# Raft on a highline: Loads and trim

Onions, C., and Collins, L.

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# Loads and Trim

**Chris Onions** MRes
R3 Safety & Rescue Ltd
Glyndyfyrdwy
Corwen
LL21 9HH
UK
and
**Loel Collins** DProf PGCert
Institute of Coaching and Performance
University of Central Lancashire
Preston
PR1 2 HE
Email chris.onions@R3SAR.com

## Abstract

This study examines the loads associated with the positioning of a 4.5m raft on a high line in moving water. Testing was conducted within a flow-calibrated channel demonstrating representative stream velocities typical (0.6 – 5.4ms/ also MPH) of those encountered during water related rescues. The raft was positioned from a high line mid-stream, and a load cell was utilised to collect force/time data. The independent variables of trim (relative positioning of the load within the boat) and average stream velocity were investigated. The findings challenge assumptions regarding the impact of trim on the loads within a highline, the relationship between flow rate and loads on highline and make recommendation for training and practice. The study contributes to understanding the loads placed on high lines by representative rafts during operational rescues.

**KEY WORDS:** High line, trim, force, current vector, water rescue training.

## Introduction

Extrication of a casualty located on an obstruction mid-stream (for example vehicle or boulder) requires fine positioning of the craft against the flow of water. *'Holding station'* may not be achievable by paddle or motor power alone. Under these circumstances the raft may be positioned by virtue of a system of tensioned ropes rigged across the moving water (a high tensioned line). The high tensioned line allows the craft to be positioned accurately and facilitate the rescue. The techniques to construct the system vary but are internationally referred to as boat on a high line techniques, *all* position of the craft in the flow from a tensioned line. Loads with in other high line applications such as mountain and technical rescue are well understood (c.f. Attaway, et.al, 2013). However, comprehension of the loads generated by boats in flowing water have not been examined. We pose the question, what force will a rescue raft typically encounter when placed upon a high line and deployed in moving water during a swift water rescue?

As an initial study we measure the force acting on a raft while tethered to a highline in representative, but controlled, real-world conditions. The influence of trim (the fore and aft balance of the raft and velocity of the water in which the raft is operating are considered. Comparisons are made with related literature to contextualise the derived data. This study represents an initial step to understanding the load on (and consequences of overloading) a high line system when utilised to position a rescuing boat within moving water. It is hoped that the results of this research will be the first step to produce working guidance associated with empirical data in this field.

**Boat High Line Rescue**

Ray (1997: p 125-128) describes a continuum of tethered boat rescues. Ray outlines a single point tether (managed with a single line. P 125), a two point tether (p. 125), and a four point tether (p. 125). All of these methods are suitable for river current velocities that allow the tethers to be *hand held* by the operators. In situation where the river velocity prevents hand held operation a high line system offers management of the boat on the flow with greater security.

In this context this system has been adapted from the high line principles used in technical rescue and has evolved from two variants. The first a drooping highline (Brown, 2000, p. 271-301; Ray, 1997. P96, figure 1) in which the tension of the line can be varied to facilitate control of the craft (see figure 1), and reeved high lines, either English (Brown, 2000, p. 285; Ray, 1997. P126-127, figure 2) or Norwegian (Brown, 2000, p.285; Ray, 1997. P126-127, figure 3) in which the tensioned line remains taught and the boat is controlled via controlling lines. Water rescue practitioners have borrowed and adapted the technique from technical rescue in which gravity provides the load and is understood. However, an additional factor, the load generated by the water velocity is not understood. The water may provide two additional considerations for the rescuer; a change in direction of and additional load. Assumptions made concerning the safety implications in the original contexts of mountain and technical rescue may not be true in this new application of swift water rescue and therefore require investigation.

# Method

The fieldwork was conducted in a calibrated channel situated within a manufacture water course. Obstructions were removed from the channel so producing an unrestricted laminar flow within a parallel-sided channel of 4.5m width.

### Calibration and Control of Water Velocity (v)

Average stream velocity was calibrated by utilising the Manning formula (Akan (2006; Gierke, 2002), at the test site. The Manning formula is an empirical tool for determining discharge with respect to the potential energy of the flow, the nature and composition of the channel bed. The test channel was selected as exhibiting a constant cross sectional area resulting in steady flow. Further, the test site was selected with a fixed, constant and known gradient with consistent use of concrete during the channel construction.

Measurements were taken from the test site to enable the relationship between pumped volume and average stream velocity to be established. A steel tape measure was used to collect the dimensions of the channel width (m) and the channel length (m). The slope of the channel was calculated by referencing the engineering drawings of the site. The levels were obtained from the top and bottom of the gradient and subtracted (height lost) and divided by the channel length.

Slope = (top datum – bottom datum) / channel length.

Flow into the channel was introduced and increased in staged increments (55, 65, 75, 85 and 100% flows) into the channel, so the average depth could be established at each setting. This procedure established a calibration curve for the channel, for pump capacity (%) and *average stream velocity* (m $s^{-1}$). This approach was preferable to taking live ultra-sonic/Doppler reading because adjusting the trim of the raft would expose the hull to water at different depths, the stream velocity changes with respect to depth.

### Load cell calibration

The data produced by the load cell were continuous mV signal with a quoted full scale deflection of 2.000V at 10kN. The data were captured via an analogue to digital signal convertor with the associated software set to sample a value every 0.5 seconds. The manufacturers calibration cited 1.987V for 10kN (0.1987mV = 1kN). This conversion factor was applied to the mV values in MS Excel™ to obtain values in N force, from which Force/Time Elapsed charts were produced.

### Personal Protective Equipment (PPE) and Safety and Management

Technicians were selected on the basis of their qualification which was mapped against the Concept of Operations module 3 training syllabus (DEFRA, 2012). The Technicians were equipped with appropriate personal protective equipment (PPE) including water rescue boots, dry suit, thermal under-suit, knife, helmet and a personal floatation device (PFD).

**The Raft**

Ray (1997) identified that 'Almost any watercraft can be used for the lower' p126. Reflecting common use in the UK a 4.5m raft was selected. The raft is an inflatable multi compartment, self-bailing, lightweight rescue platform and has capacity to carrying multiple casualties. Raft of similar size are in common use by water rescue teams in the UK. Such rafts can be paddled, pulled by hand or motor driven. Its shallow displacement and flat hull allows easy maneuvering.

**Procedure**

The raft and associated rigging was set up as per Figure 1 with the addition of a Force Logic universal column load™ cell connected in series between the focal point of the anchor on the raft and the attachment point to the high-line.

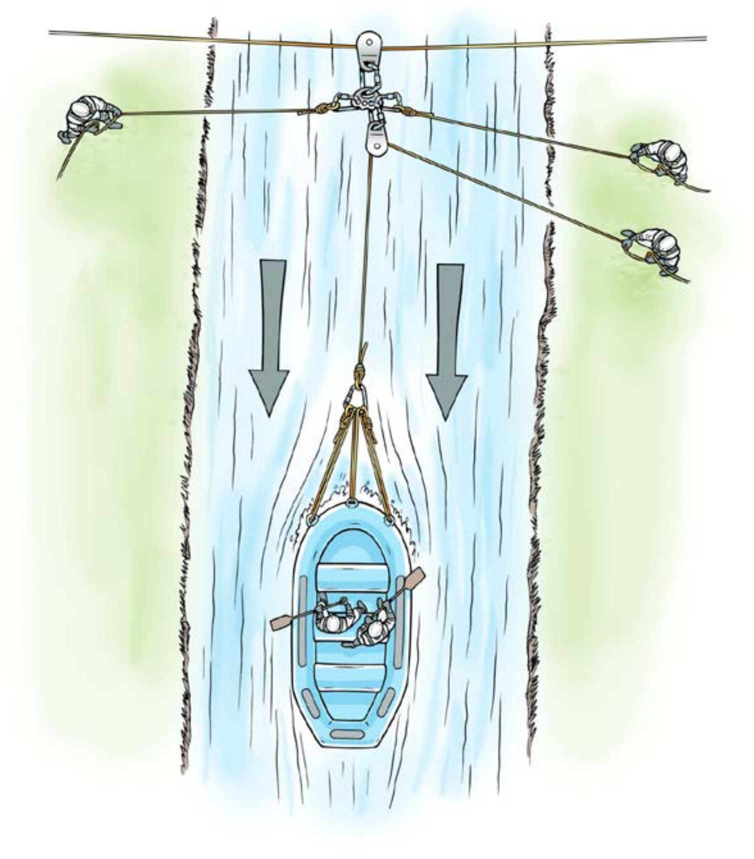

***Figure 1**. Boat on a Highline. Image by George Manley, courtesy of Rescue 3 (Europe). For clarity, the mechanical advantage rigging of the highline and reeving lines have been omitted.*

A 30m length of data cable was connected to an in-line signal amplifier positioned on the bank side which was used to collect streamed analogue data (Force/time) throughout the procedure via this equipment. The load cell, data cable length and amplifier had been calibrated by the manufacturer as a combined unit using a 5-point calibration procedure. A Data Translation™ analogue to digital signal convertor was used to transfer the mV signal to a laptop PC and was exported to Microsoft Excel.

The raft was positioned and the data recorded equipment set to record every 0.1 seconds. The Manufacturer's calibration curve was used to convert the mV signal to force (N) and the data were manipulated using MS Excel™. The nominal pumped volumes were converted into average stream velocity ($ms^{-1}$) via the Manning calculations and calibration curve

**Test 1: Measurement of the forces induced on the highline.**

The crew was positioned centrally in the boat (neutral trim) and maintained constantly. The water in the channel was switched on incrementally at 55, 65, 75, 85 and 100% flow and at each increment; the boat was deployed into the current vector via the high line. The raft was positioned mid-stream via alignment with a marker placed on the side of the channel and the loads recorded.

**Test 2: Locating the load to the rear of the craft (stern trim)**

The testing procedure for Test 1 was repeated for consistency with the crew (n=3) positioned towards the rear of the raft creating a stern trim. Force data were recorded and compared with the data from test 1.

**Test 3: Locating the load to the front (bow trim)**

The testing procedure for Test 1 was repeated for with the crew (n=3) positioned towards the bow of the raft and maintained constantly. Force data were recorded and compared with the data from Test 1.

## Results

**Test 1: Measurement of the forces induced on the highline.**

Summary of mean and peak force induced on the highline by the raft, trimmed neutrally with respect to average stream velocity and subjected to an incremental increase in average stream velocity.

| **Trim - Neutral** | | | |
|---|---|---|---|
| **Average Stream Velocity (m/s)** | Mean Force (N) | Peak Force (N) | Standard Deviation (N) |
| **0.6** | 1224 | 1408 | 89 |
| **1.4** | 1132 | 1249 | 36 |
| **2.5** | 638 | 727 | 34 |
| **4.2** | 610 | 793 | 38 |

| | | | |
|---|---|---|---|
| **5.4** | 1128 | 2566 | 34 |

*Table 1: Mean and peak force induced on the highline by neutrally trimmed raft.*

The force profile reduces with respect to average stream velocity from 0.6 – 4.2 $ms^{-1}$ and the highest force value recorded during the testing of this test (1224N) occurred at the lowest average stream velocity (0.6 $ms^{-1}$). Beyond an average stream velocity of 4.2 $ms^{-1}$ the force value increased up to 5.4 $ms^{-1}$. At the highest stream velocity, the force recorded (1128 $ms^{-1}$) was comparable with the force recorded at the lowest stream velocity (1224 $ms^{-1}$).

**Test 2: Locating the load to the rear of the raft (stern trim)**

Summary of mean and peak force induced on the highline by the raft, trimmed to the stern with respect to average stream velocity.

| | **Trim - stern** | | |
|---|---|---|---|
| **Average Stream Velocity (m/s)** | Mean Force (N) | Peak Force (N) | Standard Deviation (N) |
| **0.6** | 1120 | 1228 | 52 |
| **1.4** | 988 | 1162 | 38 |
| **2.5** | 1912 | 2081 | 56 |
| **4.2** | 2120 | 2256 | 47 |
| **5.4** | 1942 | 2072 | 33 |

*Table 2. Mean and peak force induced by the 4.5m raft, trimmed to the rear*.

The force is lowest (988N) at 1.4 $ms^{-1}$ in this state of trim, and peaks at 2120N at 4.2 $ms^{-1}$

**Test 3: *Locating the load to the front (bow trim)* with respect to force for a given stream velocity.**

Summary of mean and peak force induced on the highline by the raft boat, trimmed forward (bow trim) with respect to average stream velocity.

| **Test 3** | **Trim - Bow** | | |
|---|---|---|---|
| **Average Stream Velocity (m/s)** | Mean Force (N) | Peak Force (N) | Standard Deviation (N) |
| **0.6** | 1045 | 1158 | 34 |
| **1.4** | 1003 | 1077 | 36 |
| **2.5** | 1773 | 1886 | 49 |
| **4.2** | 2030 | 2141 | 44 |
| **5.4** | 2530 | 2674 | 60 |

*Table 3. Mean and peak force induced by the raft, trimmed forward.*

Above 1.4 $ms^{-1}$ loads are higher than the corresponding values for neutral trim. Above an average stream velocity of 4 $ms^{-1}$ the trace climbs with respect to load. Observations highlight that at velocities above 4$ms^{-1}$ the hull is no longer demonstrating planning behaviour.

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# Discussion

**Test 1: Measurement of the forces induced on the highline.**

The highest loads experienced occurred at a low stream velocity (up to 1.5m/s). The raft was observed to be functioning as a displacement hull. Beyond stream velocities of 1.5m/s the loads reduce, the raft was observed to be functioning as a planning hull. The implication for practice is that in low flow conditions the loads are higher than may be anticipated. At these low flows the raft is functioning as a displacement hull exposing a greater surface are to the flow. At higher velocity the hull demonstrates a planning behaviour corresponding to lower loads because a smaller surface area is exposed to the flow. These finding appear counter intuitive, rescuers will need to be aware and recognise the planing action of the hull in rescue settings and anticipate higher loads on anchors when the hull is not planing. The assumption of low speeds equating to low loads on the highline is not true. However, the raft hull will have a planning speed. The data also demonstrates that loads will increase at even higher stream velocities. In short the raft has an optimum stream velocity in which it can operate, a sweet spot. This will clearly vary depending of raft design, size and water line length. The rescuers need to be aware of their rafts behaviour in different conditions.

**Test 2: Locating the load to the rear of the craft (stern trim) with respect to force for a given stream velocity.**

In this test the highest loads are observed at higher stream velocities (up to 1.5m/s) during which the raft was observed to be functioning as a displacement hull. Beyond stream velocities of 1.5m/s the loads increased and peaked at 4.2m/s. The raft was observed to be functioning as a displacement hull at all flow velocities. The implication for practice is that trimming the raft towards the stern changes the hull behaviour and prevents planning behaviour, thus maintain high loads on the highline. Rescuers will need to be aware and recognise that the action of the hull is not planning. In short, compensating for high stream velocities by trimming the raft towards the stern generates high loads on the highline system and is counter intuitive. Echoing our finding in test 1, this will clearly vary depending of raft design, size and water line length. Test 2 confirms the need for rescuers to being aware of their rafts' behaviour in different conditions.

**Test 3: *Locating the load to the front (bow trim)* with respect to force for a given stream velocity.**

At a low stream velocity (up to 1.5m/s) the load is lower than in the stern trimmed position. Above 1.5m/s the loads are higher than for the neutral trimmed state. The implication for practice is that in low flow conditions the loads are higher than may be anticipated because the raft is functioning as a displacement hull. At higher velocity the hull demonstrates a planning behaviour corresponding to the lower loads. The hull appears to retain its planning function, as shown in test 1. Observation highlights that the support provided by the reeving line, lifting the bow, is in effect compensating for the bow trim.

**General Discussion**

Key to understanding the loads on the highline is the planing behaviour of the raft. Brewer,(1993) and Fontaine and Cointe, (1997) identify that the displacing hull produces two waves, a bow wave and an aft wave The positions of these waves is determined by the wetted length of the hull. (see Fontaine and Cointe, for greater detail). A theoretical maximum velocity can be established for a given hull type and length while the boat demonstrates displacement behaviour (Miller et al, 2006). For the hull to exceed this velocity, it must transition to a planing hull behaviour, in which the hull has a reduced wetted area, and so resistance. This leads us to recognise a 'sweet spot' for a given hull on a high line.

**Implications in Training and Practice,**

Encouraging neutral trim in a range of flows and exploration of the optimal performance of a range of different craft would seem paramount in training. In practice observation of the planning and displacement behaviours of the raft would appear pivotal. In particular, the assumption that high velocities equate to high loads needs to be challenged.

During a rescue the change in trim that may occur as the Subjects of the recue board the raft needs to be considered. The resultant increase in load on the highline and change to the position of the raft in the flow needs to be anticipated by the rescuers. A change in rescuer position may compensate for this effect though this warrants further investigation.

# Conclusion

The awareness of rescuers to the added dimension of stream velocity and direction is key to understanding the resultant load on the high line system. The influence of trim (how the load is distributed in the raft) has a profound effect on the resultant loads that may be counterintuitive. The results challenge the notion of low stream velocities equate to low loads in the highline. These findings expose the weakness in the transference of assumptions regarding loads from one domain to another (in this case technical rope rescue to swift water rescue). However, the importance of understanding the operational capacity of the raft is also highlighted. In particular, the transferability of knowledge regarding planning behaviour of hulls derived from power boat rescue and an ability to identify the 'sweet spot' of a rafts' performance.

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## About the authors

**Chris Onions** is Director of Training with R3 Safety & Rescue Ltd, providing technical rescue training to the emergency services. He is actively involved with the North Wales Mountain Rescue Association.

**Loel Collins** has taught swift water rescue for over 30 years. He has taught recreational kayakers and canoeists, Fire service, Royal Society for the Protection of Animals, Ambulance services, Police, Mountain Rescue and the military. He currently works as a Senior Lecturer at the University of Central Lancashire.

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## References

Akan, A. O. (2006). *Open Channel Hydraulics*. Butterworth – Heinemann. Oxford.

Attaway, S. W., Beverley, M. J., Mills, M., Weber, E., Belknap, E. and Attaway, N. (2013). *Track Lines and Guiding Lines: Forces Based on Point Loads Based Upon a Catenary*. International Technical Rescue Symposium, Albuquerque, New Mexico*. November 8 – 10*.

Brewer, T. (1993). *Understanding Boat Design.* International Marine.

Brown, M, G. (2000). *Engineering Practical Rope Rescue Systems. Delmar. Thomson Learning. NY.*

DEFRA. (2012). National Flood Rescue Enhancement Project, Concept of Operations. Available from, http://www.defra.gov.uk/publications/files/pb13676-frco.pdf Accessed, 27 September, 2012.

Fontaine, E. and Cointe, R. (1997). *A slender body approach to nonlinear bow waves*. Philosophical Transactions of the Royal Society. 355. 565 – 574.

Gierke, J. S. (2002). *Engineering Applications in Earth Sciences: River Velocity*. Available from. www.geo.mtu.edu/~raman/MiTEP-ESS-1/manning.doc. Accessed 28*, September, 2012.*

Miller, R., Gorski, L. Xing, T., Carrica, P. and Stern, F. (2006). *Resistance Predictions of High Speed Mono and Multihull Ships with and without Water Jet Propulsors using URANS*. Symposium on Naval Hydrodynamics. Rome. 17-22 September, 2006.

Ray, S. (1997). *Swiftwater Rescue:  A Manual for the Rescue Professional*. Asheville: CFS Press.