Pioneering Total Height Safety

Limpet Technology Limited

Use and Operation of the Limpet® L5 Multifunctional Height Safety System for Wind Turbine Generator (WTG) Blade Inspection

Summary

The Limpet® L5 is a multifunctional height safety system that integrates personnel hoisting with advanced rescue, evacuation, fall-prevention and climb assist capabilities in a single, intuitive product. It can be used by trained operatives to provide a fast, safe and cost effective means of accessing, inspecting and maintaining the blades on wind turbine generators.

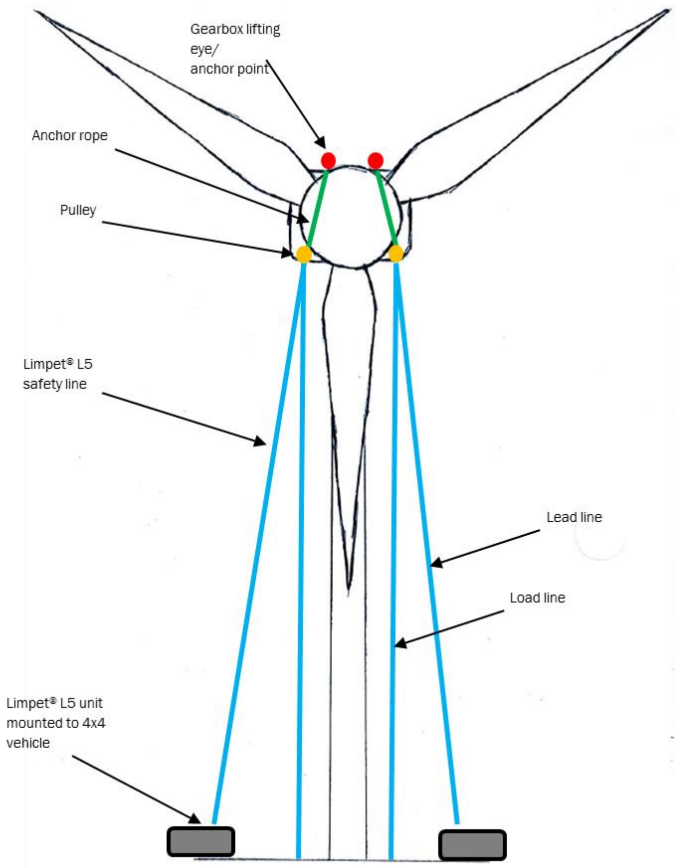
Operators use the Limpet® RF remote control unit to precisely control their ascent, descent and work position on the turbine blade. Combined with a back-up safety line, the system offers significant benefits over traditional rope access techniques, principally; a reduction in the level of physical exertion required by operators; a reduction in the technical rope skills/ qualifications required; an increase in the number of turbines that can be inspected in a day and an increase in the speed and ease with which operators can self-rescue or be rescued in the event of an emergency.

1.1 System Overview

The Limpet® L5 system is used as a means to hoist, lower and suspend personnel in order to allow them to carry out inspection and maintenance work on tall structures that are difficult, time consuming and/ or costly to inspect and maintain using other methods. The Limpet® system can be set up and operated by competent personnel who have been given the appropriate level of training and does not necessarily require advanced industrial rope access skills or qualifications, although these may be deemed desirable.

For the purpose of wind turbine blade inspection, the Limpet® main unit is anchored at ground level (e.g. to a truck or other dead-weight anchor) and its safety line fastened through an anchored pulley block that is positioned just above the blade root. The safety line therefore passes from the Limpet® L5 unit, up to the pulley block, and back down to the ground where it is connected to the safety harness of the technician who is performing the blade inspection. The technician then uses a Radio Frequency remote control device to instruct the Limpet® main unit to take in or pay out the safety line and by so doing, raises or lowers them along the length of the turbine blade.

Figure 1: System layout. Back-up line is not shown however it will be anchored to the gearbox lifting eye and routed out over the hub cone and to the ground



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1.1.2. Safety Features

Various back-up safety features are incorporated into the Limpet® L5 system in order to minimise the risks to blade inspector(s) during operation. These include:

- **Backup safety line**: The Limpet® system follows the guidelines laid out in BS 7985, BS 8437, LOLER and the Working at Height regulations regarding the principle of ‘double protection’ for suspended positioning and industrial rope access work. Consequently, Limpet® operators will be connected at all times to two, independently anchored safety lines. These lines consist of (a) the Limpet® ‘working line’, which provides the means of supporting, raising and lowering the weight of the operative and (b) the ‘back-up line’, which the operator will connect to via a mobile fall protection device (such as a Petzl ASAP) with an integrated shock absorber. This provides a means of preventing a dangerous fall by the operative in the event of a failure of the working line system. The back-up line also provides a means of escape for the operative if the working line system and its back-ups (below) become non-functional.
- **Uninterruptable Power Supply**: The Limpet® L5 system is offered with the option of a back-up battery (UPS), the standard version of which gives up to 45 minutes of use in the event of a failure in the main source of power (whether mains electricity or a portable generator). If the main supply is cut, the UPS engages automatically and emits an audio alarm to alert the user(s) that the system is now being powered by backup battery. While under power from the UPS, hoisting functionality will be disabled and if operative(s) are suspended on the Limpet® system, then they should immediately lower to the ground.
- **Manual wind/ unwind:** The Limpet® L5 system is offered with the option of a manual wind/unwind option. In the event of both mains and back-up power failure, a drill or crank can be inserted into a dedicated port at the side of the Limpet® main unit in order to rotate the drum and lower to the ground a person that is suspended on the end of the Limpet® safety line.
- **Display Control Unit**: Every Limpet® may be controlled by either the RF remote control or by the Display Control Unit that is connected to the Limpet® by a length of cable. In the event that the operator has an emergency while suspended on the Limpet® safety line and is unable to self-rescue, then they may be immediately lowered by a person on the ground using the ‘Down’ button on the Display Control Unit. This has the advantage that the rescue can be performed without any other person being put at risk and also significantly decreases the rescue time over conventional methods.
- **Load limit detection:** In the event that the system detects tension on the safety line that is in excess of a pre-defined upper limit (such as at just above the Safe Working Load), the system will immediately stop taking in the safety line and will only allow the line to be lowered unless a full system reset is performed. This ensures that the system will not continue to pull an operator against an obstruction even if the hoist button is pressed and prevents forces from rising to or being sustained at potentially dangerous levels.

More details on rescue methods under are included in Section 5.

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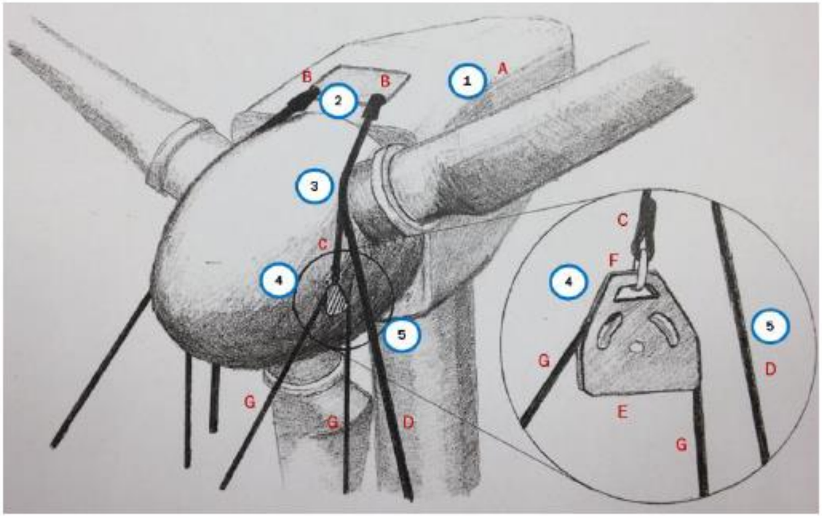
1.1.3. Anchors

The working line is the Limpet® L5 safety line. This is attached via a bolt to the drum inside the Limpet® L5 main unit and is fastened through a pulley block positioned at the WTG blade root and routed back to the ground. The pulley block is anchored to the WTG gearbox lifting eye via an anchor rope. Limpet Technology advocates the use of plastic coated steel wire anchor lines that are pre-fabricated to the appropriate length. Removing the requirement to tie knots in order to achieve the appropriate length of anchor line reduces the likelihood of error, speeds up installation on the day and minimises the need for personnel with technical rope qualifications (such as IRATA) to perform the task.

Figure 2: System Rigging and Anchors



A *Anchor strops*
B *Rope protectors*
C *Anchor line*
D *Back-up line*
E *Ball bearing pulley*
F *Connector*
G *Working line*

The back-up line is anchored to the WTG gearbox lifting eye and routed out of the nacelle, over the hub cone and to the ground. Where necessary, rope protectors must be used.

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The Limpet® L5 unit is mounted to a portable anchor at ground level. The best portable anchor will be determined in consultation with clients but could be the flatbed of a 4x4 vehicle or a deadweight anchor. More details are outlined in Section 2.

Figure 3: Limpets mounted on back of pickup truck

1.1.4. Power Supply

The Limpet® L5 is electro-mechanical device and therefore requires a source of power. This can supplied from the WTG itself. However, supply can often be best guaranteed through the use of a portable 8.15kva petrol generator. Such a generator has a small enough footprint to allow it to be mounted alongside the Limpet® unit on the back of the pick-up truck.

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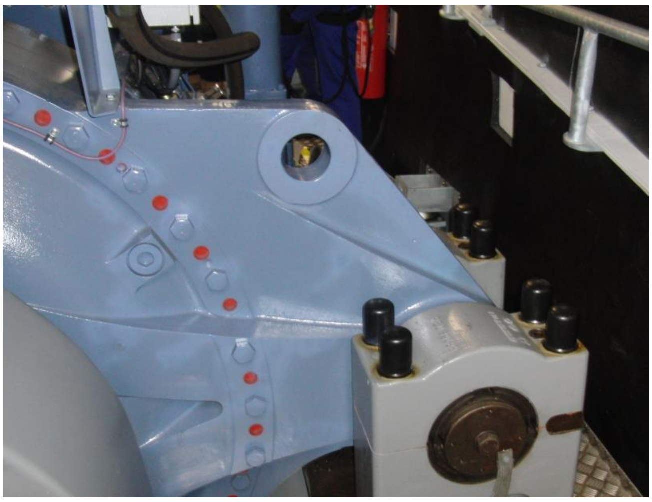
2 Anchor Points & Rigging

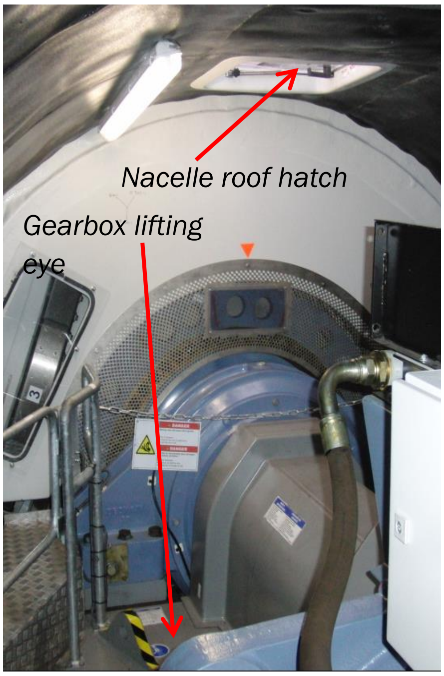
2.1 Top Anchor

The Limpet® pulley should be anchored to a certified and tested anchor point or to an unquestionably sound point inside the nacelle, using a pre-terminated rope or pre-determined wire strop lengths and connectors.

The most common unquestionably sound anchor points within a turbine nacelle are the gearbox lifting eyes; which are usually positioned beneath or near to the nacelle roof hatch. When selecting these anchor points the technicians must complete a visual inspection to ensure they are fit for use.

The back-up line also needs to be independently anchored to an unquestionably sound anchor point; the gearbox lifting eyes should be used if possible.





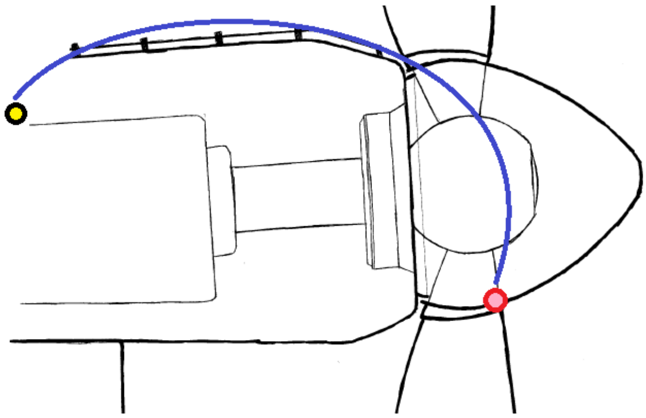


Figure 4: Top left – Gearbox lifting eye. The anchoring equipment will connect to this point using a wire strop or sling.

Figure 5: Above – Nacelle roof hatch relative to the gearbox lifting eye(s). The anchoring equipment will connect to this point using a wire strop or sling.

Figure 6: Across – Anchor point within nacelle, anchor rope path and pulley block location – back-up line anchor not shown.

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2.1.1 Top Anchor Rigging Method

The basic process for rigging and de-rigging the top anchors in the nacelle are as follows

Set-up

- Technician(s) accesses nacelle with equipment lifted by internal/external lifting device,
- Nacelle technician attaches the anchor rope to the a tag line and routing out through the nacelle and over the hub cone, lowers it to the ground;
- Ground personnel receive the anchor rope and attach the pulley block; with the Limpet® safety line tethered through the pulley;
- Radio check – nacelle technician lifts pulley and safety line;
- Radio check – confirm positioning of the pulley block;
- Nacelle technician connects the anchor rope to the designated anchor point;
- Nacelle technician attaches back-up line to the designated anchor point and, routing out through the nacelle and over the hub cone, lowers it to the ground level on the correct side;
- This process is repeated for the second system on the opposite side of the turbine;
- Rope protectors are used to protect the ropes from snagging and abrasion;
- Final checks are conducted.

De-rig

- Back-up lines are lifted into nacelle by nacelle technician;
- A tag-line is attached to the anchor rope, that is lowered to the ground level and personnel;
- Ground personnel receive and disconnect the pulley block attached to the anchor rope;
- Tag-line is lifted into nacelle by nacelle technician;
- Process is repeated for opposite side;
- The turbine blades are rotated and the equipment set-up as stated above or all equipment is coiled and bagged ready for lowering using the turbine lifting/lowering device.
- At the end of works, final sweep check completed and nacelle technician descends turbine.

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2.2 Bottom Anchor

The Limpet® L5 unit can be mounted to the flatbed of a 4x4 vehicle. The mounting method for the system is to be subjected to a thorough examination at a minimum interval of 6 months by trained and authorised persons. Please see Section 6 for additional details on the mounting method.

Figure 7: Limpet® unit mounting on pickup truck with power supply positioned behind.

Alternatively, a dead-weight anchor may be used such as the one pictured below. This requires a minimum of 350kg to be applied to the corners of the frame on which the Limpet is secured. The weights and frame may be dismantled to ease portability.

Figure 8: Limpet® unit mounting on X-Frame

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3 Forces within the system

The Limpet® system includes a pulley that is positioned just beneath the turbine hub cone, at the blade root. The pulley is used to change the direction of the working line to allow technicians access to the blades.

The stress placed on a pulley varies depending on the angle between the lead line and the load line. When both lines are parallel (line angle of 0°), the mass applied to the load line is multiplied on the pulley. As the angle between the lines increases, the stress on the pulley is reduced. Usually an additional 10% is added to this figure to account for pulley sheave friction

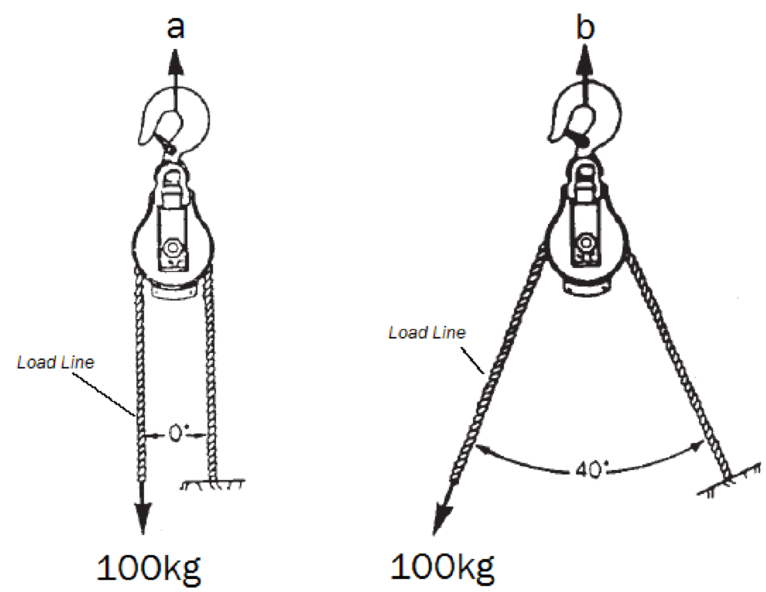
For use in blade inspection, the angle between the lines can vary between 10° and 30°. This is due to the position of the Limpet® L5 system and the turbine hub height. Although a low friction ball bearing pulley is used to minimise the effects of the sheave friction, a line angle of 0° and 10% sheave friction are always assumed and accounted for.

The maximum user weight permitted for the Limpet® L5 when operated for blade inspection purposes is 140kg. Thus the maximum stress that can be placed on the pulley during use is 308kg.

Therefore to achieve a safety factor of 10x the maximum stress applied to the system, the anchor equipment must be rated to a minimum of 3080kg or 30.8kN. Where possible, all ropes must be pre-terminated to avoid the use of rope knots.

In Figure 8, Example A below illustrates that, when 100kg is applied to the load line, the stress placed on the pulley is doubled as the lines are parallel (0° angle); therefore a = 220kg ((load line x 2) + sheave friction). Example B below, illustrates that when 100kg is applied to the load line, the stress placed on the pulley is less than figure 1 as the angle between the lines has increased (40° angle). The stress placed on the pulley is 205.7kg. ((load line x 1.87) + sheave friction).

Figure 9: Limpet® unit mounted on weighted X-Frame and inside manual handling frame



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4 Method of Inspection

The Limpet® L5 system can be controlled either through a display control unit that is connected via cable to the main Limpet® drive unit, or a radio frequency (RF) remote control unit that communicates with the display control unit. The RF remote control typically sits in a closed fabric pouch with translucent plastic window, at the end of the Limpet® safety line. The remote control has an operating range of 150 metres and is paired uniquely to an individual display control unit, ensuring that there is no risk of interference between different Limpet® units that are being simultaneously used on a single site.

The remote control is simple to use, with only 3 buttons which allow the operative to raise, lower and pause/ stop movement on the line. The hoist/ up button operates on the basis of a “dead man’s trigger”, meaning that it will hoist only for as long as the button is being pressed by the operator.

4.1 Method of Use

All personnel involved with the works are required to carry/wear all PPE necessary for manually ascending and descending.

4.1.1 Attaching to the system

At the ground level, the blade inspector(s) should attach the Limpet connector to the sternal attachment point (*chest*) on their harness, ensuring the connector gate is facing away from them[1].

Additionally, the mobile fall protection device (e.g. Petzl ASAP), must be attached to the back-up line and attached to a point on the harness that is consistent with the blade inspector’s training.

It is recommended that a small amount of weight, circa 10 – 20kg, is attached to the end of the back-up line. This will prevent the back-up line from slipping through the mobile fall protection device due to weather and wind conditions.

4.1.2 Pre-use checks

Prior to use it is important for blade inspector(s) to functionally test the system at low height to ensure it is safe and fit for use. Once attached to the system, blade inspector(s) must apply their full body weight quickly and sharply to the working line (Limpet® Safety Line) and remain suspended at a distance of no more than 2 metres above ground level.

During this test, the technician in the nacelle must assess the system rigging while the operator is suspended. To functionally test the Limpet® systems, the blade inspector(s) must ascend/descend and pause a descent.

4.1.3 Ascending the blades

Upon completion of the ‘Pre-use Checks’, the blade inspector(s) will engage the Limpet® system’s hoisting capabilities to lift themselves to the blade root. This is done by pressing the “Up” button on the RF remote control. The rate of ascent can be configured in advance using the Limpet service tool and should be no more than 0.3 metres per second i.e. 20 metres per minute. Blade inspector(s) must ensure, when approaching the pulley block that they remain at least 1 metre

[1] a Bosun’s chair must be used for work positioning activities

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below it. If it is deemed necessary, a removable plastic ball may be positioned around the safety line above the remote control pouch and karabiner in order to act as a final stopping block.

During an ascent, blade inspectors must monitor the position of the working line and ensure that it does not come into contact with the blade or the blade's trailing edge. The blade inspectors should pay particular attention as they approach the pulley block at the top of the ascent.This must be highlighted and discussed in the safety briefing at the beginning of the day.

As previously noted, during all suspended access operations, blade inspector(s) must use a mobile fall protection device such as a Petzl ASAP that is attached to a back-up safety line.

Once at the blade root, the blade inspector(s) should attach a rope around the blade that connects to either lateral attachment point on the harness. This rope, known as a 'Ring Rope'[2] will ensure that the blade inspector(s) remain within touching distance of the blade as they descend and as the blade moves away from the turbine tower.

4.1.4 Descending the blades

Having hoisted themselves up to the blade root, the blade inspector(s) are then able to descend the turbine blade using the "Down" button on the Limpet® RF remote control. Once this button is pressed, the Limpet® will continue to pay out the safety line and lower the operative until they either reach the ground (at which point the system will automatically stop spooling), or the 'Pause' button on the RF remote control is pressed.

During the lower, the blade inspector(s) should use the ring rope to remain within touching distance of the turbine blade. Before the operatives start to lower themselves, they must ensure that the working line is not and will not come into contact with the trailing edge of the turbine blade or any other edge or obstruction that might potentially abrade the line when the Limpet® is engaged. Blade inspector(s) should immediately pause a lower if they observe that the working line comes close to contacting the trailing edge of the turbine blade.

As the tip of the blade is approached, blade inspector(s) should be aware not to let their ring rope pass over the end of the blade, an event that could result in the operative swinging away from the blade in an uncontrolled pendulum. To prevent this from occurring, on completion of the blade inspection, the operative(s) should hoist themselves ~5 metres upwards and then pay out the lanyard around the blade in order to bring themselves back to the vertical plain directly beneath the pulley block, at which point they may lower themselves to the ground.

[2] *This is a ~10m rope, Grillon and two connectors, and acts as a horizontal adjustable line.*

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5. Rescue Methods

In the event that the Limpet® operator requires to be rescued while suspended on the end of the safety line, then the method of rescue will depend upon whether the operator is conscious and whether the Limpet® unit is fully or partially functional or not.

Where the Limpet® system is operating correctly, rescue should be relatively straightforward regardless of whether the casualty is conscious or unconscious:

1. **Operator conscious**: Where the operator is fully conscious and able to move, then they will be able to self-rescue by pressing the down button on the RF remote control which, with a single press, will lower them immediately to the ground.
2. **Operator unconscious**: Where the operator is unconscious or semi-conscious or otherwise unable to self-rescue by pressing the down button on the Limpet® RF remote control, then a team member at ground level can lower them to safety by through a continuous press of the down button on the Display Control Unit.

In a scenario where the main source of power is cut, then the UPS back up battery will allow the casualty to be lowered as outlined above. If the main power supply is cut and a UPS is not a part of the system or if the UPS is non-functional, then the Limpet® safety line can be unwound from the drum using a power drill or manual crank that is inserted into a dedicated port in order to rotate the motor and lower the casualty to the ground. The current Limpet® L5 mechanical unwind speed is 0.2m/s with a drill rpm of 1500 to 1800. At 0.2m/s, a rescue descent from 60m will take 300 seconds (5 minutes).

The worst-case scenario is where a casualty is unconscious and in need of rapid medical assistance and they are suspended on the back-up safety line as a result of a failure of the working (Limpet®) safety line e.g. if it was cut. In this event, a rescuer will need to use a rescue hub (constant rate descender) and rope grab in order to lower the casualty safely to the ground. The process of rescue in this scenario is as follows;

- Remove the rescue hub from its bag and using a wire anchor strop and connector, attach it to a certified/ unquestionably sound anchor point within the nacelle.
- Attach the rescue hub's rope grab to the back-up line. The rope grab must be attached outside of the nacelle to avoid moving across the nacelle roof hatch edge.
- A rope protector must be wrapped around the rope grab device to protect the turbine and rope grab from each other.
- The rescuer returns to the rescue hub and operates it to lift the casualty up enough to create slack in the back-up line anchorage.
- The rescuer then disconnects the back-up line from its anchorage and lowers the casualty using the rescue hub, doing so in a control manner with strict communication between the rescuer in the nacelle and other personnel who are present, who can observe the lower from ground level.

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Figure 10: Rescue kit to be used in event of unconscious casualty suspended on back-up line

5 Equipment

5.1 Working Line

The working line is comprised of an anchor rope, pulley block and the Limpet® safety line.

5.1.1 Limpet® Safety Line

- The Limpet® system safety line is a rope constructed using a Dyneema® core with a polyester sheath (MBL 23.9kN);
- The safety line has sewn terminations at either end; with one end terminated with a directional connector with an integrated swivel feature (DMM Locksafe) and Limpet® RF Remote Control pouch attached. The total diameter of the safety line is 7mm;
- The working line must be of sufficient length to reach the pulley(s) before returning back to the ground i.e. an 80m hub height will require a length of 170m.

5.1.2 Pulley Block

- The pulley blocks must be man riding, low friction ball or roller bearing pulleys with a large D/d ratio as possible;
- Due to the forces within the system, the pulley must have a minimum breaking load of at least 3.08 metric tons or 30.8kN, as described in section 3;
- The current pulley used has a MBL of 35kN when in use (load and lead line angle of 0^{o}).

5.1.3 Anchor Rope

- The anchor rope can be made a textile rope or an pre-determined length of wire rope;
- For a wire strop, both ends must be terminated whilst at least one end must be sewn terminated for a textile rope;
- Currently, an 11mm low stretch industry standard textile rope (conforming to EN1891 type A) is used. At 30 metres in length, one end has been sewn terminated whilst the anchor rope has a MBL is 30.9kN;

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5.2 Back-up Line

- The back-up lines will be industry standard 'Beal 10.5mm' or similar, low stretch polyester ropes which comply with EN 1891 Type A.

5.2.1 Back-up Device

- The back-up device operated will be a Petzl ASAP®, that complies with EN 353-2 and EN 2841 type A.

5.3 Anchor strops

- Anchor strops (with a protective P.V.C sleeve), conforming to EN 795B (MBL 25kN), must be used for the rigging of the pulley anchorage system;
- All rigging must be fire resistant;
- Wire Strops should be doubled up as they are rated to only 25kN.

5.4 Connectors

- Petzl Vulcan (BL of 40kN when closed, EN362 & NFPA 1983 conformity) screwgate connectors should be used in the system.

5.5 Power Supply

The Limpet® system is electrically powered from mains (230-240V, 50-60Hz). Mains power may be fed directly into the unit, or in the case of use with an optional UPS, it is fed into the UPS upstream of the Limpet® unit.

A 230Vac, 16A 6h supply is required to power the Limpet®; the cable specification for mains supply is standard 3-core H07RNF cable, 1.5sq.mm and would be terminated with a standard blue single phase plug.

Power consumption is approximately 50W when the unit is on, but not in use. When in use, power consumption depends on the type of use – this can vary from 50W to 2.2kW. The Limpet® is internally protected by a 16A fuse on the mains input.

For the purpose of blade inspection, Limpet Technology Ltd. has further developed the system to allow it to operate using generators. The Limpet® system will operate using an 8.15kva generator.

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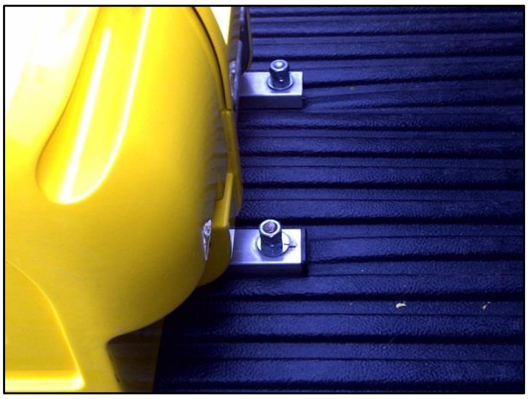
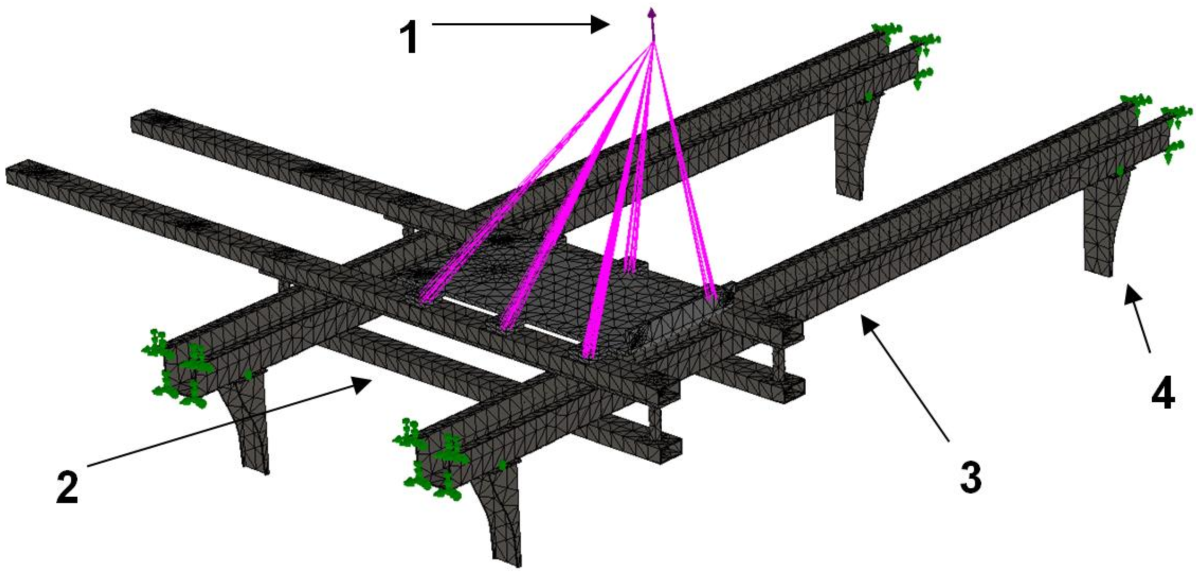
6 Toyota Hilux mounted Limpet® L5 strength calculations and study

The Hilux flatbed is attached to the main ladder frame using two cross members and 4x M12, class 8.8 bolts. To simplify the study, only the deformable cross members were considered (based on the assumption that the strength and weight of the Hilux, kerb weight of 1885kg, proved rigid and ultimately strong).



6.1 Toyota Hilux mounted Limpet® L5 strength calculations results

Test Description	Test Results
Finite element analysis (FEA). Model setup to approximate a 12kN vertical line load on the Limpet. This equates to a safety factor of x10 on a safe working load of 120kg.	Maximum VON MISES stress found in the rear flatbed cross member 432MPa < 520 MPa U.T.S of sheet steel.



1: Force applied at the location of rope exit. Limpet suppressed for simplicity.

3: Rear cross member

2: Limpet clamped about two pickup cross members

4: x4 brackets welded to main chassis rails (not shown)

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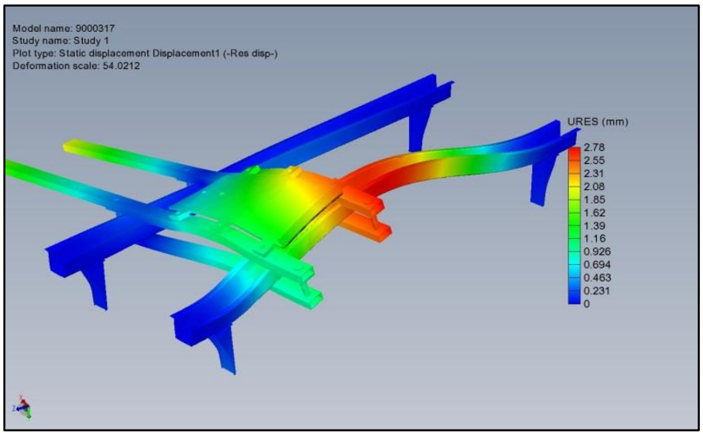
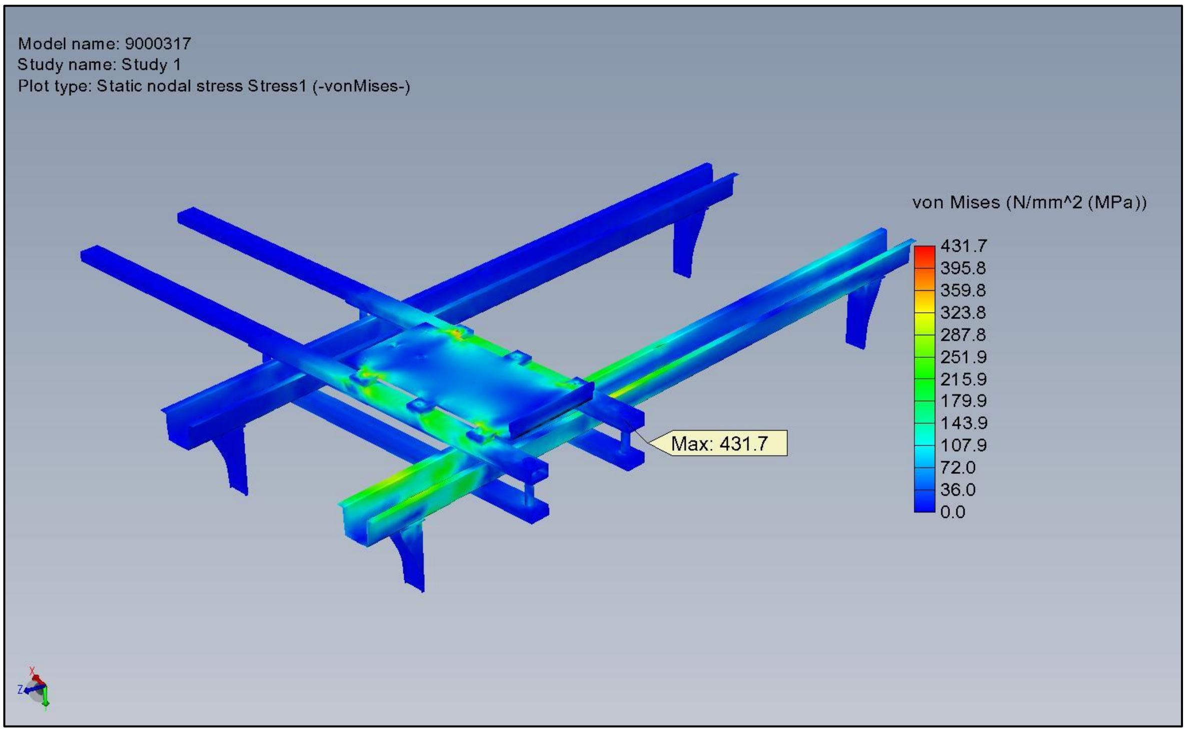


Displacement model; a maximum of 2.78mm was found to occur on the rear cross member, directly under the exit rollers of the Limpet. Figure exaggerated for clarity.



Von Mises Stress; a 12kN load was found to cause a maximum stress of 431.7MPa in the rear cross member.

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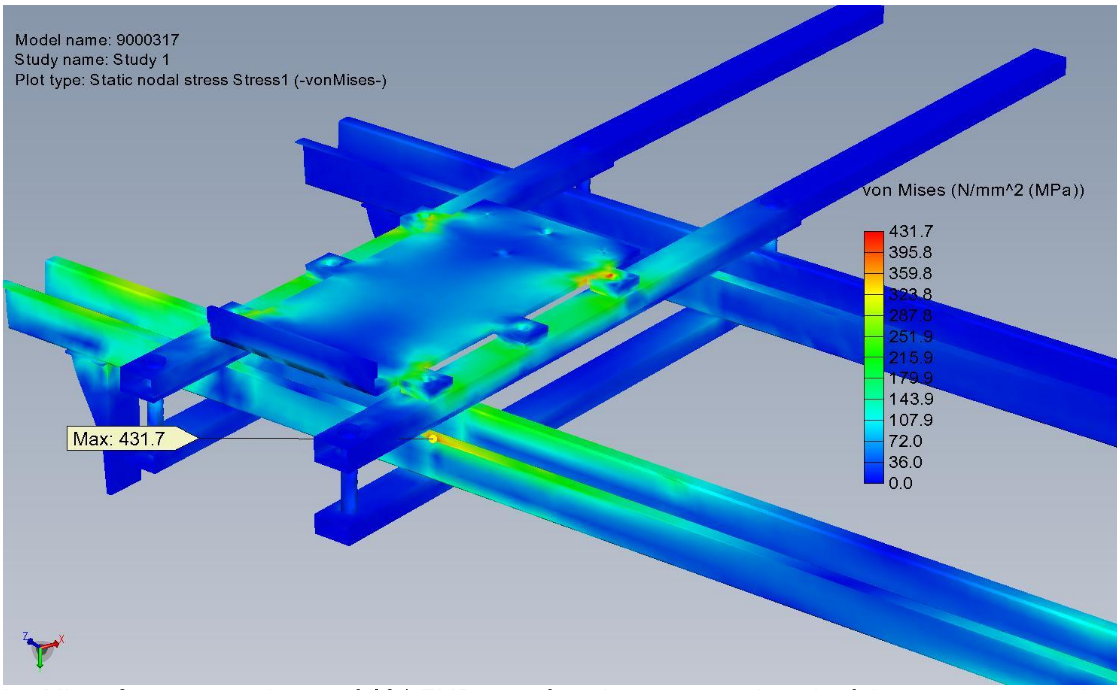
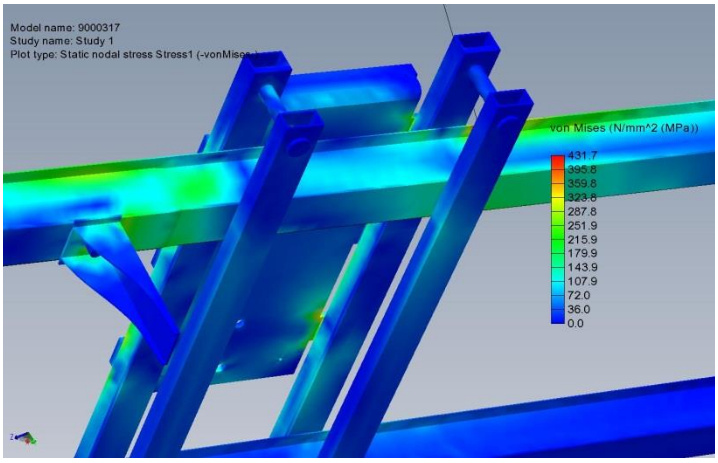
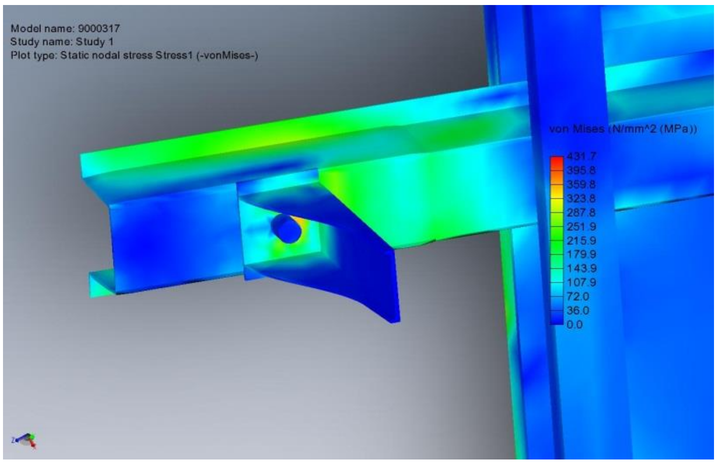


Von Mises Stress; a maximum of 431.7MPa was found to occur on the tab of the rear cross member.



Underside of flatbed; Limpet® L5 clamped to two cross members using stainless box section and threaded bar.



The Limpet® L5 is clamped around two cross members. These are bolted at each end to brackets welded to the main structural chassis rails of the pickup.

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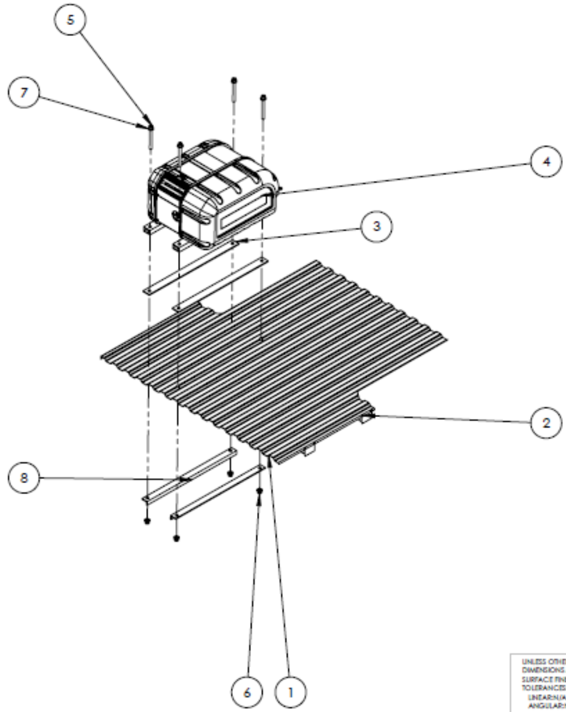
6.2 Limpet® L5 Toyota Hilux mounting technical drawing

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	9000316	2010 Toyota Hilux Rear bed	1
2	9000318	2010 Toyota Hilux cross member	2
3	9000320	Middle clamp flat bar	2
4	9000322	Limpet mounting assembly	1
5	9000326	Studs for mounting the Limpet in the truck	4
6		M14 MYLOC NUT	8
7		M14 WASHER	8
8	9000319	Lower clamp bar	2



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH: N/A
TOLERANCES:
LINEAR:N/A
ANGULAR:N/A

LIMPET TECHNOLOGY LTD.

	NAME	DATE
DRAWN	David.Currie	29/5/12
CHK'D		
APPV'D		

TITLE: Limpet Mounted in 2010 Toyota Hilux

FINISH: SEE INDIVIDUAL PARTS FOR DETAILS

MATERIAL: SEE INDIVIDUAL PARTS FOR DETAILS

DEBUR AND BREAK SHARP EDGES

DWG NO. 9000317 REV.-01.A

PART NO. 9000317

MASS g

SCALE:1:20 DO NOT SCALE DRAWING | A3 | SHEET 1 OF 1

LIMPET TECHNOLOGY

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