameter size range of 9mm to 11mm Ø.

  A modular design was used for the prototype that allow the individual components to be mounted by M5 countersunk machine screws and for this purpose a standard material section of 6mm was chosen to provide sufficient frame stiffness and support where the components attach. The manual stress calculations were used to verify the edge margins for the location of the blocking cam and guide pulley shafts. A recessed boss housing for the clutch mechanism has been place in the approximate centre of the device, and two hinge supports have been place one edge. It was anticipated that several areas of the frame can be “hollowed out” to reduce the overall weight without compromising the frame strength or stiffness.

- The hinge frame has been designed in tandem with the clutch frame to provide a enclosed unit by having the two components hinge together at one edge by a two section hinge with two M5 countersunk screws. All the supporting shafts pass through the hinge frame holes when the frames are locked closed so that each shaft is supported by both the clutch frame and hinge frame in double shear. Figure 5.3 below shows the rounded ends of each shaft passing through the hinge frame.

- The two independent open/close latch mechanism has been designed as an integral block on the hinge frame – the latches are designed as simple spring loaded –closed sliding cross pins that pass through a hole drilled in each trigger link shaft. The cross pins are placed in double shear by the hinge frame when the frame is closed. Two large simple rings have been attached to the cross pins with 1mm Ø roll pins to allow a users finger to slide the cross pins back. The latches have been designed so that the user must physically align the frame before releasing the cross pins to lock the device – this is to avoid a complacent user from assuming that the device has “snapped closed by itself.

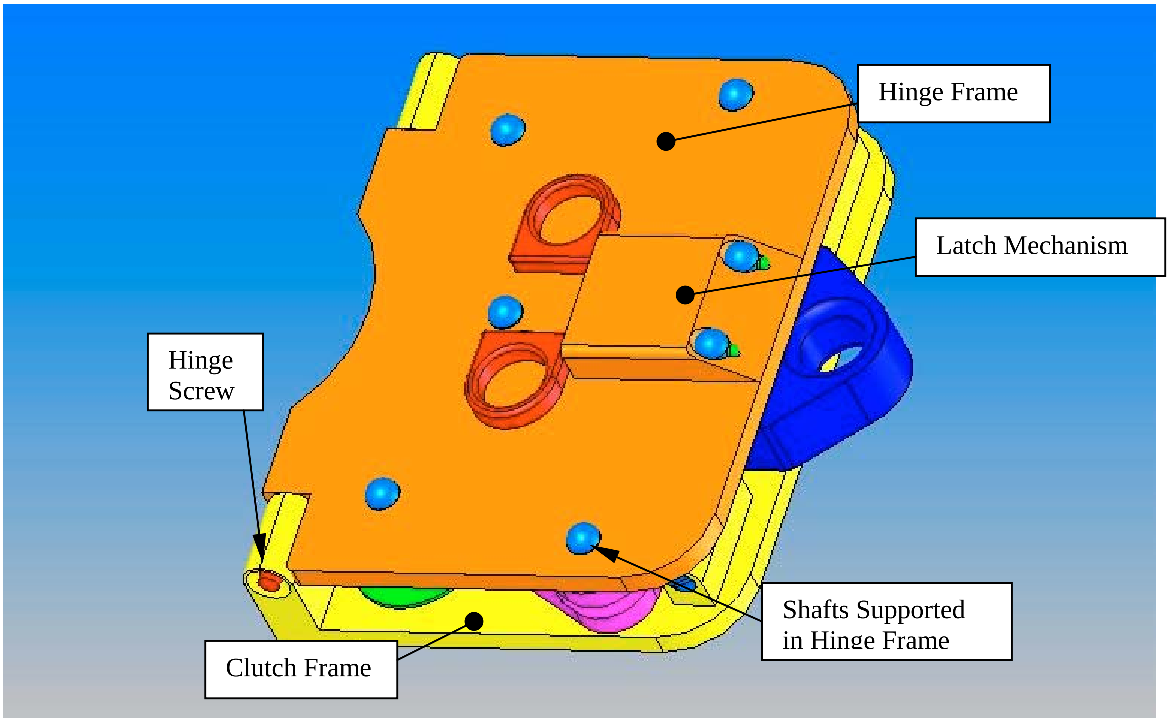

Figure 5.3. Hinge Frame in Closed and Latched Position: showing each shaft that passes through the hinge frame is supported

5.4.2 Clutch Pulley Mechanism Design Justification

While the design of the clutch mechanism is based on the Silent Partner Us Patent description, the design for the research project has used a simplified two surface parallel ramp that is milled into one side of the clutch pulley instead of the triangular ramp described in the patent document. The clutch pulley was designed to be turned from 6063-T6 aluminium alloy with an arbitrary size of

47mmØ and the two rollers from AISI 302 stainless steel machined to 11mmØ and are straight knurled on their periphery to provide the keying grip into the clutch frame recessed boss. The parallel ramp design allows for ease of milling machine set-up, and to improve the mechanism actuation a nylon actuating ring was designed to push the second roller into position by the first roller when the required angular velocity was reached. The design has been worked out by trail and error in the manufacturing stage – particularly the spring rate as the complexity of the mechanism is beyond the scope of the research project. Figure 4.2 Proposed Clutch Mechanism refers.
A simple interference fit plain bearing of yellow brass was considered for the clutch pulley as the a ball race bearing was considered not suitable due to possible problems with dust/fine particle contamination generated by the clutch roller operation. The pulley is retained by an external circlip to the shaft
To keep the rope aligned on the clutch pulley a shallow vee groove was machined with an included flange angle of 130º, again this was found by trail and error. A simple natural rubber sleeve trimmed from a bicycle inner tube is glued to the lands of the pulley lands to provide the key friction material to operate the trigger release mechanism (Chapter 4.2.5 Method of Actuation refers). Positioning of the clutch roller in the frame was also a major consideration so that the movement of the rope passing through the device would spin the clutch pulley- again linear deflection in the rope compared to the rope axis was found by trail and error, initial the high rope friction in moving the device along the rope was thought to be high but was found to be similar to the Silent Partner. A high rope drag could unnecessarily trip the device and release the blocking cams prematurely.

5.4.3 Blocking Cams and Guide Pulley Design Justification

The physical relationship between the blocking cams and the guide pulleys provides a design challenge that must be fully effective when actuated to block the fall of a user yet they must offer as low a resistance to the movement of the rope as possible in normal mode of operation.

- The guide pulley was set at an arbitrary 27mmØ in the preliminary design process and it was found during the static load tests of being able to take the high component load exerted on by the blocking cam. The guide pulleys are turned from 6063-T6 aluminium alloy. Guide pulleys were inserted at this point in the frame to both reduce the rope drag and to place a set deflection in order to effectively engage the rope with the clutch pulley. However it was an unknown if the blocking cams could effectively block a fall on a rotating/non fixed member. To reduce rolling element bearing brinelling due to the high component load, yellow brass interference bearings were designed, with external circlips specified to hold the pulleys to the shafts. The AISI 302 stainless steel pulley shafts are designed to be 10mmØ at the pulley bearing with a set shoulder and reduced 8mmØ spigot that passes through the hinge frame – the shoulder is to prevent the hinge frame from closing too far and restricting the cams from rotating.
- The blocking cam design has been geometry and location based to allow clearance for the rope to slide past in the normal mode but to effectively block and to wedge rope in a fall. The cam base profile was constructed by drawing an epicycloid given a rolling circle and a base circle, refer to Appendix G, Figure G.1 for the drawing technique described by Boundy A.W. 'Engineering Drawing', 6th Edition M^{c}Graw Hill, 2000, p102.
  A wedge angle of 10º for the cam face against the rope was selected from experience with post- fall cam release problems where devices have had to be cur from a rope after a serious fall due to too fine a wedge angle, Chapter 4.2.5 refers. Initially, a range of 90º was selected as the total cam travel from release to guide pulley contact, also considered with this was that a 9mmØ rope would be compressed to 5mm flat between. These dimensions where to ensure that the 9mmØ rope would be blocked at about 80% of cam range, however it was found that

in the static load test even a thicker diameter rope was flatten to about 3mm and the cam rotated almost the full travel distance, so a redesign was initiated to enlarge the cam effective radius. Provision was made for a helical wound activating spring on the cam shaft area to give the cam the required force and movement to block the rope. Also a 4mm wide slot machined and a 3mmØ roll pin was inserted to provide for the cam release. Several lightning holes in the cam were found to be necessary to improve the response time for the upper cam to rotate effectively into the rope when released, initially the cams were slow to move upwards due to their weight/inertia acting against the helical springs trying to drive them. AISI 302 stainless shafts were designed with an 8mmØshaft at the bearing area and 6mmØ at the hinge frame spigot, however during the initial static load test the spigot was found shear load distorted, so a redesign of just using 4mmØ straight was selected and found to be effective, the cam is retained to the shaft by an external circlip.

5.4.4 Blocking Cam Release Mechanism and Trigger Attach Link Design Justification

- The trigger link performs two important tasks in the prototype fall arrest design. Firstly it attaches the user to the device and secondly it actuates the blocking cam release. The link has been reverse engineered to actuate the release mechanism, then to fit neatly into the device and finally stress analyzed to ensure that it is strong enough to withstand the anticipated loads. The link is milled from 6063-T6 aluminium alloy and designed to slide downwards in the direction of a fall against the lower balance pin. The positioning of the two trigger link shafts is to attach the trigger link to the frame, and to guide/limit the travel of the link so the device actuates in fall and then to securely hold the trigger link at the end of its travel.
  The two centering pins are to counteract the rope drag encountered when using the device normally. The pins hold the trigger link in a central spring balanced position unless the device is manually tripped by a sharp "tug" in either direction or is actuated in fall. The spring force was found by trial and error after assembly by using two helical wound springs placed in parallel: one inside the other to give a stiffer spring constant for the centering pins.
  The two trigger link shafts are machined from AISI302 stainless steel to 8mmØ and have a 3mmØ perpendicular hole drilled through for the latch cross pins in the hinge frame.
- The blocking cam release mechanism comprises two simple sliding 6063-T6 plates that are spring loaded outwards that are limited in travel each by two 1mmØ roll pins. The mechanism allows only one blocking cam to be released in fall or both cams by manual release. When the trigger link is moved, the trigger link has two protruding milled "prongs: on one face that knocks the mating latch plates to release the blocking cam. The release mechanism is located so that it holds both blocking cams against the balance pin housings – so that the cams give clearance for the rope in the normal position. Figure 5.4 below shows the relationship between the trigger link, release mechanism and the blocking cams.

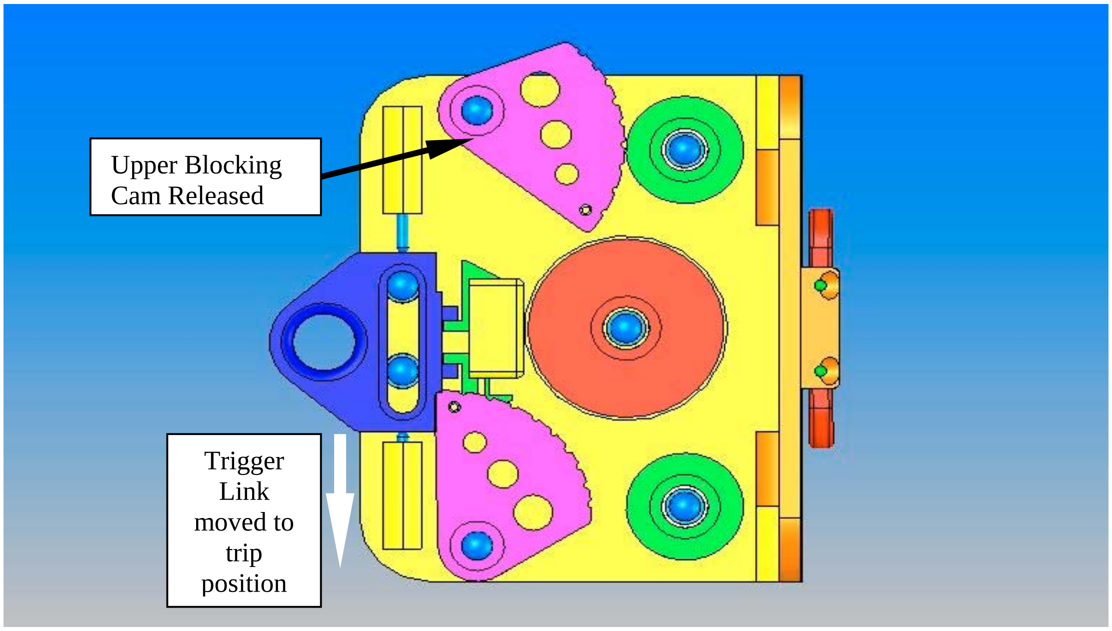

Figure 5.4. The Back Up Fall Arrest Prototype Design Shown With Trigger Link, Trigger Release Mechanism and Blocking Cam in Fall Arrest Position

5.5. Finite Element Stress Analysis of Prototype Design Components

Finite Element stress analysis was carried out using COSMOSxpress on the SOLIDworks models and using the software package ANSYS5.5 Student Edition on several of the key components to help verify the “back of the envelope” calculations. Appendix F contains the resulting plots of each analysis carried.

5.6. Manufacturing the Prototype Components

The 48 components required for the working back up fall arrest prototype were machined using non-computer numerical controlled machines. The device was constructed in a modestly equipped workshop in Sydney using:

- HAFCO AL-60 lathe with centre height of 125mm
- HAFCO HM-10 mini mill
- ½ inch bench drill press
- 100mm belt linisher
- 8 inch bench grinder

The following series of photographs show the assembled prototype device before conducting the initial static test to prove the blocking cam design:

- Figure 5.5 shows the assembled unit with the test equipment connected to the device.
- Figure 5.6 shows the initial blocking cam units found to be too small.
- Figure 5.7 shows the initial trigger release mechanism that was resized to accommodate the larger cams.
- Figure 5.8 shows the clutch pulley and nylon actuating ring during a “trial and error” approach to the design sizing of each component.

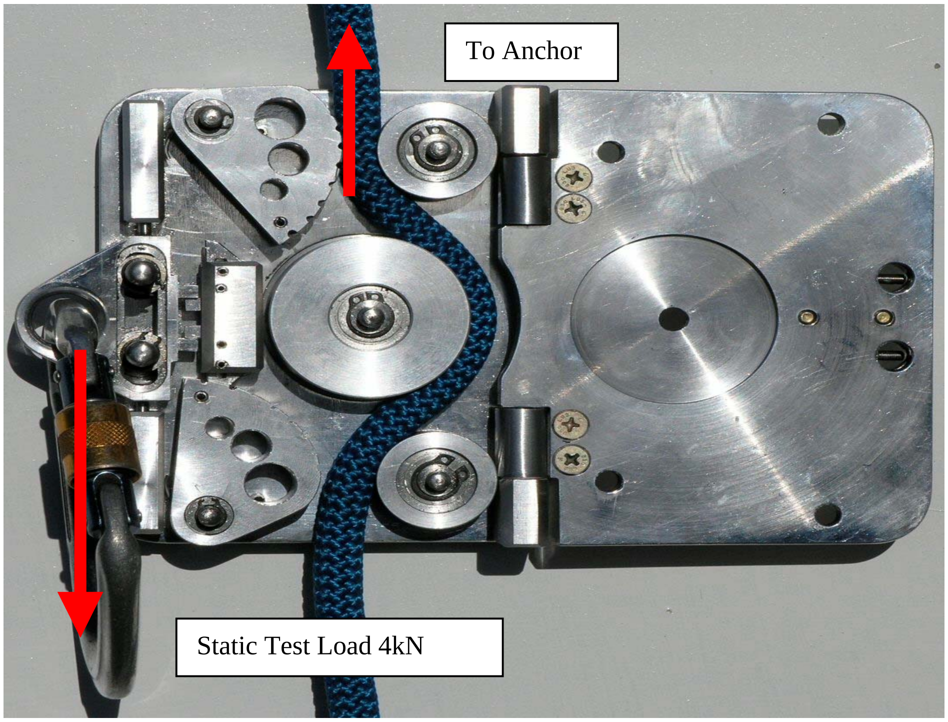

Figure 5.5. Initial Assembly of Back Up Fall Arrest Prototype Device Set Up For The Static Design Verification Test. The photograph shows:

- How the safety rope is loaded inside the device.
- The upper blocking cam tripped to block the rope against the upper guide pulley

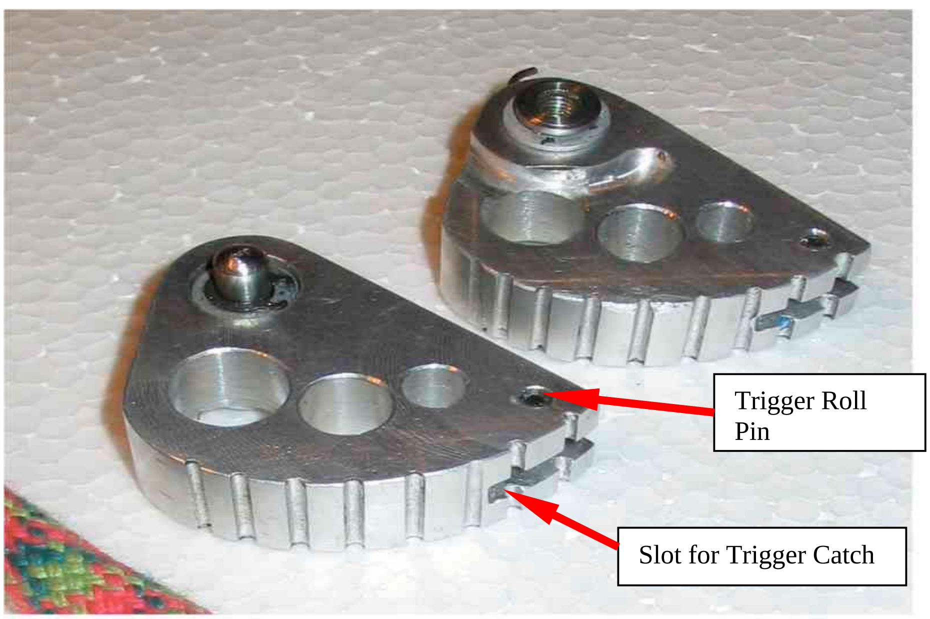

Figure 5.6. The Initial Blocking Cam Units Found to be Too Small

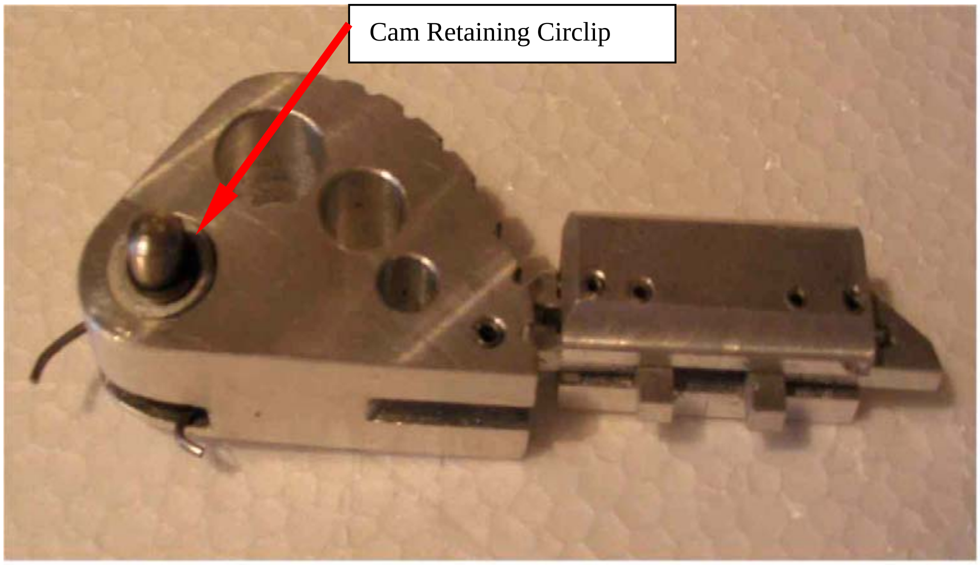

Figure 5.7. The Initial Trigger Release Mechanism: that was resized to accommodate the larger cams. The photograph also shows the blocking cam actuating spring and retaining circlip.

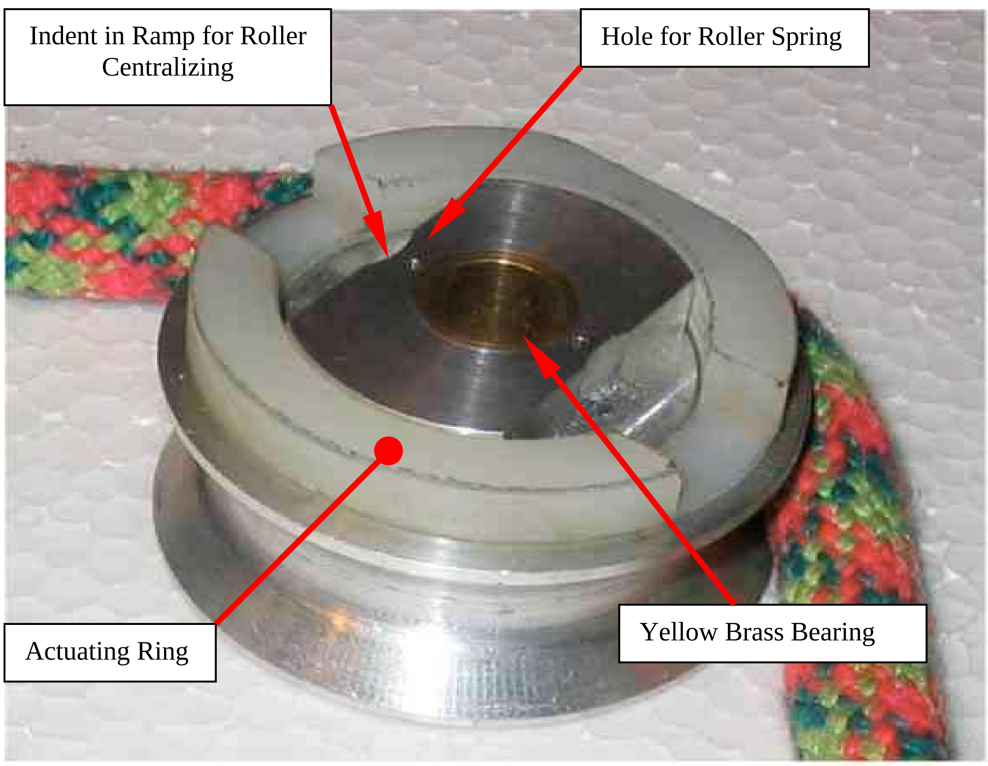

Figure 5.8. Clutch Pulley and Actuating Ring: showing the location of several features for a "trail and error" design evaluation of the operating sizes. A subsequent pulley was made with a smaller roller diameter to provide more effective pulley lock. The redesigned pulley and actuating ring were manufactured to fit the 11mmØ roller size.

Table 5.3 below shows the time taken to manufacture each component and the quantity required to produce one prototype device.

Component Description	Material Used	Quantity	Time To Manufacture Each Component (Man Hours)
Clutch Frame	6063-T6	1	14
Hinge Frame	6063-T6	1	10
Clutch Pulley	6063-T6	1	8
Clutch Pulley Bush	Yellow Brass	1	2
Clutch Shaft	AISI 302	1	5
Clutch Actuating Ring	Nylon 66	1	4
Clutch Spring	A229	2	2
Clutch Roller	AISI 302	2	4
Guide Pulley	6063-T6	2	10
Guide Pulley Bush	Yellow Brass	2	4
Guide Pulley Shaft	AISI 302	2	4
Blocking Cam Lh	6063-T6	1	8
Blocking Cam Rh	6063-T6	1	8
Cam Shaft	AISI 302	2	5
Trigger Link	6063-T6	1	6
Trigger link Shaft	AISI 302	2	8
Balance Pin	AISI 302	2	5
Balance Pin Adjust Set Screw	AISI 302	2	2
Trigger Plate	6063-T6	2	4
Latch Handle	6063-T6	2	4
Latch Pin	AISI 302	2	3
Latch Handle Set Screw	AISI 302	2	2
Lower Hinge Block	6063-T6	2	6
Upper Hinge Block	6063-T6	2	6
Trigger Housing	6063-T6	1	5
Balance Pin Housing	6063-T6	2	7
Cam Spring Lh	A229	1	2
Cam Spring Rh	A229	1	2
Latch Spring	A229	2	3
Balance Spring	A229	2	2
Total		48	233

Table 5.3 Component Manufacturing Quantity and Production Time

5.7. Chapter Conclusion

The resulting prototype back up fall arrest device design process has been a combination of meeting the design criteria by virtual modeling, coupled with review feedback from the machining and static testing processes.

The use of the Software page SOLIDworks improved the design considerably in allowing the need for cardboard mock-up to be eliminated. The animation features of the software allowed movement of the components to let interference checking to be done at the design stage without having to resort to the reworking of components in the manufacturing stage. The virtual modeling allowed for many design ideas and changes to the model to be trialed quickly in the areas of size and positioning for each component so that each of the design criteria identified in Chapters 2, 3 and 4 could be incorporated into a final design for machining.

Consideration was done at each stage of the design to avoid complex shapes that would have been difficult to machine. While several changes to the overall design were made during the machining process and after the static test – the changes were essentially to increase component sizes as the overall design was found to meet the project overall objectives. Static testing was conducted during the manufacturing stage as part of the trial and error process to confirm that the blocking cams would work effectively as there would be little point in continuing to complete the prototype design if the device could not hold the static load.

The final model was ready for the next stage of the project – the testing program defined in Chapter 6.

Chapter 6. Testing and Result Analysis for the Back Up Fall Arrest Prototype

6.1. Introduction.

6.2. Types of Verification Testing Processes for the Back Up Rope Grab Fall Arrest Device.

6.3. Results of Testing.

6.4. Analysis of the Testing Completed to Date and Feedback for the Design Process.

6.5. Chapter Conclusion.

Chapter 6. Testing and Result Analysis for the Back Up Fall Arrest Prototype

6.1. Introduction

The testing program is to intended to verify the overall effectiveness of the prototype device if possible by helping to identify any short comings in the design and to provide feedback to help rectify or allow a redesign to address them.
Testing of the prototype fall arrest device was designed to verify the blocking cam effectiveness under static and dynamic loading, and to verify the correct actuation of the clutch and cam release mechanisms.
The static and dynamic load tests used are directly adopted from the Australia/New Zealand Standards reviewed in Chapter 2. However as the clutch and cam release mechanisms lie outside the scope of the Australia/New Zealand Standards, a test was designed specifically in order to verify that the device would operate as intended.
The tests conducted to date were reviewed and the recommendations made have led to immediate improvements to the final device design.

6.2. Types of Verification Testing Processes for the Back Up Rope Grab Fall Arrest Device

Testing of the back up fall arrest device is required to verify that the device if it is intended to be used in the work place, will meet the Australia/New Zealand Standards requirements below:

- Type 1 fall arrest device static load testing as per Australian/New Zealand Standard AS/NZ 4488.3:1997 Industrial rope access systems Part 3: Fall Arrest Devices.
- Type 1 fall arrest device dynamic load testing as per Australian/New Zealand Standard AS/NZ 4488.3:1997 Industrial rope access systems Part 3: Fall Arrest Devices.

However, the design of the clutch and cam release mechanism will require that the testing program criteria will need to be expanded in range to prove several features of the proposed device that are outside the testing requirements of the Australian/New Zealand Standards for the device.

- To test the device for locking speed and arrested fall distance in vertical falls, a verification test is required to confirm correct actuation. The test has its basis by using requirements for Type 2 fall arrest devices given in the Australian/New Zealand Standards AS/NZ 1891.3:1997 Industrial fall-arrest systems and devices Part3 Fall-arrest Devices and AS/NZ 4488.1:1997 Industrial rope access systems Part 1 Specification**.**

6.2.1. Static Load Testing for Back Up Rope Grabs and Ascender Devices

The test determines the integrity of a back up rope grab and its ability to avoid damage to a rope when tested on a specific range of rope diameters with a set static load.
Australia/New Zealand StandardAS/NZ4488.1:1997 Appendix A p10 when specifying the 4kN test load says;

> “test the expected maximum static service load of 2 kN multiplied by a factor of 2”

The test specifies a tensile test apparatus capable of applying the 4.0 kN load at a cross head speed of 100 mm/minute using a test rope with a diameter of 10.5 to 11.0 mm are specified by both AS/NZ1891 and AS/NZ 4488.
The back up rope grab/ascender test specimen is attached to a rope that is tied to the test rig upper anchor and an over hand knot is tied 50mm in the rope below the device, then the test load is attached to the test specimen connection point. The test requires the 4kN load to be held for at least 60 seconds, then the device is examined for signs of fracture or permanent

deformation and the rope is then examined or signs of damage. The steps are repeated five times using the same test specimen and all results are recorded for the testing report. Figure 6.1. below shows the static test set up.

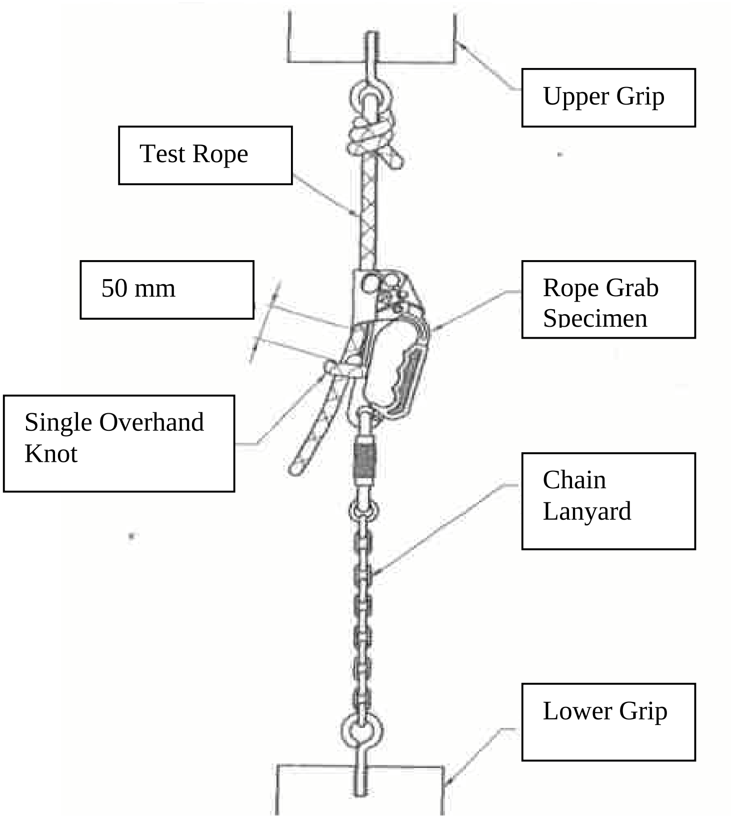

Figure 6.1. Static Test Set Up for Testing Back Up Rope-grab/ Ascender Devices as per Australia/New Zealand StandardAS/NZ4488.1:1997 Appendix A

6.2.2. Dynamic Load Testing for Back-Up Rope Grabs

The test is used to test the integrity and performance of a back up rope grab when subjected to a dynamic load. The test simulated a free fall utilizing a falling mass and measuring the peak force generated in the rope when the test specimen arrests the fall.

The test mass of 100kg is required to be in the form of a vertical 200 mm diameter steel cylinder with a release mechanism to allow it to be released without imparting any initial velocity.

The test specimen is rigidly anchored to a test rig with an in-line force measuring instrument complying to SAE J211/ 1Mar95 used to record the peak fall force in the rope. The test rope of a diameter of 10.5 to 11.0 mm and 3.5 metres in length is used with a single overhand knot tied at 3.0 metres below the top attach loop. Two test specimens that have been subjected and passed the static test are to be used for the dynamic test. (Australia/New Zealand Standard AS/NZ4488.1:1997 Appendix B p12).

The test procedure requires the mass to fall 600 mm from the release to when it applies load to the test specimen. Figure 6.2. shows the dynamic test set below. The peak arresting force on the rope is recorded and the specimen is examined for visible damage or permanent deformation, then the rope is examined for damage and the extent of any slippage down the rope.

The test is repeated using a second test specimen and a fresh length of rope.

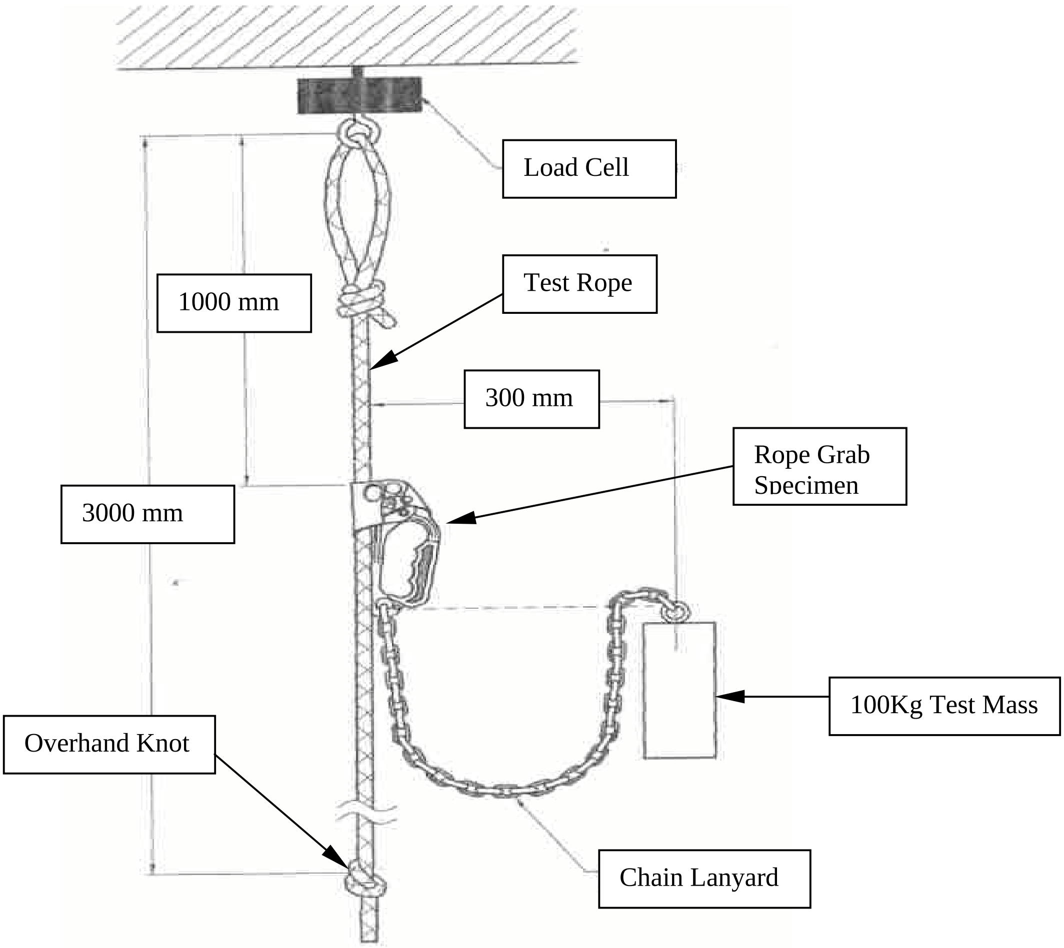

Figure 6.2. Test Set Up for Dynamic Testing of Back Up Rope-grabs as per Australia/New Zealand StandardAS/NZ4488.1:1997 Appendix B

6.2.3. Clutch and Cam Release Mechanism Verification Test

The test is used to test the integrity and performance of a back up rope grab when subjected to a simulated fall. The test simulated a free fall utilizing a falling mass and measuring the sequence of fall forces generated in the rope when the test specimen arrests the fall.
This test has been formulated to verify the operation of the clutch and cam release mechanism and uses two parameters set by Australia/New Zealand Standards AS/NZ 1891.3:1997 Industrial fall-arrest systems and devices Part3 Fall-arrest Devices and AS/NZ 4488.1:1997 Industrial rope access systems Part 1 Specification for a Type 2 fall arrest device.
The two parameters that define the test are:

- The maximum fall velocity is not to exceed 2.5 ms^{-1}.
- The maximum fall distance is limited to 0.6 m.

The test apparatus uses a load cell that reads in real time values to allow the maximum fall velocity to be calculated for specific events in the fall sequence.
The back up fall arrest device specimen is attached to overhead load cell. The test rope of a diameter of 10.5 to 11.0 mm and 3.5 metres in length is used with a single overhand knot tied at one end and the other end is tied in a loop and then attached to the 100N test load. The test rope is connected to the specimen device and the device is released by a release mechanism that does not impart any vertical velocity to the falling test mass. The sequence arresting

forces on the rope, the sequence timing and maximum fall distances are recorded and the specimen is examined for visible damage or permanent deformation, then the rope is examined for damage and the extent of any slippage down the rope. The test is repeated and then the rope is reversed and the tests repeated twice for the opposite side of the fall arrest mechanism. Figure 6.3 below show the set up of the test apparatus,

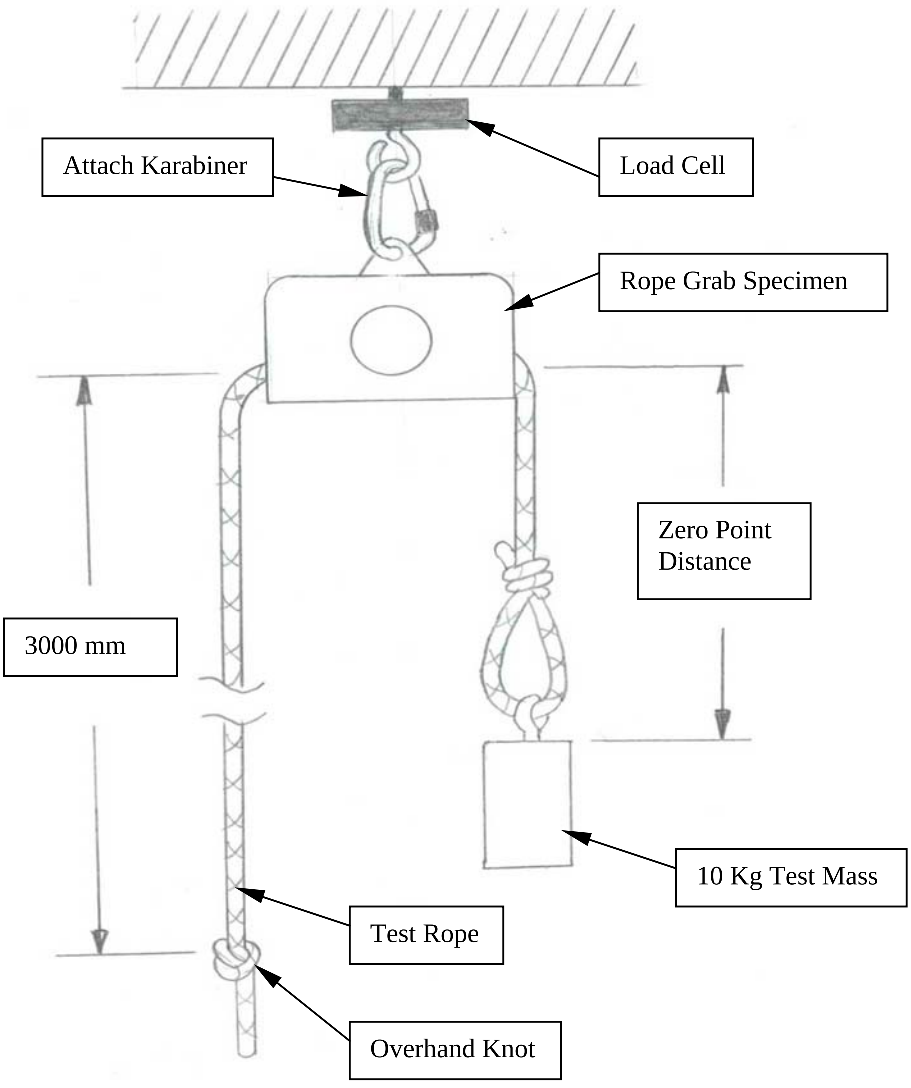

Figure 6.3. Test Set Up for the Back Up Fall Arrest Device Clutch and Cam Release Mechanism Verification Test

6.3. Results of Testing

The full test program of the back up fall arrest device was unfortunately curtailed due to the theft of the device and several other pieces of testing equipment, Appendix C refers. However several design ‘trial and error” tests were carried out to verify the operation of the cam blocking, clutch mechanism and cam release mechanism. Static testing was conducted on test rig at the Single Rope Techniques factory at 9 Stanley Street Padstow, New South Wales.

6.3.1 Provisional Static Load Test – Blocking Cam Verification Check

Test Report For Back Up Fall Arrest Device Specimen		
Type of Test Conducted:	**Test Conditions:**	**Test Date:**
Static Load Test	4000N Load	9th August 2004
Test Report: To Verify Blocking Cam Effectiveness in Preparation For Dynamic Test #1		
- Both rope blocking cams held the 4kN static load however the 11mm diameter static rope was blocked too far towards each cam end. - No slippage down the rope was noticed on either side of the device during each test, and no damage to the rope sheath was noted when the rope was removed from the device. On disassembly one cam shaft was found to is shear distorted where the upper 6mm-diameter spigot passed through the hinge frame hole. - The cams where found to be easily released from the rope when the 4kN load was removed and both cams were easily reset.		

Table 6.1. Test Report for Back Up Fall Arrest Blocking Cam Verification 9th August 2004

6.3.2. Post Rework Static Load Test – Blocking Cam Verification Check

Test Report For Back Up Fall Arrest Device Specimen		
Type of Test Conducted:	**Test Conditions:**	**Test Date:**
Static Load Test	4000N Load	12 August 2004
Test Report: To Verify Blocking Cam Effectiveness in Preparation For Dynamic Test #2		
- Both rope blocking cams held the 4kN static load, the 11mm diameter rope was blocked at approximately 80% of the cam surface. - No slippage down the rope was noticed on either side of the device during each test, and no damage to the rope sheath was noted when the rope was removed from the device. On disassembly no distortion or damage to the device was noted - The cams where found to be easily released from the rope when the 4kN load was removed and both cams were easily reset.		

Table 6. 2. Test Report for Back Up Fall Arrest Blocking Cam Verification 12th August 2004

6.3.3. Provisional Clutch and Cam Release Mechanism Test - Maximum Fall Distance Check

Test Report For Back Up Fall Arrest Device Specimen		
Type of Test Conducted:	**Test Conditions:**	**Test Date:**
Clutch and Cam Release Verification Test	100N Load, Roller Spring Rate Checking	13 August 2004
Test Report: To Determine Roller Spring Sizes by "Trial and Error" Approach, Load Cell Not Available For Test		
- Spring Diameter (mm)	Left Hand Side of Device Fall Distance (m)	Right Hand Side of Device Fall Distance (m)
0.32	1.10	1.05
	1.11	1.05
0.28	0.77	0.71
	0.79	0.71
0.19	0.55	0.60
	0.55	0.59
- No slippage down the rope was noticed on either side of the device during each test, and no damage to the rope sheath was noted when the rope was removed from the device. On disassembly slight "bedding in" of the clutch rollers was noted in the clutch frame and corresponding clutch pulley ramp surface.		
- The cams where found to be easily released from the rope when the 100N load was removed and both cams were easily reset.		

Table 6.3. Test Report for Back Up Fall Arrest Blocking Clutch and Cam Mechanism Maximum Fall Distance Check 13th August 2004

6.4. Analysis of the Testing Completed To Date and Feedback for the Design Process

The first static load test has highlighted two design deficiencies:

- Firstly, the cam shaft suffered plastic deformation at the reduced diameter area where the 6 mmØ spigot passed through the 6.5 mmØ hole in the hinge frame. The deformation may be due in part to the design was just above the calculated minimum diameter for the location of D_{min}= 5.31 mm.
- Secondly, the test also has identified that the cam surface contact point with the thicker 11 mmØ rope was too for back along the cam face.

The second static load test result confirmed the blocking cam redesign and rebuild were now working effectively and were able to be released easily form the rope after the load was removed.

The clutch and cam release mechanism test carried was a "trial and error" test to see what effect the changing of the roller springs would have on the total fall distance. Each reduction in spring material diameter reduced the fall distance.

The results of the analysis for the initial static test led to reworking the prototype in two main areas:

- The cam shaft spigot diameter was redesigned to 8 mmØ and increasing the corresponding hole size in the hinge frame to 8.5 mmØ. This has been done to prevent the cam shaft from suffering further plastic deformation due to the high shear load at this point by increasing the shaft diameter.
- The two blocking cams effective radii were increased by 2 mm, and the trigger release mechanism resized to accommodate the larger cams.

The second static load test confirmed the size change was the correct step to undertake with the blocked rope position change to only 80% of the cam surface used.

6.5. Chapter Conclusion

The testing conducted to date has proved that the blocking cam mechanism design is ready for the dynamic load test as the device was found to be the capable of blocking the 4000N load with out any rope slippage or device distortion after the cam size was increased. However testing on thinner diameter rope would have to be carried out to check if the cam re-sizing is adequate for using a 9 mmØ rope that has been specified in the design criteria of Chapter 4.

The results of achieving the 600mm maximum fall distance by a change in roller spring diameters/ spring constant has demonstrated that the device is capable of being adjusted to meet the test criteria standard. Further testing using the load cell to ascertain the maximum fall velocity reached would have been preferable, however the static load test and the clutch and cam release test results to date have been quite satisfying to have achieved.
Using load cell analysis would help to fine tune the device by determining if reducing the blocking cam moments of inertia could help in reducing the maximum fall velocity and in turn to limit the fall forces generated. By reducing the roller spring constant alone, the clutch mechanism may become too sensitive to linear movement of the rope and lead to nuisance tripping of the device in normal use. This area of testing will be crucial in finding a good balance between the clutch trip point and the inertial lag of the blocking cam movement.

For the stage that the device has reached, from a users perspective – the device has the right "feel" where it can be moved along a rope with out the feel of too much rope drag, and very little nuisance tripping occurs when the device is used for hands free climbing.

Chapter 7. Conclusion

7.1. Introduction.

7.2. The Research Project Objectives.

7.3. Achieving the Objectives.

7.4. Deficient Areas of the Back Up Fall Arrest Device.

7.5. Further Work for the Back Up Fall Arrest Device Concept

Chapter 7: Research Project Back Up Fall Arrest Device Conclusion

7.1. Introduction

Several of the key objectives in the design, prototype building and testing of a new back up fall arrest device have been met by the undertaking of this research project.

7.2. The Research Project Objectives

The objectives specified in Chapter 1. Introduction and Appendix A Project Specification have been used a plan to achieve these key objectives. These key objectives have been to:

- Conduct a thorough literature review of the government legislation specifically pertaining to Occupational Health and Safety in the workplace for working at heights. To review accident statistics to establish if a needs basis for the new device is required to overcome deficiencies in the currently available equipment in use. To review Australia/New Zealand Standards and International standards for specific requirements of equipment in current use to establish the design and test criteria for the new device. To review fall arrest methods used in both the work place and in recreational areas.
- Conduct a thorough evaluation of current fall arrest equipment in use in the workplace and in recreational areas to establish the strict requirements for a design basis that the new back up fall arrest device specifically has addressed.
- Examine the operating environment and uses that the back up fall arrest device would be expected to be used in to establish the design requirements.
- Design and build a workable back up fall arrest prototype device using the strict requirements formed from the literature review, the current fall arrest device critique and the design criteria.
- Establish and conduct a test regime to prove or otherwise the prototype device, and to critically evaluate the testing data for a design review.

7.3. Achieving the Objectives

The research project process has allowed a workable prototype back up fall arrest device to be constructed that has met many of these key objectives.
Specific requirements were identified in the Chapter 2 Literary Review and the Chapter 3 Current Fall Arrest Device Review as deficiencies that have contributed to accidents or positive features designed to eliminate the possibility of human handling errors.
Chapter 4 Design Criteria For the Back Up Fall Arrest Device, explored the requirements to both improve and incorporate the findings of Chapter1 and 2 and to examine what specific uses expected of the device would influence the final design. Another important part of the design process was the examination of what operating principles would be used to actuate the device in order to achieve the use requirements. The device uses a fall sensing mechanism that detects a fall and is then actuated to bock the fall.
The actual design and construction documented in Chapter 5 allowed for a series of conceptual ideas to trialed by virtual modeling to establish the viability of the prototype design in meeting the specific requirements before the components were manufactured. This included the design layouts, material selection, stress analysis of key components and the fits and clearances of assemblies.

After the prototype construction was completed, a series of proving tests were conducted to allow for design confirmation, Chapter 6 documents this stage in the project. A three-stage set of tests were proposed to verify the prototype design.
The tests used have a basis on the relevant Australia/New Zealand Standard for back up fall arrest devices, however the prototype device actuating mechanism design lies outside the scope of the standard, so a verification test method was established to confirm the fall detection sensing of the design.
Immeadiate feedback for the initial tests while proving the design concepts, allowed for a re-evaluation of several design issues that were quickly incorporated into the design to produce a more workable unit, particularly in the size of the blocking cams.

Cessation of the testing program occurred after the device was stolen in Singapore.

The work to date had shown that the device was close to meeting each key objective particularly:

- The device was intuitive to use, with rope handling issues significantly reduced in comparison to the evaluated devices.
    - By making the device operate multi-directional it could not be connected to a rope Inverted, thus eliminating a novice user's greatest exposure to at use risk
    - Careful component positioning in the device eliminated mis-rope rigging.
    - The device allowed the safety rope to be connected while attached to a users harness to prevent the device from being dropped particularly when at heights.
    - Single-hand, two distinct action unlocking/locking frame opening latches that must be physically positioned open/closed that also provide visual confirmation.

- The device is adaptable for several uses, in direct comparison to existing devices, which are designed to accomplish one or more purposes only.
    - Allows for fall sensing and automatic rope blocking in the advent of a fall limiting the fall distance to less than 600mm
    - Allows the user to be able to climb hands free as the device can trail the safety rope
    - The device can be manually activated so that it will block in one direction on a safety rope to allow for work positioning, or to be used as an ascender to climb the rope.
    - The device's strength allows it to be used on a horizontal safety line, and is capable of being locked to prevent any movement in either direction on the safety line.

7.4. Deficient Areas of the Back Up Fall Arrest Device

Deficient areas of the device are related directly to the theft of the device, as there was insufficient time to reproduce a second prototype device.

- Completion of the verification testing, two key areas remain uncompleted to date
    - Completing the fall sensing mechanism testing to allow the maximum fall velocity to be ascertained. This will allow for inertia design review of the fall sensing mechanism components to optimize how they operate and also the inertia design review of the blocking cams to allow for a faster response time in order to reduce the maximum fall distance.
    - Dynamic Load Test. This is the second verification test required to ensure the blocking cams operate effectively and block a fall without any distortion to the device or any visible rope damage.

- Weight considerations. The prototype was purposely built from commercially available materials to keep the project costs low, which however meant that thicker sections were required in order to give sufficient component strength and stiffness. The prototype weight was 488 grams, something that was to be reduced by hollowing out of non-critical areas on the milling machine.

7.5. Further Work for the Back Up Fall Arrest Device Concept

Several areas of interest were uncovered during the research project into a new back up fall arrest device.

- The literate review uncovered several proposed and new commercial fall arrest devices coming onto the market. Although several of these devices appear to address some of the areas that I have looked at, there are several areas that these new devices are deficient in. Namely, the need for multi directional blocking. It would appear that the new devices are intended for one direction only – which my project identified as a significant area for eliminating potential accidents.
- Use of exotic high strength and stiffness materials for construction to reduce component and overall assembly weights. The weight reduction would be beneficial for two reasons:
    - less weight for a user to carry, with a less bulky sized device
    - reduced maximum fall distances due to improved inertial qualities of the device and improved overall device strength.
- Finding an improved understanding of the devices fall sensing and actuation mechanism – unfortunately this has been outside the scope of this research project, however the understanding of the key concepts I feel may allow for accurate modeling that could improve the device design in reducing the fall distances and overall fall forces generated. I have tried to explain the operation of the device in Chapter 4 and Appendix G
- The review of the Australia/New Zealand Standard 4488 Industrial Rope Access Systems should be carried out in a timely manner for the incorporation of this type of back up fall arrest device that is coming onto the market. At the moment the standard does not cover this type of device for use in the work place. I feel that a review is now due particularly in view that the standard is quite restrictive in its scope for automatic safety fall arrest devices now that several manufacturers are selling proven devises.
- Taking out of a provisional patent. It has been suggested that I should go ahead and patent the work done to date and continue with the development of a workable commercially viable unit, however I took the decision not to take out a provisional patent. Like many people who use fall arrest equipment recreationally, incremental advances in equipment development help prevent accidents as several manufactures produce their designs and eventually find their way into work related areas. I hope this project has been one of these advances.

List of References

Material Used for Appreciation Research and References

Programs

ANSYS Version 5.5 Student Edition, 1998

Solid Works Studio 2004

COSMOSXpress 2004

Brochures, Manufacturer; No Author

Airlines Support Industries Australia Pty Ltd Brochure March 2004

Beal Ropes, 'The Dynamic Company". 2003 Catalogue

Boeing 747-400 Maintenance Manual, Boeing Proprietary, Unpublished 10 Feb 1996

Gibbs Products Ascender, 'About Gibbs Ascenders' Brochure 1978

Gibbs Products Ascender, 'Spring Loading The Gibbs Ascender' Brochure 1978

Petzl Ascension Brochure Aug 2001

Petzl 2002-2003 Catalogue

Petzl 2003 Professional (English) Catalogue

Petzl Rescucender Brochure 2001

Protecta International Technical Specifications "Cobra" Rope Grab AC202A Revision 12 2001

Silent Partner User's Manual Wren Industries Unpublished, 2000

WingGrip User Manual. Rota Limited Revision4 Jan 2000

Government Publications, No Author

WorkCover NSW Worker Compensation Statistical Bulletin Section 2000/2001

Victorian Legislation and Parliamentary Documents Occupational Health and Safety (Prevention of Falls) Regulations 2003 S.R.No.121/2003

New South Wales WorkCover Authority, Code of Practice Safe Work on Roofs, Part 1 – Commercial and Industrial Buildings, gazetted 13 Aug 1993, commenced 1 Nov 1993

New South Wales WorkCover Authority, Code of Practice Safe Work on Roofs, Part 2 – Residential Buildings, gazetted 6 Dec, commenced 1 Mar 1997

New South Wales Government Occupational Health and Safety Regulation 2001

WorkCover Victoria Code of Practice – (No.28) – Prevention of Falls in General Construction 31 Mar 2004

Journals

Peterson B., ‘Canyon and Caves’ Number 3 1971)

Patents

United States Patent Number 4,253,218. Gibbs P. ‘Spring Loaded Ascender’. 3 March 1981

United States Patent Number 4,941,548. Blanchard M. ‘Fall Arresting Device For Climbers’ 17 July 1990

Standards, No Author

Australian /New Zealand Standard AS/NZ 1657 Fixed platforms, walkways, stairways and ladders – Design construction and installation

Australian/New Zealand Standard AS/NZ 1891.3:1997 Industrial fall-arrest systems and devices Part 3 Fall-arrest Devices

Australian/New Zealand Standard AS/NZ 1891.4:1997 Industrial fall-arrest systems and devices Part 4: Selection, use and maintenance

Australian Standard 2424-1981 Plastic Building Sheets – General installation requirements and design of roofing systems

Australian/New Zealand Standard AS/NZ 2550.10 Cranes - Safe use - Elevating work platforms

Australian/New Zealand Standard AS/NZ 4488.1:1997 Industrial rope access systems Part 1: Specifications

Australian/New Zealand Standard AS/NZ 4488.2:1997 Industrial rope access systems Part 2: Selection, use and maintenance

Australian/New Zealand Standard AS/NZ 4488.3:1997 Industrial rope access systems Part 3: Fall Arrest Devices

Australian Standard/New Zealand AS/NZ 4576 Guidelines for scaffolding

British Standard: Code of Practice for the Use of Safety Nets on Construction Works CP93

British Standard: Personal protective equipment against falls from a height- Fall arrest systems BS EN 363: 1993

British Standard: Personal protective equipment against falls from a height- Test methods BS EN 364: 1993

European Standard EN 567 Mountaineering equipment, rope clamp, safety requirements and test method

Union Internationale des Association d"Alpinisme UIAA Standard: 126 Mountaineering and Climbing equipment: Rope Clamps. Jan 2004

Texts

Beer F. P. & Johnston E. R., 'Mechanics of Materials', 2nd Edition SI Units McGraw Hill 1992.

Boundy A.W., 'Engineering Drawing', 6th Edition McGraw Hill, 2000.

Meriam J. & Kraige L., 'Dynamics, Engineering Mechanics Volume 2, 3rd Edition, Wiley 1993.

Graydon D. Editor. 'Mountaineering, The Freedom of The Hills', Allen & Unwin, The Mountaineers, Seattle Washington USA 1992.

Montgomery N. 'Single Rope Techniques, a guide for vertical cavers', Sydney Speleological Society Occasional Paper No 7, 1st Edition 1977.

Warild A. 'Vertical, A Technical Manual for Cavers', The Speleological Research Council Ltd, Sydney, Australia. 1st Edition 1988.

Web Documents

Bossus P. History of the Union Internationale des Association d"Alpinisme UIAA undated, viewed 25 Apr 2004
http://www.uiaa.ch./article/aspx?c=45&a=271

Sedgman, Iain B. Climbing Accidents in Australia !955 – 2004 viewed 23 May 2004
http:/uob-community.ballarat.edu.au/~isedgman/climbing/Accidents.pdf

Storrick, Dr Gary Ascenders - Descender Collection 2001 viewed 24 Sep 2003
http://www.storrick.cnchost.com/VerticalDeciesPage/Belay/SelfBelay…

Web Documents, No Author

CE Marking, Webportal for CE Marking & Regulatory Affairs, viewed 7 April 2004
http://www.cemarking.net/article/articlrview/8/1/77

Protecta International Incorporated Website, viewed 21 Apr 2004
http://www.protecta.com/world/products

Victorian WorkCover Authority WorkSafe Online, viewed 5 Mar 2004
http://www.workcover.vic.gov.au/dir090/vwa/home.nsf/pages/so_safetybasics_falls

Figure References

Figure 2.1. Fixed Working Platforms
Reference; Airlines Support Industries Australia Pty Ltd Brochure March 2004.

Figure 2.2. Work positioning system
Reference: WingGrip User Manual. Rota Limited Revision 4 Jan 2000.

Figure 2.3.(a). Industrial rope access descent.
Reference: Australian/New Zealand AS/NZ 4488.2:1997 Figure A1 p.16.

Figure 2.3.(b). Industrial rope access ascent.
Reference; Australian/New Zealand AS/NZ 4488.2:1997 Figure A2 p.17.

Figure 2.4. Abseiling descent.
Reference: Graydon D. Editor. 'Mountaineering, The Freedom of The Hills', Allen & Unwin, The Mountaineers, Seattle Washington USA 1992, Figure.8-1 p.13.7

Figure 2.5. Bottom belay braking.
Reference: Petzl Rescucender Brochure 2001, Figure C1, p.111.

Figure 2.6. Frog method of ascender rope grab attachment.
Reference: Montgomery N. 'Single Rope Techniques, a guide for vertical cavers', Sydney Speleological Society Occasional Paper No 7, 1st Edition 1977, Figure 138, p. 92.

Figure 2.7. Dynamic rope belay of a caver climbing a caving ladder to provide fall arrest.
Reference: Petzl Rescucender Brochure 2001, Figure C3, p.111.

Figure 2.8. Rockclimbing fall arresting.
Reference: Graydon D. Editor. 'Mountaineering, The Freedom of The Hills', Allen & Unwin, The Mountaineers, Seattle Washington USA 1992, Figure.7-1 p.109.

Figure 2.9.(a). The most severe fall.
Reference: Beal Ropes, 'The Dynamic Company". 2003 Catalogue p.2.

Figure 2.9.(b). Less severe fall.
Reference: Beal Ropes, 'The Dynamic Company". 2003 Catalogue p.2.

Figure 2.10. Top rope belay
Reference: Graydon D. Editor. 'Mountaineering, The Freedom of The Hills', Allen & Unwin, The Mountaineers, Seattle Washington USA 1992, Figure.7-1 p.109.

Figure 2.11. Solo Back Roped Rock Climbing
Reference: Mark Blanchard, FALL ARREST DEVICE FOR CLIMBERS
US Patent Number 4,941,548, 17 July 1990

Figure 2.12. Method of Roping Up for Glacier Travel
Reference: Lindsay Main, 'Mountaincraft Manual 20', New Zealand Safety Council
Revised 2nd Edition 1987, Figure 94 p.p.146 & 147

Figure 3.1. Gibbs Ascender Model Type 2 rope grab
Reference: Christine Ho Collection, 03 May 2004.

Figure 3.2.(a). Aligning the components.
Reference: Gibbs Products Ascender, 'Spring Loading The Gibbs Ascender' Brochure 1978.

Figure 3.2.(b). Inserting the quick release pin.
Reference; Gibbs Products Ascender, 'Spring Loading The Gibbs Ascender' Brochure 1978.

Figure 5.4. The Back Up Fall Arrest Prototype Design
Reference: Alan Silva, SOLIDworks 2004 Edition, Unpublished, 03 August 2004.

Figure 5.5 Initial Assembly of Back Up Fall Arrest Prototype Device
Reference: Gary Silva Collection, 10 August 2004.

Figure 5.6. The Initial Blocking Cam Units Found to be Too Small
Reference: Christine Ho Collection, 08 October 2004.

Figure 5.7. The initial trigger release mechanism that was resized
Reference: Christine Ho Collection, 08 October 2004.

Figure 5.8. Clutch Pulley and Actuating Ring
Reference: Christine Ho Collection, 08 October 2004.

Figure 6.1. Static test set up for testing back up rope-grab/ ascender devices.
Reference: Australia/New Zealand StandardAS/NZ4488.1:1997 Industrial rope access systems Part 1: Specifications Appendix A, Figure A1 p.11.

Figure 6.2. Test set up for Dynamic testing of back up rope-grabs.
Reference: Australia/New Zealand StandardAS/NZ4488.1:1997 Industrial rope access systems Part 1: Specifications Appendix B, Figure A2 p.14.

Figure 6.3. Test set-up for the Clutch and Cam Release Mechanism Verification Test
Reference: Alan Silva, Unpublished, 08 October 2004.

Figure E.1. Sketch of Back Up Fall Arrest Device In Orientated Fall Arrested Position
Reference: Alan Silva, SOLIDworks 2004 Edition, Unpublished, 03 August 2004.

Figure E.2. Sketch of Blocking Cam and Guide Pulley Loads
Reference: Alan Silva, Unpublished, 08 October 2004.

Figure E.3. Sketch of Free Body Diagram for Blocking Cam and Guide Pulley Loads
Reference: Alan Silva, Unpublished, 08 October 2004.

Figure E.4. (a) Sketch of Cam Shaft Loads
Reference: Alan Silva, Unpublished, 08 October 2004.

Figure E.4 (b) Sketch of FBD for Cam Shaft Loads
Reference: Alan Silva, unpublished, 08 October 2004.

Figure E.5. (a) Sketch of Trigger Link Shaft Loads
Reference: Alan Silva, Unpublished, 08 October 2004.

Figure E.5. (b) Sketch of FBD for Trigger Link Shaft Loads
Reference: Alan Silva, Unpublished, 08 October 2004.

Figure E.6 Sketch of Clutch Shaft Loading Based on Rope Path Centre Line
Reference: Alan Silva, Unpublished, 08 October 2004.

Figure E.7. Sketch of FBD for Clutch Shaft Loading
Reference: Alan Silva, Unpublished, 08 October 2004.

Figure E.8. Sketch of Shaft Groove Nomenclature for Grooved Shaft Bending
Reference: Alan Silva, Unpublished, 08 October 2004.

Figure E.9. Sketch of Shaft Cam Shaft Under Blocking Cam Distributed Load
Reference: Alan Silva, Unpublished, 08 October 2004.

Figure E.10. (a) Shear Force Diagram for Blocking Cam Shaft
Reference: Alan Silva, Unpublished, 08 October 2004.

Figure E.10. (b) Bending Moment Diagram for Blocking Cam Shaft
Reference: Alan Silva, Unpublished, 08 October 2004.

Figure E.11. Bearing Stress for Clutch and Hinge Frames at Shaft Holes
Reference: Alan Silva, Unpublished, 08 October 2004.

Figure E.12. Trigger Link Section Sketch
Reference: Alan Silva, Unpublished, 08 October 2004.

Figure E.13. Trigger Link Section A-A Sketch
Reference: Alan Silva, Unpublished, 08 October 2004.

Figure E.14. Trigger Link Section B-B Sketch
Reference: Alan Silva, Unpublished, 08 October 2004.

Figure E.15. Vector Force Diagram at Section B-B
Reference: Alan Silva, Unpublished, 08 October 2004.

Figure F.1 Constraints and Distributed Load Applied to Simplified Initial Cam Shaft ANSYS Model
Reference: Alan Silva, ANSYS 5.5 ED, Unpublished, 16 October 2004.

Figure F.2 Initial Cam Shaft ANSYS Solution
Reference: Alan Silva, ANSYS 5.5 ED, Unpublished, 16 October 2004.

Figure F.3 Constraints and Distributed Load Applied to Simplified Final Cam Shaft ANSYS Model
Reference: Alan Silva, ANSYS 5.5 ED, Unpublished, 16 October 2004.

Figure F.4 Final Cam Shaft ANSYS Solution
Reference: Alan Silva, ANSYS 5.5 ED, Unpublished, 16 October 2004.

Figure F.5 Constraints and Distributed Load Applied to Simplified Trigger Link ANSYS Model
Reference: Alan Silva, ANSYS 5.5 ED, Unpublished, 16 October 2004.

Figure F.6 Final Trigger Link ANSYS Solution
Reference: Alan Silva, ANSYS 5.5 ED, Unpublished, 16 October 2004.

Figure F.7 COSMOSxpress Trigger Link Plot showing the von Mises stress levels
Reference: Alan Silva, COSMOSxpress 2004 Edition, Unpublished, 08 August 2004.

Figure F.8 Constraints and Distributed Load Applied to Simplified Hinge Frame ANSYS Model
Reference: Alan Silva, ANSYS 5.5 ED, Unpublished, 15 October 2004.

Figure F.9 Final Hinge Frame ANSYS Solution
Reference: Alan Silva, ANSYS 5.5 ED, Unpublished, 15 October 2004

Figure F.10 COSMOSxpress Hinge Frame Plot showing the von Mises stress levels
Reference: Alan Silva, COSMOSxpress 2004 Edition, Unpublished, 08 August 2004.

Figure G.1 Clutch Mechanism Nomenclature
Reference: Alan Silva, Unpublished, 16 April 2004.

Figure G.2 (a) FBD of Forces on Upper Roller
Reference: Alan Silva, Unpublished, 16 April 2004.

Figure G.2 (b) FBD of Forces on Lower Roller
Reference: Alan Silva, Unpublished, 16 April 2004.

Figure G.3 Final Design Layout of Clutch Mechanism
Reference: Alan Silva, SOLIDworks 2004 Edition, Unpublished, 03 August 2004.

Figure G.4 Vector Forces Generated by Rope Sliding Over the Locked Clutch Pulley
Reference: Alan Silva, Unpublished, 16 April 2004.

Figure G.5 Fall Forces Generated by Unlocked Falling Fall Arrest Device and Locked Fall Arrest Device
Reference: Alan Silva, Unpublished, 16 April 2004.

Figure H.1 Drawing Construction of an Epicycloid
Reference: Boundy A.W. ‘Engineering Drawing’, 6th Edition McGraw Hill, 2000, p102.

Figure H.2 Initial Layout Sketch of Back Up Fall Arrest Device Design
Reference: Alan Silva, Unpublished, 06 March 2004.

Figure H.3 SOLIDworks Model Back Up Fall Arrest Device Prototype Assembly
Reference: Alan Silva, SOLIDworks 2004 Edition, Unpublished, 09 June 2004.

Figure H.4 SOLIDworks Model Back Up Fall Arrest Device Prototype Cam Left Hand
Reference: Alan Silva, SOLIDworks 2004 Edition, Unpublished, 11 August 2004.

Figure H.5 SOLIDworks Model Back Up Fall Arrest Device Prototype Cam Right Hand
Reference: Alan Silva, SOLIDworks 2004 Edition, Unpublished, 06 June 2004.

Figure H.6 SOLIDworks Model Back Up Fall Arrest Device Prototype Cam Shaft
Reference: Alan Silva, SOLIDworks 2004 Edition, Unpublished, 11 August 2004.

Figure H.7 SOLIDworks Model Back Up Fall Arrest Device Prototype Centering Pin
Reference: Alan Silva, SOLIDworks 2004 Edition, Unpublished, 06 June 2004.

Figure H.8 SOLIDworks Model Back Up Fall Arrest Device Prototype Clutch Spring
Reference: Alan Silva, SOLIDworks 2004 Edition, Unpublished, 05 June 2004.

Figure H.9 SOLIDworks Model Back Up Fall Arrest Device Prototype Clutch Frame
Reference: Alan Silva, SOLIDworks 2004 Edition, Unpublished, 07 June 2004.

Figure H.10 SOLIDworks Model Back Up Fall Arrest Device Prototype Clutch Pulley
Reference: Alan Silva, SOLIDworks 2004 Edition, Unpublished, 08 June 2004.

Figure H.11 SOLIDworks Model Back Up Fall Arrest Device Prototype Clutch Pulley Bush
Reference: Alan Silva, SOLIDworks 2004 Edition, Unpublished, 07 June 2004.

Figure H.12 SOLIDworks Model Back Up Fall Arrest Device Prototype Clutch Roller
Reference: Alan Silva, SOLIDworks 2004 Edition, Unpublished, 07 June 2004.

Figure H.13 SOLIDworks Model Back Up Fall Arrest Device Prototype Clutch Shaft
Reference: Alan Silva, SOLIDworks 2004 Edition, Unpublished, 06 June 2004.

Figure H.14 SOLIDworks Model Back Up Fall Arrest Device Prototype Guide Pulley
Reference: Alan Silva, SOLIDworks 2004 Edition, Unpublished, 07 June 2004.

Figure H.15 SOLIDworks Model Back Up Fall Arrest Device Prototype Guide Pulley Bush
Reference: Alan Silva, SOLIDworks 2004 Edition, Unpublished, 08 June 2004.

Figure H.16 SOLIDworks Model Back Up Fall Arrest Device Prototype Guide Pulley Shaft
Reference: Alan Silva, SOLIDworks 2004 Edition, Unpublished, 06 June 2004.

Figure H.17 SOLIDworks Model Back Up Fall Arrest Device Prototype Hinge Frame
Reference: Alan Silva, SOLIDworks 2004 Edition, Unpublished, 08 June 2004.

Figure H.18 SOLIDworks Model Back Up Fall Arrest Device Prototype Handle
Reference: Alan Silva, SOLIDworks 2004 Edition, Unpublished, 08 June 2004.

Figure H.19 SOLIDworks Model Back Up Fall Arrest Device Prototype Handle Set Screw
Reference: Alan Silva, SOLIDworks 2004 Edition, Unpublished, 07 June 2004.

Figure H.20 SOLIDworks Model Back Up Fall Arrest Device Prototype Latch Pin
Reference: Alan Silva, SOLIDworks 2004 Edition, Unpublished, 08 June 2004.

Figure H.21 SOLIDworks Model Back Up Fall Arrest Device Prototype Clutch Actuating Ring
Reference: Alan Silva, SOLIDworks 2004 Edition, Unpublished, 06 June 2004.

Figure H.22 SOLIDworks Model Back Up Fall Arrest Device Prototype Trigger Adjustment Set Screw
Reference: Alan Silva, SOLIDworks 2004 Edition, Unpublished, 06 June 2004.

Figure H.23 SOLIDworks Model Back Up Fall Arrest Device Prototype Trigger Catch
Reference: Alan Silva, SOLIDworks 2004 Edition, Unpublished, 11 August 2004.

Figure H.24 SOLIDworks Model Back Up Fall Arrest Device Prototype Trigger Link
Reference: Alan Silva, SOLIDworks 2004 Edition, Unpublished, 11 August 2004.

Figure H.25 SOLIDworks Model Back Up Fall Arrest Device Prototype Trigger Link Shaft
Reference: Alan Silva, SOLIDworks 2004 Edition, Unpublished, 06 June 2004.

Drawing References

Drawing: SOLIDworks Model Back Up Fall Arrest Device Prototype Assembly
Reference: Alan Silva, SOLIDworks 2004 Edition, Unpublished, 09 June 2004.

Drawing: SOLIDworks Model Back Up Fall Arrest Device Prototype Cam Left Hand
Reference: Alan Silva, SOLIDworks 2004 Edition, Unpublished, 11 August 2004.

Drawing: SOLIDworks Model Back Up Fall Arrest Device Prototype Cam Right Hand
Reference: Alan Silva, SOLIDworks 2004 Edition, Unpublished, 06 June 2004.

Drawing: SOLIDworks Model Back Up Fall Arrest Device Prototype Cam Shaft
Reference: Alan Silva, SOLIDworks 2004 Edition, Unpublished, 11 August 2004.

Drawing: SOLIDworks Model Back Up Fall Arrest Device Prototype Centering Pin
Reference: Alan Silva, SOLIDworks 2004 Edition, Unpublished, 06 June 2004.

Drawing: SOLIDworks Model Back Up Fall Arrest Device Prototype Clutch Spring
Reference: Alan Silva, SOLIDworks 2004 Edition, Unpublished, 05 June 2004.

Drawing: SOLIDworks Model Back Up Fall Arrest Device Prototype Clutch Frame
Reference: Alan Silva, SOLIDworks 2004 Edition, Unpublished, 07 June 2004.

Drawing: SOLIDworks Model Back Up Fall Arrest Device Prototype Clutch Pulley
Reference: Alan Silva, SOLIDworks 2004 Edition, Unpublished, 08 June 2004.

Drawing: SOLIDworks Model Back Up Fall Arrest Device Prototype Clutch Pulley Bush
Reference: Alan Silva, SOLIDworks 2004 Edition, Unpublished, 07 June 2004.

Drawing: SOLIDworks Model Back Up Fall Arrest Device Prototype Clutch Roller
Reference: Alan Silva, SOLIDworks 2004 Edition, Unpublished, 07 June 2004.

Drawing: SOLIDworks Model Back Up Fall Arrest Device Prototype Clutch Shaft
Reference: Alan Silva, SOLIDworks 2004 Edition, Unpublished, 06 June 2004.

Drawing: SOLIDworks Model Back Up Fall Arrest Device Prototype Guide Pulley
Reference: Alan Silva, SOLIDworks 2004 Edition, Unpublished, 07 June 2004.

Drawing: SOLIDworks Model Back Up Fall Arrest Device Prototype Guide Pulley Bush
Reference: Alan Silva, SOLIDworks 2004 Edition, Unpublished, 08 June 2004.

Drawing: SOLIDworks Model Back Up Fall Arrest Device Prototype Guide Pulley Shaft
Reference: Alan Silva, SOLIDworks 2004 Edition, Unpublished, 06 June 2004.

Drawing: SOLIDworks Model Back Up Fall Arrest Device Prototype Hinge Frame
Reference: Alan Silva, SOLIDworks 2004 Edition, Unpublished, 08 June 2004.

Drawing: SOLIDworks Model Back Up Fall Arrest Device Prototype Handle
Reference: Alan Silva, SOLIDworks 2004 Edition, Unpublished, 08 June 2004.

Drawing: SOLIDworks Model Back Up Fall Arrest Device Prototype Handle Set Screw
Reference: Alan Silva, SOLIDworks 2004 Edition, Unpublished, 07 June 2004.

Drawing: SOLIDworks Model Back Up Fall Arrest Device Prototype Latch Pin
Reference: Alan Silva, SOLIDworks 2004 Edition, Unpublished, 08 June 2004.

Drawing: SOLIDworks Model Back Up Fall Arrest Device Prototype Clutch Actuating Ring
Reference: Alan Silva, SOLIDworks 2004 Edition, Unpublished, 06 June 2004.

Drawing: SOLIDworks Model Back Up Fall Arrest Device Prototype Trigger Adjustment Set Screw
Reference: Alan Silva, SOLIDworks 2004 Edition, Unpublished, 06 June 2004.

Drawing: SOLIDworks Model Back Up Fall Arrest Device Prototype Trigger Catch

Reference: Alan Silva, SOLIDworks 2004 Edition, Unpublished, 11 August 2004.

Drawing: SOLIDworks Model Back Up Fall Arrest Device Prototype Trigger Link
Reference: Alan Silva, SOLIDworks 2004 Edition, Unpublished, 11 August 2004.

Drawing: SOLIDworks Model Back Up Fall Arrest Device Prototype Trigger Link Shaft
Reference: Alan Silva, SOLIDworks 2004 Edition, Unpublished, 06 June 2004.