Recommended Procedures for Operating the Linescale 3 for Buggy Safety Testing

Author: Wade Gordon, MCS 2012
Reviewed By:

DO NOT SKIP THIS PART!!!

The procedures outlined in this document will enable you to put hundreds and even thousands of pounds of tension on a rope. Naively imitating these procedures with improper preparation or equipment can easily result in death and dismemberment. This is not an exaggeration.

Even following the letter and intent of these instructions, there is still significant risk that some part of the system will fail abruptly and send chunks of metal or shards of carbon fiber flying at your face.

If you are not going to approach this seriously and with caution, please return the materials to the Safety Chair so that the buggy community retains the privilege of their use.

If you have questions, comments, or concerns about these procedures, contact the current Safety Chair, or reach out to Wade Gordon on the BAA Discord.

The Equipment

1) 1x Linescale 3
2) 1x Tyvek tarp
3) 5:1 pulley system
4) 4x soft shackles
5) 3x steel carabiners
6) 2x runners with chafe sleeves
7) 1x whoopie sling, adjustable from 40” - 80”

Fig: components with a 16” ruler for scale

Linescale 3

“The difference between screwing around and science is writing it down.” - Adam Savage

The Linescale enables us to accurately measure the peak force exerted during static and dynamic tests. The device has a configurable sample rate of up to 1280 Hz, and accurately measures forces up to 30kN. The device has a working load limit of 30 kN and an MBS of 90 kN. Above 30 kN, the electronics will be permanently damaged.

The Linescale must be kept in its protective case any time it is not securely attached to your testing system. Please treat it like the $1k piece of scientific equipment that it is, and ensure that if it is ever damaged, it is in the line of duty advancing our understanding of buggy safety and not accidentally dropped on your shop floor.

Refer to the manual here: https://www.linegrip.com/linescale-3/
Logging configuration overview: https://www.youtube.com/watch?v=M-NmMwO0meo
App download: https://www.linegrip.com/linescale-3-user-page/

The Tarp

The tarp is included to protect the ropes from abrasion on concrete, and the harsh chemical environment of a buggy room floor. Please feel free to stand on it.

5:1 Pulley System

30' of rope is pre threaded through 2 double pulleys to form a 5:1 pulley system. One end of the rope is permanently fixed to one of the pulleys with an eye splice.

The pulleys are "double micro pulleys" manufactured by GM Climbing. Each leg of the pulley is rated for 10kN (2248 lbf) MBS and the overall strength is 40kN (8992 lbf) MBS.

The rope is ¼" diameter Amsteel Blue and has an MBS of 7,700 lbf. More realistically, the strength of the rope is limited by the tight bend that the eye makes over the middle plate of the pulley. The splices were done by Wade Gordon following the Samson Splicing Manual in February 2023.

Amsteel Blue is chosen for its "hyperstatic" property. At 30% of its MBS, the rope will stretch less than 1%. This reduces the potential energy stored in the rope's elastic recoil in the event of a catastrophic failure.

Soft Shackles

Soft Shackles are preferred as a light weight attachment that can be loaded in any direction. Reducing the overall weight of the system, reduces the risk of injury during a catastrophic failure.

The MBS of a soft shackle is generally 2x the MBS of the material it is constructed from. Yes, that is 2x and not 4x for the number of strands. The overall strength of the soft shackle is limited by the tight bend radius of the throat.

The original soft shackles provided with the kit were spliced and tied by Wade Gordon in February 2023. These soft shackles made from ¼” Amsteel Blue have a nominal MBS of 15,400 lbf.

Left: a closed soft shackle arranged in its “preferred orientation”
Right: an open soft shackle showing the knot on the left and the “throat” on the right

Steel Carabiners

Whenever possible, please use the soft shackles. If you must use a carabiner, use the provided steel carabiners.

DO NOT USE ALUMINUM carabiners that are intended for general buggy use. Subjecting an aluminum carabiner to a significant fraction of its MBS has the risk of permanently damaging the carabiner in a way that significantly lowers the MBS. For a more detailed explanation, please ask a materials scientist.

The provided steel carabiners are Petzl Oxan oval carabiners and have an MBS of 38 kN (8,542 lbf) along the primary axis when the gate is locked.

The Runners

The runners are provided as anchors and backup tethers for a drop test. They have chafe sleeves made from tubular nylon webbing. The chafe sleeve protects the runner from damage by abrasion.

Note that the runner will crush whatever you wrap it around with immense force. Think of it more like methodically smashing the surface with a hammer everywhere the runner touches it.

Best practice is to install a sacrificial layer of 2x4s for the runners to bite into if you are building an anchor around wood.

Consult with EHS on where and how to build anchors suitable for high impact drop tests.

The runners are constructed of ⅜" Amsteel Blue with an eye splice on each end. The length of the runner is protected by a chafe sleeve of tubular nylon webbing. ⅜" Amsteel Blue has an MBS of 17,600 lbf. Samson's splicing manual indicates that an eye splice retains 90% of the materials strength, so these runners have a nominal MBS of 15,840 lbf in the end to end configuration. The splices were done by Wade Gordon following the Samson Splicing Manual in July 2021.

Whoopie Sling

Whoopie slings are adjustable length slings. The sling originally included in this kit is adjustable between 40" and 80".

The whoopie sling is constructed of ¼" Amsteel Blue and was spliced by Wade Gordon following the Samson Splicing Manual in February 2023. Per the Samson Splicing Manual, A whoopie sling retains 70% of the strength of the original material, so this sling has a nominal MBS of 12,320 lbf.

Safety

You are responsible for your own safety and the safety of your peers.

Always inspect the equipment before use, and always wear appropriate PPE.

Inspection

Before you use this equipment, you must inspect it. The shared nature of this equipment means that you do not know the full history of how it has been used. Never use any equipment that you do not know the full history of in a life supporting situation.

If a component needs to be replaced, consult with the Safety Chair. Any expense incurred maintaining or replacing this equipment is eligible for reimbursement as part of a Buggy Endowed Fund grant. If a spliced component needs to be replaced, please feel free to contact Wade Gordon.

Metal Components

The lifespan of metal components is indefinite with proper care. At a minimum, inspect the material to ensure it is free of cracks, deformation, and signs of corrosion.

Petzl provides an inspection checklist for all of their products on their website: https://www.petzl.com/US/en/Professional/Connectors/OXAN

Textile Components

The Amsteel Blue used in this kit is manufactured by Samson. Follow Samson's guidelines on when to retire the ropes. The best place to find said reference is currently via the Resources section of the Samson app.

PPE

The following are recommended as minimum requirements for the person operating the equipment.

- Safety goggles
- Helmet
- Leather palmed gloves

Don’t Touch Ropes Under Tension

“Bowing” a rope under tension by pushing or pulling its middle can dramatically increase the tension on the line and may cause a sudden catastrophic failure. Any contact with the system while it is under tension may cause a sudden catastrophic failure.

600 LBF Static Pull Test

This procedure is designed to apply a 600 lbf pull between 2 of the 3 harness attachment points required by the Sweepstakes Bylaws. The practical constraints of rigging the pulleys inside of a buggy and securely holding the buggy during the test limit the force you are able to exert on the working end of the rope. Higher forces are certainly possible, but the intention of this system is that 600 lbf is fairly easy to achieve.

This test was designed to be a proof test as part of the initial safety review of a newly constructed buggy. If you need to verify a new technology that you are incorporating into your safety system, it is recommended that you perform a destructive test on a sample and perform a proof test on each implementation.

If you have a secure method for mounting the buggy between 2 anchors, this method may be adapted to pull between a harness point and an external anchor.

Procedure

1) Inspect all of the components
2) Check that everyone is wearing appropriate PPE
3) Rig the system
4) Pad any places where metal is touching carbon fiber with a towel
5) Set the Linescale 3 to “peak mode”
6) Check that everyone is wearing appropriate PPE
7) Slowly increase the tension on the pulley and listen for any sounds that might indicate damage to the buggy and therefore a failed test

Releasability

These systems intentionally do not include any sort of progress capture. Tension is released by the operator letting go of the rope.

Padding and Covering

Padding with a towel is important to ensure that the metal parts of the system do not damage the shell of your buggy. Covering components with a towel can also help protect the operator from fragments that may go flying.

Rigging 5:1 Pulley System

We’ll work our way from one end of the system to the other starting and ending with the buggy.

1) Harness attachment point A
2) Soft shackle

3) Linescale 3 (Option 1)
4) Soft shackle
5) Pulley end with the eye splice “the far end”
6) 5 strands of rope
7) Pulley “the near end”
8) Soft shackle
9) Linescale 3 (Option 2)
10) Soft shackle
11) Harness attachment point B

With the Linescale rigged as Option 1, the working end of the rope is pulling on the Linescale, so you get a true measurement of the force exerted on Point A. Point B will experience a lower load because you are pulling with rather than against it.

With the Linescale rigged as Option 2, you are measuring the forces exerted on Point B. Point A will experience a higher load than what you measured.

Depending on your access to either end of the buggy, you might prefer Option 1 or Option 2 to be able to monitor the forces during the test.

Tip: Clove hitch a wrench or a carabiner to the working end of the rope to use it as a handle. You’ll be able to pull a lot harder.

Rigging 15:1 Compound Pulley System

If you need more mechanical advantage to reach the desired peak force, you can introduce a compound pulley into the system. This system has been used to exert over 2000 lbf during demonstrations (not inside of a buggy) at Design Comp. A buggy driver was able to exert over 800 lbf with this system.

1) Rig the 5:1 pulley as described above
2) Attach a carabiner to the working end of the rope with a clove hitch
3) Attach a second carabiner to the inside eye of the pulley on the B side of the system
4) Clip the rope through the carabiner on the eye of the pulley
5) Clip the working end of the rope back through the carabiner from step 2
6) The working end should come back out on the B side of the system

When you pull on the working end, you now have a 3:1 moving pulley acting on the working end of a 5:1 pulley for a nominal mechanical advantage of 15:1. In practice, the friction in the pulleys will reduce this significantly.

The clove hitch is specifically chosen because it is easy to slide off of the carabiner. Avoid putting knots in the rope because they will become extremely difficult to untie.

Pictures

Note that the soft shackles are wrapped through the pulleys twice in these pictures. This is done to make the system more compact and is not required to increase the strength of the soft shackle. You will find that the length of all the components adds up quickly.

Fig Left: 5:1 pulley system
Fig Right: adding the carabiners to rig the 15:1 compound pulley

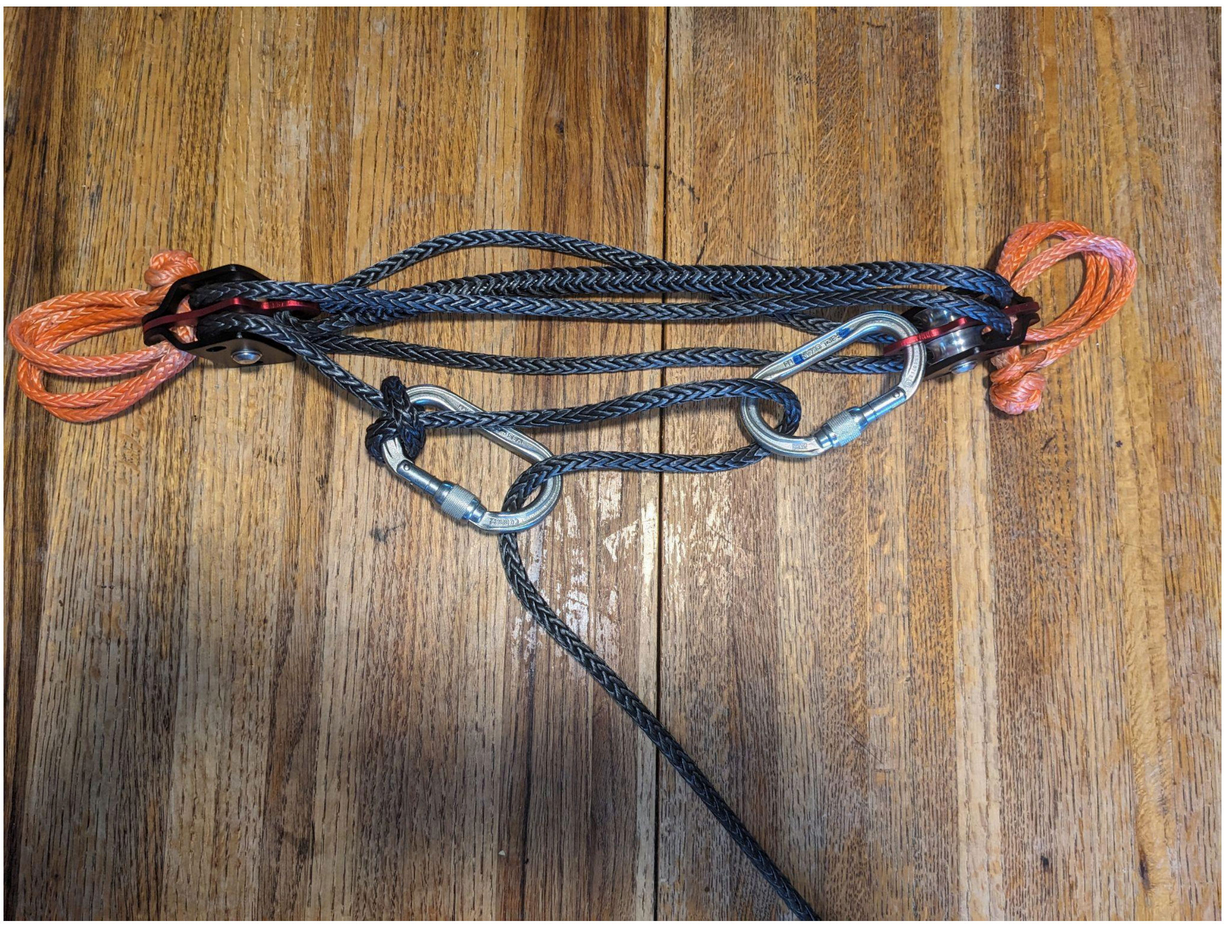

Fig: 15:1 compound pulley system

Fig: connecting the Linescale to the pulley as compact as possible by double wrapping the soft shackles

Drop Testing

This is an advanced technique that requires a serious safety plan. Consult with the Safety Chair and EHS.

The standards used for the bolts that anchor a seatbelt to the car's chassis are 22 kN or ~5,000 lbf [citation needed]. With an appropriately designed test, you should be able to reliably generate forces approaching this threshold. Do not exceed the 30 kN working load limit of the Linescale 3 or you will permanently damage the electronics.

The materials provided in this kit were used in a proof of concept drop test that used a 45 lbm test mass to exert a 3,500 lbf peak load when dropped from head height with a fall factor of approximately 1.5.

The Linescale is capable of reading at a rate of 1280 Hz. Lower sample rates may not accurately characterize the peak force experienced during a drop test. The recorded values can be logged to internal memory and read over a micro-usb connection after the fact, or streamed over bluetooth at up to 40 Hz.

ALWAYS start small and work your way up. Do not exceed the MBS of any part of the kit. Especially do not exceed the 30 kN working load limit of the Linescale 3 or the electronics will be permanently damaged.

Consult with EHS to design a remotely releasable system, or appropriate protective barrier to manually release the test mass.

In order to maximize the peak force during a drop test:

1) Reduce the elasticity of the system
    a) Nylon is very stretchy compared to Amsteel
    b) Carabiners may flex significantly under the forces involved
2) Increase the fall factor
    a) Fall factor is computed as the distance fallen divided by the amount of rope in the system
    b) Further reading: Fall Factor
3) Settling the system
    a) Do several drop tests at a lower load to settle any parts that might shift during a test. This shifting disperses energy.
    b) This is built into “ALWAYS start small and work your way up”

Practical Demonstration with a Retired Harness

A retired harness was acquired for a practical demonstration intended to simulate a head on collision with a curb.

The test setup dropped a 100 lbm test mass ~10ft onto the rear attachment tether of an actual buggy harness. This represents a worst case scenario where the harness is the only element absorbing the impact in a ~17 mph collision.

In a real world collision at comparable speeds, the forces will be lower. Damage to the buggy during a severe collision plays an important role in spreading out the distance and time over which the kinetic energy of the buggy/driver is dissipated; this decreases the peak force. The viscoelastic properties of the human body (in contrast to the metal plates used for the test) also play an important role in decreasing the peak force. That is to say that this test represents a conservative over estimate for the theoretical maximum force that a harness could exert on the driver’s body during a 17 mph collision.

In practice, an A team buggy typically travels closer to 35 mph.

The harness originally featured 4 “screamer” stitches which ripped out and absorbed energy on the first impact only. It is estimated that each screamer stitch extended the length by 1.5”, so the effective length increased by 6” after the first drop test. The effective length of the harness was 46” after the “screamer” stitches were extended. Due to time constraints, no effort was made to compensate for this extension in the second and third drop tests.

Significant settling was observed where the test mass was attached to the waist belt of the harness and likely introduced an additional 6” in the effective length of the harness after the first test. Due to time constraints, no effort was made to compensate for this extension in the second and third drop tests.

The material along the principle axis of the harness was 1.75” nylon webbing similar to the standard material used in seatbelts and recommended in the Sweepstakes Bylaws. This material generally has a 30% stretch at 11 kN [citation needed].

Data collected from these tests can be found here
March 2023 Harness Testing

References

Equipment

LineGrip LineScale 3

GM CLIMBING 40kN Micro Double Pulley

AMSTEEL-BLUE - Samson Rope

https://www.wyeth-scott.com/pdf/Amsteel-Blue-Rope-Inspection-Retirement.pdf

Refer to the Resources section of the Samson app for more detail on when to retire ropes.

Forces Involved

UIAA 105 Harnesses - simplified pictorial presentation

Petzl's practical study of forces involved in a climbing fall (not representative of buggy)
https://www.petzl.com/US/en/Sport/Forces-at-work-in-a-real-fall

Knots

Clove Hitch – Loops Method

Figure 8 Follow Through Loop

Other

A History of Tug-of-War Fatalities

Analysis of Fatigue Failure in D-shaped Carabiners

Authors Notes

The diamond knots used in the soft shackles consumed 9" of tail on each strand when tied with ¼" Amsteel Blue.