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Evaluating the stability requirements for mounting and dismounting from the top of leaning ladders

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Evaluating the stability requirements for mounting and dismounting from the top of leaning ladders

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This report evaluates reasonable ladder use and quantifies the demands placed on the ladder system when used to access platforms and surfaces. This method of use is commonly found amongst certain trades such as window cleaning or roofing and places unique challenges to the stability of the ladder. The work described quantifies the needs of the user and goes on to present a means of both modelling the stability provided by a given ladder and undertaking a workshop test. This work builds upon previous peer reviewed research undertaken for the HSE and employs a similar methodology. In combination with this previous work it aims to provide a reliable means for determining safe equipment for use in the field as well as assisting in the development of new and improved access devices.

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Executive Summary

This report details the methodology and findings of an investigation into the suitability of leaning ladders as a means to access high surfaces. This work has been funded by the Health and Safety Executive to provide a factual basis on which to make recommendations regarding safe practice. In particular it addresses a gap in the knowledge generated in previous studies into safe ladder use. This gap is generated by those individuals for whom the pressures of work make use of a ladder necessary but for whom safe practice is compromised. In particular, environmental demands, multiple unpredictable locations and challenging tasks combine to make a ladder an obvious, yet arguably unsafe, choice of equipment.

Previous work has addressed the stability provision of ladders and ladder devices, when used as a work platform. Those users who need to utilise a ladder to access their work were potentially excluded form the benefits of the findings of that previous work. Accordingly a need remained to determine whether a ladder, with or without the benefit of a stability device, could provide adequate stability to be safely used in this fashion.

The methodology employed to address this issue closely followed the heavily scrutinised and peer reviewed techniques used to quantify the stability for leaning ladders, documented in the HSE Research Report 205 published in 2004. Essentially, by recruiting representative participants and engaging them in self regulated yet demanding tasks, the demand placed on the ladder system under reasonable use could be quantified. The data from this experimentation could then be used, through extensive mathematical interpretation, to generate parametric loads which could be applied to any given ladder in the form of a stability test. The test may be practical, to be conducted in a workshop on real world products, or theoretical where it may be applied to design concepts.

In either case the stability limits may be determined. For the workshop test these are binary pass/fail outputs. The modelled evaluation will provide a quantification of performance above or below the threshold in each of four stability modes.

In this research 1500 trials were undertaken, based on activities deemed as reasonable through discussion with relevant stakeholders. These trials provided enough variation to establish the most onerous conditions of use that could be considered as reflecting ‘reasonable’. The demand on the ladder system from these activities would provide the stability challenge.

Whilst the models described in this report provide the means to determine whether any combination of ladder and device can meet the requirements of these tasks, whether they are actually ‘reasonable’ and should be undertaken on a ladder has not been addressed. Provisional findings based on modelling of conventional naked ladders indicate that it is unlikely for such structures to be able to reliably provide acceptable levels of stability. This may suggest that policy interventions ensure that in future other structures are used to perform these activities. Alternatively, the prescription of augmenting stability devices or other interventions such as tying off may be considered as necessary to ensure worker safety. By utilising the models described here it will be possible to determine what combinations of equipment, if any, can meet these demands and hence frame safe working practice.

Finally, the key recommendations are that:

- The test specification may be independently validated against a range of proprietary ladders and ladder stability devices. This could take place within the relevant industries.
- A technical standard is developed for ladders or ladder stability devices which may be used specifically for the access task and which is based on the test methodology outlined in this report.
- Policy recommendations for conditions where ladder use is not appropriate to access platforms or surfaces could be more specifically made based on the findings of this report.
- Stability devices could be certified (perhaps as part of any technical standard) prior to being released for specified use. Any such certification should rest upon demonstration of minimum acceptable levels of stability provision in all four failure modes

1.0 INTRODUCTION

Despite advances in both product knowledge and design, leaning ladders continue to be a highly injurious group of products. Recent work commissioned by the HSE (HSE Research Report RR205 Evaluating the performance and effectiveness of ladder stability devices 2004) has established clear and enforceable guidelines on the suitability of leaning ladder and leaning ladder stability device designs in providing adequate stability during normal and reasonable use. However, a significant group of users remain at the periphery of this knowledge due to the nature of their professional activities. These individuals are often required to work alone at height and access objects and surfaces that may be beyond reach from the top of a ladder, but for whom the use of more permanent access is not viable. Examples include window cleaners, roofers or satellite reception equipment engineers.

The safety of these individuals may be compromised through environmental factors (the inability to tie off the ladder due to the variety of work locations) as well as logistical ones, such as the need to climb onto a roof or other surface, or financial ones such as pressure of work or time constraints. Current practice appears to involve mounting and dismounting at the upper margins of leaning ladder in order to undertake these activities. This will place unusual demands on the stability provided by the ladder. This research aims to determine whether conventional ladder design (or a combination of ladder and stability device, referred to as a 'Device Augmented Ladder' or DAL) can provide adequate stability for this practice to be recommended or, indeed, continue.

This work will enhance that already done on leaning ladder stability devices and provide a more complete range of solutions to the problems of misuse of ladders. Failure to determine whether a ladder may be safely used to access high surfaces will leave a loophole in any proposed new policy and undermine the value of the stability devices work already undertaken. It may also mean that certain groups will claim exclusion from the policy due to a lack of evidence, and consequently may account for continuing accidents and injuries that could otherwise be avoided.

Previous work on stepladder (HSE reports CRR 418/2002 and CRR 423/2002) and leaning ladder stability (RR205 2004) funded by the HSE has significantly contributed to a scientifically credible range of policy proposals. Establishing the correct balance between safety and productivity when working at height remains highly emotive, especially for small businesses which may typically make up the user groups of interest in this project.

The knowledge gained in this study will build upon the current understanding and can be used to determine whether the practice of using un-tethered ladders to access high surfaces is safe or not, or could be made safe. Subsequently, recommendations for inclusive policy or standards can be made to remove the emotive element of this safety practice.

1.1 AIMS AND OBJECTIVES

The aims of the project can be summarised as:

- To evaluate the stability demands placed on an un-tethered, or partially tethered, ladder by typical users using the ladder to access high surfaces.
- To determine whether conventional ladders or ladders and stability devices can meet these needs and so provide a safe working environment.
- To attempt to offer a means to quantify any modification which may be required to conventional equipment in order to meet the user demands.
- To provide an evidence-based answer as to whether this practice is appropriate or not.
- To provide information which will help shape the policy on working at height so as to only permit safe practices.
- Ultimately, to reduce the number of accidents and associated injuries.

These project aims are achieved by satisfying a number of specific objectives:

- Construction of a rig capable of collecting real time data relating to the forces generated by typical users climbing on and off a ladder.
- Recruiting a suitable selection of participants to use in data collection trials.
- Undertaking the trials and collecting the real time data.
- Processing the data to determine the stability demands placed on the ladder system.
- Calculating the key variables associated with the stability of the system.
- Determining an appropriate model for appraising the stability of systems.
- Reporting the process and findings such that dissemination can be meaningful, effective and worthwhile.

The success of the project is marked by the ability to define useful measures to establish what is ‘safe’ and what is ‘unsafe’ equipment for mounting and dismounting at the top of ladders used in a reasonable manner to access high surfaces.

1.2 METHODOLOGY

The technique employed is a modification of the innovative and unambiguous approach previously used by the authors in the assessment of the stability of both stepladders and leaning ladders. A fully dynamic balance platform is used to evaluate the centre of gravity (C of G) inherent in the ladder system. By continually monitoring the C of G whilst the ladder is being used it can be determined when the system becomes unstable and hence fails. This point can be quantified such that direct comparison can be made between systems. These systems will be functionally dependent upon the nature and degree of restraint of the ladder and the strategy of mount and dismount adopted by the user.

This methodology and equipment has been highly effective in the measurement of the stability of stepladders, leaning ladders and ladder stability devices and is ideally suited to addressing the issues in this project. The data produced can be readily used as the basis for a simple testing protocol or a more complex stability evaluation model, either of which may be appropriate for inclusion in procedural assessment and guidelines or a technical standard.

2.0 STAKEHOLDER SURVEY

2.1 LADDER USAGE WITHIN DIFFERENT TRADES

It was essential that the structure and methodology in which these trials were conducted be a true representation of typical ladder usage throughout industry. Therefore, in order to design a trial methodology that achieved this, it was necessary to establish what procedures industry employees were required to follow when using ladders, with a specific focus on procedures for climbing on and off the top of ladders. In order to establish this, Trade Associations and industry organisations were contacted and interviewed. These two stakeholder groups were contacted separately so as to identify whether any differences existed between what is recommended by the trade associations and what actually happens in practice.

All interviews were conducted over the phone and any relevant literature that trade associations supplied to their members regarding procedure safety was obtained. A telephone protocol was developed, a full copy of which can be found in Appendix A.

The trade associations contacted are listed below:

- National federation of Master Window and General Cleaners
- National Access and Scaffolding Confederation (NASC)
- The Confederation of Aerial Industries Limited
- Association of Technical Lightning and Access Specialists
- Arboriculture Association
- House Builders Federation

The policy and procedure section of Table 1 lists the policies that Trade Associations recommend and the procedures followed by industry organisations.

Table 1 – Summary of feedback from stakeholder survey

Trade Association	Ladder used for climbing on to	How do they climb on & off	Policy & Procedures	PPE worn by user	Equipment carried	Approx weight
The Confederation of Aerial Industries Limited	Roofs Other ladders Scaffolds Platforms	Majority sideways to climb onto roofing ladder to access chimney	• Use ladder without fall protection equipment if it can be securely fixed from slipping outwards or sideways, the work is of short duration, and the installer can carry his tools, equipment and material whilst maintaining 3 points of contact • Risks associated with ladder erection/stabilisation are evaluated in the risk assessments • All installers who work at height must be trained in the use of ladders and associated devices	- Helmet and chin strap - Safety footwear - Eye protection - Hearing protection - High visibility vests - Face masks - Gloves	Tool belt: - hammer - Screwdriver - Spanner, etc.. - Aerial or sky-dish approx 1m diameter	10kg
National Access & Scaffold Confederation (NASC)	Scaffolds Platforms	Forwards Backwards Sideways (new policy being developed only recommends sideways)	• Currently writing a guidance note which will recommend that ladders are no-longer placed face onto the scaffold as it requires workers to step backwards off the working platform when climbing back on to ladder (recommending side on) • Currently climb on and off forwards and backwards • All ladders must be tied (at least at the top) • Risk assessment should be carried out before every job (not specific to ladder erection) • Recommend no equipment is carried up ladders, tool belts are acceptable	- Footwear - Harnesses - Hardhats - Safety glasses - Gloves - Overalls	Toolbelt - spanner - spirit level - tape measure	5kg

Table 1 (Continued) – Summary of feedback from stakeholder survey

Trade Association	Ladder used for climbing on to	How do they climb on & off	Policy & Procedures	PPE worn by user	Equipment carried	Approx weight
National Federation of Master Window and General Cleaners	Flat roofs	Sideways	• Ladders should be a positioned a meter above the step off point • Always climb on and off ladders sideways. • Proprietary ladder stability devices should be used to secure ladders at the top (used instead of tying off) • Wherever possible place the top of the pointed ladder in a corner so that it cannot slip sideways	Adverse weather clothing Hard hats (Occasionally)	Belt kit: - Pint of water Polypropylene holster Water applicator Scraper squeegee Dry cloths Bucket & sponge	2.5kg – 3kg max 5 kg Bucket – 10kg when full
Association of Technical Lightning and Access Specialists	Roofs Roofing-ladders Scaffolds	Lightning conductors – sideways Steeplejacks – dependent upon the structure they are working on	• Have to comply with construction safety regulations. • No standard procedure to the way they should climb on and off ladders. • Use a 5 step risk assessment. • Steeplejacks wear fall arrest when climbing and descending ladders.	Steeplejacks - Full body harness & 2 tailed lanyard, helmet with chin strap.	Screw driver, Battery drill Occasionally carry a rope and a block (20kgs)	Typically 8kg but may increase to 20kg
Arboriculture Association	Trees	All directions, dependent upon the structure	• Ladders are only tied off if people are working from them • Policy states – a ladder must be fixed at the top if used as a means for gaining access to and from the work place. • Wherever possible erect ladder against trunk not branches • Carryout a generic risk assessment relating to ladders prior to each job	- Safety boots - Gloves - Goggles - Helmet with chin strap or climbing helmet	No equipment is carried up the ladder apart from the safety rope which is used to hoist up the necessary equipment.	

Table 1 (Continued) – Summary of feedback from stakeholder survey

Trade Association	Ladder used for climbing on to	How do they climb on & off	Policy & Procedures	PPE worn by user	Equipment carried	Approx weight
House Builders Federation Building Contractors	Scaffold	Sideways onto working platform if possible, however is dependent upon structure. Sometimes may be forwards or backwards	• Ladders are always to be tied off • Follow Health and Safety guidelines • No specific policy in relation to ladder use within trade	- Safety boots - Hard hat - High visibility vest	Tools in bags on back or in tool belt Bricks Lead rolls Sometimes carry spirit levels, trowels, vent covers, alarm boxes.	Approx 5kg for building trades. Hod carriers carry approx 20kg of bricks Plumbers carry similar weight of lead for edging windows.
The National Federation of Roofing Contractors	Response not received within project timescale	Response not received within project timescale	• Ladders must be adequately tied • Extend at least a metre above resting place • Access point area to the ladder is kept clear of materials and debris	Response not received within project timescale	Response not received within project timescale	Response not received within project timescale

2.2 SUMMARY OF FINDINGS

Findings from the telephone interviews show that:

2.2.1 Ladder use

- Ladders are used to climb on to and off roofs, roofing ladders, trees, scaffolding, platforms and flat roofs.

2.2.2 Methods of climbing on and off

- There is no single set way in which trades climb on and off ladders. Trades such as lightning conductors, aerial installers and window cleaners claim to always climb off and on ladders sideways, whereas tree surgeons, scaffold erectors and steeplejacks claim to climb on and off ladders forwards, backwards and sideways.

2.2.3 Climbing on and off ladders

- Only the National Federation of Master Window and General Cleaner's policy specifically states how individuals working within this trade should climb on and off ladders (i.e. sideways). However, The House Builders Federation recommends this method.
- The National Access & Scaffold Confederation (NASC) is currently writing guidance that recommends the same procedure.
- The majority of the remaining trades interviewed had no procedures in place for the method in which individuals should climb on and off ladders.

2.2.4 Securing ladders

- The Scaffold Trade Confederation and the House Builders Federation policies state that all ladders should be tied off at the top.
- The National Federation of Roofing Contractors states that ladders should be adequately tied and that the access point area to the ladder should be kept clear of all materials and debris.
- The Confederation of Aerial Industries states ladders should be "securely fixed by means of an eyebolt and ratchet strap and a proprietary stabilisation and stand off device". This method can be seen illustrated in Figure 1.

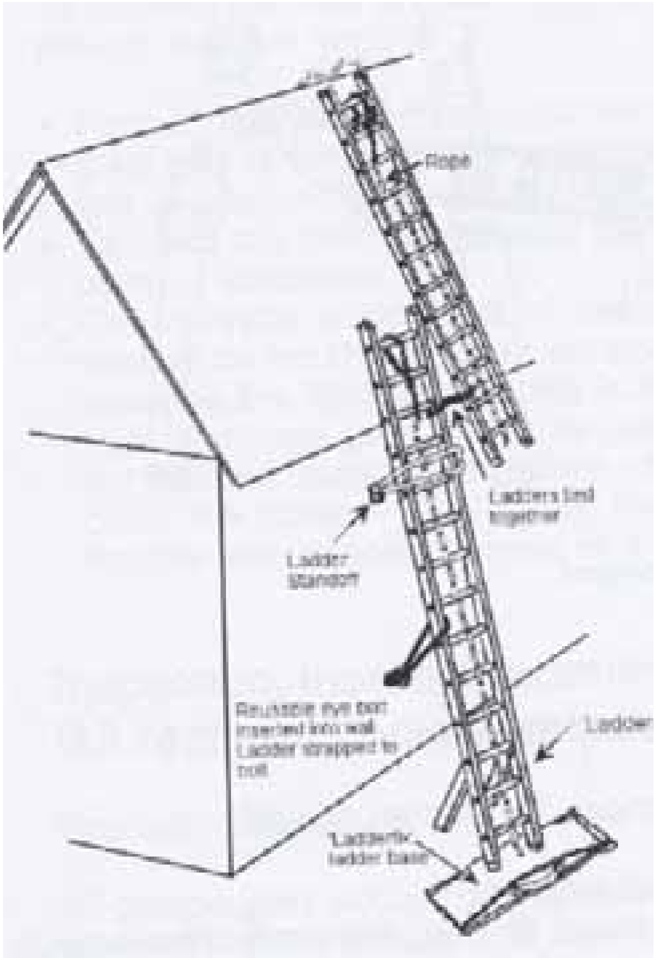


Figure 1 – Recommended ladder fixing method by Confederation of Aerial Industries

- None of the other trade associations questioned stipulate in their policies that ladders should be tied off at the top when people are climbing on and off.

2.2.5 PPE worn

- Of all possible Personal Protective Equipment only hard hats are recommended to be worn during all outside work, including ladder work. Other PPE is only recommended to be worn when conducting particular tasks.
- Steeplejacks were the only group required to wear a fall arrest system when climbing and descending ladders (possibly because their ladders may be mounted vertically).

2.2.6 Equipment carried

- The Arboriculture and Scaffold trade associations' policies recommended that no equipment is carried whilst climbing or descending ladders. However, tool belts were considered as acceptable and not grouped in with 'equipment'.

- All other trades carried equipment on and off ladders e.g. aerial installers would carry television or radio aerials and satellite dishes on and off ladders, lightning conductor engineers would carry drills and window cleaners would carry buckets of water. Many tradesmen would carry raw materials, for example roofers carrying rolls of lead flashing, but it is difficult to specify such items precisely.

2.2.7 Weight of equipment carried

- The majority of the equipment carried was estimated to weigh between 2kg and 10kg.
- 10kgs was the estimated weight of a full bucket of water for window cleaners.
- Hod carriers and plumbers were the two trades that carried the greatest amount of weight on and off ladders. Plumbers were cited as carrying rolls of lead and hod carriers would carry a hod of bricks on and off ladders. Both of these items were estimated to weigh approx 20kg each.

2.2.8 Accidents and near misses

The trade associations/federations interviewed were asked of any accidents or near misses that had been reported in relation to ladders. They offered the following information:

- The National Access & Scaffold Confederation (NASC) reported that ten individuals had fallen from ladders last year.
- The Association of Technical Lightning and Access Specialists reported there are approximately 3 accidents per year which occur with workers getting on and off ladders.
- No other trade associations reported any accidents or near misses.

3.0 LADDER TRIALS

An essential component of this research is the collection of data whilst individuals are undertaking ladder activities they consider reasonable. This forms the basis for the subsequent forces used in the modelling and testing regimes. It is paramount that the participants in the data collection process behave as naturally as possible to ensure the forces they apply to the ladder system are truly representative.

In order to gather the loading information when individuals use the ladder to access elevated surfaces, it was necessary to conduct extensive user trials with volunteer participants. This process mirrored the techniques used by the authors in previous ladder research undertaken on behalf of the HSE and fully documented in HSE RR205 (2004). In essence, the procedure was replicated but the task activities and environment were changed to reflect the new area of interest and associated tasks. The trial structure is outlined in the following sections.

3.1 OVERVIEW

The tasks designed to be carried out within these trials were based on information obtained directly from trade associations and industry organisations. Additional information was obtained form the participants themselves, many of whom used ladders for access as part of their professional lives. The combination of these information sources allowed for the specification of trial tasks that reflected activities undertaken during normal working life.

The ladder trials were setup and conducted at the Ergonomic and Safety Research Institute, in Loughborough during 2005. All trials were carried out on the same test rig, which allowed for the collection of comparable and robust data. The test rig can be seen illustrated in Figure 2.

Figure 2 – The test rig as installed

The rig consisted of a professionally erected scaffold platform, approximately 4.5 metres above the ground. In the centre of the rig an access portal was created of sufficient size that a user could climb the ladder whilst carrying a significant load. Through this portal was mounted the ladder used in the trials, such that an accessible platform was available to all four sides of the ladder and users could readily step from the ladder either forwards, backwards to the left or right. The ladder used was a conventional aluminium two stage extendible model, rated for industrial use (BS2037 1994 Class 1). The ladder was mounted at approximately 75°, the angle universally recommended for safe practice. The ladder was lightly tethered against the dynamometer rig in order to restrain it from falling but with sufficient freedom to provide accurate and normal user feedback.

In order to provide protection for the participants a full body harness and self-retracting lanyard were attached above the top of the ladder. This was located with sufficient clearance to enable the participants to adopt normal and routine climbing, mounting, dismounting and descending strategies.

Ethical clearance from Loughborough University Ethical Advisory Board was not considered necessary for these trials, since participants were undertaking activities which formed part of their normal work routine. Comprehensive risk assessments were completed to ensure the highest level of safety for participants and researchers and resulted in numerous interventions. The majority of these were procedural, with only the requirement to wear a harness and hard hat having any potential impact on the participant's behaviour on the ladder. To minimise any risk compensation effects users were not allowed any pre-trial activity on the ladder or rig.

Prior to each participant taking part in the batch of trials, they were informed of the activities required of them and the principle of the trials, but not the motivation. This information was made available after they completed the trials if requested. Participants were screened on the basis of any health conditions which may affect their ability to carryout the tasks, and were required to read and sign an informed consent agreement prior to taking part.

Before each task, clear instructions were given to each participant telling them what was required of them and directed when to start and stop once they had declared themselves ready. There was no time limit for the tasks to be completed. All trials were supervised by two ESRI researchers to ensure consistency and participant welfare throughout. Since it was critical that participants did not influence each other's perceptions or behaviour during the trial each participant's arrival time was staggered so there was no overlap.

3.2 TRIAL METHODOLOGY

As previously stated, the tasks carried out within the trials were determined from the research findings obtained from the telephone interviews which were conducted with trade associations and industry organisations. However. the tasks involved in the trial were designed to be challenging, and all tasks were based on the normal activities that are carried out on ladders. More importantly, all the tasks were self regulated with each user determining not only the appropriate strategy to undertake the task but also the degree of exertion and risk which they wished to accept. Because of the need to reconfigure the test rig in between groups of trials, it was only possible to randomise the trials presentation within each configuration group (i.e. randomised trials within the balcony set, or in the stepping on and off set step). However, such randomisation was utilised to restrict any learning effects.

3.3 LADEN AND UNLADEN TASKS

From the interviews conducted it appears that the majority of tradesmen carry equipment, materials or tools on and off ladders. Tools (through the use of tool belts) and ropes are generally carried around the body which in effect generates a heavier person with the load centralised. However, other tradesmen such as aerial installers and window cleaners carry equipment on and off ladders with their hands. Carrying equipment in this way will alter the individual's centre of gravity more profoundly. This will require compensation by the individual to remain balanced, especially when climbing on and off the ladder. The effects of carrying equipment in this way was investigated in the trials, to determine the effect when climbing on and off at the top. Participants were therefore required to carryout the tasks both laden and unladen.

Unladen tasks – Participants were required to complete the tasks carrying nothing. The tasks involving the participant transferring their mass from the ladder to the surrounding platform in a number of different configurations.

Laden tasks – These tasks are modified to replicate the work practice of trades within industry. Participants were required to complete the majority of tasks carrying a 2.5 gallon (11.3 litres) bucket of approximate mass 11.5kg (representing the bucket being full of water or cement). The bucket and weights used can be seen illustrated in Figure 3.

Figure 3 – The bucket and weights used for the laden tasks

This weight and form of equipment was selected as it currently represents a reasonable yet onerous case scenario in terms of size and weight of equipment carried on and off ladders.

The use of a bucket also provided an asymmetric carrying task involving an unstable load where the user may only hold on to the ladder with one hand. This requirement drives the user to adopt an appropriate management strategy which may vary depending on their strength and confidence. Consequently, speed in undertaking the task, the degree of mass offset and other factors were suitably varied amongst the participant group.

3.4 PILOT TRIALS

Prior to the main trial undertaking, pilot trials were conducted using ESRI staff to test the equipment, the suitability of the tasks devised and to validate and calibrate the test rig and metrics. In addition, the test rig itself required some considerable development to ensure sufficient stiffness and reliability. This process resulted in a robust and repeatable experimental technique.

3.5 TRIALS RIG CONFIGURATION

Due to the number and variety of tasks that had to be performed, it was necessary to conduct the trials in four phases with the rig configuration being altered between each phase. This reflected the need to erect a simulated balcony roof surface and required appropriate safety precautions. Accordingly, the participants attended three batches of trials each on a separate day. This also helped to reduce learning effects, often apparent in intensive and highly repetitive trials. As in previous research, the ladder was not tied or footed during the trials but was lightly restrained to the rig. This allowed normal feedback from the ladder system whilst maintaining alignment on the rig. A plan view of the platform and ladder layout can be seen illustrated in Figure 4.

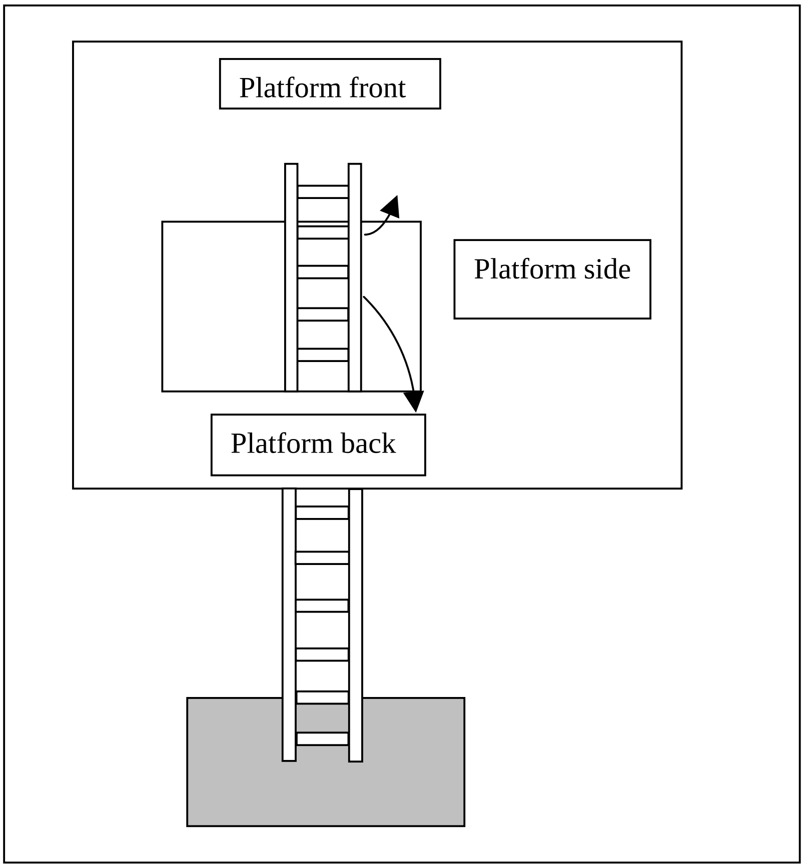


Figure 4 – Schematic representation of the test rig setup

Approximately 1500 individual trials were undertaken and recorded, forming a significant data set. Details of the recording systems used are given in Section 5 onwards. Each trial consisted of a single ascent or descent of the rig in a specific configuration and either laden or unladen. A more detailed account of the trials structure is given in the following sections.

3.6 TRIAL TASKS

The trial tasks were structured and coded to facilitate management and to assist with the identification of the resultant data sets. The individual tasks and coding letters are shown, by configuration, in Tables 2 to 5:

Ladder mounting and dismounting trials coding (See Sections 3.7 to 3.10 for details)

Table 2

Task codes in configuration 1

Task code	Activity
A	On platform – unladen – front
B	Off platform – unladen – front
C	On platform – laden – front
D	Off platform – laden – front
E	On platform – unladen – back
F	Off platform – unladen – back
G	On platform – laden – back
H	Off platform – laden – back

Table 3

Task codes in configuration 2

Task code	Activity
J	On platform – unladen – side
K	Off platform – unladen – side
L	On platform – laden – side
M	Off platform – laden – side
N	On balcony
P	Off balcony

Table 4

Task codes in configuration 3

Task code	Activity
Q	Placing roof ladder
R	On roof ladder
S	Off roof ladder
T	Removing roof ladder

Table 5

Task codes in configuration 4 (specialist trials – hod carriers only)

Task code	Activity
U	On platform – laden – front
V	Off platform – laden – front
W	On platform – laden – back
X	Off platform – laden – back
Y	On platform – laden – side
Z	Off platform – laden – side

It will be seen that one set of trials included only hod carriers. This was undertaken because of the safety implications of requiring participants to carry loaded hods. Professional hod carriers were recruited for this set of trials and the tasks involved just laden participants.

As previously stated, the trials were separated in to four distinct elements determined by the requisite rig configuration. These can be summarised as;

Configuration 1 (week 1) – Rigged for tasks – A to H (Rig basic front and back platforms only)
Configuration 2 (week 2) – Rigged for tasks – J to P (Rig with side platform and balcony only)
Configuration 3 (week 3) – Rigged for tasks – Q to T (Rig with roof only)
Configuration 4 (at end) – Rigged for tasks U to Z (Rig with front back and side)

It was also important to be able to uniquely identify each and every trial, both for the purposes of trial management but also to facilitate the data processing and subsequent analysis. Accordingly, each trail was allocated a code based on the variables of task, participant and repetition. The coding protocol is shown in Table 6

Table 6

Trials coding protocol

Variable	Coding
Task Coding	A through to Z
Participant Coding	01 through to 99
Repetition	1 onwards

An outline of the activities undertaken in each of the four configurations is given below.

3.7 CONFIGURATION 1 – FORWARD AND REARWARD MOUNT/DISMOUNT

Tasks A and B – Front platform unladen

The tasks involved participants climbing the ladder, once at the top participants were required to step off the ladder forwards onto the front platform (task A). Participants were then required to climb back onto the ladder from the platform, this involved stepping backwards off the platform onto the ladder and descending to ground level (task B).

Tasks C and D – Front platform laden

For tasks C and D participants were required to climb on and off the ladder in the same way as specified in tasks A and B, however for these tasks participants were laden.

Tasks E and F – Rear platform unladen

Participants were required to climb up the ladder unladen, and then get off the ladder on to the back of the platform (task E). Once on the platform they were then required to climb on to the ladder from the back of the platform and descend to ground level (task F).

Tasks G and H – Rear platform laden

For tasks G and H participants were required to climb on and off the ladder in the same way as specified in tasks E and F; however for these tasks participants were laden.

3.8 CONFIGURATION 2 – SIDEWAYS MOUNT/DISMOUNT AND BALCONY TASKS

Tasks J and K – Sideways platform unladen

Participants had to climb the ladder unladen and get off sideways onto the side of the platform (task J), then get back onto the ladder from the side platform and descend to ground level (task K).

Tasks L and M – Sideways platform laden

For tasks L and M participants were required to climb on and off the ladder in the same way as specified in tasks J and K; however for these tasks participants were laden.

Tasks N and P – Balcony tasks unladen

For task N participants were required to climb the ladder unladen, once at the top, participants had to climb off the ladder over a balcony guardrail and on to the front of the platform. For task P participants had to climb from the front of the platform over the balcony guardrail onto the ladder and then descend to the floor. The balcony, approximately 1 metre high, that participants were required to climb over, is illustrated in Figure 5

.

Figure 5 – The configuration for balcony trials

3.9 CONFIGURATION 3 – ROOFING TASKS

Configuration 3 involved participants carrying, positioning and climbing onto and off of a roofing ladder. In order to obtain accurate data sets for each participant, it was necessary to split the trial into 4 separate tasks.

Task Q – Roofing ladder installation

Participants were initially required to climb the existing ladder whilst carrying and handling a roofing ladder. Once an appropriate height had been gained, the participant had to position the roofing ladder (single section, approx 4 metres long and 11kg in weight) over the elevated roof section of the rig. Once the roofing ladder was securely positioned participants then descended the ladder. A participant undertaking this task is shown in Figure 6.

Figure 6 – Manipulating the roofing ladder during a trial

Task R and S – Roofing ladder mount/dismount

Once the roofing ladder was installed participants then had to climb up the original ladder and then on to the roofing ladder. Having mounted the roofing ladder, participants had to ascend up two rungs (releasing any grip on the main ladder), signifying the completion of Task R. For task S, participants were required to descend the two rungs of the roofing ladder and climb back onto the original ladder before descending to the floor.

Task T – Roofing ladder retrieval

For Task T participants were required to climb the trial ladder, remove the roofing ladder from the elevated roof section of the rig and return it to ground level.

3.10 CONFIGURATION 4 - SPECIALIST TASKS

The tasks involved in trials one through to three were designed to imitate regular ways in which trade persons within industry climb on and off ladders to access alternative areas. However, there are certain trades that are required to routinely carry materials and equipment of significant mass on and off ladders. Hod carriers were identified as potentially the most compromised of these given the relatively large load, high degree of instability, asymmetric nature of the load and routine nature of the task. Accordingly, specialist trials were undertaken to model this activity. Because of the risks involved this task was only undertaken by professional hod carriers or roofers, who advised as to the size of the load (20kg – approximately 10 bricks).

Although hod carrying is relatively prescriptive, participants were free to adopt whatever style they chose to carry the load.

The participants were asked to fill the hod with a quantity of bricks that they would typically carry (most chose approximately the same quantity – 10 bricks). This specialist trial was split into 6 different tasks (tasks U – Z). Participants were required to perform the same mount and dismount tasks as in the previous trials with the exception of climbing over the balcony.

The task itself is illustrated in Figure 7.

Figure 7 – Participant carrying a laden hod prior to stepping off the ladder

Task U and V – Forward mount/dismount

The task involved participants climbing the ladder with a hod of bricks before stepping off the ladder forwards onto the front of the platform (Task U). Task V involved the participants then having to step off backwards onto the ladder and descend to ground level whilst still carrying the hod of bricks.

Task W and X – Rearward mount/dismount

Participants were required to climb and descend the ladder in a similar manner to the previous trial, however, this time they were required to mount and dismount the ladder from the back of the platform.

Task Y and Z – Sideways mount/dismount

Again participants were required to climb and descend the ladder, this time getting on and off the ladder from the side of the platform.

4.0 TRIALS PARTICIPANTS

4.1 PARTICIPANT PROFILE

Ladder users are represented in virtually all segments of society, although primarily they can be grouped into professional and domestic categories. Whilst this has ramifications in terms of the equipment they should be using, in practice the boundaries are less well defined. Many individuals using ladders at work choose, or are issued with, equipment intended for the domestic market. Similarly, it is common for professional ladder use to take place without training. Accordingly, in creating a sample population it is defensible to represent the normal population. In particular, it can be argued that, for the same equipment, domestic users and untrained professional users are effectively the same individuals.

For these trials it was important to recruit individuals who were likely to press the ladder system towards the limits of stability. Accordingly, in recruiting participants to undertake the user trials emphasis was placed on identifying those individuals who used ladders as part of their profession. However, some non-professional users were also participants to ensure that all types of user were fairly represented. However, a section of the trials required specialist tasks to be completed, for this professional hod carriers or roofers were recruited through necessity. The profile of the participants recruited is presented in the following sections.

In total, 91 participants were selected at random from ESRI's database of volunteer participants and from local organisations, the selection criteria being age, sex, occupation, ladder experience and availability during the trials period.

4.2 AGE

Ladder users are primarily adults, and so a typical 18 plus aged population was used to represent them. It was particularly important to include older users, since they appear more vulnerable when involved in accidents and consequently more seriously injured. A further justification for this banding is that it also represents the age of the typical working population, so direct comparison between the groups could be made on this basis. In practice an age range of 19 to 63 years was recruited which, despite a bias to the 21-40 age range, adequately covers the working population and, particularly, the vulnerable older user group. The age banding is shown in Table 7.

Table 7

Participant summary - age

Youngest	Mean	Oldest
19	30.5	63

Table 8 gives the data for age bands. It can be seen that the majority of participants (60%) were in the 20 – 30 year age band, with the remainder spread fairly evenly across the range 20 to 70 years. Three individuals exceeded 60 and four were below 20 years of age. The data are presented graphically in Figure 8.

Table 8

Participant age bands

Age Band	Count (n)
<20	4
21-30	55
31-40	14
41-50	8
51-60	7
61-70	3

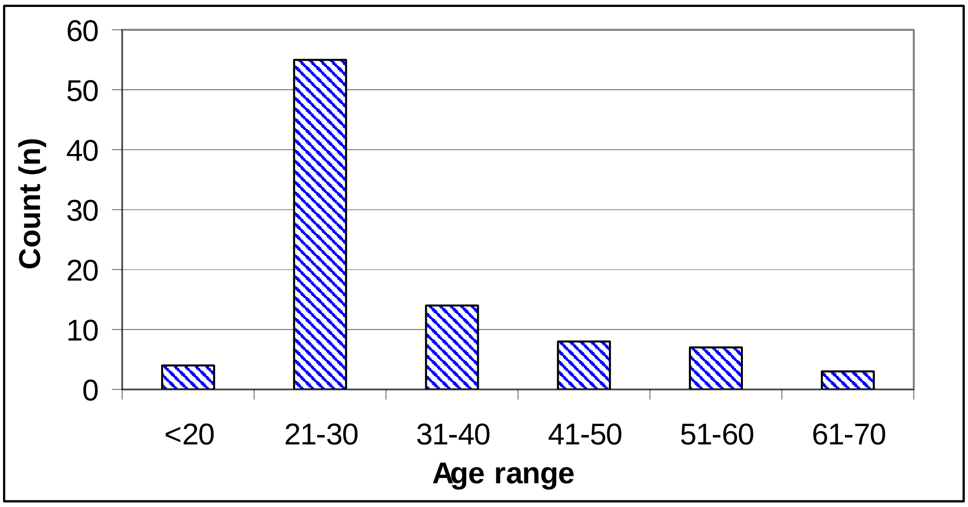


Figure 8 – Age distribution within the sample population

4.3 GENDER

More men use ladders than women, though this relationship is affected by the use environment. However, from accident statistics it was determined that 70% of injured users were male and 30% female. Accordingly the participant panel attempted to follow this, although in practice recruitment difficulties meant that the final ratio was 89 % male to 11% female.

The distribution of females to males was 1:9, somewhat short of the 1:3 which would reflect the proportion of males and females observed in the accident records relating to ladders, may more accurately represent ladder users undertaking such strenuous tasks in the workplace. Table 9 summarises the data.

Table 9

Participant summary - gender

Males	Females
81	10

4.4 EXPERIENCE

Experience is more difficult to control for, since it covers exposure to ladder products as well as duration of direct use. However, all participants were required to have first hand experience of ladder use to qualify for participation. All other key parameters, such as body dimensions, dynamic capabilities, etc. were considered to be adequately represented by effective sampling from the general population.

4.5 CLIMBING ON AND OFF TECHNIQUES

Ladders are commonly used to access higher working platforms as well as workstations in their own right. The nature of the platforms which ladders are used to access clearly varies greatly and can never be fully defined. Consequently the platforms need to be loosely grouped by properties. These will have to embrace trees, roofing structures, scaffold platforms and many more. In order to maintain a degree of control over the safe use of ladders in these circumstances it is necessary to recommend properties the platform must possess in order to provide a suitable surface. This will, by necessity, be quite exclusive and may be reduced to the simple parameters of solid, stable, secure and offering reasonable levels of friction.

Even with these criteria a large range of possible platforms remain and consequently users need to adopt a variety of strategies to manage the transition from ladder to platform. Those strategies will be defined by the platform type but are unlikely to vary hugely.

In the trials undertaken gross differences were noted between where participants were required to scale a balcony guardrail or climb onto another ladder rather than step onto a surface. Within these categories of use, variation was more limited. Essentially the participants fell into one of two possible strategy groups when mounting and dismounting the ladder. These were:

- One hand and one foot in contact with the ladder
- Both hands and one foot in contact with the ladder

It should be noted that only the second of these strategies complied with the 'three points of contact' guidelines, yet was the least preferred of the two options. Figure 9 shows examples of participants employing the one hand and one foot approach

Figure 9 – Climbing on and off with one hand and one foot in contact with the ladder

This technique was adopted by the many of the participants for climbing on and off ladders. The technique involved participants having one arm and foot on the ladder whilst having one leg outstretched to step onto the platform or ladder, and outstretching their other arm for balance. Such loading is likely to be highly asymmetric on the ladder structure and hence provide the highest drives towards flip type failures.

Figure 10 shows the both hands and one foot approach which embraces the ‘three points of contact’ philosophy.

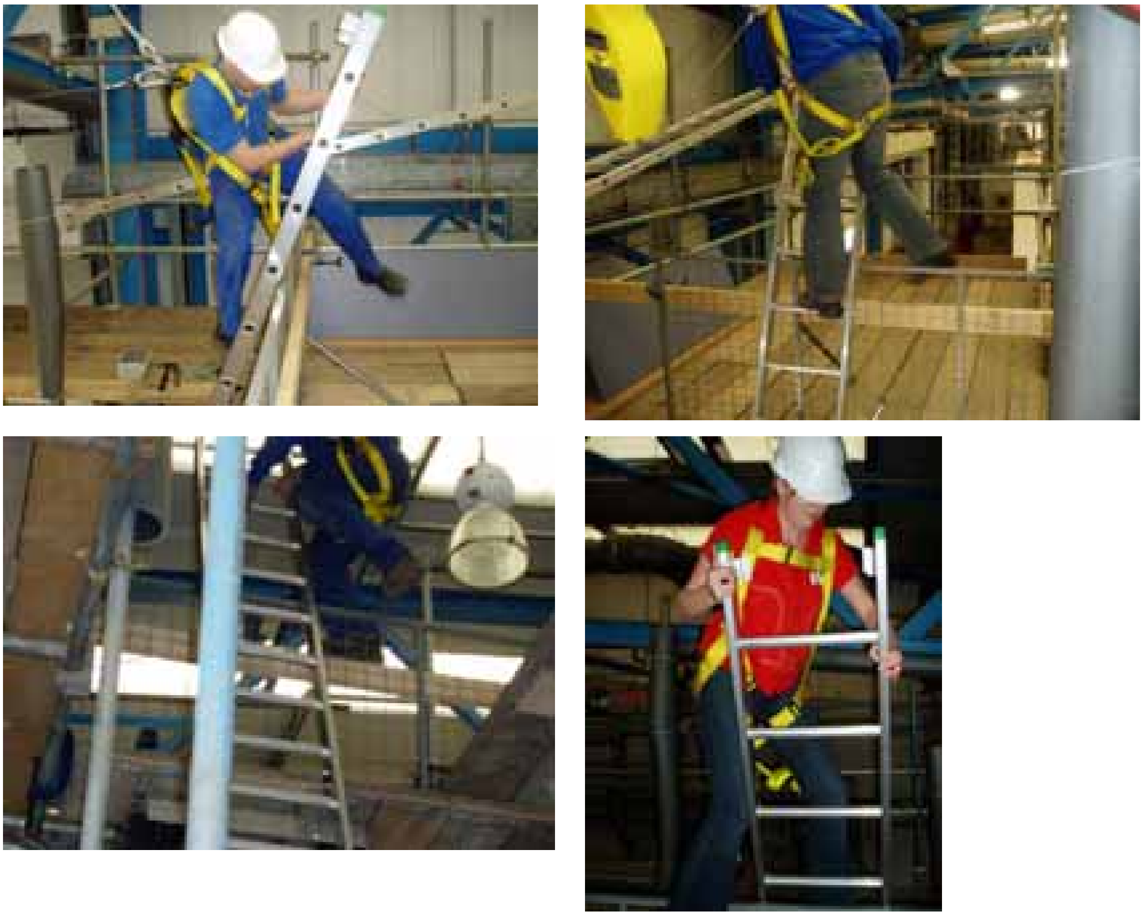


Figure 10 – Climbing on and off with both hands and one foot on the ladder

Holding the ladder with both hands with one foot off the ladder was a common technique adopted by most participants when climbing off or on the ladder when unladen or over the balcony guardrail. Participants would hold the ladder with both hands for stability when stepping off or onto the ladder.

This approach, whilst still asymmetric, may be less likely to load the ladder in a disadvantageous manner. However, the forces involved in displacing the body mass away from the ladder, such that the stance may be transferred to the platform, may still be significant and may still challenge the ladder stability to extremes.

5.0 TECHNICAL SECTION

The following sections detail the technical analysis of the data collected throughout the participant trials. The process is complex and comprehension requires a strong knowledge of mechanics and mathematics. The presentation in this form is unavoidable however, given the need to present a transparent and robust methodology that will withstand scrutiny.

The approach is similar in principal to the work presented in the HSE RR205 report detailing the findings of the ladder stability device research, and relies on the same basic principles. Much of the theory is established and in no way unorthodox, although the application to this product group does appear novel. It is necessary, though, to present the entire process in a step-by-step manner for the sake of completeness and to ensure that the accuracy is apparent.

This complexity can make the process seem inaccessible to the non-technical reader. However, the technical detail is subordinate to the findings and it is plausible to accept the methodology as stated and merely deal with the output – a model and test regime.

The modelling product will allow interested parties to predict, with a high degree of surety, whether any design of DAL (real or virtual) is capable of providing sufficient stability to resist the reasonable demands of users undertaking normal activities. In order to use this model it is only necessary to possess some basic geometrical data of the ladder system which can be predicted or directly measured.

A workshop test is also presented which will provide a simple pass or fail output. This is simply a physical manifestation of the theoretical model. It should be noted that the theoretical model is not only capable of indicating the amount of stability provision above or below the threshold, but is also more accurate due to the inevitable experimental error likely to be encountered in practical testing.

It remains though, that the workshop test may find the most practical applications. An understanding of the technical issues behind that test will permit the user to appreciate which elements of the design are most significantly affecting the performance. In such instances, it may be worthwhile accessing appropriate professional resources to assist with the interpretation of the mechanical science.

6.0 OBJECTIVES AND TECHNIQUES

The objective of this work is to investigate the usage of a leaning ladder or Device Augmented Ladder (DAL) for the purpose of transitory access, and to provide definitions and proof tests of standing stability. This type of usage is characterised by a user employing the ladder as a means of access to, or from, a high platform or similar, rather than the more conventional tasks undertaken whilst on the ladder. In this new form of use the user fully leaves the ladder structure at some elevated position and entirely transfers their body mass, plus any burden, off the ladder and onto an adjoining structure. Clearly this action is also highly likely to be reversed when the user wishes to descend. Professional users who routinely employ this type of use include roofers and window cleaners.

While a sound analysis of the Newtonian mechanics and physics of the ladder as a free standing system is necessary and important in explaining the various mechanisms of ladder stability failure, by itself such technical comprehension is of limited practical use. Likewise, detailed and prolonged passive observation of users and deep studies in accident statistics will potentially yield classes of failure and technical weaknesses of design, but will still leave ladder designers and safety practitioners with restricted insight to the mechanisms involved. There is no metric and hence no common ground.

The strategy within this project is to create a genuinely realistic working environment for a user panel of representative participants, and to instrumentally measure the generated activity and driven demands made on the climbing structure. Equipped with this extensive field of empirical dynamics data, it is then possible to refine out some maximal duress loading intensity (representing reasonably foreseeable misuse) which, with suitable statistical qualification, represents worst case demand of the ladder by the user. Such high intensity reference loads, expressed either as an outright absolute or sub classified by specific task or working scenario, can be used either predicatively or retrospectively through an appropriate scientific supporting model. In this way it can give scale to the level of stability on a case by case basis.

The derived maximal equivalent load is referred to as a parametric. The meaning and derivation of such a device is explained in previous work undertaken for the HSE (Clift, L - HSE Research Report RR205 - Evaluating the performance and effectiveness of ladder stability devices. HSE, 2004) but in recognition of the importance of both the practical justification of the work and comprehension of the principles for designers and others, this issue is discussed more deeply in this report.

It should be noted, however, that even if such a parametric maximal equivalent is known it is of restricted use unless it can be linked to any arbitrary real climbing structure. Only when this is done can a meaningful and quantifiable insight can be gained into the stability status of that particular system. Significant emphasis is therefore placed on a standard mechanical modeller, the kernel of which has already been developed, used and described in previous work for the HSE (RR205 2004). This modeller takes the form of a quite conventional analysis of a multi-point stance registered object - a reasonable description of a leaning ladder system.

To develop this model the orthodox physics of Newton is observed, as well as the orthodox physics of limiting friction. In addition the principals of kinematic freedoms and restraint are recognised and employed, as are the theoretical and demonstrably real existence of six-point grounding contacts.

In this work, a ladder or DAL is treated as a strictly rigid structure. It is recognised, of course, that a real ladder flexes under load. This deflexion will also modulate with instantaneous load intensity. However, it should be realised that the geometrical distortion produced in this way has negligible impact on scale measurements or modelling. In practice, the fractional impact on relevant output parameter values is below any meaningful level.

Friction is also treated with simplicity and parameters for reliable frictional limits at top and base positions are determined. All that is demanded by the modelling is that a physically demonstrable value can be guaranteed by the DAL designer. As a matter of good safety practice it is suggested that sliding rather than static frictional coefficients are adopted and quoted. This is reasonable because certain soft failure modes imply motion onset, and the relevant indices thereby identify this critical condition. It is usually accepted that static limits, sometimes termed ‘stiction’ coefficients, are frequently higher in magnitude than the sliding value, and are more erratically obtained in the lab. User safety therefore suggests taking the lower and more reliable of the values. The workshop verification tests are direct empirical proof in their own right, since tractional capability is maximally pressed. The techniques by which friction limits are obtained are not restricted, no special insight into the deeper physical mechanisms which underpin tribology is required or commented upon.

Given the leaning ladder as a generic problem, an engineer might at first sight observe four basic end-points to the ladder. He or she might then postulate that each point supports three orthogonal force vectors in conventional orientations, so there are twelve vectors in operation.

The analyst will quickly find that a definitive solution for all ground reactions, given some simple static load, cannot be found. Strictly, such a modelled structure is indeterminate, and unique values for the vectors are impossible to find. There is a good reason why such a model produces this result, and is resolved by the fact that the stance is inevitably and naturally due to six vectors only, corresponding to the six innate kinematic points of contact.

As a direct result of this treatment and recognition of such physical mechanisms, it can be shown that certain elementary forces, appearing as ground counter reactions, are either negligibly small or are truly non existent. By these means it is possible to obtain a tractable modelling engine which is representative of the real world and mathematically determinate.

The adoption of kinematic analysis has lead to the conclusion, for example, that vertical forces at the ladder top are consistently zero. This assertion has previously caused some surprise with observers, and significant additional work has been conducted to explain and verify this fact (HSE RR205 2005: Appendix 6). The detail of this work is not replicated in this report, but have shown theoretically and empirically through instrumentation that vertical forces at the ladder top are degenerative (that is they are relentlessly driven to zero). There is, in fact, a relaxation process where small deviant forces from zero, which do arise from time to time, are quickly transferred to other naturally preferential points of ladder contact, maintaining stance stability throughout.

An additional and very pragmatic simplification is that lateral x-axis forces at the ladder base are practically nil. This is just a reasoned argument based on adverse leverages, which indicates that a user at high altitude cannot generate any activity which will sensibly appear as ground reaction at the base, and is certainly negligible in the face of the ordinarily high normal z-axis and forward y-axis base reactions The stability modelling in this report implicitly recognises this force as technically existing, but assigns it value zero throughout.

The parametric load is designed and used as a high intensity system constant which, through a conventional algorithmic process, yields important predictive results indicating stance assurance. It also generates supportive dynamics and frictional demand data. This algebraic process is formally defined in this document, and can be constructed or synthesised by any convenient means. The given parametric load along with certain strategic geometrical measures, weight and mass distribution figures, and reliable sliding frictional limit parameters, is sufficient to fully determine the standing duress on the structure.

The distance to system instability, as a deficit or surfeit, is measurable and is ultimately expressed as normalised intrinsic stability indices.

The modelling process is a direct counterpoint to a series of practical workshop verification tests. The workshop tests and modelling passes both employ identical load configurations. The laboratory based workshop tests will indicate simple pass or failure, and a given applied load will either hold or the structure will move. The model however has a scaled response, and will indicate the proximity to critical stability points. In this way the model is preferable since it offers a quantifiable insight into key design parameters and their respective impact on stability performance.

7.0 OPERATIONAL UTILITY OF AN EQUIVALENT PARAMETRIC LOAD

Loads are generated on a ladder by a user. These loads arise primarily from the user's dead weight but are also associated with action centres of gravity and from inertial demands associated with more or less rapid movement. The actual nature of the mechanical drive into any ladder or DAL in any given activity will generally be both complex and erratic and rapidly variable in time. Literally, the drive will exist as a spatially distributed field of direct linear actions and rotational torsions, all acting into the rigid structure of the ladder. The totality of all these elemental forces is accumulated however, and is permanently counterpoised by the available ground reactions supporting that structure. It is important to recognise that there are a whole sub-set of local or strictly internal forces, which the user will feel as limb tensions and so on, and which will exist as counter stresses within the material of the ladder. However, these are not bodily driving the structure. Such closed-loop forces may be high, but play no part in stability determination. In mathematical terms they integrate to zero, and in practice they are not sensed at the ground contact reaction points.

Using quite conventional mechanical analysis, and given a particular set of values for ground reaction pertaining in some definite structure, it is possible to define and calculate a hypothetical load acting into the ladder. This will duress the structure precisely to cause the original ground reactions. Such an equivalent load can be seen as the cause of actions into the ladder, and similarly the cause of counter ground reactions. This parametric load and the consequent ground reaction are each the determinant of the other – given one the alternative is findable. The term 'parametric' is merely a technical mathematical description which implies this type of numerical linkage or mapping, where one set of parameters are implicitly defined in an alternative set of parameters, through formal algebraic transformations. The term is being precisely and properly used therefore. It should be appreciated that the mathematical coherence is the justification for the term.

All the determined loads are originated directly by human users, and consequently the term 'equivalent' may be used to refer to the anthropometric significance.

There are certain restrictive rules which govern the specific choice and definition of a suitable parametric, or equivalent load:

- It must be capable of generating any concurrent linear or torsional forces which can arise in the structure, as seen as ground reactions.
- It must have sufficient operational degrees of freedom to selectively fully press in all motional and, by definition, failure modes.
- There is surprising latitude of choice allowed however, and numerous legitimate configurations can be postulated. Provided that a full set of ground reactions can be fully realised and determined in value, then stability may be determined.
- It may be understood that there is no obligation to require any kind of intuitive similarity between a valid parametric and the actual originator of the forces, human users in this case, and the particular way actions might atomistically appear in the ladder.

Any parametrically modelled load, expressed in terms of six discrete ground reaction vectors, is necessarily itself a six dimensional parameter also. For a given causal load on the ladder, as counter-load to any particular set of independent ground reaction values, an appropriate parametric must be constructed as a six dimensional object. If it is accepted, as indicated earlier, that base lateral reactions are zero, then the dimensionality of the system can be reduced by one, and hence becomes a five dimensional parametric load. The chosen parametric load here is composed of three orthogonal vectors acting, and constrained, in the plane of the accessible ladder. It is therefore a five dimensional parameter, 3 force and 2 spatial, and complies with this requirement. This load is capable of generating any ground reaction of the types recognised to exist, and can match any plausible concurrent set of values representing 'normal' use. This, therefore justifies utilising this formation.

Given the technical freedom of choice, this work utilises a parametrically expressed load which is conceptually reasonable, readily modelled for mathematical stability prediction, and can be easily replicated in practical workshop tests. Applying this load in specified and logical configurations will systematically and maximally test the standing surety of a DAL structure in each of the four possible failure modes, and hence qualifies the compete structural stability. It can be said that the 'effective' stability is being measured.

Any final loading standards, while strictly artificial as explained, are nevertheless fixed in numerical value directly by the activities of real users undertaking realistic trials activities. The final computed and quoted values, expressed as the Prescribed Standard Parameters, are designed to equate to the statistical edge of maximal mechanical demand observed in and across all trialling. In simple terms it is a reference worst case user.

Through the formal algorithm defined as the DAL Transitory Access-Standard Model, the Standard Load Vector (SLV) and Applied Load Point (ALP) are systematically constructed and configured, and subsequently may be used to challenge any ladder arrangement. A relatively simple data field representing key parameters including geometry, frictional factors and mass distribution is required. Ground reactions are calculated, and hence registration stability is logically determined.

8.0 STABILITY DURESS UNDER TRANSITORY ACCESS

Where ordinary on-ladder type activity is undertaken, there always exists a more or less high value of vertical or z-axis force primarily due to the user's mass. Forces in the x- and y- axis in the horizontal plane oscillate about and may reach zero at any time, and can reverse directional polarity and become technically negative. The action centre location will also move over time, and become more or less adverse depending on the stability question being asked. The published standard z values for ordinary DAL usage modelling are, in fact, expressed as upper and lower figures, and are used according to the test being simulated or practically done. The ever presence of a reliable minimum of vertical action component is characteristic of ordinary ladder activity. In addition, any regular on-ladder task is typically undertaken over time and without obvious duration limit. At no time does a user leave contact with the ladder, which is bearing approximately dead weight at all times. The mechanical nature of this type of activity, plus the associated ascent and descent from some upper position, has already been investigated and quantified in previous research (HSE RR205 2004, HSE CR418/423 2002) and is not of central interest here.

During transitional access type activity, the dead mass representing a user is transferred entirely off the structure in a relatively short time. For the ascent journey, once a user has reached a comfortable height this mass is driven essentially in a flat planar direction, invoking either x- or y-, or both, force components, moving the user away from the ladder. Simultaneously as these planar forces are rising and active, so a steady and sure reduction in vertical z-force ensues, ultimately reducing to zero, as the user completes the transfer. The event is often initiated and achieved in sub-second duration. The descent activity is essentially identical but reversed in time sequence. As a crude rule of thumb, a healthy human undertaking arbitrary and normal, but intense, physical activity can generate momentary inertial forces of the order of their bodyweight, in any direction.

It is evidently the case that the stability condition of a ladder type structure can be determined by applying strategic sets of high duress loads in concert. During the load transferral event, and when analysed in isolation, discrete peaks corresponding to momentarily strong or adverse combinational levels of net drive arise and can be seen. These may be very short lived. It is these type of extrema which are of interest, where totalities of load and action position are the intensity determinants. These events form the basis for evaluation of the reference high duress figures eventually produced.

For the z-load particularly, it is shown that it is incorrect and simplistic to assign a value of exactly zero for a standard value, arguing that this must be worst case in this task class, where low z promotes instability.

To give some qualitative insight into our use and meaning of adversity consider, for example, the likelihood of failure expressed by the Top Contact (#) index. The higher a positive directed y-force, the more the drive to failure. A lower z-force will likewise promote failure. Hence the propensity to failure is more essentially obtained by the ratio of these values, rather than their absolute values alone. This approach is used to assign numerical weights indicating impetus towards instability (or equally stated as drive intensity) determined at each instant during the transient. The clustering centres of representative parametrics are then obtained as adversity weighted averages. It may be apparent that this approach effectively preserves the phase relationship inherent in the real-time instrumentally measured data streams.

Given these considerations, assessment of this type of ladder use can be anticipated to be dealing with generally low effective values of load in z-axis, similar in scale to the higher x- and y-axis loads, and typically of the order 10 kg. These values are enough to destabilise light structures with possible resultant failure.

9.0 MECHANICAL ADVERSITY FACTORS AND PROPENSITY TO INSTABILITY

The observation of the intensity behaviour of any single vector component, or action location of the time variant parametric load, in isolation is not capable of yielding the objective set of high duress vectors which are formally denoted as Prescribed Standard parameters. Taking sophisticated percentile maxima or minima in this fashion, and lumping them as worst qualified case, is not a viable analytic route. The stability status in each of the failure modes is essentially determined by combinations of forces, or more particularly as ratios of forces. Therefore the transient load is observed over time and concurrent measures developed corresponding to ratios of the relevant vector intensities. These are expressed generally as Adversity Factors. The values obtained in this way become weighting factors, and serve to concentrate out numerically characteristic high load combinations. This same concept is tactically used with variation throughout the analysis. The exact implementations are expressed in the relevant sections with proper definitions, but the underlying technical rational is consistent and should be clear.

To illustrate this, consider Top Contact failure mode. A high duress load is characterised by high positive y-vector with simultaneous low z-vector. Neither vector alone can properly constitute an equivalent or parametric load but the ratiometric combination can. Similarly, for Top-Slip failure mode but with bipolar x- and z-vector combination. Base-Slip failure is likewise characterised by a high ratio between y- and z-vector. Flip mode is dependent on a yet more complex combination of high negative y- and high z-vector, plus simultaneous large action point asymmetry.

In analytic terms this methodology corresponds to phase preservation of time locked but otherwise independent parameters. These are numerically managed as sets. Maximal drives are computed and expressed generally as concurrent groups of values.

10.0 ANALYTIC PROCESS

Raw data files are generated at source by suitable multi-channel data acquisition equipment and saved for analysis. These files contain volt level time variant signal at a 30 Hz sampling rate, varying linearly across each of 6 sensory channels. These signals are tare zeroed immediately prior to data collection and hence represent force deviations entirely due to the user, free from any static baseline level due to electronic artefact or ladder weight and consequent pre-stress on the dynamometer.

Each one of approximately 1500 raw data files is sequentially processed through the means detailed in, and referred to as, Microsoft Excel Spreadsheet-“Analyser1”.

An initial parsing out of data identifies a 10 second contiguous time block, fully containing the transient signal with some pre- and post-amble. Initial incoming raw data sets are corrected to kg units to produce calibrated dynamometer ground reactions R1Z(kg) … R3X(kg) as a time sequence series.

Using appropriate rig corrective geometry, the known ground reaction combination leads directly to a number of key time variant measurable parameters representing an equivalent or parametric point load of magnitude LZ(kg), LY(kg) and LX(kg). Action point offset parameter H(m) is also determined. Rotational adverse torsion is determined as M0(kgm). Finally, base frictional demand U_{base}(#) is determined.

A logical series of data conditioning rules isolate out signal purely occurring within the transient phase. This transient valid data is held over for subsequent analysis, all else being rejected, and is qualified as free of pre or post-amble signal due to ordinary ascent or decent. Such clusters of data are necessarily of limited size, being garnered from an event easily of sub-second duration. However the data is assured uncontaminated and representative of the transitional task proper. With appropriate statistical handling this data will yield reliable maximal loading measures.

The Spreadsheet “Analyser1” generates a small set of key output parameters which quantify the maximal duress observed in any particular trial. These are termed the Trial Characteristic Parameters.

The contents of “Analyser 1” are temporary, being sequentially re-loaded with raw data sets from which the useful output parameters are generated. These outputs are immediately transferred to a new Spreadsheet, referred to as “Collation1”. Approximately 250 randomly selected images of particular spreadsheet computations are saved however and exist as a reference collection.

Collation and analysis of the Trial Characteristic Parameters is made in the Spreadsheet “Collation1”. The core analysis is the generation of a set of task specific measures termed the Task Characteristic Parameters.

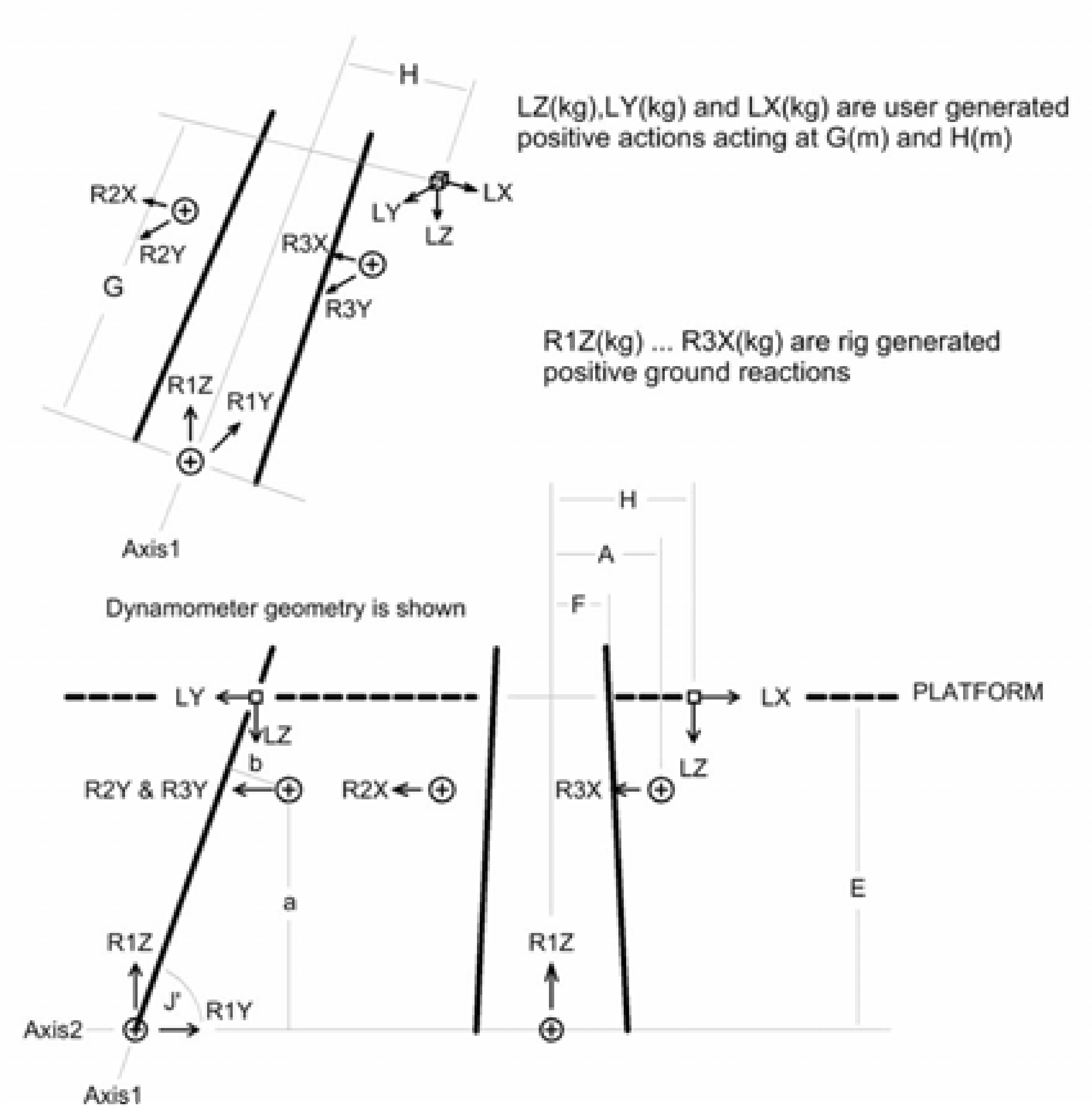
Collation and analysis of Task Characteristic Parameters is made in a further Spreadsheet termed “Collation2”. Final high duress values are now determined and define a standard load set and loading regime, formally referred to as the Prescribed Standard Parameters. This is qualified across all users and all tasks in the measured class, and to that extent is universal.

10.1 DETERMINATION OF INSTANTANEOUS PARAMETRIC LOAD

When considering an instantaneous point load acting on the ladder it is allowed only those positional freedoms necessary to replicate any stance and, in particular, graded duress towards any failure mode. The location of the driven point is constrained to the line intersecting the accessible ladder plane and the working platform plane. This correction and referral to a standard action locus is a necessary basis for the construction of a complete parametric load.

LZ(kg)	Instantaneous Load in z-Axis
LY(kg)	Instantaneous Load in y-Axis
LX(kg)	Instantaneous Load in x-Axis
H(m)	Instantaneous Applied Load Point lateral Offset

The determination of the instantaneous parametric load is shown diagrammatically in Figure 11.



Notes:

Equation (1) – Vertical $\sum F = 0$ $\qquad LZ = R1Z$

Equation (2) – Horizontal $\sum F = 0$ $\qquad LY = R1Y - (R2Y + R3Y)$

Equation (3) – Axis 2 $\sum M = 0$ $\qquad LX = \dfrac{(R2X + R3X)a}{E} + \text{Error}(1)$

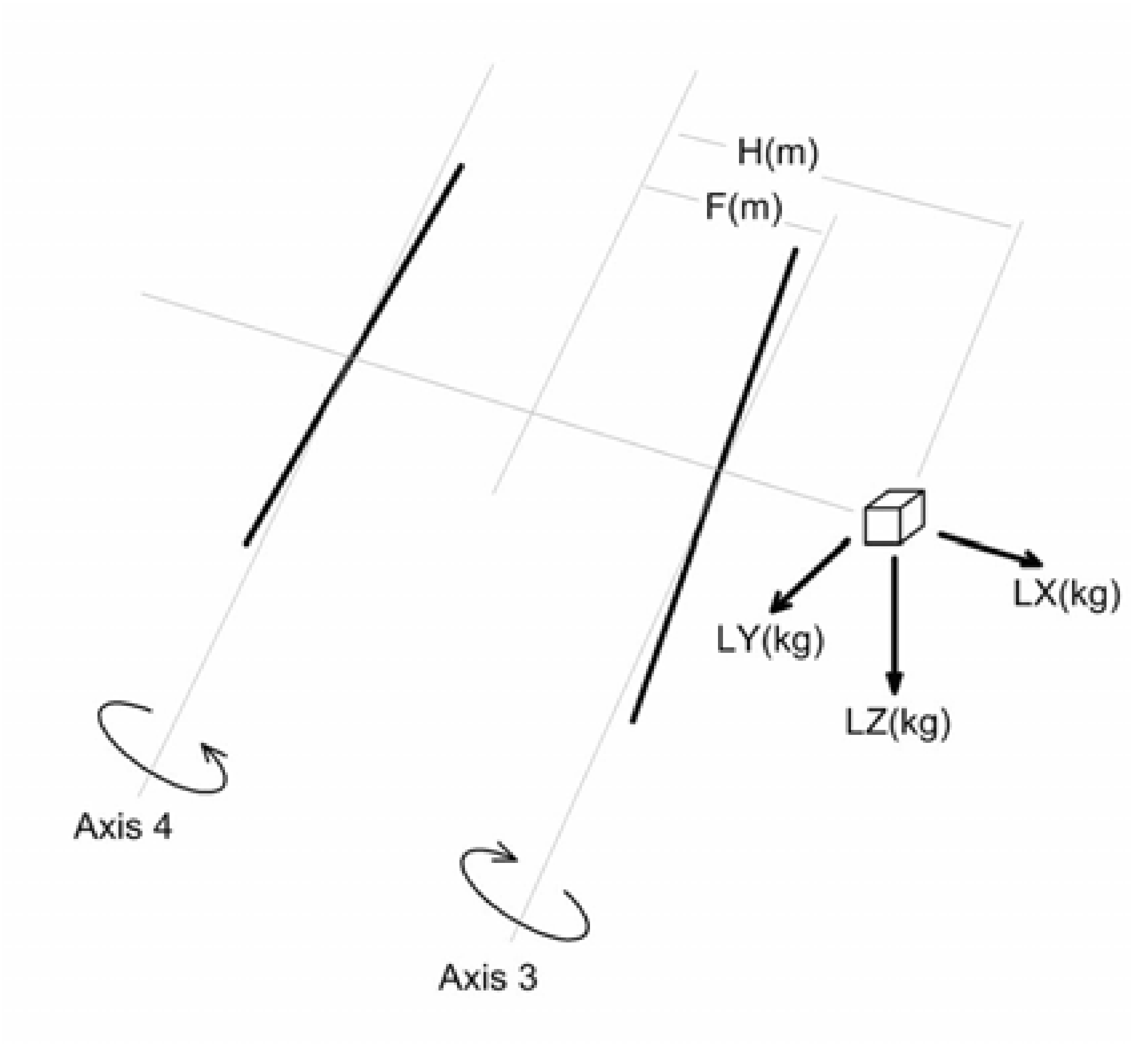
NB: Error (1) – Negligible component due to LZ (kg) acting off-centre

Equation (4) – Axis 1 $\sum M = 0$ $\qquad H = \dfrac{(R3Y - R2Y)\text{SinJA} - (R2X + R3X)b}{\text{LZCosJ} - \text{LYSinJ}}$

Figure 11 – Determination of instantaneous parametric load

Similarly, instantaneous adverse torsion is determined as M0(kgm), described thus:

M0(kgm) – Instantaneous Adverse Torsion about Axis3 or Axis4. The demonstration of this is given in Figure 12.



Notes:

LZ (kg), LY (kg) and LX (kg) are instantaneous measured loads

H (m) is instantaneous measured action point offset

F (m) is Footing Access dimension at altitude G (m) and is a dynamometer constant

M0 (kgm) is instantaneous destabilising torsion about Axis 3 or Axis 4

Equation (5) $M0 = (\mathrm{ModH} - F)(\mathrm{LZCosJ} - \mathrm{LYSinJ})$

Adverse torsion exists if M0 (kgm)>0

$\mathrm{AdvM0}(\mathrm{Kgm}) = \mathrm{MaxM0}(\mathrm{kgm})$ evaluated over transient

Figure 12 – Determination of instantaneous adverse torsion M0 (kg)

The third parameter, Instantaneous Base Frictional Demand, is determined as U_{base}(#):

U_{base}(#) - Instantaneous Base Frictional Demand

$$U_{base} = \frac{R1Y}{R1Z} \qquad \text{Equation (7)}$$

10.2 DETERMINATION OF TRIAL CHARACTERISTIC PARAMETERS

A key set of five trial-specific parameters are generated which collectively constitute a maximal equivalent load.

AdvLX(kg)	Maximum of all Modulus LX(kg)
AdvLY(kg)	Maximum of all Positive LY(kg)
AdvLZ(kg)	AF1(#) Weighted mean of all LZ(kg)
AdvM0(kgm)	Maximum of all M0(kgm)
AdvU_{base}(#)	Percentile 99 of all U_{base}(#)

AdvLX(kg) and AdvLY(kg) are found simply as the maximum occurrences of all LX(kg) and LY(kg) in the set of transient validated values. Only occurrences of positive polarity LY(kg) are considered at this stage, since this adversely affects stability in top-contact and top-slip failure mode.

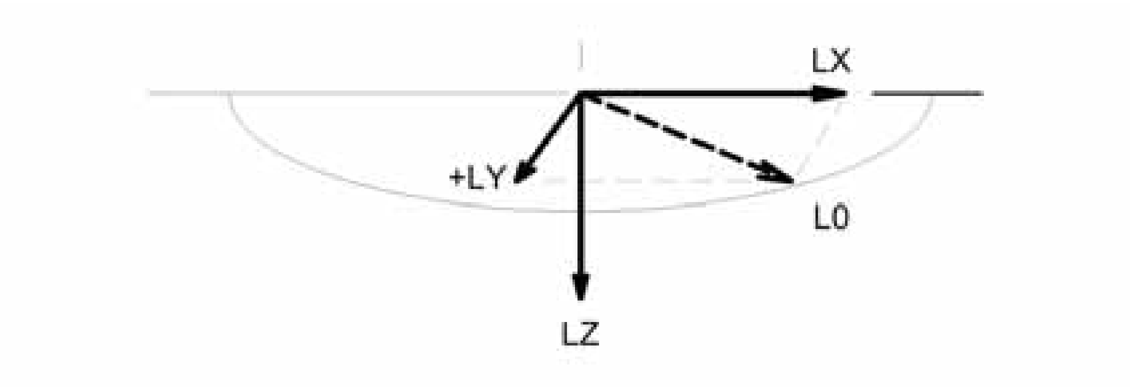
AdvLZ(kg) is determined as an adversity-weighted average of all LZ(kg) in the set of transient validated values. This assigns a final vector intensity which is most associated with adverse loading ratios. Such adverse conditions arise with high x- or positive y-axis loading with a low z-axis, hence AdvLZ(kg) is linked to AdvLX(kg) and AdvLY(kg).

The parameter AF1(#) is designed to measure the strength of drive on structural stability with emphasis on the mechanics of top-contact and top-slip failure modes. A high horizontal planar vector due to x- or positive y-load, independently or together, coupled with low z-vector is high duress. AF1(#) responds accordingly, and effectively power weights the importance of the particular LZ(kg) component. Each AF1(#) is not explicitly rescaled to a sum-of-unity normalised value, but is in effect used in this way.

AdvM0(kgm) is found simply as the maximum occurrences of all M0(kgm) in the set of transient validated values.

AdvU$_{base}$(#) is taken as a high percentile of all U$_{base}$(#) rather than full maximum to remove occasional outlandish results which can be computed at very low actual force levels. Such volatile and meaningless high values can emerge at the very onset or end of a transferral event, where forces are hovering near zero, and numerical divisions are overly sensitive to scale. The transient validation filter rules will eliminate almost all such rogue data points, but the additional value conditioning is advisable.

The determination of AdvLZ (kg) and the definition of AF1(#) are further shown in Figure 13.



Notes:

An adverse load exists when vector LY is acting in the positive semi-plane as shown

LX (kg), LY (kg) and LZ (kg) are the instantaneous measured parametric load

L0 (kg) is total horizontal planar load magnitude due to LX (kg) and +LY (kg)

$$\mathrm{ModL0} = \sqrt{\mathrm{LX}^2 + \mathrm{LY}^2}$$

AF1(#) is instantaneous determined adversity

$$\mathrm{AF1} = \frac{\mathrm{ModL0}}{\mathrm{LZ}}$$

WtLZ (kg)is instantaneous determined adversity weighted load in z-axis

$$\mathrm{WtLZ} = \mathrm{LZ} \times \mathrm{AF1}$$

AdvLZ (kg) is AF1 weighted characteristic z-load – evaluated over transient

$$\mathrm{AdvLZ} = \frac{\sum \mathrm{WtLZ}}{\sum \mathrm{AF1}}$$

Figure 13 – Determination of AdvLZ (kg) and definition of AF1(#)

10.3 DETERMINATION OF TASK CHARACTERISTIC PARAMETERS

A key set of five task specific parameters are generated which collectively constitute a maximal load empirically observed on the ladder across all users, and which pertain to each given task type. These are parametric grade mechanical point load forces or torsions, and serve as the basis for subsequent generation of the Prescribed Standard Parameters. They are:

CharAdvLZ (kg)	Task characteristic maximal Load in z-axis
$CharAdvLY_{Pos}$ (kg)	Task characteristic maximal Load in positive y-axis
CharAdvLX(kg)	Task characteristic maximal Load in x-axis
$CharAdvLY_{Neg}$ (kg)	Task characteristic maximal Load in negative y-axis
CharAdvM0 (kgm)	Task characteristic maximal Torsion

An additional task specific maximal base frictional demand parameter $CharAdvU_{base}$(#) is generated and utilised. This parameter correctly indicates the worst case demands in an appropriate fashion, however is not in the class of a parametric as it stands. This figure is the maximal demand observed on the particular dynamometer arrangement and at the experimental geometry, hence requires interpretation and treatment before it can deliver a result in terms of a universally valid causal load. $CharAdvU_{base}$(#) is used as an intermediate means to find $CharAdvLY_{Neg}$ (kg)

$CharAdvU_{base}$ (#)	Task characteristic maximal Base Frictional Demand

Initially the three parameters CharAdvLZ(kg), $CharAdvLY_{Pos}$ (kg) and CharAdvLX(kg) are determined as a composite set, and are characteristic of each task. The process is to assign an adversity level NormAF2(#) to the particular combinations of AdvLZ(kg), AdvLY(kg) and AdvLX(kg) – which pertain to each trial of that task only. This factor then weights the significance of each elemental loading combination corresponding to each trial and gives rise to the final task characteristic set of vectors.

High magnitudes of main axial torsion acting adversely and promoting flip instability are determined as CharAdvM0(kgm), thus:

CharAdvM0 = Percentile 99 of all AdvM0(#)

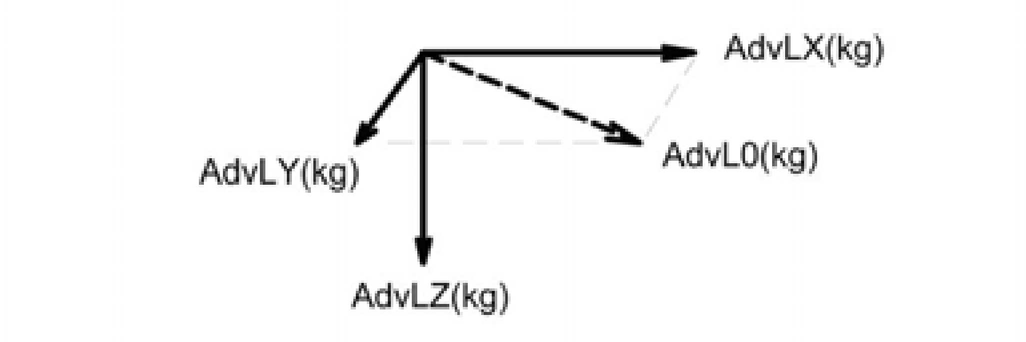
The highest levels of base frictional demand arise from a simultaneous high ground reaction magnitude in y and a corresponding low magnitude in z. At the base we observe a certain level of maximal demand $AdvU_{base}$(#), assignable to each trial in the task set.

High magnitudes of base frictional demand promoting base-slip instability are determined as $CharAdvU_{base}$(#) where:

$CharAdvU_{base}$ = Percentile 99 of all U_{base}(#)

This measure is not in a parametric form as stands, and requires an appropriate transformation. A low intensity ground normal load is assumed to exist equal to, and caused by, the already determined CharAdvLZ(kg). This is reasonable since it is known that high levels of base frictional demand arise with reduced base normal reaction. Knowing CharAdvLZ(kg) and $CharAdvU_{base}$(#) determines the consequent base reaction in y. This condition then logically fixes the mechanics and through geometrical dynamometer corrections allows a consistent value of $CharAdvLY_{Neg}$ (kg) to be uniquely determined. This is taken as a parametric grade load component.

Determination of CharAdvLZ (kg), CharAdvLYPos (kg) and CharAdvLX (kg) and definition of AF2 (#) are shown in Figure 14, while the Determination of CharAdvLYNeg (kg) is shown in Figure 15.



Notes:

AdvLX (kg), AdvLY (kg) and AdvLZ (kg) are a maximal combined set result for any given trial.

AdvL0 (kg) is total horizontal planar load magnitude due to AdvLX (kg) and AdvLY (kg)

$$\mathrm{AdvL0} = \sqrt{\mathrm{AdvLx}^2 + \mathrm{AdvLY}^2}$$

AF2(#) is the determined adversity factor pertaining to any given trial in the task set.

$$\mathrm{AF2} = \frac{\mathrm{AdvL0}}{\mathrm{AdvLz}}$$

The Parameters AF2 (#) are rescaled to a normalised value NormAF2 (#)

$\sum \mathrm{NormAF2} = 1.000$ Evaluated across all AF2 (#) components in the task set.

Keeping the sets of vectors intact, elemental components are calculated and accumulated.

WtAdvLZ (kg) is the NormAF2 (#) weighted elemental load component in the z-axis

WtAdvLY (kg) is the NormAF2 (#) weighted elemental load component in the y-axis

WtAdvLX (kg) is the NormAF2 (#) weighted elemental load component in the x-axis

$$\left.\begin{array}{l}\mathrm{WtAdvLZ} = \mathrm{AdvLZ}\\ \mathrm{WtAdvLy} = \mathrm{AvdLY}\\ \mathrm{WtAdvLx} = \mathrm{AdvLx}\end{array}\right\} \times \mathrm{NormAF2}$$

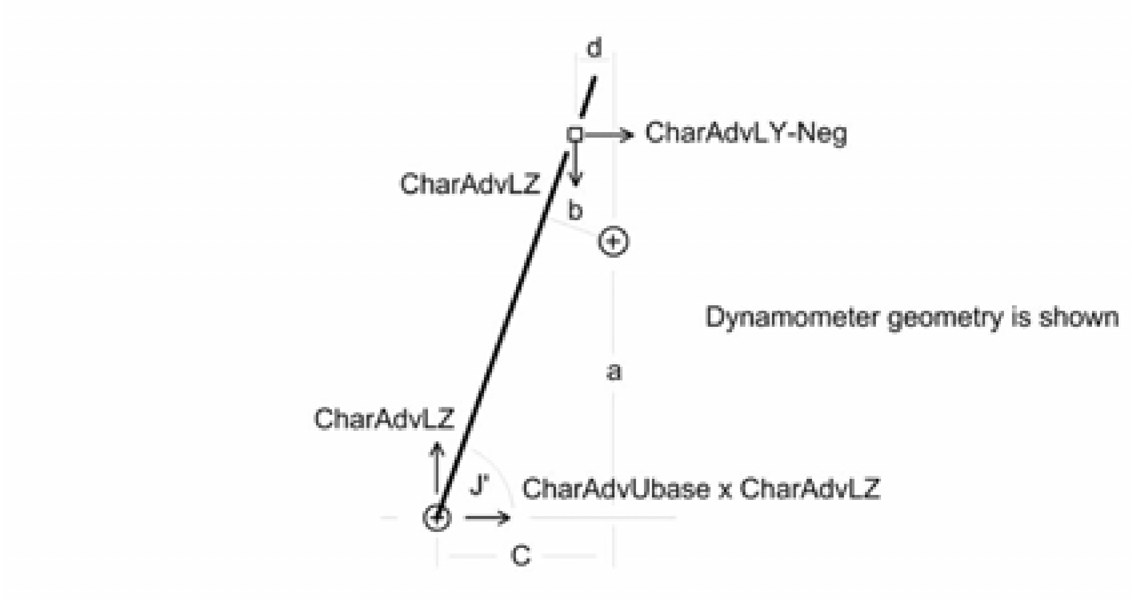
Final task characteristic parameters are generated from elemental components.

$$\mathrm{CharAdvLZ} = \sum \mathrm{WtAdvLZ}$$

$$\mathrm{CharAdvLY}_{\mathrm{Pos}} = \sum \mathrm{WtAdvLY}$$

$$\mathrm{CharAdvLX} = \sum \mathrm{WtAdvLX}$$

Figure 14 – Determination of CharAdvLZ (kg), CharAdvLY$_{\mathrm{Pos}}$ (kg) and CharAdvLX (kg) and definition of AF2 (#)



Notes:

High magnitudes of $CharAdvU_{base}$ (#) arising from simultaneous high load level in negative y-axis and low level load in z-axis.

Balanced moments about upper contact pair.

Equation (6) $\sum M = 0$ $$CharAdvLY_{Neg} = \frac{CharAdvLZ(CharAdvU_{base} \times a + d - C)}{E - a}$$

Figure 15 – Determination of $CharAdvLY_{Neg}$ (kg)

10.4 DETERMINATION OF PRESCRIBED STANDARD PARAMETERS

The final Prescribed Standard Parameters must represent a finite and concurrent set of loads which characterise a qualified worst-case driven impetus towards structural instability. It must include maximal intensities observed and obtained across a sample field of users performing representative tasks of the class in question. These values are obtained from the set of Task Characteristic Parameters, and are technically analysed in the Spreadsheet “Collation2”.

An adversity factor AF3(#) is defined which assigns a stability duress significance to each task class.

$$AF3 = \frac{\sqrt{(CharAdvLX^2 + CharAdvLY^2)}}{CharAdvLZ}$$

AF3(#) is rescaled to NormFS3(#)

$$\sum \text{NormAF3} = 1.000$$

A NormAF3(#) weighted composite vector is determined

$$L_{std}Z = \sum(\text{CharAdvLZ} \times \text{NormAF3})$$

$$L_{std}Y_{Pos} = \sum(\text{CharAdvLY}_{Pos} \times \text{NormAF3})$$

$$L_{std}X = \sum(\text{CharAdvLX} \times \text{NormAF3})$$

The maximal negative y-axis vector is determined from all CharAdvLY_{Neg}(kg) values

$$L_{std}Y_{Neg} = \text{Max}(\text{CharAdvLY}_{Neg})$$

The standard torsional vector $L_{std}M$(kg) is determined from all CharAdvM0(kgm) values

This torsion can be delivered by adjusting H_{set}(m) and $L_{std}M$(kg) to match

Define H_{set}(m) - This value choice is arbitrary but fixes $L_{std}M$(kg)

$$H_{set} = 0.25$$

$L_{std}M$(kg) is determined

$$L_{std}M = \frac{\text{Max}(\text{CharAdvM0})}{H_{set}}$$

11.0 GENERAL REVIEW OF RESULTS

The overall mechanical dynamics are best interpreted by reference to graphical displays. The following is a sequence illustrating one typical trial of the approximately 1500 conducted in total. It is suitably representative and illustrates the features and activity history of this one experimental event. Figures all relate to the same 10 second period containing the transferral activity of specific interest. Note that although pre- and post-amble signal is shown for visual continuity, the data in these regions is never taken in the systematic analysis. In each instance z-axis is vertically down, y-axis is perpendicular to the supporting wall and x-axis in parallel to the supporting wall.

Trial task ID : G382

Task : On Platform / Laden / Back

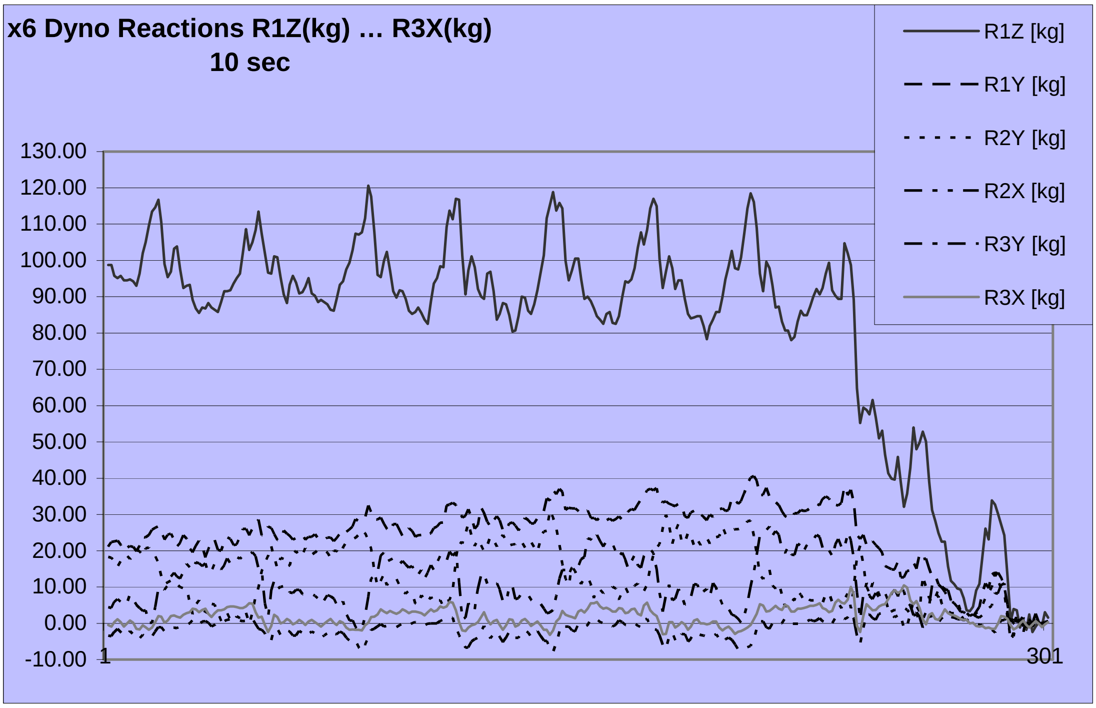


Figure 16 – The six dynamometer ground reaction magnitudes

Figure 16 shows the basic six dynamometer ground reaction magnitudes. The cyclic type signature of the user rising to the platform level is easily visible. The transferral activity is most obviously evident as a massive fall-off in z forces occurring over the final 2 seconds or so of the 10 second history. Peaks of activity in other channels can be discerned in this interval. Finally mechanical contact is lost and all signals reach zero.

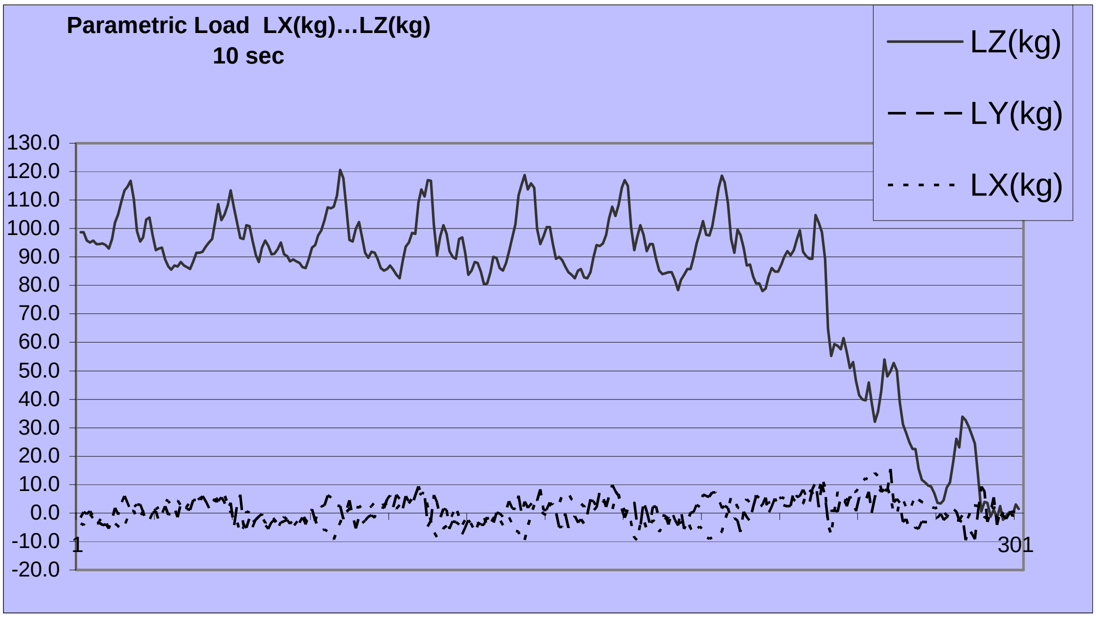


Figure 17 – Load vector intensities

Figure1 7 data is similar to dynamometer signal, but shows the vector intensities of the driven load properly corrected for parametric format.

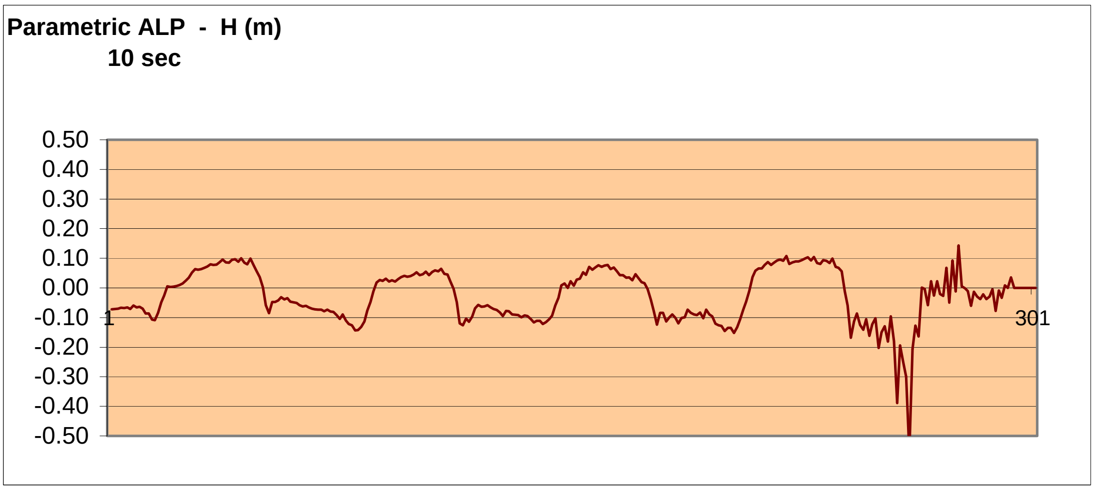


Figure 18 – Action point offset –H (m)

In Figure 18 the action point offset H(m) is shown. This parameter is essentially a measure of lateral loading asymmetry, and is an important component of the parametric load. The preamble of the ascent is obvious, with marked disturbance evident during the transferral activity.

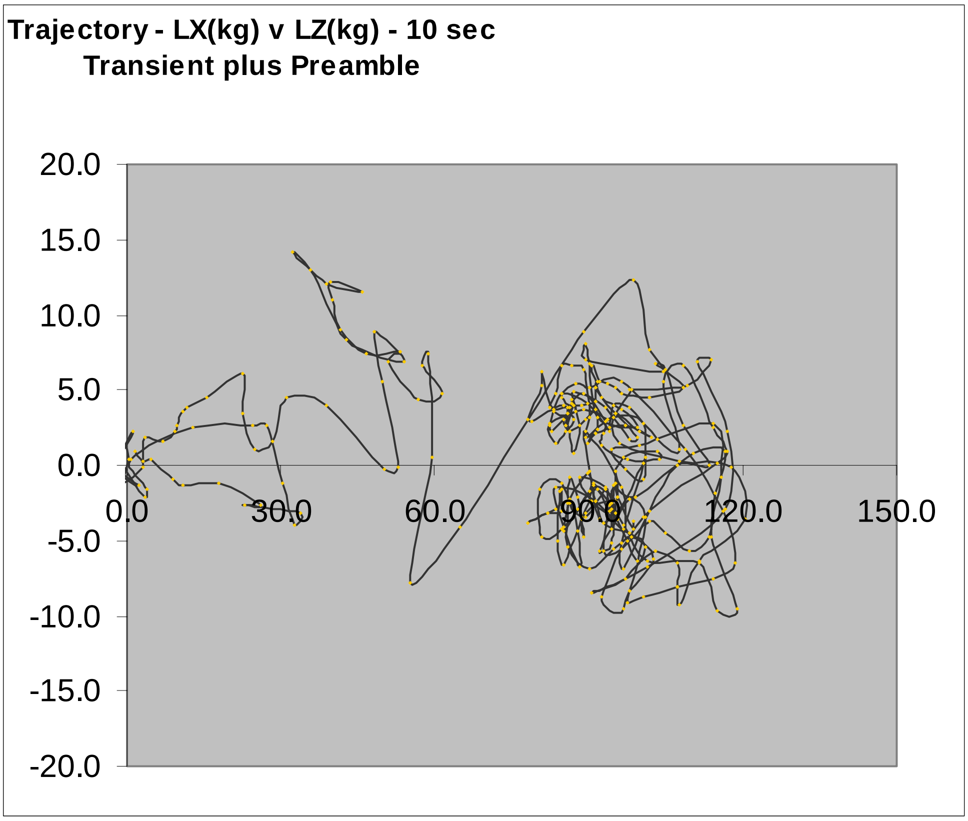


Figure 19 – LX (kg) versus LZ (kg) trajectories

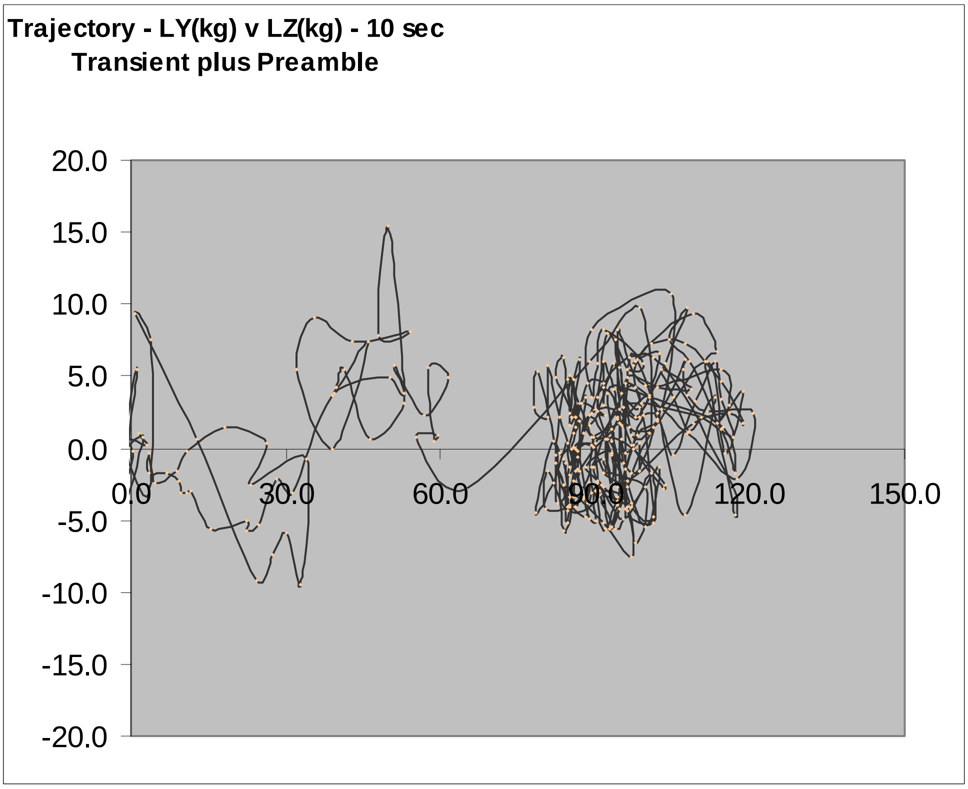


Figure 20 – LY (kg) versus LZ (kg) trajectories

Figures 19 and 20 show the intensity and phase interplay between pairs of parametric forces. They are time histories over 10 seconds, and are the trajectories of the linked parameters. The transferral event can easily be seen as the filamentary pathways terminating at the zero origin. The heavy clusters are related to preamble. The action is evidently erratic and somewhat less than direct, and the source and potential for momentary peaks in ladder loading can be easily appreciated. These are quite typical.

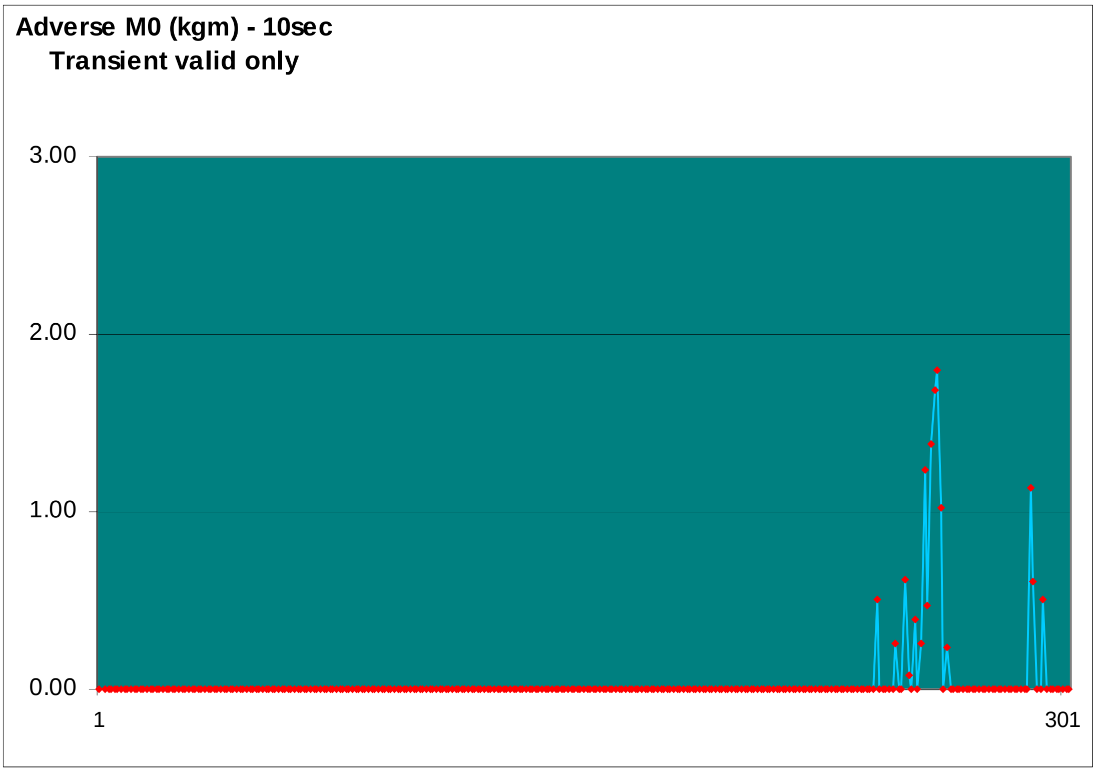


Figure 21 – Adverse torsion

Figure 21 illustrates the occurrence of adverse driven torsion about the ladder during the transferral activity only, with pre and post-amble suppressed (since mounting from, and dismounting to, the floor are chaotic events which do not threaten the overall safety through instability). Values above zero are not obliged to arise in any given situation, negative values corresponding to inward acting torsions, and only serving to enhance rotational stability. Note the periods of high intensity interspersed with clear periods of zero detected action.

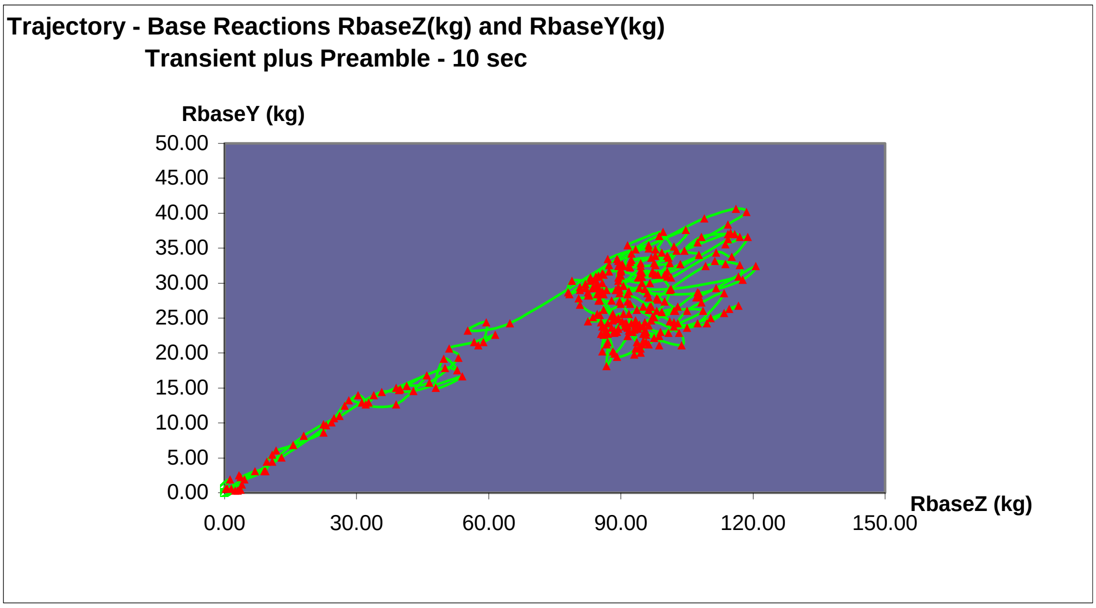


Figure 22 – Dynamometer base forces

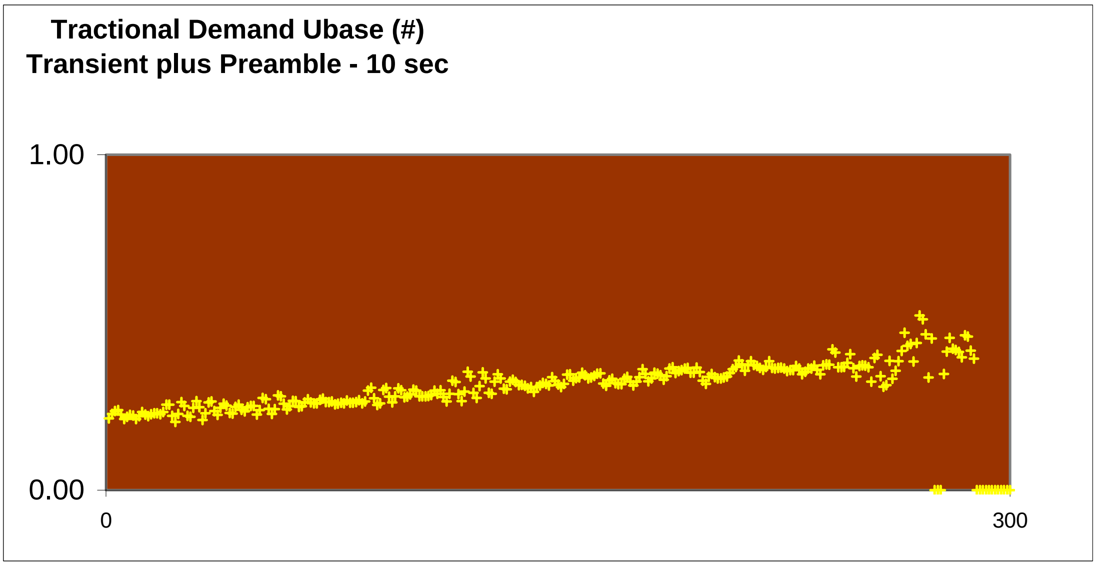


Figure 23 – Base frictional demand

Figures 22 and 23 are respectively displaying dynamometer base forces and consequent frictional demand. The essentially well ordered and benign nature of the signals is evident, despite animated activity elsewhere in the system. The frictional demand intensity is reliably at a low level for almost the entire period shown, but displays some short lived and peaky activity, evidently occurring during the transferral activity.

The global values and distribution of the Task Characteristic Parameters can now be scrutinised. These sets of loads are parametric grade variables, and represent the high drive signature of each task separately. The all-task valid and universal parametric, expressed as the Prescribed Standard Parameters, is the derived maxima of the full set.

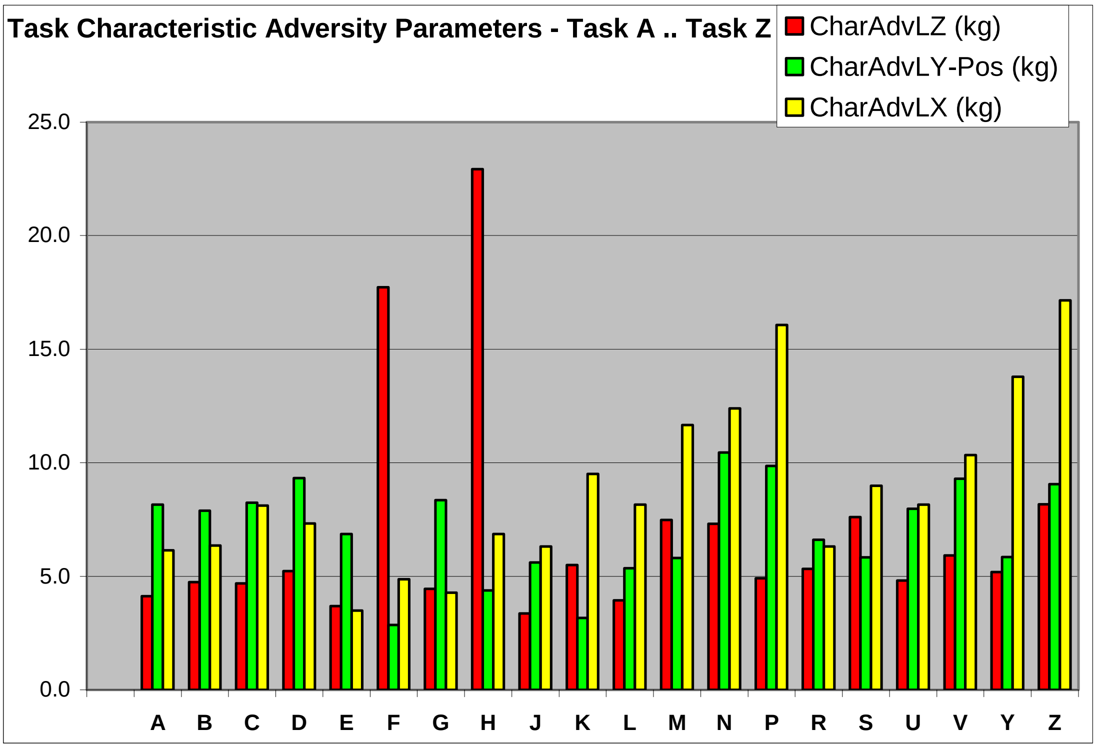


Figure 24 – Task characteristic adversity parameters across task type

Figure 24 shows the parameter sets of CharAdvLZ(kg), CharAdvLY$_{Pos}$(kg) and CharAdvLX(kg), as evaluated across each task type. Each set of three values is a linked group, and is collectively responsible for high duress, directed primarily towards both top-contact and top-slip stability failure. Interpretation should be undertaken with care since any load component taken alone is insufficient to specify a realistic duress intensity. The parameter NormAF3(#) is designed to quantify such duress (see Figure 25), and is a derived function from CharAdvLZ(kg), CharAdvLY$_{Pos}$(kg) and CharAdvLX(kg), and is the best indicator for ranking against task.

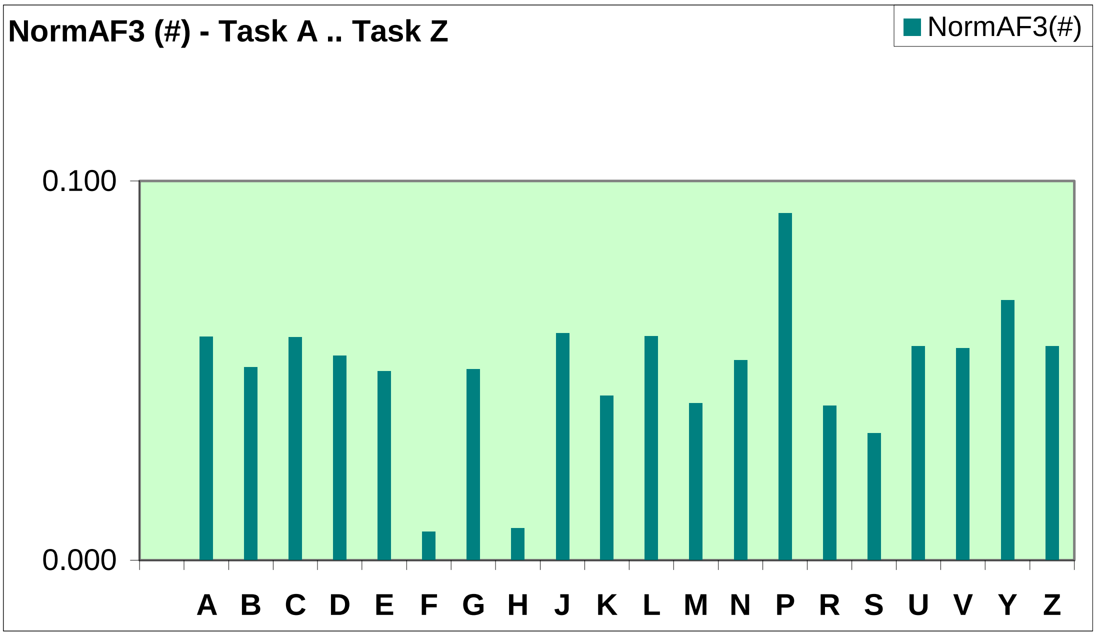


Figure 25 – Norm AF3 (#) weighting factor across task type

Figure 25 illustrates NormAF3(#), a weighting factor which considers the set of linked parameters CharAdvLZ(kg), $CharAdvLY_{Pos}$(kg) and CharAdvLX(kg), and assigns a net drive towards instability, or adversity rating, based on the underlying vectoral combination.

Table 10 shows a severity ranking of Task against NormAF3(#) - expressed as percentage (%) contribution to the final weighted determinations which are taken as the Prescribed Standard Parameters. The rating is primarily the level of mechanical drive pressing both Top Contact and Top Slip failure mode.

Table 10

NormAF3 (#) by task

Task	%
P	9.2
Y	6.9
J	6.0
L	5.9
A	5.9
C	5.9
Z	5.7
U	5.7
V	5.6
D	5.4
N	5.3
B	5.1
G	5.0
E	5.0
K	4.3
M	4.2
R	4.1
S	3.4
H	0.8
F	0.8

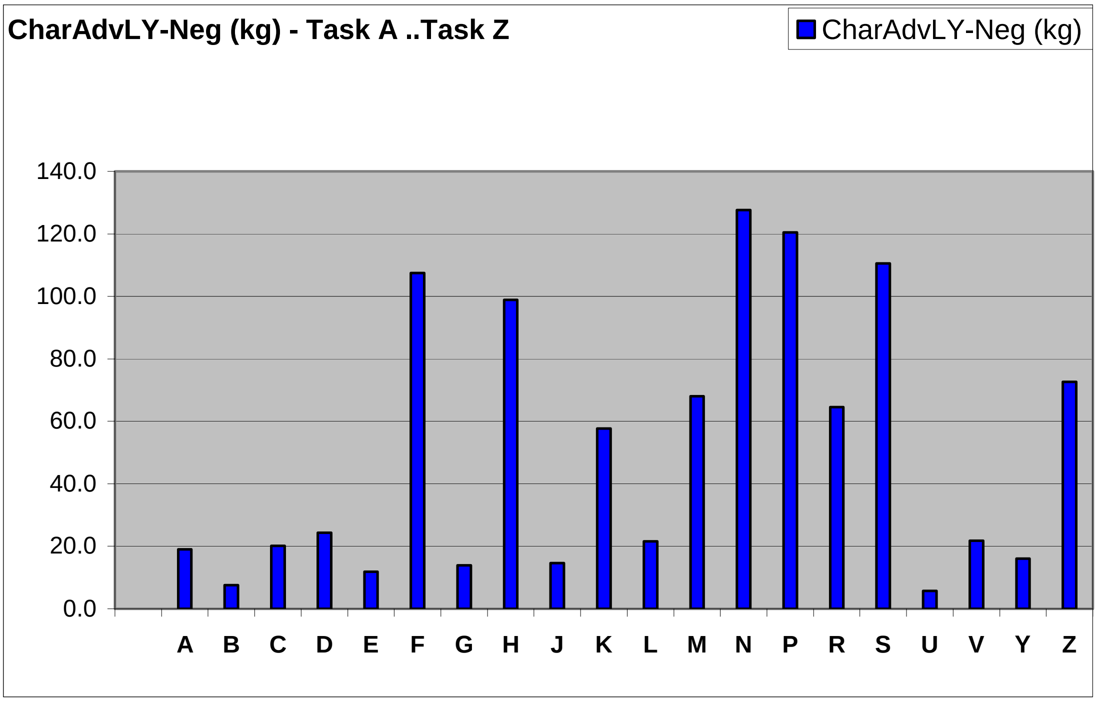


Figure 26 – CharAdvLY$_{Neg}$ (kg) across task type

The CharAdvLY$_{Neg}$(kg) parameter, as shown in Figure 26, is representative of a high load in negative y-axis, linked to the concurrent low value of CharAdvLZ(kg), of each trial. This situation arises directly from the large horizontal mass transfers typical of the class of tasks under investigation, and transmitted through foot contact. This parameter in conjunction with some forms of DAL geometry, can give rise to short duration but unusually high levels of base frictional demand. Clearly this will have a particular bearing on base-slip failure mode.

Table 11 shows a severity ranking of Task against CharAdvLY$_{Neg}$(kg). The rating is primarily the level of mechanical drive pressing base-slip failure mode.

Table 11

CharAdvLY$_{Neg}$ (kg) by task

Task	kg
N	127.7
P	120.5
S	110.5
F	107.5
H	98.9
Z	72.6
M	68.0
R	64.5
K	57.6
D	24.3
V	21.7
L	21.6
C	20.2
A	19.0
Y	16.1
J	14.6
G	13.9
E	11.8
B	7.5
U	5.7

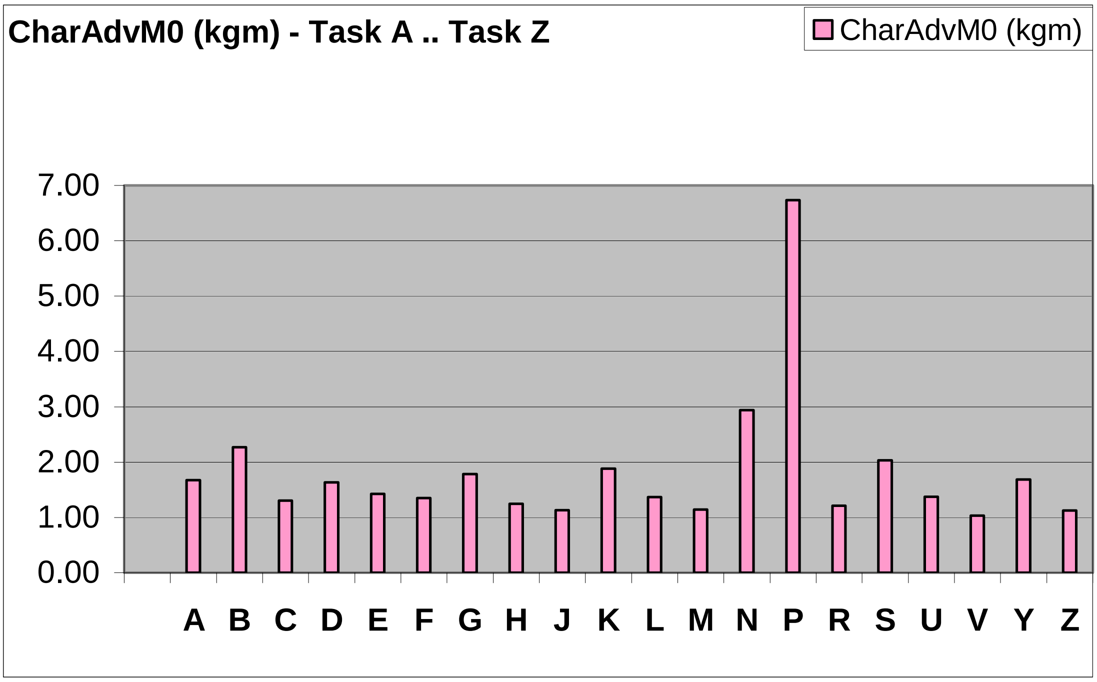


Figure 27 – CharAdvM0 (kgm) across task type

Figure 27 shows the CharAdvM0(kgm) parameter which indicates maximal levels of destabilising type torsions about the accessible ladder and has particular bearing on flip failure mode.

Table 12 is a severity ranking of Task against CharAdvM0(kgm). The rating is primarily the level of mechanical drive pressing flip failure mode.

Table 12

CharAdvM0 (kgm) by task

Task	kgm
P	6.73
N	2.94
B	2.27
S	2.03
K	1.88
G	1.79
Y	1.69
A	1.67
D	1.63
E	1.43
U	1.37
L	1.37
F	1.35
C	1.31
H	1.25
R	1.21
M	1.14
J	1.13
Z	1.12
V	1.03

12.0 DEFINITION OF DAL TRANSITORY ACCESS - STANDARD MODELLER

The modeller requires various classes of parameters of differing type as input, and will generate a normalised set of four stability indices and other key mechanical values as output, via the defined algorithm.

Once a particular ladder or DAL configuration has been numerically decided the recommended mechanical load can be impressed on the structure and the prevailing stance condition is calculated. The actual SLV and ALP combination values presented to the model at any one time are determined according to the constructs of each of four prescribed loading or verification tests, and are designed to maximally press towards a particular mode of instability. The SLV and ALP parameters are generated on the basis of the Prescribed Standard Parameters.

Stability index values and other pertinent mechanical measures are calculated for all four failure modes, for any singly applied SLP and ALP configuration. However no single load can maximally press the structure in all stability failure modes simultaneously. For both modelling and real world structural testing, four discrete high duress loading combinations are both necessary and sufficient. The totality of these tests is designed to constitute an exhaustive proven envelope of performance. Stability indices are fielded from the model and accepted as valid according to the described method.

It is important to note that while there are four tests and four indices, that no implicit paired correspondence should be assumed.

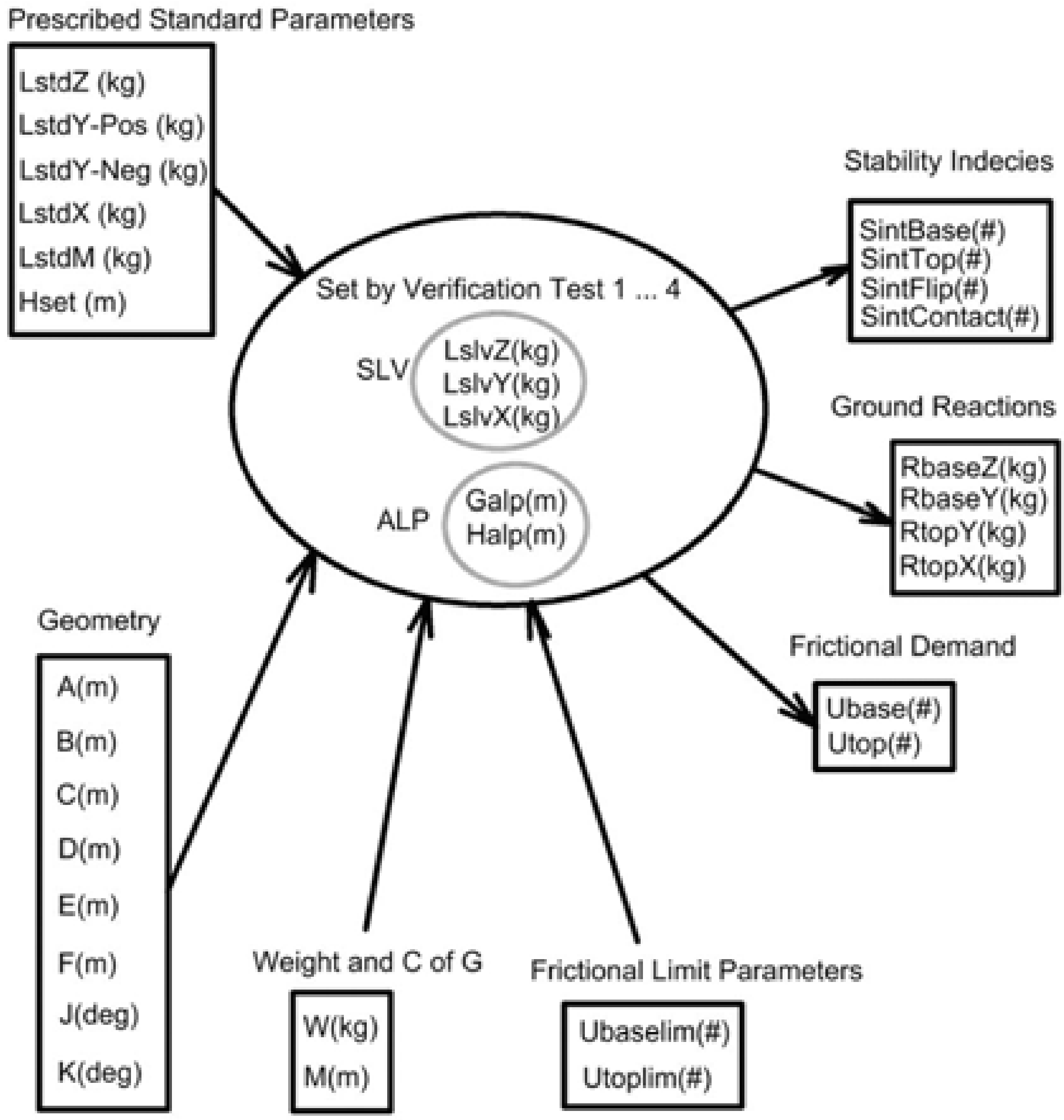


Figure 28 – Predictive modelling process for the mount and dismount activity

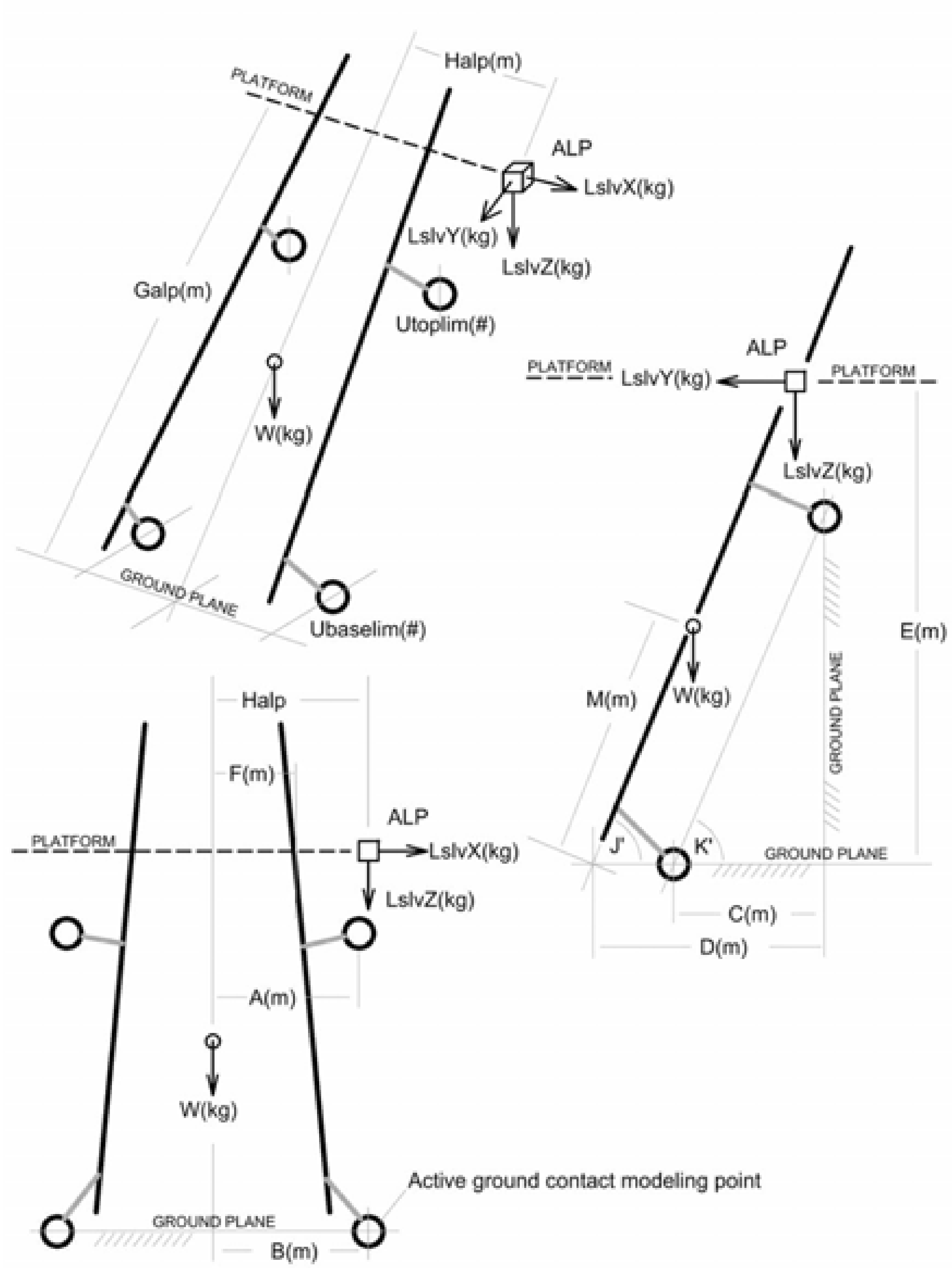


Figure 29 – Mount and dismount model parameter definitions

Listed are the formal DAL Transitory Access modelling parameters. These are also shown diagrammatically in Figures 28 and 29.

Prescribed Standard Parameters

$L_{std}X$ (kg)	Standard load vector – x-axis
$L_{std}Y_{Pos}$ (kg)	Standard positive load vector – y-axis
$L_{std}Y_{Neg}$ (kg)	Standard negative load vector – y-axis
$L_{std}Z$ (kg)	Standard load vector – z-axis
$L_{std}M$ (kg)	Standard load vector - Adverse torsion
H_{set} (m)	Standard offset dimension to determine H_{alp}(m)

Modelled input SLV Parameters – Configured as per Verification Test 1.. 4

$L_{slv}X$ (kg)	Applied load vector (SLV) – x-axis
$L_{slv}Y$ (kg)	Applied load vector (SLV) – y-axis
$L_{slv}Z$ (kg)	Applied load vector (SLV) – z-axis

Modelled input ALP Parameters – Configured as per Verification Test 1.. 4

G_{alp} (m)	Applied load point (ALP) – Linear altitude in Accessible ladder
H_{alp} (m)	Applied load point (ALP) – Linear horizontal offset

Measured Structural Parameters

A (m)	Upper Semi-width - Active Ladder
B (m)	Lower Semi-width - Active Ladder
C (m)	Ground contact displacement of Active Ladder – Real contact
D (m)	Ground contact displacement of Accessible Ladder – Projective contact
E (m)	Platform Working Height
F (m)	Access Limit dimension at G_{alp} (m)
W (kg)	Total weight – combined Ladder + Devices
M (m)	Linear altitude of structural CofG referenced within Accessible Ladder
J (deg)	Base Elevation Angle – Accessible Ladder
K (deg)	Base Elevation Angle – Active Ladder

User-specified Frictional Limit parameters

U_{base}lim (#) Maximum reliable frictional limit - Base

U_{top}lim (#) Maximum reliable frictional limit - Top

Normalised Stability Indices – Validated across Verification Test 1.. 4

S_{int}Base (#) Normalised Intrinsic Stability Index – Base-slip mode

S_{int}Top (#) Normalised Intrinsic Stability Index – Top-slip mode

S_{int}Flip (#) Normalised Intrinsic Stability Index – Flip mode

S_{int}Contact (#) Normalised Intrinsic Stability Index – Top-contact mode

Ground contact point Frictional Demand

U_{base} (#) Friction Demand - Base

U_{top} (#) Friction Demand – Top

Ground contact point Reaction Intensity

R_{base}Y (kg) Total Reaction – Base – y-axis

R_{base}Z (kg) Total Reaction – Base – z-axis

R_{top}X (kg) Total Reaction – Top – x-axis

R_{top}Y (kg) Total Reaction – Top – y-axis

Intermediate Modelling Parameters – Transient usage only :

i, p, g, h, m, n, r ,s, t (m) Virtual dimensions defining Active Ladder

X1 .. X8(m) Temporary construction dimensions

Q1 .. Q3(deg) Temporary construction angles

12.1 ANALYTIC MODEL PARAMETERS – FORMAL DERIVATIONS

Standard Load Vector and Applied Load Point parameters take values as required by Verification Tests 1…4 and are detailed in the SLP and ALP Loading Table (Table 5 in Section 10).

$G_{alp} = \frac{E}{SinJ}$ Equation (31) $G_{alp}(m)$ is a constant for all verification tests

$H_{alp} = 0 \text{ or } F + H_{set}$ Equation (32) $H_{alp}(m)$ is verification test dependent

Geometric identities used in algebraic process

1. $Sin(90 \pm Q) = CosQ$
2. $Cos(-Q) = CosQ$
3. General Sin Rule

$$\frac{Sin(90 - K)}{X1} = \frac{Sin(90 + K - J)}{D - C}$$

$$X1 = \frac{(D - C)CosK}{Cos(J - K)}$$ Equation (1)

$$X2 = G_{alp} - X1$$ Equation (2)

$$\frac{SinJ}{X3} = \frac{Sin(90 + K - J)}{D - C}$$

$$X3 = \frac{(D - C)SinJ}{Cos(J - K)}$$ Equation (3)

$$Sin(J - K) = \frac{X4}{X2}$$

$$X4 = X2Sin(J - K)$$ Equation (4)

$$\mathrm{Tan}(K + Q1) = \frac{X5}{X3 + X4}$$

$$X5 = (X3 + X4)\mathrm{Tan}(K + Q1)$$ Equation (5)

$$\mathrm{Sin}(K + Q1) = \frac{X5}{X6}$$

$$X6 = \frac{X5}{\mathrm{Sin}(K + Q1)}$$ Equation (6)

$$\mathrm{Tan}Q2 = \frac{X7}{X6}$$

$$X7 = X6\mathrm{Tan}Q2$$ Equation (7)

$$\mathrm{Cos}J = \frac{(D - C) + X8}{M}$$

$$X8 = M\mathrm{Cos}J - (D - C)$$ Equation (8)

$$\mathrm{Tan}Q1 = \frac{L_{slv}Y}{L_{slv}Z}$$

$$Q1 = \mathrm{ArcTan}\frac{L_{slv}Y}{L_{slv}Z}$$ Equation (9)

$$\mathrm{Tan}Q2 = \frac{L_{slv}X}{\sqrt{(L_{slv}Y^2 + L_{slv}Z^2)}}$$

$$Q2 = \mathrm{ArcTan}\frac{L_{slv}X}{\sqrt{(L_{slv}Y^2 + L_{slv}Z^2)}}$$ Equation (10)

$$TanQ3 = \frac{B - A}{i}$$

$$Q3 = ArcTan\frac{B - A}{i}$$ Equation (11)

$$CosK = \frac{C}{i}$$

$$i = \frac{C}{CosK}$$ Equation (12)

$$Cos(J - K) = \frac{P}{X2}$$

$$P = X2Cos(J - K)$$ Equation (13)

$$CosK = \frac{X8}{m}$$

$$m = \frac{X8}{CosK}$$ Equation (14)

$$TanQ3 = \frac{B - n}{m}$$

$$n = B - mTanQ3$$ Equation (15)

$$g = p - X5$$ Equation (16)

$$h = H_{alp} + X7$$ Equation (17)

$$r = B - gTanQ3$$ Equation (18)

Torsion balance condition – Location of limit point β

$$\mathrm{sCosQ3L_{std}ZCosK = sCosQ3L_{std}YSinK + WnCosQ3CosK}$$

$$\mathrm{sL_{std}ZCosK = sL_{std}YSinK + WnCosK}$$

$$\mathrm{s(L_{std}ZCosK - L_{std}YSinK) = WnCosK}$$

$$\mathrm{s = \frac{WnCosK}{L_{slv}ZCosK - L_{slv}YSinK}} \qquad \text{Equation (19)}$$

$$\mathrm{t = r + s} \qquad \text{Equation (20)}$$

Ground reactions – Resolving Horizontal – Balance condition

$$\mathrm{R_{base}Y = L_{slv}Y + R_{top}Y} \qquad \text{Equation (21)}$$

Ground reactions – Resolving Vertical **-** Balance condition

$$\mathrm{R_{base}Z = W + L_{slv}Z} \qquad \text{Equation (22)}$$

Moments about Base - Balance condition

$$\mathrm{R_{top}Y = \frac{L_{slv}ZgCosK - L_{slv}YgSinK + mWCosK}{iSinK}} \qquad \text{Equation (23)}$$

$$\mathrm{R_{top}X = \frac{L_{slv}XgSinK - WB - (B - h)L_{slv}Z}{iSinK}} \qquad \text{Equation (24)}$$

Frictional Demand Parameters

$$\mathrm{U_{base} = Mod\frac{R_{base}Y}{R_{base}Z}} \qquad \text{Equation (25)}$$

$$\mathrm{U_{top} = Mod\frac{R_{top}X}{R_{top}Y}} \qquad \text{Equation (26)}$$

Normalised Intrinsic Stability Indices (Stable if parameter > 1.0)

$$S\,int_{Base} = \frac{U_{base}\,lim}{U_{base}}$$ Equation (27)

$U_{base} > 0$

$$S\,int_{Top} = \frac{U_{top}\,lim}{U_{top}}$$ Equation (28)

$U_{top} > 0$

$$S\,int_{Flip} = \frac{t}{h}$$ Equation (29)

$h > 0$

$$S\,int_{Contact} = 1 + \frac{R_{top}Y}{R_{base}Y}$$ Equation (30)

$R_{base}Y > 0$

12.2 LIMITS OF APPLICABILITY

The pure algebraic modeller is scale insensitive and will compute technically accurate output for any size or absolute magnitude of structure under any strength of applied load. However, in practice there are some desirable limitations of application.

- Accepting that the anthropomorphic interpretation of the maximal prescribed standard load could have limited meaning when applied to working at low altitude or on a very small structure, the lower gross size of the DAL is restricted.
- There is no upper gross size or weight restriction.
- Working altitude angles are limited but should not be restrictive.
- The accessible ladder can terminate at any spatial location, the actual end to end length being irrelevant, and does not appear as a variable in the model. It is assumed simply that the ladder rises well above the working platform. It is the platform which fixes the achievable working height of a user, and is properly the determinant of the parametric load action altitude.

- The DAL is forced to posses two base feet by requiring B(m) commensurate with F(m). However, Parameter A(m) can be reach zero, implying a single upper ground contact. Hence the model can represent a conventional tripod formation such as a traditional window-cleaners' ladder.
- Other practical bound limits are placed on the modelling input variables but should not be restrictive.

Designers are at liberty to enter numerical models at will, bound only by the scale limitations specified. Highly unconventional or extreme modelled structures are nevertheless allowed, and can comply with the rule filters. Returned computed values will always be technically correct, but may deliver extreme or unexpected values. Such values can require careful practical interpretation and this should be done with caution and with the benefit of expert advice if necessary.

12.3 SUMMARY OF THE MODELLING RULES

1.	E(m) >= 1	Minimum real-world scale
2.	A(m) >= 0	Allows true tripod formation
3.	B(m) >= F(m)	Ensures pair symmetric ladder feet at base with minimum allowable separation
4.	C(m) >= 0.5	Minimum real-world scale
5.	D(m) >= 0.75	Minimum real-world scale
6.	F(m) >= 0.1	Minimum real-world scale
7.	45=< J(deg) =< 80	Bounded real-world scale
8.	45=< K(deg) =< 80	Bounded real-world scale
9.	U_{base}lim(#) >= 0.1	Minimum real-world scale
10.	U_{top}lim(#) >= 0.1	Minimum real-world scale
11.	0 =< M(m) =< E(m)	Bounded M(m) within physical ladder and below platform
12.	W(kg) >= 0	Minimum real-world scale

13.0 SPECIFICATION OF PRESCRIBED STANDARD PARAMETERS

The final determined values of the set of Prescribed Standard Parameters are given in Table 13. These collectively represent a reference high-burden, anthropometric equivalent, drive. The load is assembled in four configurations in accordance with the SLP and ALP Loading Table in Section 10.

The sequence of verification tests, either numerically modelled or physically done, will in turn press for instabilities in all four modes which will be found through exhaustion.

Table 13

Prescribed standard parameter values

Parameter	Value
$L_{std}Z$	6 kg
$L_{std}Y_{Pos}$	8 kg
$L_{std}Y_{Neg}$	128 kg
$L_{std}X$	10 kg
$L_{std}M$	27 kg
H_{set}	0.25 m

14.0 SPECIFICATION OF WORKSHOP STABILITY VERIFICATION TESTS

There are four prescribed load configurations necessary to fully press the ladder in all four possible failure modes. There is no guaranteed simplistic one-to-one correspondence however, and none should be assumed when considering DALs as an unrestricted generalised set.

These loading conditions are modelled algebraically in the predictive algorithm and practically realised in the workshop. The empirical tests will indicate the basic ability to stand, purely as a pass/fail result. Figure 30 shows schematics of each of the described tests.

The theoretical model is, however, capable of indicating a scale of the effectiveness of the stance. The stability excess or deficit of a design will be shown as by the distance from unity of the stability indices.

For each test in the order, the load is configured according to the SLV and ALP loading detailed in Table 14.

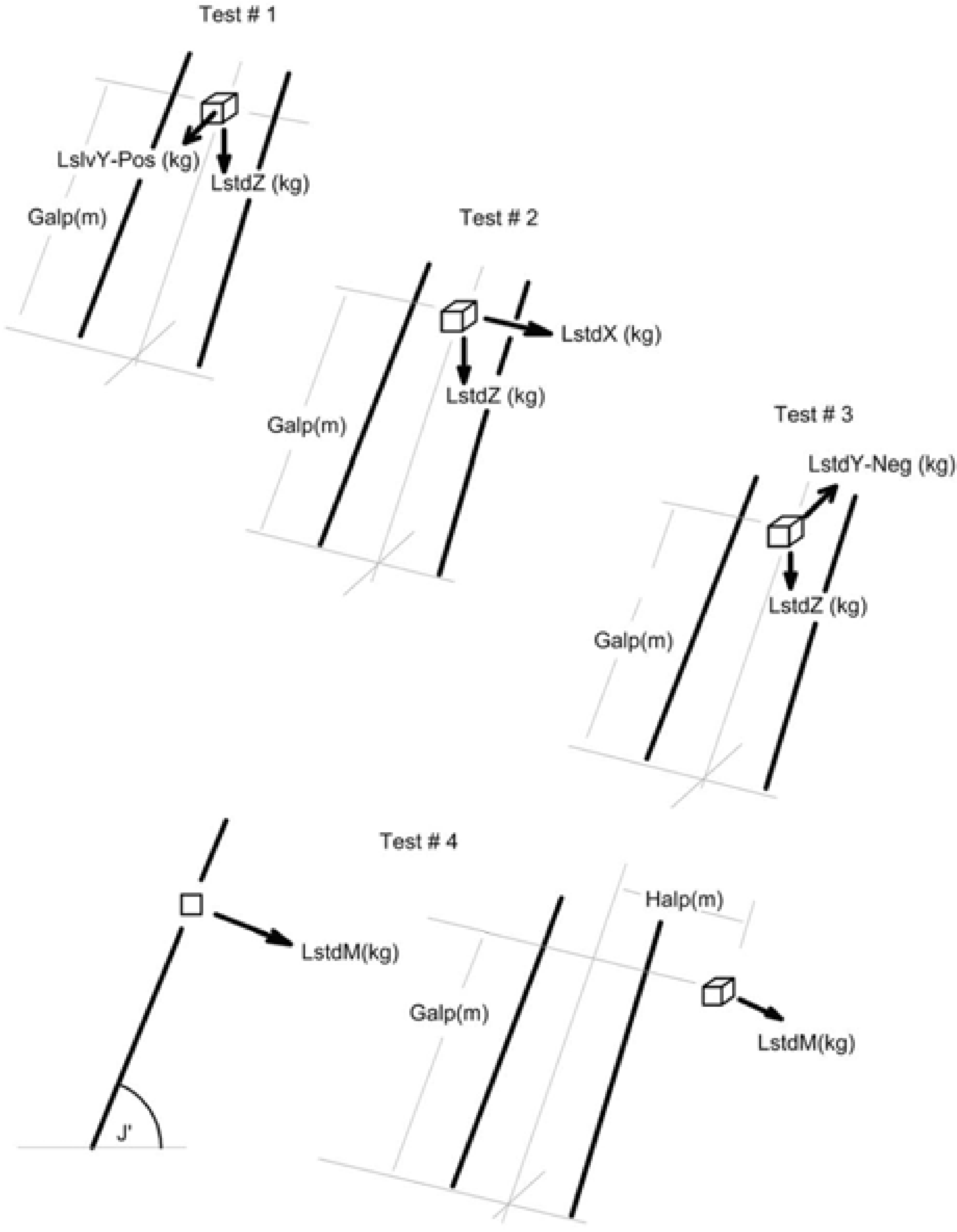


Figure 30 – The four workshop verification tests

14.1 SLV AND ALP LOADING TABLE

Test loads are constructed and applied as shown in the following table.

Table 14
SLV and ALP loading configuration table

SLV&ALP	$L_{slv}Z$ (kg)	$L_{slv}Y$ (kg)	$L_{slv}X$ (kg)	G_{alp} (m)	H_{alp} (m)
TEST# 1	$L_{std}Z$	$L_{std}Y_{Pos}$	ZERO	E / SinJ	ZERO
TEST# 2	$L_{std}Z$	ZERO	$L_{std}X$	E / SinJ	ZERO
TEST #3	$L_{std}Z$	$-(L_{std}Y_{Neg})$	ZERO	E / SinJ	ZERO
TEST #4	$L_{std}M$ CosJ	$-(L_{std}M$ SinJ)	ZERO	E / SinJ	$F + H_{set}$

Note 1: Observe the correct action polarities for $L_{slv}Y$(kg)

Note 2: Test#4 as shown is constructed with two vectors of the given magnitudes acting in rectangular axis. However a single vector of magnitude $L_{std}M$(kg) can be applied provided it is directed normal to the accessible ladder plane and inwards towards ground, and at $H_{alp}(m) = F(m) + H_{set}(m)$

14.2 STABILITY INDEX DETERMINATION AND VALIDATION

Each of the four verification tests requires a pass of the modeller, and taking the particular set of SLV and ALP values as defined, at each pass the modeller will generate particular output values for each of the four stability indices. The returned index values at each stage are genuine measures of stability of the ladder under the particular load applied at that time. However all failure modes cannot be simultaneously pressed and assessed by any single load, hence the strategic configurations of loading arrangement. The final determined index for any failure mode, and the output proper of the model, necessarily has to be the lowest contender value returned and observed in the sequence.

The valid stability index for the modelled DAL, will therefore generally be taken as the minimum of the four contender values, generated sequentially by Test#1.. Test#4

Given the range of design parameter latitude which the modeller allows the possibility exists that, for a given DAL formation, the highest duress on stability can potentially arise in any one of the tests without a prior certainty. While dependence upon the particular test can be predicted in principal, and indices can be extracted on this criteria-driven basis, it is good safety practice to adopt a simple protocol where in every case the minimum value is always obtained from the field as stated.

The workshop tests are the real world counterparts of the various states which the modeller assumes, and both regimes will necessarily find all instabilities through exhaustion.

To clarify the process an example is given below. The subject of the example represents an arbitrary but typical simple ladder formation. The upper ground contacts are taken to exist at the platform edge itself. Table 15 gives the variable values for the example ladder.

Table 15

Variable values for example ladder

Parameter	Value
A	0.2 m
B	0.2 m
C	1.92 m
D	1.92 m
E	4.75 m
J	68 deg
K	68 deg
F	0.17 m
W	19 kg
M	2.6 m
U_{base}lim	0.6
U_{top}lim	0.6

The series of Standard Prescribed Parameters as previously described are shown in Table 16.

Table 16

Parameter values used in the assessment

Variable	Value
$L_{std}Z$	6 kg
$L_{std}Y_{Pos}$	8 kg
$L_{std}Y_{Neg}$	128 kg
$L_{std}X$	10 kg
$L_{std}M$	27 kg
H_{set}	0.25 m

Running this design through the modeller and systematically configuring Test#1 to Test#4 gives rise to intermediate returned values of stability index, as shown in Table 17. For each index the lowest returned value is revealed in a specific test and that value is highlighted in bold.

Table 17

Intermediate stability index values for example ladder

Returned Index	Test#1	Test#2	Test#3	Test#4
$Sint_{Base}$(#)	2.37	2.37	2.40	**2.19**
$Sint_{Contact}$(#)	**0.73**	2.00	> 10	5.14
$Sint_{Top}$(#)	0.96	**0.42**	> 10	> 10
$Sint_{Flip}$(#)	Undefined	Undefined	Undefined	**0.60**

Note: $Sint_{Flip}$(#) is undefined but also irrelevant for a dead centre and symmetric handed load as applied in Test#1 and Test#3 . It is also undefined in Test#2 in this particular case because the ALP is in the coincident main axes of both the Accessible and Active ladder. A more complex DAL with some grounding point displacement would deliver a finite result here. Technically this occurs whenever the SLV drives through the active ladder main axis with modelling parameter h(m)=0. Flip stability is entirely unchallenged and the flip-mode index would be computed at infinity. Logically, since this is maximum possible stability in flip-mode, the returned index taken as undefined can be accepted as an arbitrarily high value default pass.

The lowest observed value in each series is taken as the Stability Index proper and is the final determined result for the DAL.

Hence the final Intrinsic Stability Indices for this structure are obtained and given in Table 18.

Table 18

Final stability indices for example ladder

Variable	**Value**
$Sint_{Base}$	2.19
$Sint_{Contact}$	0.73
$Sint_{Top}$	0.42
$Sint_{Flip}$	0.6

15.0 DYNAMOMETER CONFIGURATION

The dynamometer is a high performance, kinematically compliant, registration system employing a determinate six-point contact support. The method efficiently holds the rig reference ladder in rigid spatial lock with a minimum degree of restriction, and eliminates the potential for internal structural stresses which could otherwise appear as phantom ground reaction signal errors.

High friction wheels capable of free vertical running are employed at the dynamometer top. These assure zero vertical reaction forces at this location and transfer the entire vertical load component to base immediately and with accuracy. It should be noted that this accords with empirical ladder behaviour and is a mechanism fully investigated and described in previous work elsewhere (HSE RR205 2004). A single spherical free bearing is implemented at the base, ensuring all main axial torsions are borne by the upper transducer pair.

Loose tethering of the ladder is employed at the upper grounding position, hence the ladder is free to move by limited amounts laterally and rotationally, and for the user retains the feel of a regular climbing structure. However, clearly the ladder can never actually destabilise, and demands placed by a user from instant to instant are never curtailed by such an event. This is a justifiable experimental strategy, since the natural user feedback and subsequent demand limits can be observed and enumerated without the interruption of real stability failure.

15.1 DYNAMOMETER STRUCTURAL CONSTANTS

These figures, shown in Table 19, represent the measured dynamometer geometry, and are used in the various corrections and parametric transformations.

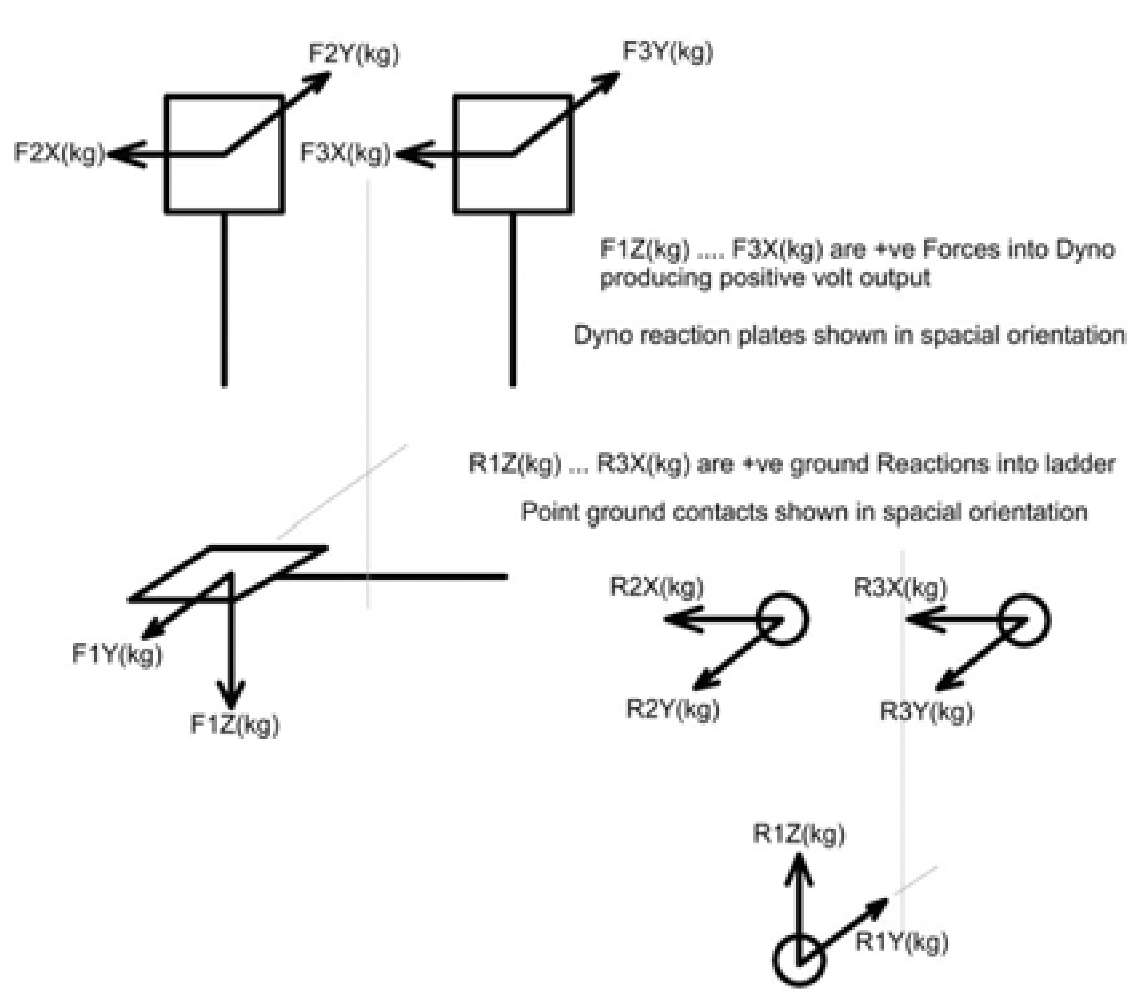
Table 19

Dynamometer geometry measurements

Variable	Value
E	4.13 m
A	0.3 m
C	1.92 m
F	0.143 m
J	68 deg
a	3.95 m
b	0.28 m
d	0.26 m

15.2 PRIMARY RIG SENSORY PARAMETERS

Figure 31 shows the primary dynamometer rig actions and reactions, intrinsic to the modelling methodology.



Notes:

Amplifiers generate instantaneous volt signal modulated by detected force.

Tare zeros are subtracted by acquisition software and volt deviations from zero are data logged.

Calibration and zero tare equations:

$$R1Z = K1Z(V1Z - Zero1Z)$$

$$R1Y = K1Y(V1Y - Zero1Y)$$

$$R2Y = K2Y(V2Y - Zero2Y)$$

$$R2X = -K2X(V2X - Zero2X)$$

$$R3Y = K3Y(V3Y - Zero3Y)$$

$$R3X = -K3X(V3X - Zero3X)$$

V1Z (V) to V3Z (V) are amplifier raw volt outputs

K1Z (kg/V) to K3Z (kg/V) are scaling factors

Zero1Z (V) to Zero3Z (V) are tare zero volt levels obtained immediately prior to logging.

Figure 31 – Dynamometer actions and reactions

For clarity and completeness, Table 20 details the channel assignments for the dynamometer amplifier:

Table 20

Amplifier channel assignment

Channel	Variable
1	Not used
2	Not used
3	V1Z
4	V1Y
5	V2Y
6	V2X
7	V3Y
8	V3X
9	Not used

15.3 CALIBRATION METHODOLOGY

The transducer sensors themselves are bi-axial cantilever suspensions. A symmetric and thermally balanced strain gauge half-bridge responds to differential surface strain. By design the system is highly linear in the operational loading range, and inherently insensitive to channel cross-talk. High quality electronic management preserves both short and long term performance stability. Initial electronic gains were set for nominal full scale dynamometer responses as shown in Table 21.

Table 21

Gain settings for dynamometer full scale response

ADC Channel DS/16/8/TC	Scaling Factor Designation	Scaling Factor Nominal (kg/V)	Nominal FS (kg) @ 5V ADC FS	Amp Gain (#) 0...10
3	K1Z	30	150	5.0
4	K1Y	15	75	10.0
5	K2Y	15	75	10.0
6	K2X	15	75	10.0
7	K3Y	15	75	10.0
8	K3X	15	75	10.0

Initial calibration involved the systematic application of accurately known point loads to each of the dynamometer transducers in turn. The transducers were all energised and at stable running temperature. Provisional values of scaling factors were determined.

A second phase was undertaken with the dynamometer and general rigging in place. Independent point loads were again systematically applied. Real time data files were obtained for later analysis.

A third phase involved applying known loads to the rig reference ladder directly. Real time data files were obtained for later analysis.

Final integrated scaling factors were determined using all available sources as cross checks. These parameter values appear as system constants in the Excel Spreadsheet “Analyser1” and calibrate volt (V) recorded signal to engineering dimensions (kg).

The detailed numerical record exists in an archive Microsoft Excel Spreadsheet entitled “Master Calibration”.

Further archive support files also exist and are retained for scrutiny and verification if required. These have been supplied to the HSE in a directory labelled “Calibaration files”.

15.4 DATA LOGGING AND STRUCTURE OF RAW DATA FILES

The following information is provided for reference purposes.

Specification

- Data acquisition utilised a suitable VI implemented in DasyLab 7.0 running an IOTech Datashuttle type DS/16/8/TC – Serial # 6301. Channel range was +/- 5V at 12 bit resolution.
- Acquisition rate was 30 Hz synchronous all channels.
- Data files are CSV format and of arbitrary length.
- A header contains core information including date and time of creation.
- The first column contains acquisition time at 33ms increment.
- The next six columns are electronic measurement channels CH3..CH8 with logical correspondence to the six dynamometer sensory reaction axes. These are volt level values. Tare zeros are previously accounted for and signals respond to and indicate user generated drive only.

16.0 CONCLUSIONS AND RECOMMENDATIONS

This project set out to measure the performance of, and provide empirical data on, the level of safety provided for users of leaning ladders when they mount or dismount at the top of the structure. In so doing it has explored the variation in the safety demand made by different mounting techniques and has quantified by how much the safety of the ladder system is challenged by such techniques.

In the same manner as provided for stability devices, minimum acceptable stability values have been indicated by the provision of a stability threshold, as well as simple test techniques which can assess the performance of ladders or ladder products which aim to improve stability for ladders used in this fashion. This tool offers the capacity for ladders (or ladders and stability devices) to be categorised by the level of safety they offer. Clearly, an initial application could be the identification of those interventions which offer the same, or less, levels of safety as employing a traditional 'naked' ladder as well as those which bring genuine benefits.

Whilst this may initially seem challenging and commercially potentially damaging, on closer consideration this is not substantiated. Understanding and quantifying the demands of the user, and providing products which meet those demands brings advantages to all the stakeholders. Users, clearly, gain immediate safety benefit and can trust that ladder systems will provide reliable support for the activities they wish to undertake. Ladder manufacturers can review current products and identify means to meet any performance shortfall or make recommendations as to appropriate applications for given models, thereby constraining their liability. Device manufacturers will be able to design more effective products and will have firm guidelines for quantifying performance. These devices may well have commercial potential in formal relationships with ladder manufacturers. Employers and safety practitioners will be able to prescribe appropriate equipment and work strategies – specifically identifying when ladder systems can not provide adequate stability. Lastly, enforcement agencies will have a means of determining when individuals may have been undertaking tasks outside of the 'reasonable' domain and, as such, may account for liability themselves. In theory, at least, this offers tangible progress in making ladder use safer.

The main immediate conclusion from the applied research conducted is that it is unlikely that an un-tethered, naked, ladder can provide sufficient stability to resist the demands of reasonable users trying to mount or dismount at the upper reaches.

This clearly reinforces the need to tie off ladders in use, or to employ devices which will enhance the stability in a manner that will demonstrate compliance with the requirements of the four stability indices described in this report.

In conclusion, the original aims of the project were summarised:

- To evaluate the stability demands placed on an un-tethered, or partially tethered, ladder by typical users using the ladder to access high surfaces.
- To determine whether conventional ladders or ladders and stability devices can meet these needs and so provide a safe working environment.
- To attempt to offer a means to quantify any modification which may be required to conventional equipment in order to meet the user demands.
- To provide an evidence-based answer as to whether this practice is appropriate or not.
- To provide information which will help shape the policy on working at height so as to only permit safe practices.
- Ultimately, to reduce the number of accidents and associated injuries.

These project aims were achieved by satisfying the of specific objectives defined at the onset, as shown below:

- Construction of a rig capable of collecting real time data relating to the forces generated by typical users climbing on and off a ladder (Section 3.0 and Section 5.0).
- Recruiting a suitable selection of participants to use in data collection trials (Section 4.0).
- Undertaking the trials and collecting the real time data (Section 3.0).
- Processing the data to determine the stability demands placed on the ladder system (Section 5.0 onwards).
- Calculating the key variables associated with the stability of the system (Section 13).
- Determining an appropriate model for appraising the stability of systems (Section 14).
- Reporting the process and findings (All Sections).

Whilst the longer term implications of the work have yet to be established, the fulfilment of all of the original aims holds great promise that ultimately accident rates can be reduced by the practical application of the knowledge acquired.

16.1 RECOMMENDATIONS

The following recommendations are made:

- The test specification may be independently validated against a range of proprietary ladders and ladder stability devices. This could take place within the relevant industries.
- A technical standard is developed for ladders or ladder stability devices which may be used specifically for the access task and which is based on the test methodology outlined in this report.
- Policy recommendations for conditions where ladder use is not appropriate to access platforms or surfaces could be more specifically made based on the findings of this report.
- Stability devices could be certified (perhaps as part of any technical standard) prior to being released for specified use. Any such certification should rest upon demonstration of minimum acceptable levels of stability provision in all four failure modes

17.0 APPENDIX A – STAKEHOLDER QUESTIONNAIRE

Telephone protocol

Loughborough University is conducting some research into ladder use within industry. We are looking at occupations in particular that climb on and off the top of ladders. The research is investigating into the sorts of forces that are exerted upon the ladder. For this were going to be conducting some trials, but we want the trials to imitate as close as possible what goes on in the real world/industry. I was hoping to talk to somebody about the sorts of tasks performed by ……………., about the type and weight of equipment carried and the ways in which the users get on and off ladders.

1) Occupation:____

2)

What is the ladder used for:

Climbing onto roofs ☐

Climbing onto other ladders ☐

Climbing onto scaffolds ☐

Climbing onto balcony's ☐

Climbing onto flat areas/ledges ☐

Climbing onto platforms ☐

Other: ☐

3)

How do they climb off ladders

Get off forwards ☐

Get off sideways ☐

Get off backwards ☐

Other ……………….................... ☐

4)

How do they climb back onto the ladder

Get on forwards ☐

Get on sideways ☐

Get on backwards ☐

Other ……………….................... ☐

5) Do they tie the ladder off?

Yes ☐

No ☐

____

____

6) Is there a policy on how they should get on and off ladders?

Could we see a copy?

Yes ☐

No ☐

What does the policy state: ____

____

____

7) Are people working in this trade required to do a risk assessment before using a ladder? (could we see a copy)

Yes ☐

No ☐

What factors are included in the risk assessment? ________________________________

____

____

8) What safety procedures do they follow? Safety equipment? Tying off? Footing ? etc...

____

____

____

____

9) Is a 'near miss' book kept? What sort of getting on and off near misses are there?

10) Do they carry any equipment with them when climbing on and off the ladders? (or is it placed there by other means, winch, crane, forktruck)

11) What equipment do they carry on a regular basis when climbing on and off ladders?

Do the loads differ when climbing off the ladder compared to climbing back on?

12) What is the approximate size and weight of this equipment?

13) Is there any equipment that they have to carry on a one off basis (i.e. not a regular part of the job but may have to carry on and off ladders now and again or in specialist circumstances)

14) What is the approximate size and weight of this equipment?

____

____

____

____

15) What tasks are performed when climbing on and off the ladders?

(reason for climbing on and off the ladders e.g. to fix aerial to roof)

____

____

____

____

16) We would also like to speak to companies that are members of your trade association, would you be able to give me the contact details of them?

____

____

____

____

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