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SEBED - Seat belt degradation

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(Phases I and II)

Seat Belt Degradation

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EXECUTIVE SUMMARY

Objectives

During the lifetime of a seat belt it is considered that mechanical performance may deteriorate in response to normal use and exposure to environmental conditions such as natural aging of the fabric and in-service contamination by various liquids and substances. Additionally, seat belts experience mechanical degradation due to frequent normal use (e.g. daily operation – opening, closing and adjustment) and some may be exposed to improper cleaning and poor maintenance.

The aims of Phase 1 of this research were to ascertain:

1. by testing of seatbelts that had been in service for a number of years whether there was a deterioration in performance due to this service.

2. whether it was feasible to construct a small scale test rig which would duplicate the loading conditions experienced by the seatbelts during dynamic testing

By comparison of the performance of new seatbelts versus old, the difference in their performance would be determined by measuring the change in their elongation properties with age, determined by static testing in accordance with AS8043B section 9 and dynamic testing, using a 16g horizontal impact test, in accordance with AS8049A. The results obtained would then be used to construct age vs. degradation curves for the belts.

A second phase of this research was commissioned in order to improve upon the data obtained in Phase 1. The aims of Phase 2 of this research were as follows:

1. to obtain and statically test further used belts in order to form a more complete data set for 3000 lb belts.

2. to conduct further statistical analysis in order to a) compare the dynamic test data with the feasibility data, b) consider the effects of colour and buckle design on belt performance and c) repeat the full data analysis to incorporate any new data from Phase 2 static testing

3. to conduct further tests using the feasibility rig to assess the relationship between belt length and energy absorption

4. to conduct further head trajectory analysis

Main Findings

Static testing showed that there was a relationship between the age of a belt and its performance (i.e., elongation characteristics) under test. The test results were broken down into two groups based on the rated load of the belts and analysed accordingly. Belts, which were manufactured since 2004, were rated at 3000lbs and showed an increase in their elongation with increasing age. Belts manufactured prior to 2004 were rated at 2000 lbs and showed a decrease in elongation characteristics with increasing age.

Slippage of the webbing through the buckles of the belts was observed during static testing and it was found that those belts which exhibited large amounts of slippage all had buckles of the same design. Buckles with a smooth surfaced, stepped profile slider bar allowed slippage to occur in some cases. Buckles with a knurled, cylindrical slider bar showed little or no slippage.

Dynamic testing showed that, similarly, there was a relationship between the elongation characteristics of the belts and their age, although these results showed greater scatter. Slippage of the webbing through the buckle of the belt was not observed to occur during dynamic testing.

The findings of the feasibility study show that it is possible to create a small scale rig to test a small sample of seat belt, in this case the short or tongue side of the belt, reproducing the forces that the belt was exposed to in the dynamic test. The rig would need to be fine-tuned, however, for each type of belt tested as the load profile is dependant on the length of the sample being tested and its elongation characteristics.

It was observed during belt procurement that a large number of belts were obtained which had illegible labels. These belts must have been in service for some time with labels in poor condition prior to being removed from service in order for them to have become so worn that the text could no longer be read.

It was almost impossible to visually distinguish between the polyester and nylon belts used in this study. The only means of identifying different belts was by the manufacturer's part number on the belts, but this would require prior knowledge of which code applied to which material in order to identify them. Since belts and seats are tested together in order to achieve conformity to aviation standards, it is important to ensure that the correct belt is used with the correct seat set (i.e. nylon belts should not be used on seats tested only with polyester belts and vice versa). If belts had some indication of which material they were manufactured from, this would help to ensure that the correct belts were fitted to seats.

Recommendations

It is recommended that the use of a small-scale rig is considered for the testing of repaired or replacement seatbelts (For more recent types of aircraft belts must be tested with seats). The feasibility study showed that it is possible to replicate the loading conditions to which a seatbelt is subjected in dynamic sled testing using a small-scale test rig. It is recommended that a fixed sample length be used for testing in order to make the use of a small-scale test rig practical and simple.

It is recommended that, in order to better determine when a belt should be removed from service, that service history of the belts should be recorded. It was found during this study that little or no information appears to be kept by the operators regarding the service history of belts. There appears to be little knowledge of the conditions in which the belts are used, the cleaning regimes to which they are exposed or the frequency of inspection.

It is recommended that the date when a belt first goes into service is recorded. This would allow a more accurate assessment of the service history of the belt to be determined, and therefore allow a better assessment of the continued airworthiness of the belt during routine inspection.

It is recommended that inspection of the seatbelts should be carried out at a maximum interval of every 12 months, or more frequently depending on the extent of use. This is consistent with the recommendations from the manufacturers. This approach would avoid situations where labels become illegible whilst belts are in service.

It would be prudent to adopt a maximum lifespan for belts in service of 10 years from the date of manufacture (this would include both time in storage and service life) until further information can be gained about long-term performance. This lifetime is based on the natural deterioration of polymer fibres that occurs even when they are in storage in ideal conditions.

It is recommended that guidance be issued to air operators about the importance of ensuring that belts are made up of matched parts. When gathering belts from various sources, it was common to find belts, which were assembled from mismatched parts.

It may be useful to issue each belt with its own unique serial number to enable records about individual belts to be kept. This would allow belts to be tracked throughout their service life. Belts are currently issued with part numbers and date of manufacture, but these details usually apply to large batches of belts and so are not unique, with no way of identifying or tracking an individual seat belt.

1 INTRODUCTION

1.1 BACKGROUND

There is concern that during the lifetime of a seat belt its performance may deteriorate in response to normal use and exposure to environmental conditions such as natural aging of the fabric and in-service contamination by various liquids and substances. Additionally, seat belts experience mechanical degradation due to frequent normal use (e.g., daily operation – opening, closing and adjustment) and some may be exposed to improper cleaning and poor maintenance.

This concern led the European Aviation Safety Agency (EASA) to issue a Safety Information Bulletin 2010-15R1 [1], in relation to the maintenance of seat belts on aircraft and the potential impact on passenger safety during turbulence or emergency landing conditions.

There is no fixed life-time limitation for aircraft seat belts. Seat belts are replaced by different airlines after different service lives depending on the specific airline's policy, class of travel, and more general decisions to re-furbish and replace seats.

For regulatory reasons, the safe performance of seat belts used on aircraft has to be demonstrated by meeting standard SAE AS8043[2] to allow certification under ETSO-C22g [3] and TSO-C22g [4]. Additionally, Certification Specifications CS25.561[5] and CS25.785[6] require that seat belts need to be tested for static stress to comply with the load envelope and interface requirements for installation.

Seat belts and seats installed on more recent aeroplanes (including A330, A380 and B777) need to comply with CS25.562 [7] dynamic crash landing conditions.

There is an overall concern about passenger safety arising from seat belts not performing to the required standards during their service life.

The project was commissioned in two phases, as detailed below.

1.2 AIMS AND OBJECTIVES OF THE PROJECT

The main objectives of the project were to assess the degradation of aeroplane seat belt performance and consequently service life, and to assess whether it is feasible to use a small-scale test method to achieve a dynamic test pulse as a substitute for the dynamic test.

1.2.1 Phase 1

In Phase 1 we carried out the following tasks:

Task a): Production of a test plan, including an analysis to determine the relevant and statistically significant number of samples for static and dynamic tests.

Task b): Static tests with balanced-loop tensile tests with a body block in accordance with SAE AS8043B (and AS8049A respectively).

Task c): Dynamic tests using a deceleration sled in accordance with CS25.562 on a representative rigidised aircraft seat. Belt forces and elongation were measured during the dynamic pulse.

Task d): Feasibility study of alternative small-scale test methods using seat belt webbing to simulate dynamic test pulse and belt force using a specialised rig. This feasibility study has allowed HSL to comment on the acceptability of using this test as a simple and cost effective way of comparing seat belt fabric performance with age and use.

The seat belts were of different ages and also comprised a significant number of repaired seat belts in line with the EASA requirement.

1.2.2 Phase 2

Phase 2 of the project was commissioned in order to carry out further analysis on the data gathered in Phase 1, generate more static test data to fill in some of the data gaps identified in those data, and to gain a better understanding of the performance of the feasibility test rig. In Phase 2 we carried out the following tasks:

- **Production of a test plan**

- **Procurement of more belts** in order to fill the gaps in the Phase 1 data, specifically to include newer, used belts, including polyester belts, if available

- **Static tests** with balanced-loop tensile tests with a body block in accordance with SAE AS8043B (and AS8049A respectively) to test the belts procured for Phase 2.

- **Feasibility testing** using the specialised rig developed by HSL. Further testing on samples of the same age and service history in order to understand how varying the sample length changes the energy absorption requirements of the rig.

- **Statistical analysis of the Phase 1 data** to determine a) the relationship between the dynamic test method and the feasibility test method, in particular their respective reliabilities, b) to examine whether colour or buckle design has an effect on performance and c) to repeat the analysis conducted in Phase 1 to take account of the new static test data generated in phase 2.

- **Further analysis of head trajectory data** and dummy kinematics to gain a better understanding of the loading imparted to the belts during dynamic testing and to further examining the relationship between belt performance and head trajectory.

1.3 SEATBELT SAMPLE REQUIREMENTS

A range of seatbelts was specified to be included in the overall test programme. These were new belts from a range of manufacturers, used belts from a range of manufacturers, and repaired belts. Specifically, 30% of the total number of belts to be tested was required to have been repaired, of which some were to be new, unused belts and some used belts.

1.4 CONSORTIUM

In order to carry out all the tasks in this project, a consortium was formed between MIRA Ltd and the Health and Safety Laboratory (HSL). MIRA was responsible for carrying out the static and dynamic testing and HSL was responsible for the project management, analysis and assessment of the test results, and development of the small-scale test rig in order to conduct the feasibility study.

2 TEST PLAN

2.1 INITIATION/PLANNING

2.2 PHASE 1

2.2.1 Procurement of samples

The distribution of belts procured for testing in Phase 1 is shown in Table 1 below, with 289 samples in total being obtained. A total of 35 new belts were obtained direct from manufacturers; 25 from one manufacturer, designated A, and 10 from another, designated B. These new belts were manufactured from both nylon and polyester in order to investigate any differences between the performance characteristics of the two types of material.

Repaired belts were ordered from two repair companies; however, one of these companies (repairer Z) supplied new, unused belts from manufacturer A, which had been in storage for five years. The other repair company repaired 25 belts supplied to them by HSL, and will be referred to as repairer Y. New repaired belts obtained were all manufactured from Nylon 6.6[1].

A total of 219 used belts between three and 13 years of age were obtained from either the service department of a UK air operator, or from two different air salvage firms. Amongst these were a number of repaired belts. These used, repaired belts had all been manufactured by the same manufacturer, manufacturer A and repaired by the same repair company, referred to as repairer X. All used belts and used repaired belts obtained were manufactured from nylon 6.6 webbing, except those manufactured in 2002, which were made from Nylon 6 webbing[2]. Nylon 6 is similar in heat and chemical resistance to Nylon 6.6., but is slightly less resistant to abrasion, and has a lower modulus of elasticity.

Of these used belts, 74 were obtained which were identified as being suitable for testing, in that they had legible labels. The remainder of the belts had either heavily worn labels (the reason for their removal from service), so these could only be used for commissioning tests in the feasibility study, or were made up of mismatched parts (i.e. the tongue and buckle side had different manufacture dates).

The aim was to procure at least 40 repaired belts (both new and used), to satisfy the requirement from EASA that 30% of all of the samples are repaired belts.

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[1] *Identified by flame tests at HSL*
[2] *Identified by flame tests at HSL*

Table 1. Details of all of the belts received for testing in Phase 1

Manufacture year	*Rated load, lbs*	*Number of samples*	*Manufacturer /repairer*	*Service history*	*Material*	*Colour*
2011	3000	20	A	New	Nylon	Black
2011	3000	15	A	New	Polyester	Black
2010	3000	10	B	New	Polyester	Beige
2006	3000	25	A	New/stored	Nylon	Green
2011	3000	20	A/Y	Repaired, new	Nylon	Black
2008	3000	9	A	Used, long haul	Nylon	Royal Blue
2007	3000	4	A	Used, short haul	Nylon	Mixed
2006	3000	4	A	Used, short haul	Nylon	Black
2005	3000	4	A	Used, short haul	Nylon	Black
2004	3000	4	A	Used, short haul	Nylon	Black
2003	2000	10	A	Used, long haul	Nylon	Indigo blue
2002	2000	10	A	Used, long haul	Nylon	Indigo blue
1998	2000	10	A	Used, long haul	Nylon	Indigo blue
2008	3000	2	A/X	Used repaired, short haul	Nylon	Black
2001	2000	1	A/X	Used repaired	Nylon	Indigo blue
2000	2000	3	A/X	Used repaired	Nylon	Mixed
1999	2000	2	A/X	Used repaired	Nylon	Indigo blue
1998	2000	1	A/X	Used repaired	Nylon	Navy blue
Mismatched	2000/3000	6	A	Used, short & long haul	Nylon	Mixed
Unusable	3000	129	A	Used short haul	Nylon	Black
TOTAL		**289**				

2.3 PHASE 2

2.3.1 Procurement of samples

In Phase 2, a further selection of 33 belts were obtained of various ages and histories, of which 29 were obtained from a UK air salvage firm, and four were sourced from a European air operator. Table 2.1 shows the details of the belts, which were procured.

Table 2. Details of belts procured for Phase 2

Manufacture year	Rated load	Number of samples	Manufacturer/ repairer	Service History	Material	Colour
2010	3000	5	A/X	Refurbished long haul	Nylon	Royal blue
2010	3000	2	A	Refurbished long haul	Nylon	Navy blue
1996	2000	6	A/X	Used refurbished	Nylon	Black
2007	2000	6	A/X	Used refurbished	Nylon	Black
1995	2000	1	A/X	Used refurbished	Nylon	Black
2002	2000	1	A/X	Used refurbished	Nylon	Black
2009	3000	7	C/W	Refurbished short haul	Polyester	Black
2010	3000	1	C/W	Refurbished short haul	Nylon	Black
Unusable	3000	4	A	Refurbished short haul	Nylon	Black
TOTAL		**33**				

These belts all appeared to be in good condition, with no localised damage.

27 of the belts obtained had been refurbished, the majority by repairer X, having been originally made by manufacturer A. Seven of the belts obtained were from a different manufacturer, new to this study, designated Manufacturer C. These belts had been refurbished by a repairer who was also new to this study, designated Repairer W. These belts were found, by testing at HSL, to be manufactured from polyester.

A small number of belts obtained in Phase 2 were found to be unsuitable for testing as they also had labels, which were illegible. The text on one of the belts faintly indicated the year 2007 and interestingly, some of the belts received in Phase 1, which had suffered label fading, were also manufactured around this time. Readability of the label is a required condition for airworthiness of the belt. The bad condition of the labels strongly suggests that the belts remained in service for quite some time even though the labels were already in a state where the belts should have been removed from the aircraft.

The aim was to procure at least 40 refurbished belts (both new and used), to satisfy the requirement from EASA that 30% of all of the samples are repaired belts. This requirement was satisfied as a result of obtaining a large number of refurbished belts in Phase 2.

2.4 DIFFICULTIES ENCOUNTERED

Sourcing of used belts proved to be very difficult. Four major airline operators were approached and asked to provide samples, however, they were reluctant to become involved with the project and refused to help. This lack of co-operation lead to great difficulties in sourcing used belts for testing. Another operator, however, proved very helpful and supplied a large quantity of belts.

Many operators had their belts repaired when they were removed from the aircraft and, as such, placed a high financial value on them. These operators refused to supply belts, in some cases, on the basis that they would be repaired. Belts which had only been in service for one or two years could not be obtained as this would have required operators to remove them prematurely from aircraft; these newer used belts would not normally be replaced unless they were severely damaged. Again the lack of co-operation from the operators approached meant that these newer used belts could not be obtained.

Most of the used belts obtained were manufactured by manufacturer A. The lack of participation of aircraft operators meant that few used belts from other manufacturers could be sourced. An advantage of these belts being sourced from one manufacturer is, however, that the data obtained from them is more comparable as the method of manufacture, the quality of manufacture and the quality of the components should be reasonably consistent. This removes a variable from the analysis of the data making the results more robust.

Few used, refurbished belts could be obtained in Phase 1, despite many attempts to obtain them. More used refurbished belts were obtained in phase 2, resulting in 56 out of a total of 183 usable belts being refurbished, meeting the EASA requirement that 30% of the belts in the study were refurbished.

An attempt was made to gather as much information as possible about the history of the belts when they were collected. A questionnaire was produced which was passed on to the operators in order to gather additional information such as typical cleaning procedures. The only operator to fill out this form, the one who supplied a large quantity of belts, informed us that they knew very little about the history of the belts, the cleaning procedures or the criteria for discard of the belts. Discussion with other operators confirmed that this lack of knowledge was industry wide.

All the available details about the service history of the belts are shown in Appendix A, Tables A.1, A.2 and A.3.

2.5 SAMPLE DISTRIBUTION

The age distribution of samples of used belts received for testing is listed in Table 1, along with the rated load. The material from which the used belts were manufactured was determined after testing.

It was determined at this stage that the belts manufactured prior to 2004 were all rated at 2000lbs and complied with TSO-C22f, whereas those manufactured in 2004 and later were all rated at 3000lbs and complied with TSO-C22g. This meant that subsequent analysis of the test data had to be divided into two groups to account for the difference in the rated load of the belts and therefore performance.

2.5.1 Pre-test inspection

Prior to testing, each belt was visually examined and measured and any defects or signs of wear were noted. The belts were then photographed to create a visual record of their condition. Each belt was issued with a unique sample number, which was then used to identify it throughout the test programme, thus anonymising the belt and its origins. The belts were issued to MIRA in a randomised way, and referred to only by these sample numbers, ensuring that no bias was introduced to the test results.

All of the belts tested showed little or no evidence of damage, with only the older belts showing slight curvature of the webbing, due to pulling through the buckle, and abraded fibres at the attachment hooks, which appeared to be associated with the metal identification tags. The belts did not appear to be faded, nor was there any evidence of stiffening or discolouration, which would be associated with chemical attack. The surfaces of the belt material showed no evidence of abrasion; this was only evident at the edges.

Many of the belts acquired were of different overall lengths, with slightly different fittings and buckles. The dimensions of these belts are shown in Appendix A, Table A.4.

2.6 DETERMINATION OF THE SAMPLE NUMBERS

An initial test regime for Phase 1 was determined, based on the anticipated supply of belts; however, it was not possible to obtain any belts from airline operators, which were relatively new. The newest used belts, which could be obtained in Phase 1, were manufactured in 2008. The revised test plan, which was agreed with EASA, based on the belts we were able to obtain, is shown in Table 2 below. During Phase 2, belts manufactured in 2009 and 2010 were obtained.

It was decided that a large number of tests would be carried out statically, in order to generate a 'performance vs. time' curve, with a smaller number of tests carried out dynamically for comparison. Similarly, feasibility testing was to be carried out on a small number of samples of different ages in order to compare results obtained by each test method.

A time window for selection of the belts was agreed with EASA. The intervals used meant that 1 year old belts are considered to be belts manufactured between 8 and 16 months previous to the date of receipt at HSL/MIRA, 2 year old belts would be those manufactured between 20 and 28 months, 3 year old belts would be those manufactured between 32 and 40 months etc. The age of the belts in this study, and therefore the service life, is taken as the difference between the date of manufacture and the date of receipt at HSL/MIRA. Tables of belt manufacture dates for each phase, Tables A.4.1 and A.4.2, and the corresponding age/service life are shown in Appendix A. New belts from manufacturers A and B were all considered to be 0 years of age since they had never been in service. In Phase 1, the belts were received during June 2011, in Phase 2 the belts were received in May 2012.

The experimental design shown in Table 2 incorporates the limitations arising from the number of tests that can be carried out for each age and the number of samples, which were available. Where possible, belts of different service history comprised the sample group for each age in order to randomise the group. A sample size of three belts was considered to be the minimum required, thereby allowing calculation of the standard deviation of the results for each age. The general acceptability of only 3 samples/tests is based also on experience from previous research (carried out by HSL [9]) into the degradation of webbing, where little scatter was observed between the test results for each test condition; the majority of results in these research programmes lay within half of a standard deviation.

Three age groups were selected for more extensive testing in order to assess the precision of the results and to determine whether more samples will need to be tested for each age group to increase precision. Provided that the results for three samples lie within one standard deviation, then three samples were determined to be sufficient based on discussion with Statisticians in HSL. During Phase 1 a larger number of static tests were carried out than shown in the test plan, these are detailed in section 3. During Phase 2 further static tests were carried out, these are detailed in section 3.

Table 2. Test plan Phase 1: number of belts per test

	Static test	***Dynamic test***	***Feasibility test***
New nylon belts	8	5	5
New polyester belts	3	3	-
New belts, different manufacturer	3	3	-
6 year old unused belts	5	3	3
3 year old belts	3	-	3
4 year old belts	3	3	-
5 year old belts	3	-	-
6 year old belts	3	3	3
8 year old belts	3	3	3
9 year old belts	3	3	
13 year old belts	3	3	3
Repaired belts - new	8	5	5
Repaired belts used	6	3	-
TOTAL	**54**	**34**	**25**

2.7 NOMENCLATURE

The samples were all obtained by HSL and issued with unique sample numbers, in accordance with the HSL Sample Handling procedure. The sample numbers were issued in a randomised way, so that belts of the same age group did not have consecutive numbers. The belts were then issued to MIRA, identified only by these sample numbers for testing, to ensure that no bias was introduced by testing in batches of the same age. The HSL sample numbers consisted of a four digit number.

Tests conducted by MIRA were then given test references numbers. The static tests were issued with a numerical test number from 001 to 064. The dynamic tests were issued with unique alpha-numeric references of the form H134B1 RH. The test numbering system for the tests was based on: Hyge (H), the year (1), the week (34), the customer (B) and the number of tests for the customer (1), giving for example H134B1. Two rigid seats were positioned on the sled, these were designated as RH and LH and this designation was used to indicate which seat was fitted with a particular test sample.

The feasibility tests, conducted at HSL were given test references 'F1, F2' etc. The feasibility rig tests in Phase 2 were designated by their test numbers (SB60, SB61 etc).

2.8 BELT SPECIMENS

Full belt assemblies were tested, including the buckle, tongue and belt attachments, as described in AS8043B. The total belt length tested, from attachment mounting pin to attachment mounting pin, varied from 990 mm to 1340 mm, with the belt in its fully extended condition (no belt extended through the buckle). Figure 1 shows an illustration of a belt of length 1340mm. In this condition 1020mm of actual webbing will be loaded during testing and there will be no webbing slippage through the buckle.)

In the AS8043B protocol the total length of the belt assembly tested should be between 1220mm and 1270mm, or as near to that length as possible, which would result in between 120mm and 70mm of the belt pulled through the buckle if a 1340 mm belt were tested. A belt of only 990 mm in length, however, could only be tested at its maximum extension.

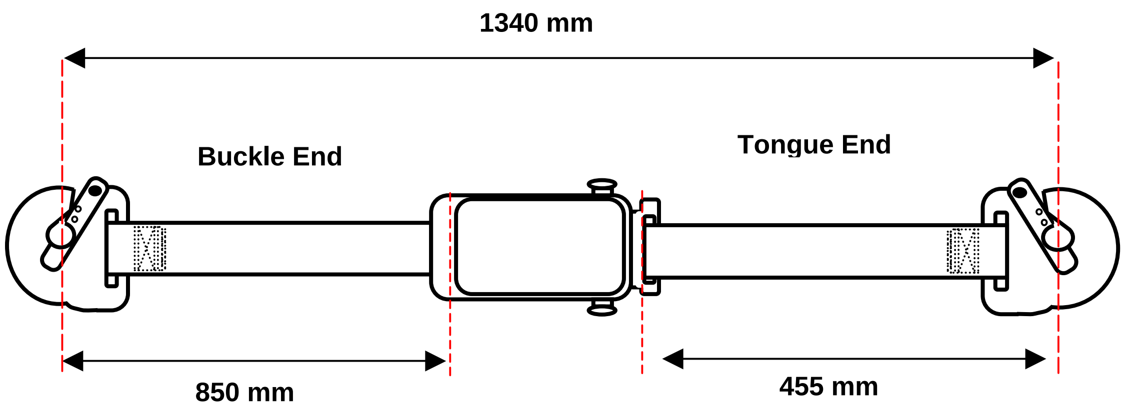

Figure 1. Dimensions of a 1340mm long belt in its fully extended condition

In actual service, however, there is approximately 200mm – 250mm of the belt pulled through, giving a total belt length of 1140mm – 1090mm. In a dynamic 16g sled test, because the belt is pulled a lot tighter (using two fingers between the belt and the pelvis as a guide for tightening), as much as 480mm of the belt is pulled through the buckle, giving a total belt length of 880mm as shown in Figure 2. In this condition 540mm of actual webbing will be loaded and potentially there could be webbing slippage through the buckle.

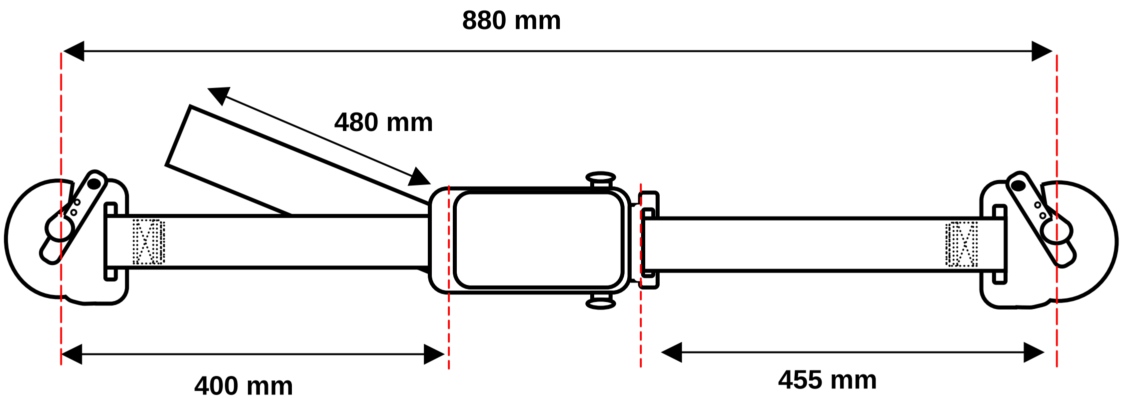

Figure 2. Dimensions of 1340 mm belt in 16g Dynamic Test

In order to directly compare the results from the static tests with those from dynamic tests it was important that the belt specimens were tested in a consistent manner. The loading of the seatbelt in the dynamic test method was considered to be more representative of the condition of the belt in service.

It is important that a similar length of belt is used for testing to that used in service as it is essential to test the portion of the webbing, which would be loaded by the seat occupant in actual service. Also, the buckle will be located on the part of the belt, which may have been subject to wear due to continual buckle tightening and loosening during normal use.

In order to determine the most representative belt specimen length to be used for testing the following procedure was used.

1. In the rigidised test seat for the dynamic tests a SAE826 H-Point (i.e., hip-point)[3] manikin was installed and the H-point for the seat determined.

2. A 50%ile Hybrid II dummy (Hybrid II does not have an official H-point) was installed to the procedure in AS8049A [8] and then adjusted to match the SAE 826 manikin H-Point.

3. A typical aircraft seat lap belt (in this case a new OEM belt) was put round the dummy's pelvis, buckled, and a 2kg pull load applied to the free end. The amount of free belt through the buckle was measured.

A consistent belt specimen length was then selected, based on the buckle location when the belt was fitted to the 50%ile dummy, which reflects the actual buckle position used in service.

[3] *This is the point where an occupants hip will be when sitting in the seat, and so is the pivot point between the torso and upper-leg parts of the dummy*

3 STATIC TESTING

3.1 BACKGROUND

The primary objective of the static belt tests was to ascertain any degradation or decrease in the elongation characteristics in aircraft seat belts as a function of their time in service. The test programme, which included both new belts of different materials and manufacturers, from which a generic baseline was selected, and used belts of known age and, potentially, time in service, involved measuring their elongation or strain characteristics.

Where possible, the tests were conducted in accordance with the procedures in AS8043B, however, due to the different belt lengths tested and the use of the AS8049A pelvis block, these could not always be achieved. Deviations from the procedures in the AS8043B Section 9 protocol are highlighted in the test method presented in this report.

Two main test procedures were used:-

Test Method A: Elongation Characteristics Tests (deviation from required test) –The test comprised loading the belt to 18kN, at the rate specified in AS8043B, and maintaining the load for 2 minutes to ensure that all belt elongation and slippage had occurred before unloading the belts at the same rate to record the hysteresis. These tests were conducted with full instrumentation.

Test Method B: AS8043B Compliance Tests – To compare the belts with the requirements of AS8043B, all belts completing the elongation characteristic test, Test A, were reinstalled in the test rig and loaded up to 26.6kN using the protocol in AS8043B. Due to the high probability of belt failures or webbing slippage these were conducted without the seat belt load cell and string potentiometer instrumentation.

The older belts obtained for testing had only been manufactured to a rated load of 2000lbs. These belts had been designed to meet the TSO-C22f specification rather than the more recent TSO-C22g, and so were required to sustain a lower load under testing. Because of this, it was determined during test rig development and calibration that the 2000 lb rated aircraft seat belts were failing within the range of 20 – 24kN, below the 26.6kN level specified in AS8043B. For this reason, in order to generate a performance history over the entire range of belt specimens tested, all belts were initially tested to 18kN, test method A The reason for the selection of this load is described in section 3.4.1. All belts were subjected to both test methods, but many of the 2000lb rated belts failed prior to attaining the 26.6kN level, while several of the newer 3000lb rated belts experienced large amounts of belt slippage through the buckles, causing the tests to be aborted.

3.2 SAMPLES TESTED IN PHASE 1

The total number of belts tested statically was 64 of which 17 were refurbished. This means that 27% of the samples tested were refurbished. Table 3, below, shows the distribution of samples that were tested statically.

In total, nine tests were carried out on the 0 year old nylon belts from manufacturer A. Five tests were carried out at the beginning of the test programme, one in the middle and three at the end, in order to provide a consistency check.

Table 3. Numbers of belts tested in the Phase 1 static test programme

Age, years	*Rated load, lbs*	*Number of samples*	*Manufacturer*	*Material*
0	3000	9	A	Nylon 6.6
0	3000	3	A	Polyester
0	3000	3	B	Polyester
0	3000	10 refurbished	A/X	Nylon 6.6
3	3000	6	A	Nylon 6.6
3	3000	2 refurbished	A/X	Nylon 6.6
4	3000	3	A	Nylon 6.6
5	3000	5	A	Nylon 6.6
6	3000	4	A	Nylon 6.6
7	3000	4	A	Nylon 6.6
7	3000	1 refurbished	A/X	Nylon 6.6
8	2000	4	A	Nylon 6.6
9	2000	3	A	Nylon 6
10	2000	1 refurbished	A/X	Nylon 6.6
11	2000	2 refurbished	A/X	Nylon 6.6
13	2000	3	A	Nylon 6.6
13	2000	1 refurbished	A/X	Nylon 6.6

3.3 SAMPLES TESTED IN PHASE 2

The total number of belts tested statically was of which all were refurbished. Table 4, below, shows the distribution of samples that were tested statically.

Table 4. Numbers of belts tested in the Phase 2 static test programme

Age, years	*Rated load, lbs*	*Number of samples*	*Manufacturer*	*Material*
2	3000	3 refurbished	A/X	Nylon 6.6
3	3000	3 refurbished	C/W	Nylon 6.6
5	2000	3 refurbished	A/X	Nylon 6.6

3.4 TEST METHOD

Full details of the test set-up, instrumentation and sample loading procedure are given in Appendix B.1. A test frame was constructed as shown in Figure 3, fully instrumented to allow measurement of the applied load via the ram load cell, belt loads on each side using seatbelt loadcells and the elongation of the belt, both total and on each side. A more detailed photograph showing the instrumentation can be seen in Appendix B.

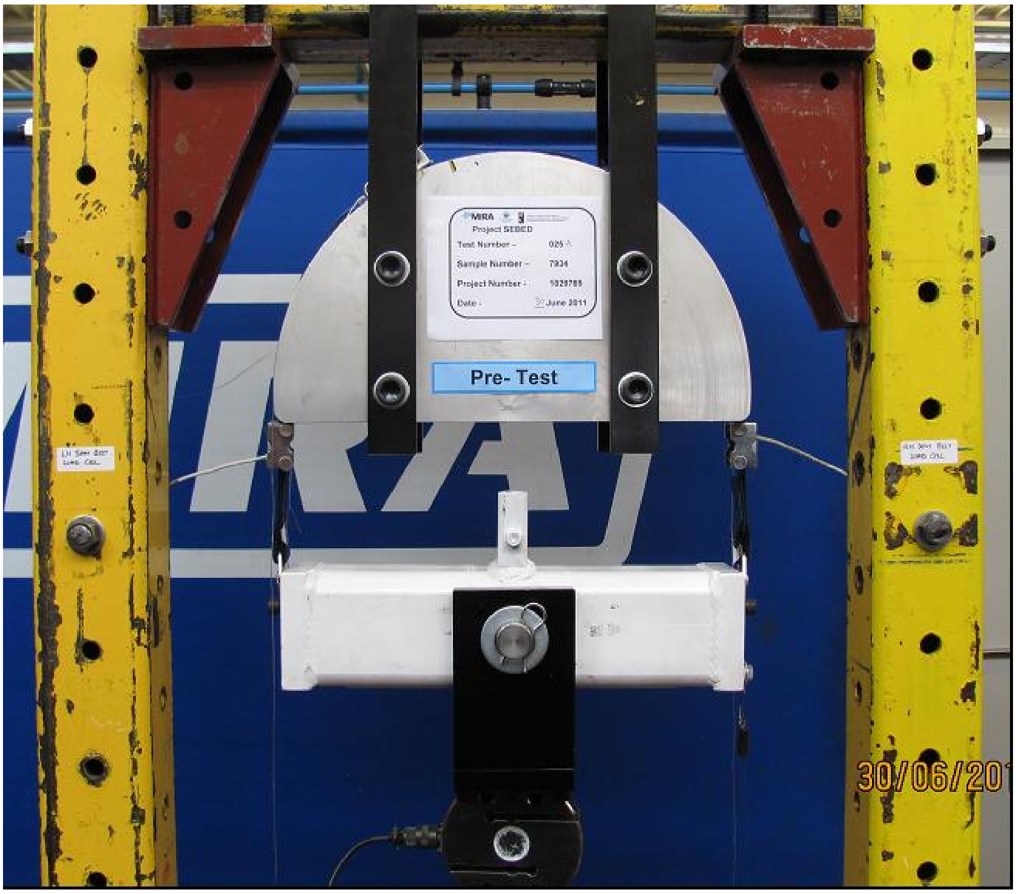

Figure 3. Photograph of the Test Set-up showing Pelvis Block, Seat Belt Attachments and Balance Beam

3.4.1 Elongation Tests

The elongation characteristic tests, Test Method A, were used to ascertain the stress-strain or elongation characteristics and hysteresis of the belt. In the development of the test methodology and procedure, several belts showed catastrophic failures prior to reaching the required AS8043B peak load of 26 kN. In order to gain accurate elongation characteristics and protect the instrumentation the load was reduced to 18kN [4].

The tests started at the initial load of 150N, due to the installation procedure, and were conducted at a loading rate of 9 kN per minute, (equating to a displacement of approximately 75 – 100mm per minute for nylon seat belt webbing material) to a maximum ram load of 18 kN. The load was then maintained at 18 kN for 2 minutes to allow the belt elongation to stabilise, before being reduced at a rate of 9 kN per minute to zero load. The belt was then left to stabilise for 2 minutes with the instrumentation recording before being unbuckled.

3.4.2 AS8043B Compliance Tests

The compliance tests, Test Method B, were used to ascertain whether the belts conformed to the requirements of AS8043B. The belts were loaded to a total ram load of 26.6 kN (13.3 kN on each attachment of the belt).

The tests again started from 150N load, with the test fixture operating at a loading rate of 9 kN per minute, to a maximum ram load of 26.6 kN. The belts were then held at this load for 2 minutes, providing they did not fail, and were then unloaded at the same rate. The belt was then left to stabilise for 2 minutes with the instrumentation recording before being unbuckled.

3.5 ASSESSMENT, DATA ANALYSIS AND REPORTING

3.5.1 Belt Assessment

Prior to performing both Test Method A and Test Method B, each belt was inspected and photographed. Following each test the unbuckling characteristics were assessed, by operation of the buckle, and the belt photographed and visually inspected for any signs of failures, damage or abrasion. Detailed photographs of these specific areas were taken.

3.5.2 Data Analysis

The data recorded during testing was processed to calculate the total belt elongation, buckle and tongue side elongations, along with the belt loads from the seat belt load cells. Peak belt loads and elongations were computed and graphs of belt extension vs. time, load vs. time and belt elongation vs. load produced. The data and photographs were then transferred to HSL for further analysis.

3.5.3 Reporting

Each test was reported with a data sheet, combining all the pre- and post-test observations, peak belt loads and elongations with belt elongation characteristics for both Test Method A and Test Method B. All data was processed and analysed from the seat belt load cell and string

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[4] *Previous testing conducted by MIRA found that this was in good agreement with seat belt loads recorded in dynamic aircraft seat tests to AS8049A..*

potentiometer instrumentation while for Test Method B, only the data from the ram load cell and ram potentiometer was recorded.

All data for each test was then transferred to a test report, an example of which is shown in Appendix B, Section B.3.

4 DYNAMIC TESTING

4.1 BACKGROUND

The purpose of the dynamic testing was to determine whether there was any change in the dynamic performance of the belts as a function of time in service. Fewer dynamic tests were scheduled in the test plan due to the complexity of the testing and instrumentation, the complexity of the data analysis, and the time constraints of the project.

The dynamic test results were then compared with the static test results to ascertain whether there was any relationship between the static and dynamic test results.

4.2 TEST EQUIPMENT

The dynamic tests were performed on the MIRA 'HyGe' reverse accelerator apparatus to the requirements outlined in CS 25.562 for the 16g dynamic test acceleration profile in AS8049A. Two rigidised single seats were used in accordance with the specification in FAA Memorandum ANM-115-05-10 [9], located diagonally offset with respect to each other to ensure no dummy-to-seat interactions could occur, shown in Figure 4. Testing in single seat row configurations allowed high speed digital views to be recorded of the dummy trajectory as well as detailed views of the seat belt and seat belt attachments (stills shown in Figure 5).

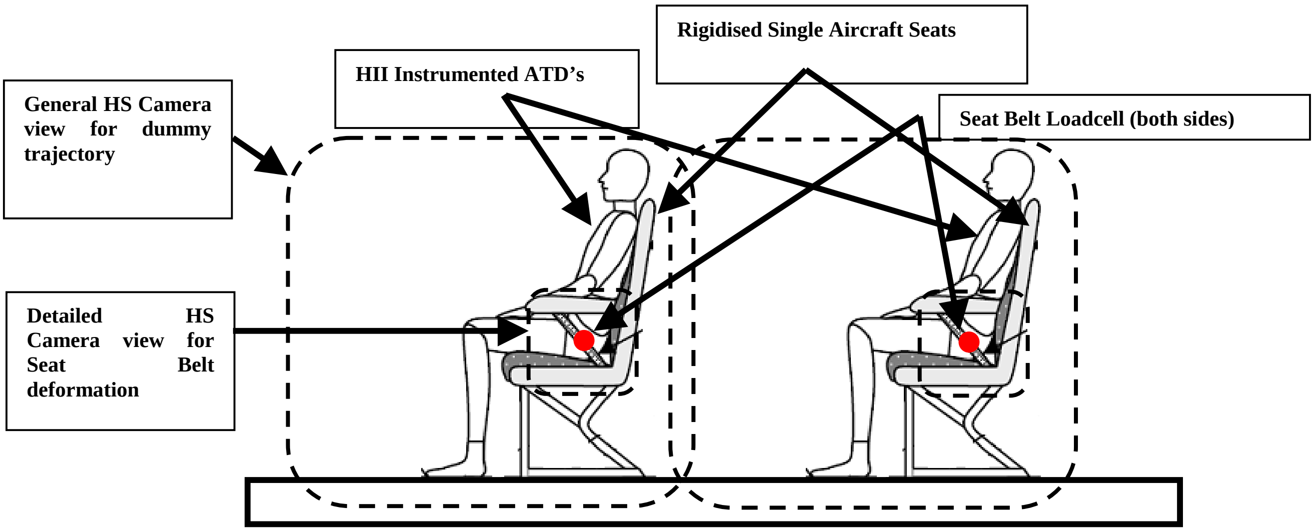

Figure 4. Schematic of reverse acceleration sledge

Fully calibrated HII Anthropomorphic Test Devices with head, chest and pelvis accelerometers were used. Seat belt loads and elongation were measured using high-speed imaging, seat belt load cells, and potentiometers (i.e., the same load cells as used in the static tests to ensure consistency). The same 2 dummies were used throughout the test programme to ensure consistency of dummy location and results.

Further details of the test equipment and procedures are given in Appendix B.4.

Figure 5. High speed video stills

4.3 SAMPLES TESTED

In all 36 belt samples were tested, of which seven were refurbished (i.e. 19% of the belts tested were refurbished). The details and distribution of the samples tested are shown in Table 5.

Table 5. Samples used in dynamic test programme

Age, years	*Rated load, lbs*	*Number of samples*	*Manufacturer*	*Material*
0	3000	6	A	Nylon 6.6
0	3000	3	A	Polyester
0	3000	3	B	Polyester
0	3000	5 refurbished	A/Y	Nylon 6.6
4	3000	3	A	Nylon 6.6
5	3000	3	A	Nylon 6.6
8	2000	3	A	Nylon 6.6
9	2000	5	A	Nylon 6
12	2000	2 refurbished	A/X	Nylon 6.6
13	2000	3	A	Nylon 6.6

4.4 ASSESSMENT, DATA ANALYSIS AND REPORTING

4.4.1 Data Analysis

The data recorded during testing was processed to calculate the total belt elongation, buckle and tongue side elongations, along with the belt loads from the seat belt load cells. Peak belt loads and elongations were computed and graphs of belt extension vs. time, load vs. time and belt elongation vs. load produced. The data was then transferred to HSL for further analysis.

4.4.2 Reporting

Each belt sample dynamically tested was reported separately on a test sample data sheet as shown in Appendix B.6. The test data sheet including:-

- Sample Number, Test Number, Sample Number, Date of Manufacture, and pre test condition.
- Belt Loads, Elongations and Elongation Characteristic.
- Head Forward Trajectory at 138msec.
- Belt Post Test Condition.

4.5 HEAD TRAJECTORY ANALYSIS AND DUMMY KINEMATICS

In evaluating the seat belt, elongation characteristics were considered important to assess the actual belt loading mechanisms and how this related to the dummy kinematics. Therefore a detailed analysis was conducted of one of the nylon baseline tests, namely B135B1 LH seat with a new 3000lb nylon belt. In the analysis, four major phases of belt loading were identified based on the sled, dummy and seat belt loading graphs and instrumentation data presented in Appendix B.4.3-4.5.

Phase 1 - To the first belt load peak at approximately at 70 – 90 msec.

Phase 2 - From the first to the second belt loading peak at 120 130 msec

Phase 3 - From the second belt loading peak to the maxiumum dummy forward trajectory at 135 – 155msec

Phase 4 - Belt unloading from the maxiumum dummy forward trajectory to the end of the test.

4.5.1 Belt Elongation Analysis

The belt elongation characteristic was calculated directly from the string potentiometer and seat belt load cell instrumentation data. This allowed elongation characteristic curves to be produced, as exemplified in Figure 6.

Analysis of the dummy kinematics showed two belt loading peaks. To ensure consistency, the seat belt elongation value used for comparison with the static tests and in the statistical analysis has been taken to the first belt loading peak as shown in Figure 6.

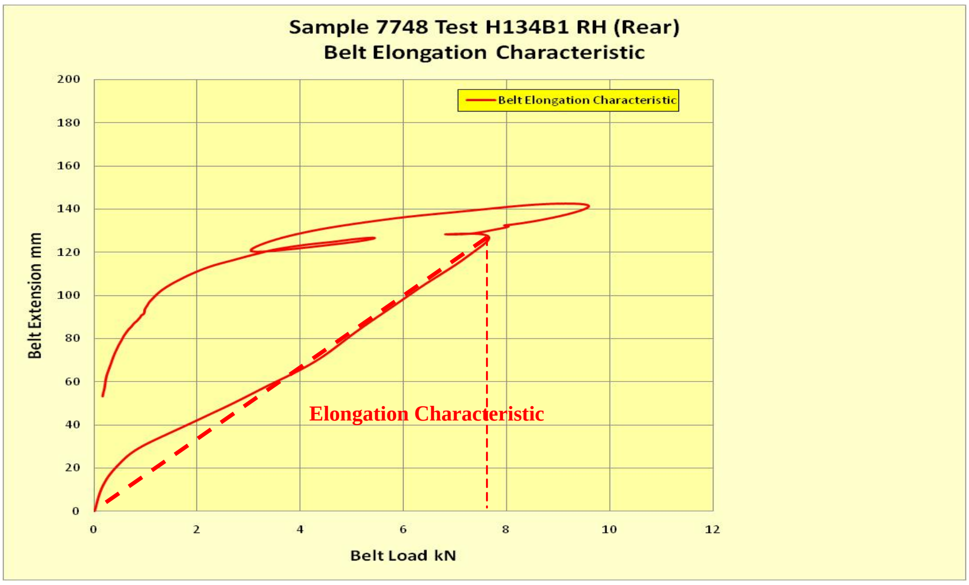

Figure 6. Definition of Seat Belt Elongation Characteristic used in Statistical Analysis

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4.5.2 Comparison of Nylon and Polyester Seat Belts

As part of the analysis of the dynamic tests a comparison was conducted between the baseline new Nylon Belt and new Polyester Belt. This is detailed in Appendix B.4.5.

5 RESULTS AND OBSERVATIONS

5.1 STATIC TEST DATA – COMBINED RESULTS FROM PHASES 1 AND 2

Tables of all the static test results from Phases 1 and 2 are shown in Appendix B.2. All of the data from each phase were then grouped according to the strength rating of the belts, and each group analysed. Graphs of elongation versus age were produced for each of the test methods A and B. The static test data were statistically analysed in order to investigate data trends and statistical significance. The results of this analysis are presented in Section 8.

5.1.1 Test method A results

Figure 7, below, shows the graph of elongation versus age for 3000 lb belts tested to 18 kN load. The overall trend in this data is that as the age of the belts increases, their elongation increases. Newer belts appear to be stiffer. New repaired belts appeared to be as strong, if not stronger than new original belts. The new polyester belts tested showed much lower elongation properties than new nylon belts.

There appears to be a discernable trend in the data, with elongation appearing to increase with increasing age of the belt.

Figure 8 shows the relationship between elongation and age for 2000lb belts tested to 18 kN static load. This graph has fewer data points than Figure 7, and so the data is not as robust. It clearly shows, however that used, repaired nylon belts have a much lower elongation compared to used, original nylon belts. These elongations appear to be fairly similar for all ages, suggesting little influence of ageing effects.

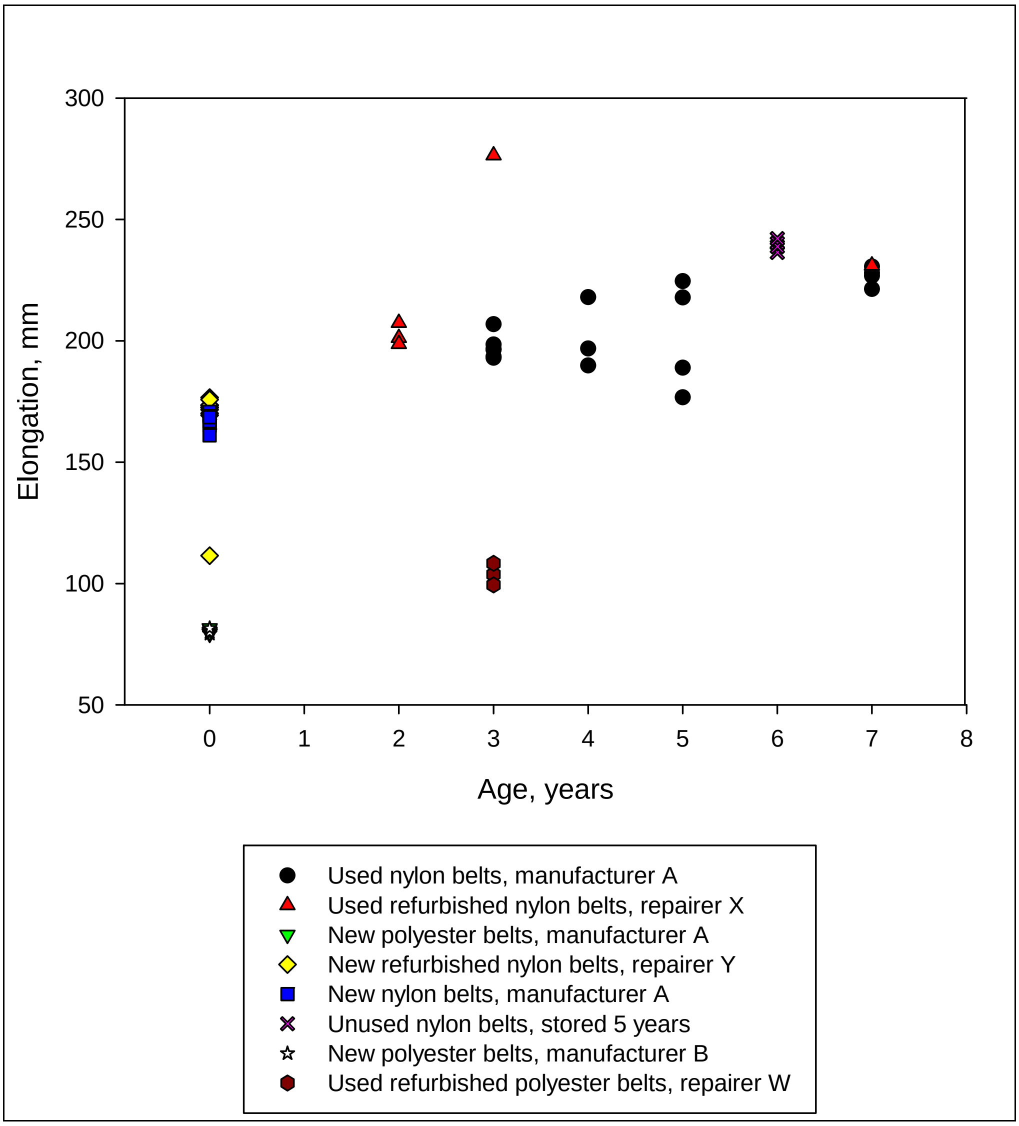

Figure 7. Graph of elongation versus age for 3000lb belts at 18kN static load

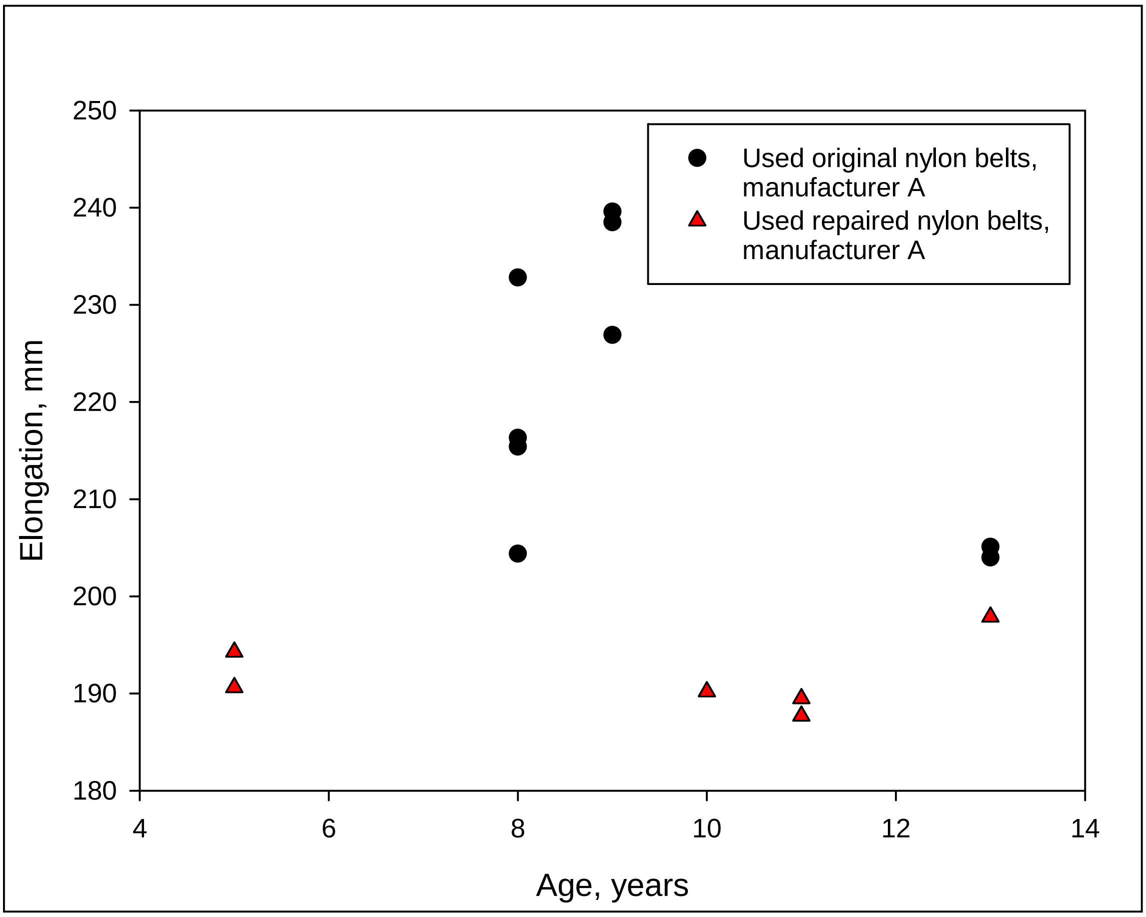

Figure 8. Graph of elongation versus age for 2000lb belts at 18 kN static load

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5.1.2 Test method B results

Figure 9 shows the relationship between elongation and age for the 3000lb rated belts tested in accordance with the AS8043B compliance test. More scatter was observed in the results of this test method, compared with test method A, possibly as a result of the large amounts of slippage of the webbing through the buckle observed during testing. Thirteen fewer results were obtained during this testing, due to the excessive slippage, resulting in the static load of 26.6kN failing to be achieved by those belts.

Many of the 3000lb belts which did sustain the 26.6 kN load were observed to have some degree of slippage. This has not however, been accounted for in the data as the interaction between the slippage, the subsequent relaxation of the webbing and then the further elongation on continued loading is complex. This may account for the increased scatter in the results.

The most significant slippage result observed was for the new polyester belts from manufacturer A. All of these belts slipped on reaching the required load, and were unable to sustain it for the required time, hence no results are recorded for these belts. (Slippage is discussed further in Section 5.4).

One of the belts from Manufacturer C, repairer W tested in Phase 2 (test 70), failed the static test due to the webbing severing at the buckle. Both of the other belts by the same manufacturer/repairer exhibited full width abrasion damage at the position where the buckle had been (tests 68 and 69). Two other belts exhibited post-test damage in the form of unravelling of the edges of the webbing (tests 66 and 67). These belts originated from manufacturer A and had been refurbished by repairer X.

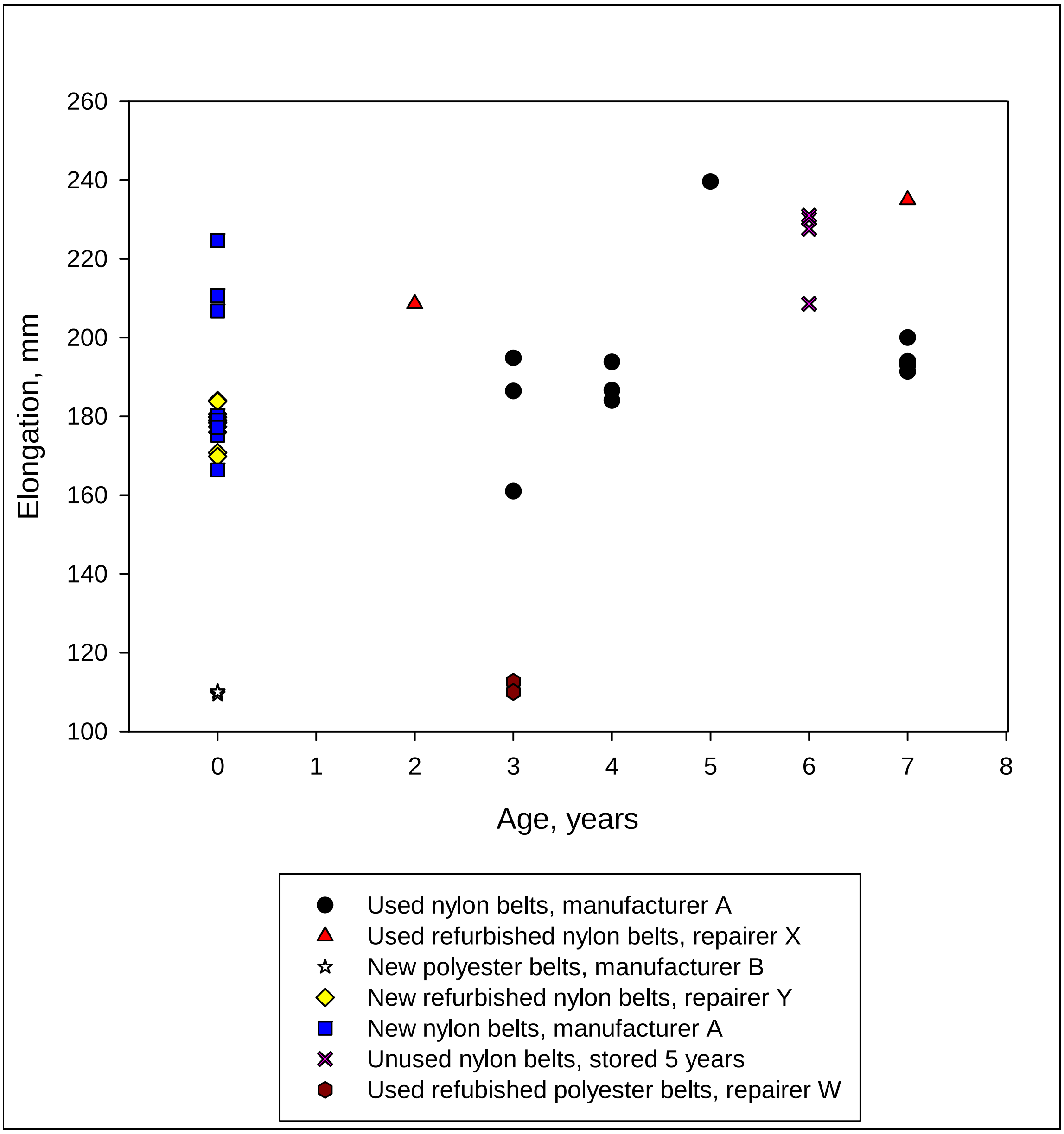


Figure 9. Graph of elongation versus age for 3000lb belts at 26.6 kN static load

The data appears to show a possible increase in elongation with age, although the trend is less obvious in this data. As before the polyester belts (Manufacturer B) show lower elongations than the nylon belts.

Figure 10 shows a graph of elongation versus age for the 2000lb belts at 26.6kN. Sixteen belts of this strength rating were tested to 26.6kN and interestingly, seven of these were able to meet the requirements despite being manufactured to meet a lower maximum strength specification. The belts, which could not sustain the load in Phase 1, had all failed at the hooks. These hooks were made from aluminium, and many were heavily worn (the hooks on the 3000lb belts are made from steel). All three 2000 lb belts tested in Phase 2 failed, two due to hook failures and one due to buckle failure (test 72). Four of the belts, which met the test requirements, were repaired. These are interesting results since the hooks on these belts were likely to have been in service longer than the used original belts.

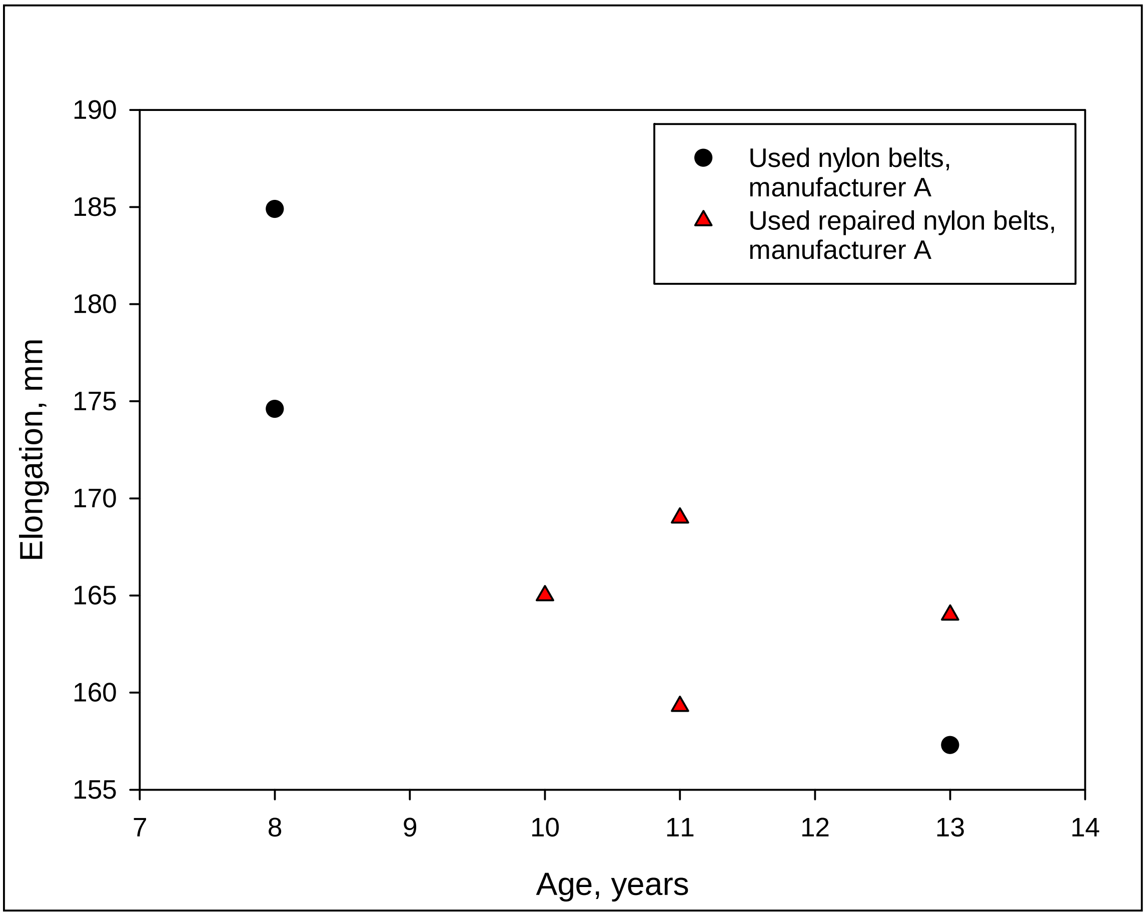


Figure 10. Graph of elongation versus age for 2000lb belts at 26.6 kN static load

The data shows a definite downward trend, indicating elongation decreases with age for the 2000lb belts. Due to the low number of data points however, the data cannot be considered statistically sound. Further data would be required over all the age ranges in order to establish a trend and to investigate whether there is a steady decline or a sudden drop off.

5.2 DYNAMIC TEST DATA

A table of all of the dynamic test results is shown in Appendix B.5. The data were sorted into two groups based on the rated strength of the belts and each group analysed separately.

Figure 11 shows a graph of elongation per unit load for all tests conducted for both the 3000lb and 2000lb belts. This graphs shows a slight increase in elongation with time for 3000 lb belts. The data obtained for the unused stored nylon belts show a slightly higher elongation than that for the new belts. The polyester belts displayed lower elongation than the nylon belts.

Figure 11 also shows the data obtained for 2000lb belts from the dynamic tests. These data show that there appears to be a decline in elongation of the belts in the range of 9 to 13 years service. The repaired belts tested appear to fit this trend.

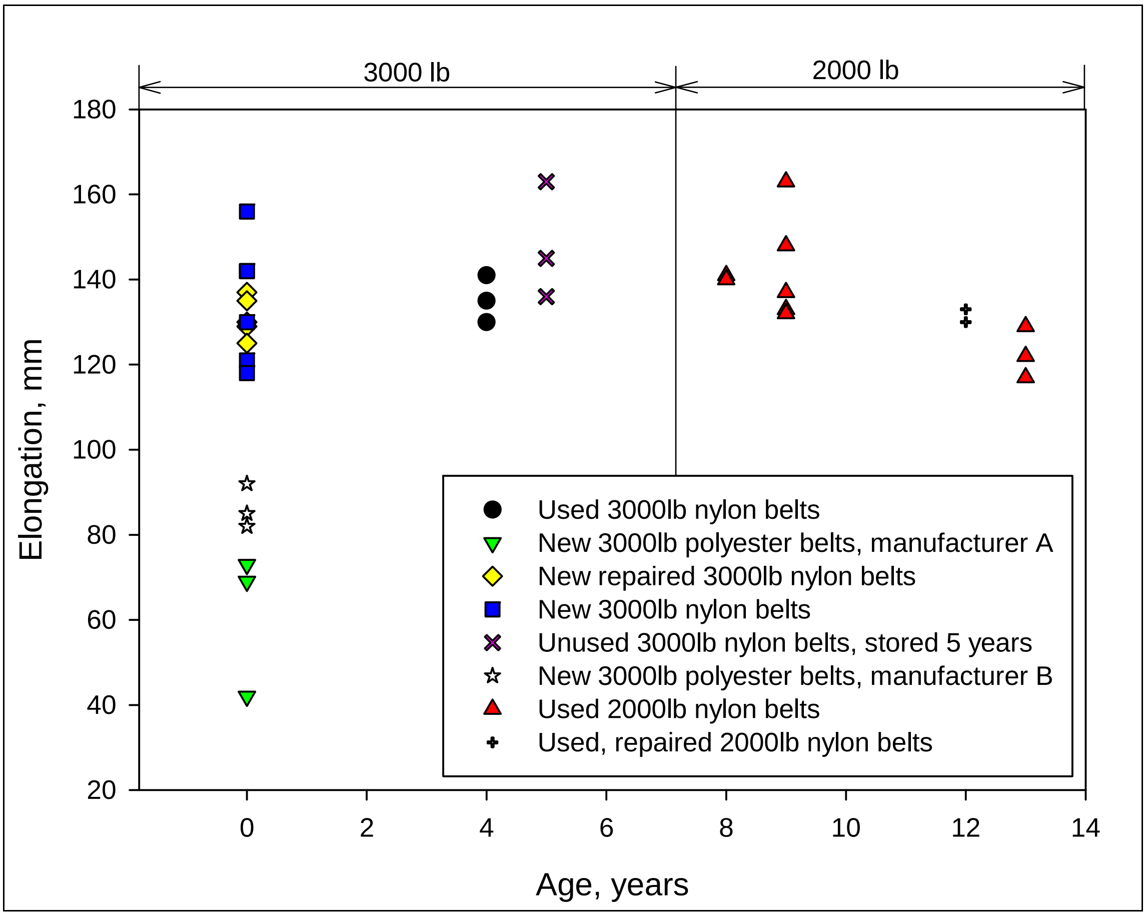


Figure 11. Graph of elongation versus age for belts tested dynamically

5.3 COMPARISON OF STATIC AND DYNAMIC TEST DATA

The data obtained in the static and dynamic tests were compared to determine whether there was a relationship between them. Belt loads recorded during dynamic testing were analogous to those used in Static Test Method A, 18kN. Belt extensions were uniformly lower across the entire range of samples tested dynamically compared with the static data.

The reason for this difference is thought to be related to the way in which load is dissipated in webbing when subjected to dynamic loads. During static loading the fibre bundles, or yarns, in the weave of the webbing have time to align themselves longitudinally to spread the load uniformly across the fabric. The longitudinal, or warp yarns, take the load and the transverse, or weft, yarns hold the warp yarns in place. As the load increases, the fibres continually re-orientate within the yarns and stretch; the warp yarns are spread further apart, taking a small proportion of the load, but also stretch to allow extension of the webbing.

During dynamic loading, however, the load is applied sufficiently rapidly that there is less time for movement of warp or weft yarns and any alignment of fibres to take place. Some of the dynamic energy is also dissipated as heat. This results in lower overall extension of the fabric occurring for any given load compared with static testing.

Graphs of load versus extension were produced for both the static and dynamic tests for each sample. These were then compared by overlaying the data for each test method. It can be seen from Figure 12, which shows a comparison of the data obtained for new nylon belts from Manufacturer A, that the load versus elongation curve obtained in static testing closely follows that for dynamic testing initially but shows greater final elongation.

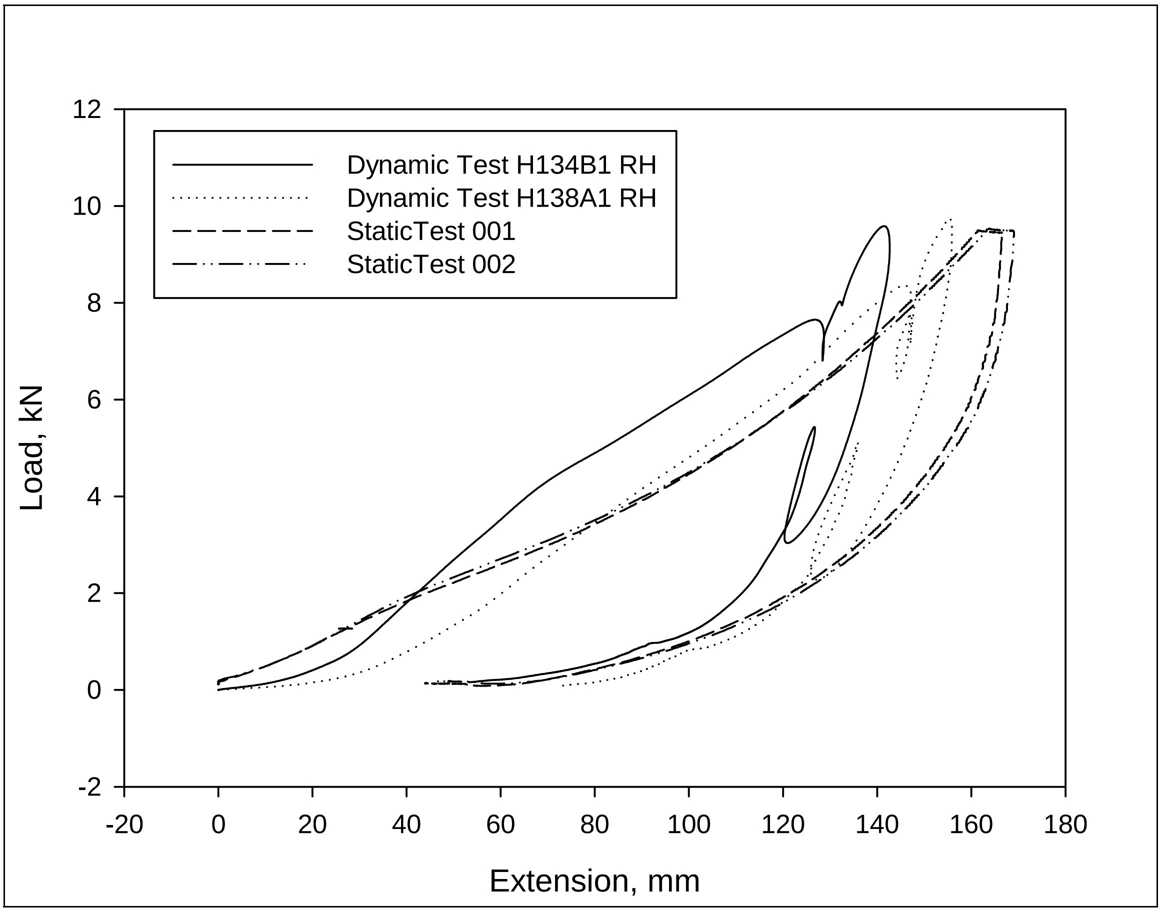


Figure 12. Comparison of load extension curve for dynamic and static test methods on new nylon belts from manufacturer A.

Examination of the maximum elongations found that there was no obvious relationship between static and dynamic results, and that the differences between the two ranged from 28% to 14% for different age groups of webbing. Figure 13 illustrates the difference between the results obtained for the 2000lb belts by both static and dynamic testing. These data were selected since they have fewer variables than for the 3000lb belts.

The lower values obtained for elongation in dynamic testing have arisen due to the elongation values being taken here from the first peak on the load-elongation curve, the reasons for which are discussed in section 4.4.3.

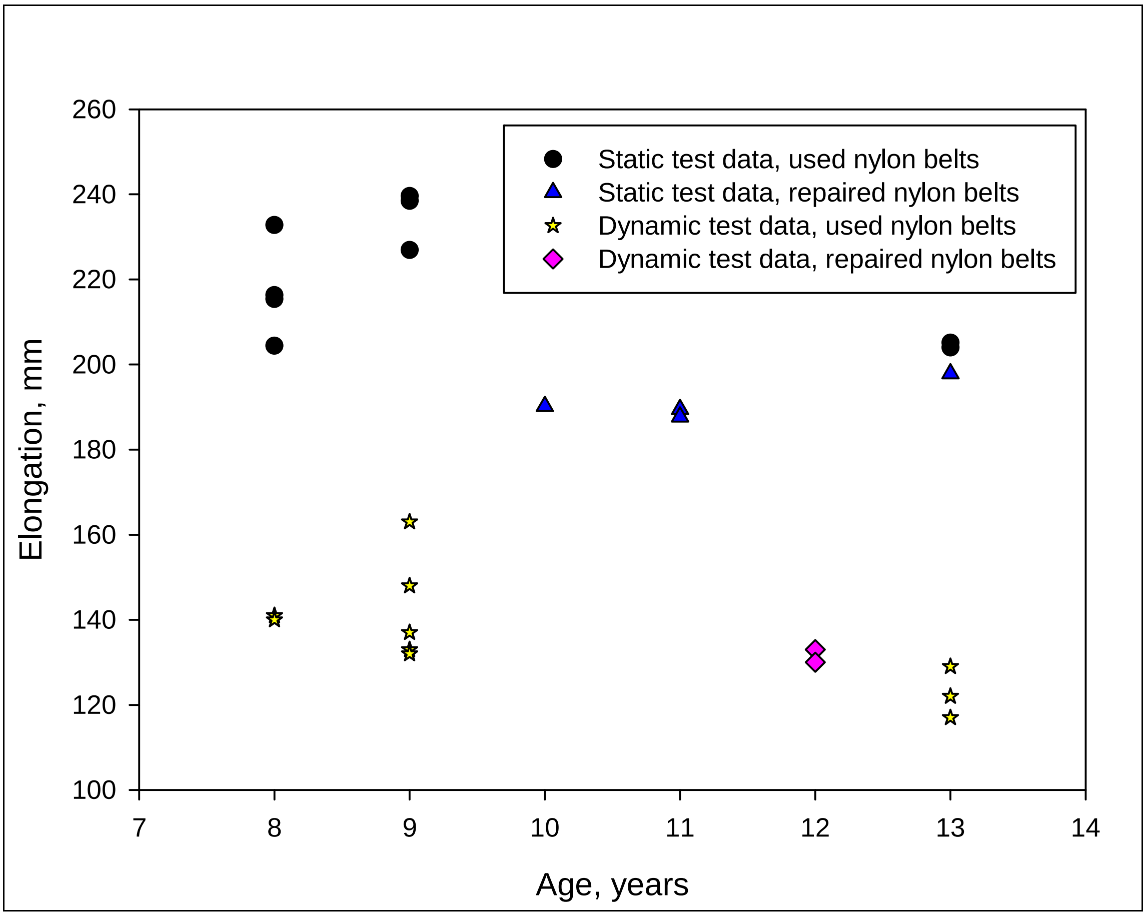


Figure 13. Comparison of static and dynamic test results for 2000lb belts

5.4 OBSERVATIONS

It was observed during testing that many belts failed to sustain a load of 26.6 kN due to the webbing slipping through the buckles. All of the belts had lift-lever buckles fitted to them, of similar designs and all of the belts affected by this slippage had the same design of buckle. The buckle design which allowed slippage was one in which the bar or slide is smooth-surfaced with a stepped profile (Figure 14a) made by manufacturer A. All of the other buckle designs tested incorporated a bar or slide with a knurled finish, providing a higher friction surface (Figure 14b). Manufacturer A also produced buckles of this design.

Slippage of the webbing through the buckle caused considerable damage to the used belts and damaged the new nylon belts to a lesser extent, but no such damage was caused to the new polyester belts. This may indicate that polyester webbing has a lower coefficient of friction than nylon webbing.

Figure 14 a) Stepped profile buckle slide bar (left) and b) knurled cylindrical slide bar (right)

AS8043B allows the use of fabric and a small amount of padding to prevent slipping of the webbing through the buckle. No particular fabric type is specified, however, and manufacturers are allowed to use a material of their choice. No fabric was used between the belt and pelvic block during the static tests conducted in this study.

Other failure mechanisms observed were attachment hook failures on the 2000lb rated belts; webbing being cut by the buckles and failure of buckles themselves.

5.5 HEAD TRAJECTORY ANALYSIS

Head trajectory information was recorded during the dynamic tests. and the data can be seen in the table in Appendix B.5. These data were scattered and showed no overall trend as a function of age. There was also little difference between the 3000lb belts and the 2000lb belts, as is shown graphically in Figure 15, below.

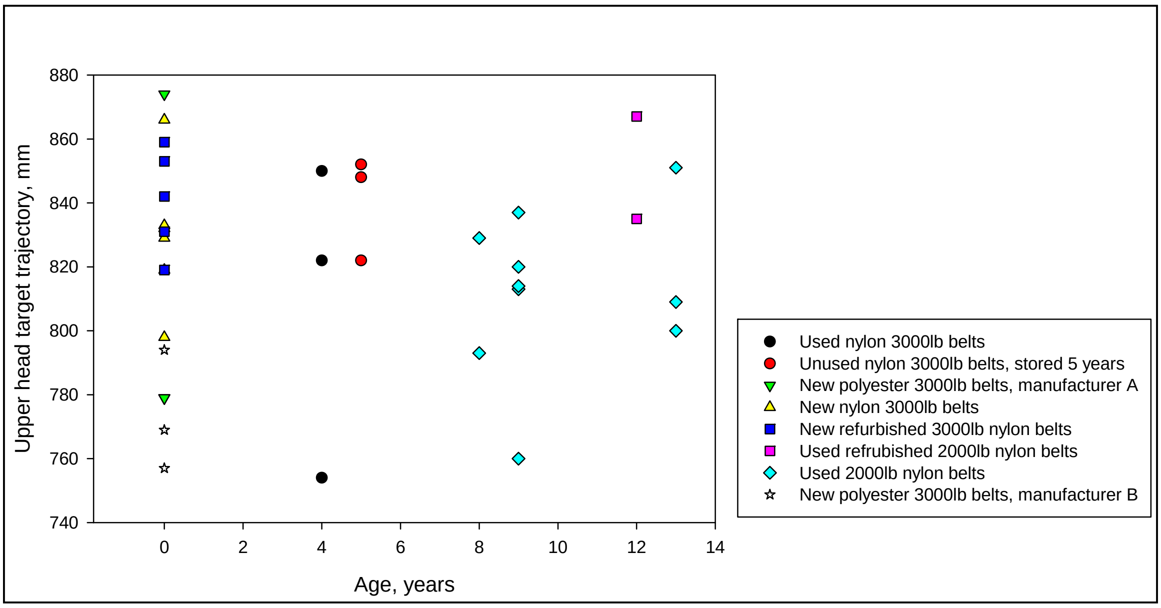


Figure 15. Graph showing head trajectory with age of belt

New polyester belts from manufacturer B showed smaller head trajectories than the polyester belts from manufacturer A, however the results for Manufacturer A showed a large amount of scatter, with the resulting head trajectories being of a similar order to both new and used nylon belts of all strength ratings. Figure 16 shows the relationship between the upper head trajectory and elongation of the belt, again showing no obvious overall trend. There do appear to be two distinct groups, however with the elongations and head trajectories for polyester belts being generally smaller than those for nylon belts.

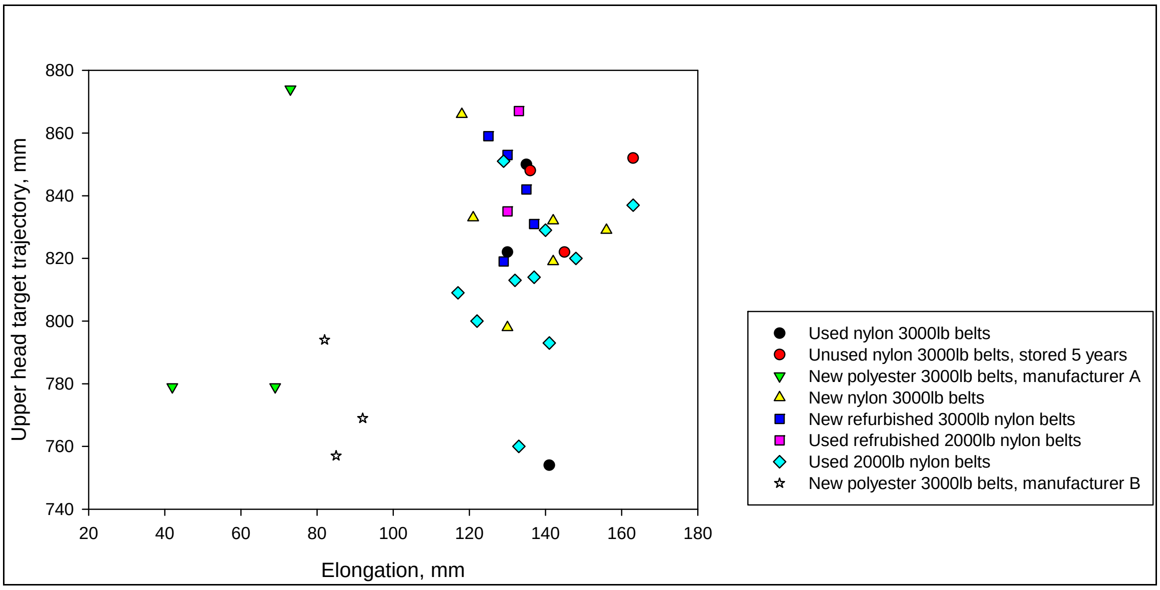


Figure 16. Graph showing head trajectory with elongation of belt

6 FEASIBILITY STUDY PHASE 1

6.1 BACKGROUND

The purpose of the feasibility study was to develop a small-scale test method, which would dynamically load a belt sample in the same manner as would testing using the sled test method specified in AS8049A.

A requirement of the small-scale test method, in the original proposal from EASA was that it should be able to reproduce the 16g deceleration pulse defined in AS8049A, identical to that created in the sled test.

This was considered unfeasible because the 16g pulse is measured on the sled itself and is a feature of that method of testing. The 16g pulse is therefore, specifically related to a full scale simulation of the test criteria, which the sled and the acceleration method employed.

The actual pulse experienced by the belt is attenuated by the fixtures and fittings on the sled, i.e., the seat and fixings, seat cushions and the abdomen of the dummy. Each of these fixtures and fittings will therefore experience a different deceleration (g-force). This means that the 16g pulse is only relevant to the motion of the sled itself and not the dummy or the belt. Dynamic testing of the webbing showed that the actual abdominal deceleration of the dummy was very different to the 16g pulse in both magnitude and duration, and that the profile was complex and would be difficult to match.

As a result of eliminating the sled test, and therefore the seat and the dummy, the 16g pulse is no longer relevant to the small-scale test. Applying a 16g deceleration pulse to such a small-scale rig would result in different loading conditions to those, which would be seen during the dynamic test. Effectively, the application of such a pulse would not be representative of the dynamic test.

The decision was taken therefore, with the agreement of EASA, to base the small-scale test method on the force pulse experienced by the belt rather than the deceleration pulse. In this manner, the belt would be loaded in exactly the same way as in the dynamic test method, over the same timescale. Deceleration would still be measured using an onboard accelerometer.

6.1.1 Limitations

In order to keep the test rig small, it would have been unfeasible to accommodate a full seatbelt into the rig and load it in a meaningful manner without employing a large pelvis block such as that used for static testing, thus increasing the size of the rig. It was important to keep the test rig heavy enough to achieve the correct level of force in the belt, but light enough that it could be effectively decelerated over a short distance.

The preferred option, therefore, was to test the short section of the belt (referred to as the ‘tongue side’), using the fittings already stitched onto it to attach it to the test rig. Capability for testing the other side of the belt, was included in the form of a scroll grip attachment, which could clamp the webbing without damaging it. However, testing using the scroll grip was not the preferred option, as the elongation of the sample occurs not only in the gauge length of the sample, but also in the fabric which passes around the scroll grips, to different extents. This means that measuring the elongation is difficult and prone to inaccuracies in this case.

Since the string potentiometers used for both the static and dynamic testing directly measure the elongation of each part of the belt, as well as the belt as a whole, direct comparison can be made when testing the short section of the belt, which would not be possible if testing a sample of the belt webbing alone or gripping the belt in any other way.

6.2 EVALUATION OF POSSIBLE APPROACHES

6.2.1 Hydraulic test equipment

The use of hydraulic test equipment, such as servo-hydraulic test machines, was not a viable method of testing the belts as the reaction times of hydraulic pistons were too slow. To reproduce the required impact forces, hydraulic pistons would be unable to produce the required force pulse.

Also, servo-hydraulic test machines do not generally have sufficient stroke to produce the necessary displacement to accelerate the belt to the required velocity. The belts exhibited a large elongation during static testing, which many commercially available test machines are unable to accommodate.

6.2.2 Pneumatic equipment

Pneumatic cylinders operate faster than hydraulic cylinders, but still cannot operate fast enough to produce the required force pulse, unless in the form of a gas gun. The reverse accelerator used for dynamic testing incorporates a gas gun and a braking system; however, to replicate this on a smaller scale would have been too time consuming to attempt as part of this project. Also the cost of such a rig as a small-scale test would be large with skilled operators required. This made it an unfeasible choice for a small-scale test rig.

6.2.3 Pendulum impact test

The limitations of a pendulum test machine meant that it was also too slow to use for this research. Pendulum impact testers typically produce low energy, long duration impacts. The energy produced by the swinging pendulum depends on its mass and the arm length. In order to create sufficient velocity in the pendulum, the arm length would have had to have been too large for the test rig to be considered small, and therefore this approach was considered unsuitable. Also, the energy absorption system would need to be much more compact and integrated into the arc of the swinging pendulum.

6.2.4 Drop test

The method which was considered to be the most likely to produce the test pulse required was drop testing.

A purpose made drop test machine, called a Rosand tester, was considered for this purpose. It has the capability of achieving impact velocities up to 20 ms^{-1}, using a bungee accelerated drop mass. The limitations of the testing machine, however, meant that whilst suitably fast, the small size of the drop mass meant that meaningful samples of belt could not be accommodated within the machine. Also, the machine depends on all of the mass deceleration being provided by the sample under test, with no other means of tuning the deceleration. For this reason, another existing test rig, manufactured by HSL ,was considered more appropriate. The HSL test rig had been manufactured in order to test samples of webbing material to failure. It was a separating drop rig on guide wires with in-built loadcells. It was considered that with a redesign of the weighted part of the rig, coupled with the introduction of an energy absorption system, this rig would be capable of providing the required force pulse in a small space.

6.3 DESIGN AND CONSTRUCTION OF TEST EQUIPMENT

The webbing drop test rig was originally designed to determine the dynamic breaking load of webbing materials. It was designed only to hold webbing samples by the use of scroll grips, and had no energy absorption in the system. The rig was designed to fit inside an existing drop test facility at HSL, as it had an inbuilt winch, and interlinked safety and control system. It was decided to use this facility since it addressed all the safety concerns related to drop testing.

The design of the test rig comprised a lightweight carrier section for the top of the rig, onto which a grip was attached. Figure 17 shows a photograph of this design. The bottom section comprised a fixed lower plate onto which slotted weights could be stacked, with an upper clamping plate. Rectangular plate slotted weights, each of 20 kg, were manufactured to vary the drop forces that could be produced. Two load cells were attached to the upper clamping plate of the weight pack, which held another grip. Two threaded bars were fixed to the lower clamping plate, which passed through the weight pack, through holes in the clamping plate where the weight pack could be secured by nuts, and through the top section of the rig to which they were not bolted, but acted as guides. A nut on each bar, underneath the top section allowed any slack in the belt to be adjusted, allowing the belt to be pre-tensioned prior to drop testing.

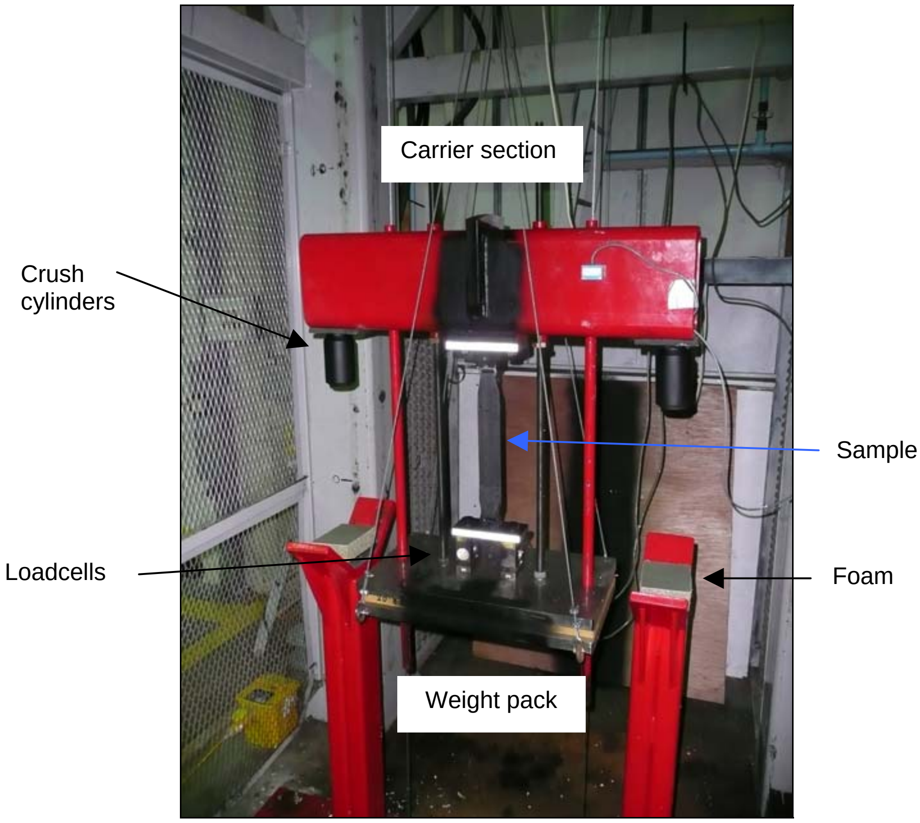


Figure 17. Photograph of feasibility study test rig

The test rig was substantially redesigned in order to accommodate aircraft seat belt fittings. It was decided after discussion with EASA representatives that the best part of the belt to test would be the short section incorporating the tongue of the buckle mechanism at one end and the attachment hook at the other. This removed the risk of slippage through the buckle, which was observed to affect the static test results.

Fittings were manufactured to allow the hook and the tongue to be clamped securely in the test rig. A scroll grip was also manufactured to allow the webbing from the longer, buckle side of the belt to be gripped at one end and fastened using the attachment hook at the other. Since only the tongue side of the belt was tested, this had the benefit of avoiding the use of scroll grips in this testing.

In order to control the drop, tensioned guide wires were secured to a support frame installed in the tower facility and to a base plate, using eye bolts, and tensioned using turnbuckles until just taut. Both top and bottom sections of the rig ran through the guide wires ensuring they would impact in the correct position on the arresting devices. In order to prevent damage to the guide wires, they were designed to be fully enclosed in tubes attached to the top section of the rig. These tubes passed through holes in the bottom of the rig so as to allow unhindered separation of the two parts.

The base plate incorporated arresting devices for both parts of the rig: two impact columns positioned one metre apart, and one metre tall arrested the top section, and two energy absorbing pads in the centre of the plate formed an arrest buffer for the bottom section (should it separate due to failure of the belt).

The rig was designed to be raised and lowered on the existing winch in the drop tower facility, allowing a drop from any height up to two metres. It was lifted using wire strops attached to the fixed lower plate of the bottom section. The rig was dropped from the winch hook using a remotely operated electronic release hook.

6.4 INSTRUMENTATION

6.4.1 Loadcells

Two calibrated Tedea-Huntleigh 2000 kg capacity S-Beam Type 620s loadcells were built onto the weight pack section of the test rig and acted as the mounting points between the lower attachment and the weight pack. These directly measured the force applied to the belt during testing.

6.4.2 Accelerometer

A Sensortec +/-20g uniaxial accelerometer was mounted onto the cross-beam on the upper part of the test rig in order to measure the deceleration of the test rig. The positioning of this accelerometer was analogous to the sled-mounted accelerometer on the reverse deceleration test rig used for the dynamic testing.

6.4.3 Line-scan camera

The line-scan method of measuring displacement was originally developed in the Field Engineering Section (now the Engineering Safety Unit) of HSL. The line-scan camera was designed for precise measurement of components for quality control. It was originally used to measure the distance between two points by scanning across an item, recording the data as a line of 1024 greyscale pixels. Measurements can then be taken between areas of high contrast, either naturally present on the item, or created by placement of markers. In order to create a time history, software was developed by Software and Control Section, HSL, to store individual lines of pixels as a single bitmap image. Images captured by a line-scan camera have a much higher resolution than those of a conventional video camera, and the image is captured much faster.

The camera was set up to measure two points on the test rig: one on the top attachment point and one on the bottom. These two points were identified with thin strips of retro reflective tape. This gave a high contrast area which could be clearly seen by the camera from the distance required to fit the whole rig in the frame. The camera was set-up with a line rate of 2 kHz, a capture period of 2000ms. This meant that the resultant bitmap showed a time period of 2 seconds, with each row of pixels being equivalent to 0.5 ms.

The separation of the two sample grips was measured before each test, to calibrate each image, and allow calculation of the extension to failure.

6.4.4 Logger

Both loadcells and the accelerometer were recorded using a Nicolet Vision data logger, logging at 2 ksamples/second. The data was unfiltered. The loadcells were signal conditioned by a pair of 378-TA Fylde amplifiers. The accelerometer was powered using a similar Fylde amplifier, however the output from this was also recorded unfiltered.

6.5 LINE-SCAN IMAGE ANALYSIS

The data from the line-scan camera was recorded in the form of a bitmap, measuring 1024 pixels wide by 4000 pixels in length (Figure 18). The width of the bitmap corresponds to the size of the image on which the camera is focussed, in this case the resting position of the drop rig. The length of the bitmap corresponds to the recording time, which in this case was set to 2 seconds, and therefore each pixel represents 0.5 milliseconds.

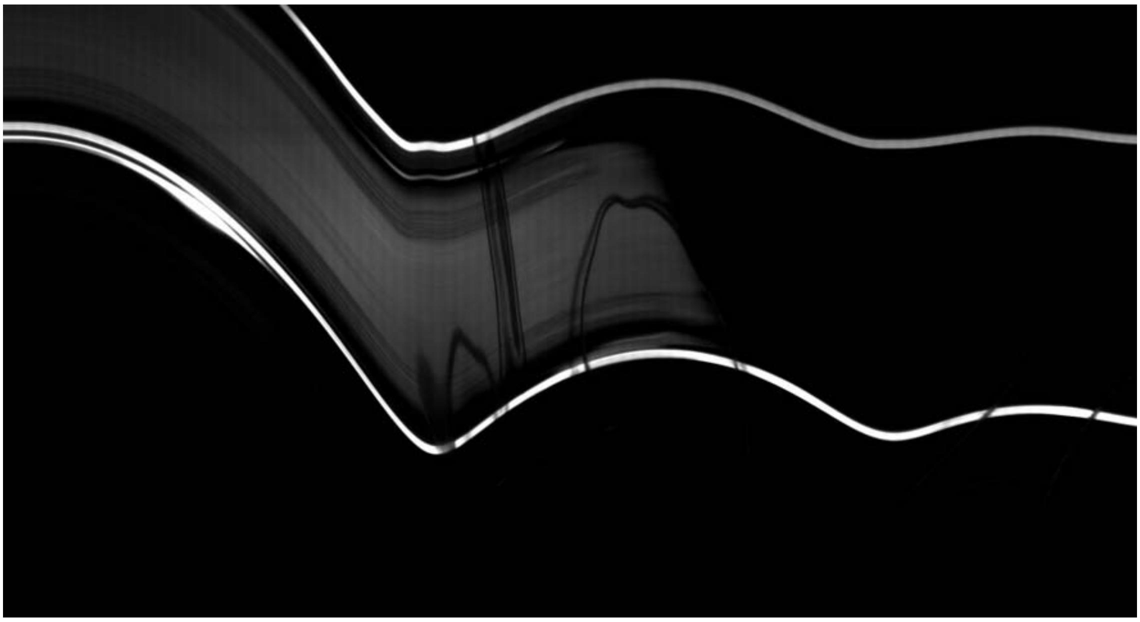


Figure 18. Original image captured by line-scan camera

The bitmaps were analysed using bespoke software developed by HSL (Figure 20). Each image consisted of a black background with two white lines passing through it. These bands were made up of single line-scan images of the changing position of the marker strips, on the sample grips of the rig, recorded at 0.5 ms time intervals. The line to the top of each image represents the position of the top section of the rig, and the line to the bottom represents the position of the bottom section of the rig.

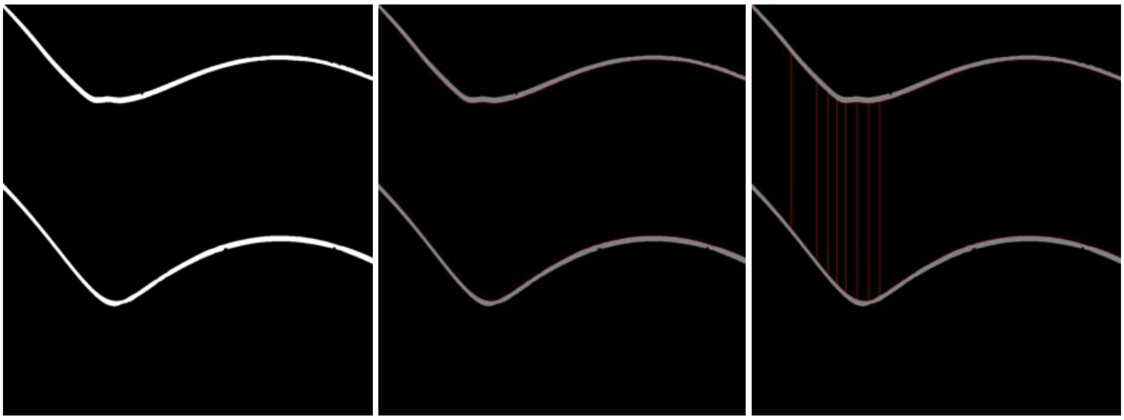


Figure 19. Analysis conducted by HSL in-house software. *From left to right: thresholding to remove background noise, insertion of red reference lines, measurement of reference line separation*

Before each test, the separation of the marker strips was measured, and this measurement was then applied to the line-scan image data to calculate the elongation. A plot of elongation versus time was then generated, from which elongation to failure could be determined (Figure 20).

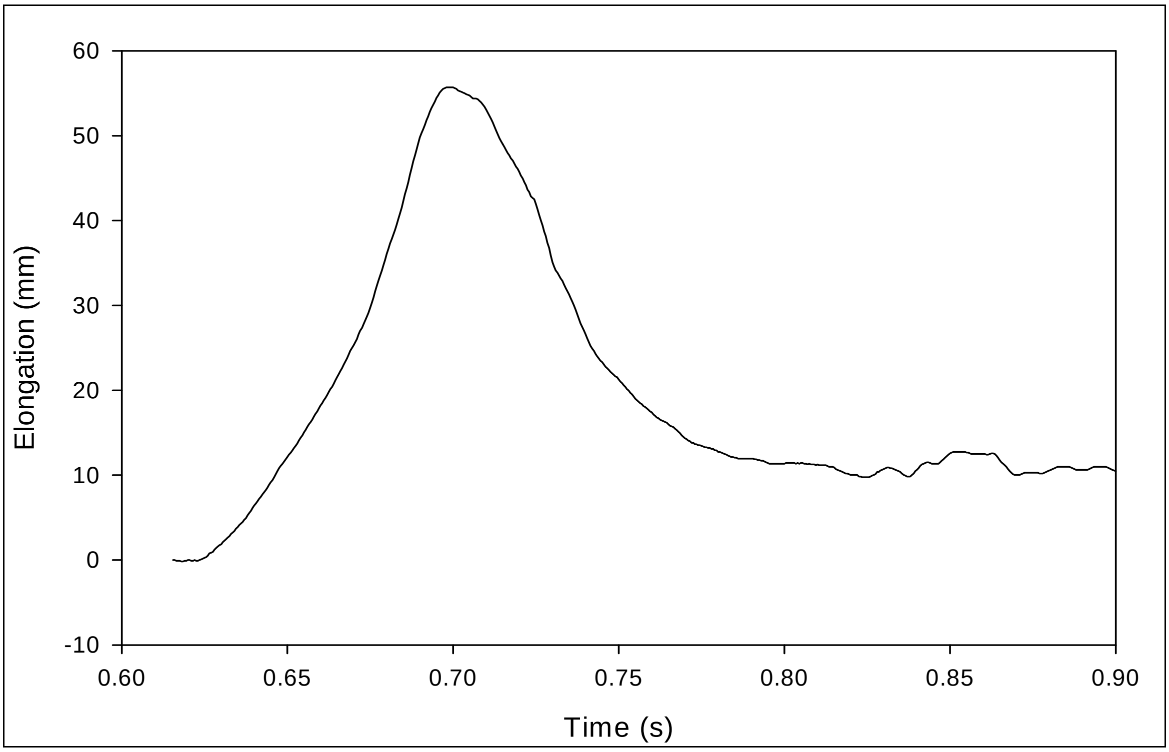


Figure 20. Graph of extension (change in separation) against time, created from the measured data.

The point of failure could be seen on the plot at the peak of the triangular pulse. Using both the data from the line-scan images and the loadcell data, graphs of load against extension were plotted. The time to reach peak load was typically of the order of 80 ms.

6.6 DEVELOPMENT OF ENERGY ABSORPTION SYSTEM

Initial calculations of the energy absorption requirements of the test rig indicated that, based on a drop test mass of 37.5 kg (half the mass of the Hybrid II ATD) and a required deceleration of 16g, the deceleration distance would be 1.2 metres for a full belt.

A variety of different materials with different mechanical properties were used during commissioning tests. Materials were chosen with different energy absorption characteristics, in order to provide a range of possible deceleration profiles. Materials chosen included aluminium honeycomb, expanded foams, rubbers and aluminium crush cans.

These materials were used both on their own and combined together.

The properties of the most successful energy absorber, i.e., the material or combination of materials would then be used to specify a shock absorber, which would replicate the stiffness and stroke of these energy absorption materials.

6.7 COMMISSIONING TESTS

Thirty-six commissioning tests were carried out using different drop heights and combinations of energy absorbing materials. Varying the drop height changed primarily, the impact force experienced by the belt, with a secondary effect of changing the duration of the pulse. Changing the energy absorbing materials changed primarily the duration of the pulse, with a secondary effect of changing the impact force.

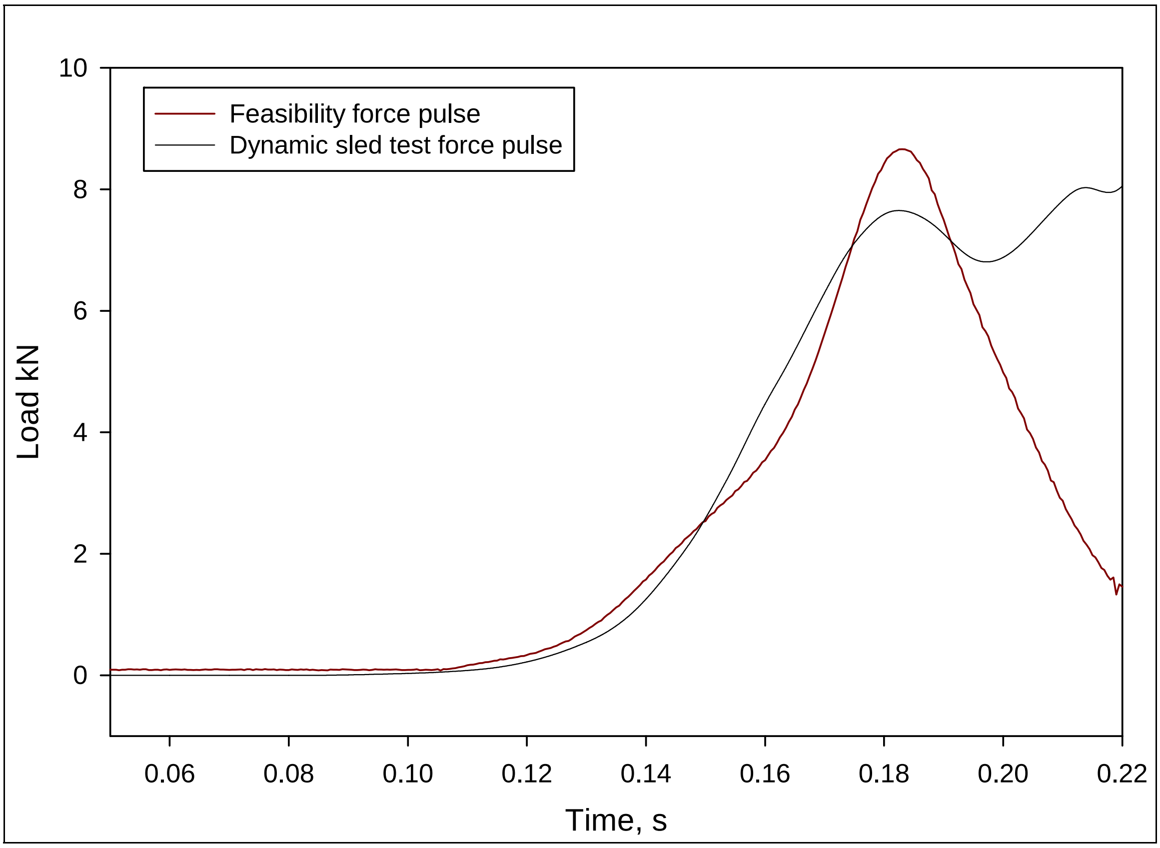


Figure 21. Comparison of force pulse from dynamic sled test with that achieved in the feasibility rig

Tests were carried out using the tongue side of used belts, all of which had been procured from the same source and were of the same age. As these belts were from the batch which had worn labels, the samples were used for commissioning only, the data being used only for development of the feasibility rig. Each seatbelt sample was used for only one test.

By an iterative process during the commissioning tests, a drop height of approximately 300mm was found to generate the correct force for the length of belt being tested.

A combination of three stiff rubber pads, each 10mm thick, a 115mm tall aluminium crush can filled with expanding polyurethane foam and a 40mm thick polyurethane foam pad on each of the two catching arms were found to provide the optimum energy absorption, resulting in a force duration approximately equal to that obtained during dynamic testing (Figure 21). The compressive properties of all three materials were determined by compressive testing in a 50 tonne capacity universal test machine, and are presented in section C.2 of Appendix C.

6.8 TEST METHOD

The total mass of the drop rig was 77 kg. A drop height of 300 to 350mm was used depending on the length of the samples tested (shorter drop distances were used for shorter belts) in order to generate similar force pulses.

Only the tongue side of the belt was tested, clamped by the hook and tongue at either end by specially manufactured fittings.

Force data was recorded with respect to time. Linescan displacement data was recorded with respect to time, and the two data sets processed and synchronised as described in Section 6.5.

The belts were measured and examined before and after testing.

6.9 RESULTS AND OBSERVATIONS

A series of 25 tests were conducted on the samples detailed in Table 6 below, including new, used and refurbished belts. The full table of results is included in Appendix C1.

Table 6. Samples used for feasibility study testing

Age, years	*Rated load, lbs*	*Number of samples*	*Manufacturer*	*Material*
0	3000	5	A	Nylon 6.6
0	3000	3	A	Polyester
3	3000	3	A	Nylon 6.6
5	3000	3	A	Nylon 6.6
8	2000	3	A	Nylon 6.6
14	2000	3	A	Nylon 6.6
0	3000	5	A/Y	Nylon 6.6

The initial tests carried out were on new nylon seatbelts from Manufacturer A. The results obtained from these tests were then compared with those obtained during dynamic sled testing. Figure 22 shows a comparison of the load versus extension curves obtained from the feasibility study and those obtained during dynamic sled testing. The feasibility study load extension curves were found to generate more consistent force extension profiles than the dynamic sled tests.

Comparison of the force extension traces, in red, showed good agreement between the profiles obtained from the feasibility test rig, demonstrating the high repeatability of the test method.

Comparison of the feasibility traces with the traces obtained during dynamic testing shows good agreement between the two test methods, however it can be seen that the dynamic test is more variable (and so has lower repeatability) than the feasibility test.

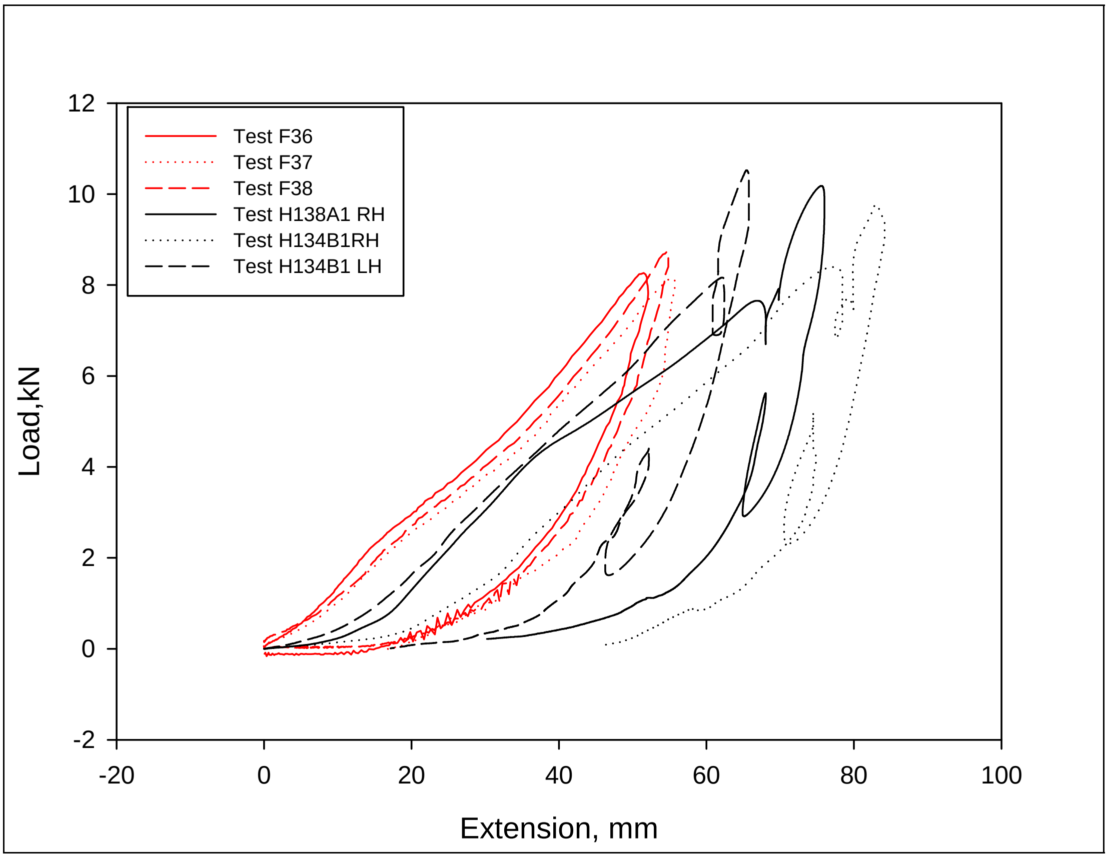


Figure 22. Comparison of force profile from dynamic testing (black) and the feasibility test rig (red) for the tongue part of belts for new nylon belts from manufacturer A

Figure 23 shows an overview of the results obtained from the feasibility study. Results for both 2000lb and 3000lb belts are included in this graph as only a small sample of belts were tested. In general the trends shown in both the dynamic and static test data are reflected in the feasibility test data, except for new belts which had been stored for five years. These belts showed much lower elongations because the length of the samples tested was very much shorter than all of the other belts.

It was noticed during testing that the peak loads generated were affected by sample length. This is because, in the feasibility rig, the load is attenuated by both the energy absorbers and the belt, i.e., the belt is instrumental in generating the force profile. The shorter the length of belt tested, the stiffer the system, so less energy absorption occurs and the belt experiences higher forces.

Further research would be beneficial both to analyse the data generated and to make further comparison with static and dynamic test data, as well as to analyse the effects of belt length.

It would be possible to modify the test rig to accommodate full-length belts, however, further development testing would be required. The rig would have to generate higher energy, and so would require either a larger drop distance or a heavier weight pack to achieve this, thus making the rig larger.

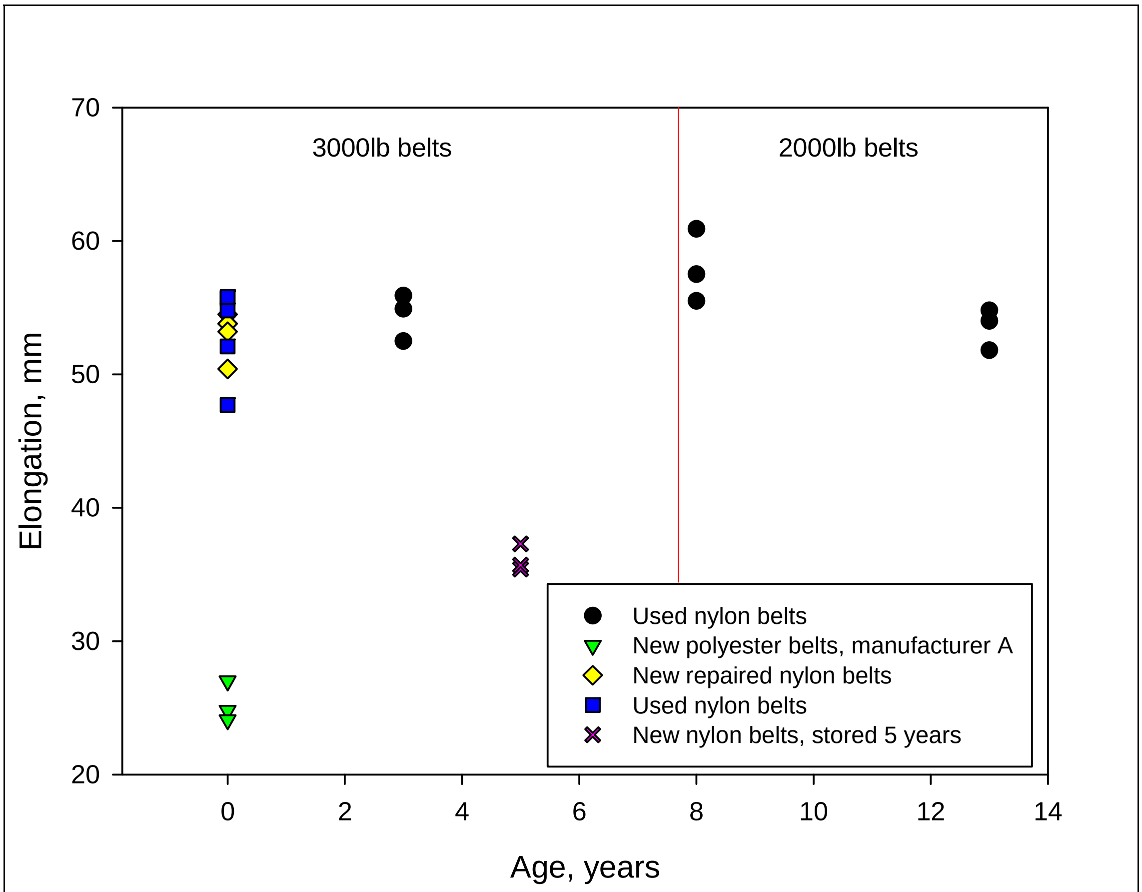


Figure 23. Graph of elongation versus age for the tongue side of 2000lb and 3000lb belts tested in the feasibility rig

7 FEASIBILITY TESTING – PHASE 2

7.1 AIMS AND OBJECTIVES

The aim of the Phase 2 feasibility rig testing programme was to perform a series of tests aimed at getting a better understanding of how the length of belt samples affected the operation of the test rig and the test set-up requirements. This would then allow the rig to be fine-tuned to the correct load and duration for different sample lengths.

7.2 TEST METHOD

7.2.1 Rig configuration

The top grip on the carrier section of the feasibility rig was a pin assembly to accommodate the hook on the end of the belt.

The bottom grip on the weight pack was a split pin scroll grip, allowing the belt webbing to be gripped in the test rig without introducing any potential sources of damage. (The previous test configuration had a grip to hold the tongue of the belt, allowing the tongue side only to be tested). The buckles were removed from the long side of the belts tested, allowing the webbing to be fed through the scroll grip. The webbing was loaded into the scroll grip in order to minimise slippage, as illustrated in Figure 24, and this was checked during the test programme by monitoring the position of chalk marks on the webbing before and after testing.

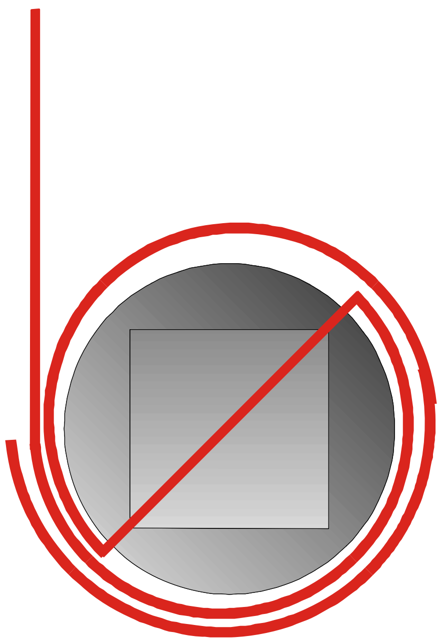


Figure 24. Method of securing webbing into the split pin scroll grip

Due to the nature of the method of gripping the sample, the loading of the webbing around the scroll grip is complex, with both the material around the grip and the vertical part of the webbing being subjected to the load. The load imparted to the webbing around the scroll grip will vary, thus making it difficult to define a sample length. For this reason the separation of the retro-reflective marker strips on the test rig was taken as the measurement of choice for the set-up of each test (Figure 25).

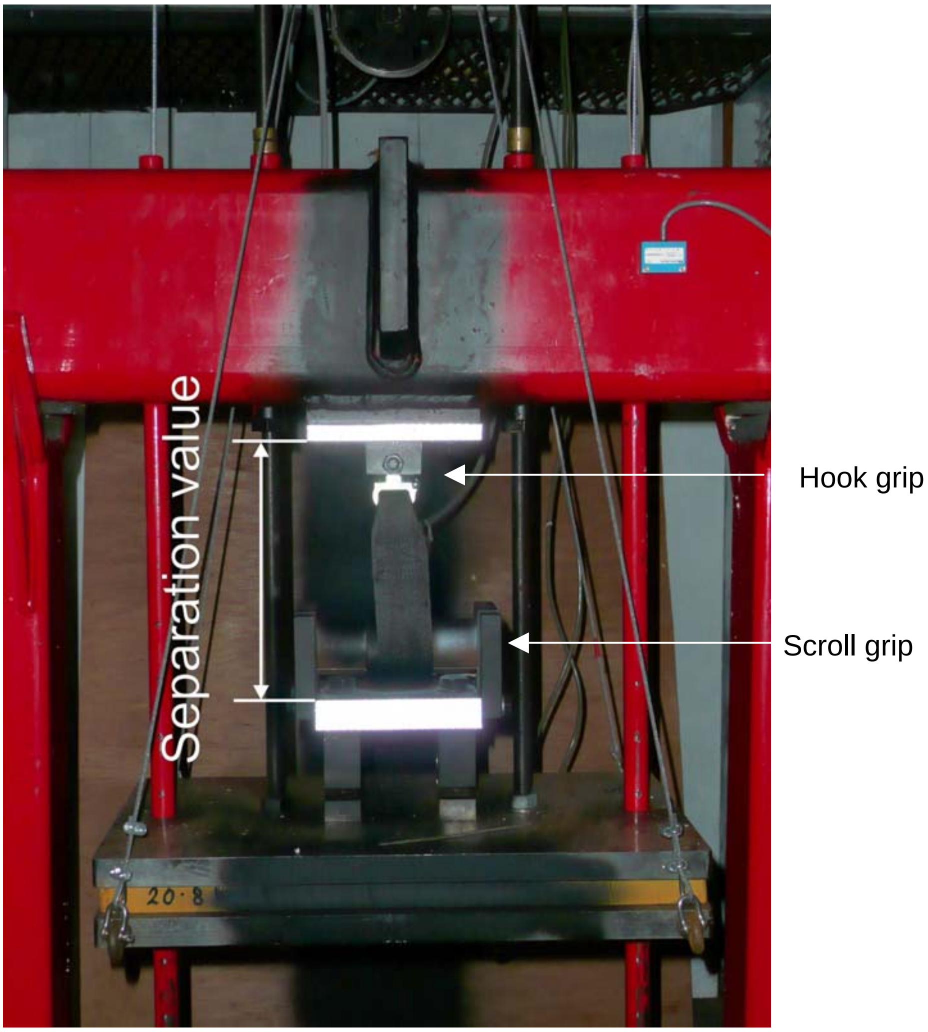


Figure 25. Testing arrangement for Phase 2 tests

The total drop mass of the system was 77 kg, as used in Phase 1 of the feasibility testing. The input energy of the test rig was therefore controlled by varying the drop height. The drop height is defined as the distance between the contacting surfaces when the rig was raised prior to the tests, i.e. the free space between the crush can, attached to the underside of the carrier section, and the impact surface on the catching arms (Figure 26).

The energy absorption system used on each catching arm was a combination of three stiff rubber pads, each 10mm thick, a 40mm thick polyurethane foam pad and crush cans filled with expanding polyurethane foam of either 115mm in height or 150mm in height. The cans of 115mm height were manufactured from steel, the 150mm tall cans were manufactured from aluminium.

The webbing samples used for this phase of the project were from the 129 belts received, which had worn labels. The belts chosen were those where the date was barely discernible, but all appeared to be 5 years old, rated at 3000lbs and in a similar condition to each other.

The instrumentation used was the same as that described for Phase 1 of the feasibility test programme, however only force and duration was analysed for Phase 2 as the investigation was focussed on the performance of the test rig rather than the samples.

Figure 26. Measurement of drop height

7.2.2 Tests carried out

Two series of tests were carried out. The first series of tests, termed fixed sample length tests, were conducted in order to gain an understanding of how input energy, in terms of varying the drop height, was related to duration for fixed rig separation (and therefore sample length), and two different energy absorbers. This data would then allow a drop height to be selected for a particular energy absorber configuration to get the optimum force-duration curve. A sample length of 300 mm was used throughout this series of tests

The second series of tests, termed varying sample length tests, was carried out to ascertain how changing the rig separation (and therefore sample length), affected the input energy requirements, in terms of drop height, in order to obtain the necessary force-duration profile. Due to the limitations of the test rig, only the 150mm cans were used for these tests in order to provide a wide enough window of energy absorption, as determined by the first series of test (this will be discussed further in section 7.3.).

7.3 RESULTS AND OBSERVATIONS

7.3.1 Fixed sample length tests

The results of the first series of tests showing the relationship between drop height and test rig performance for fixed separations are shown in the figures below. These results are also summarised in Appendix C.3.

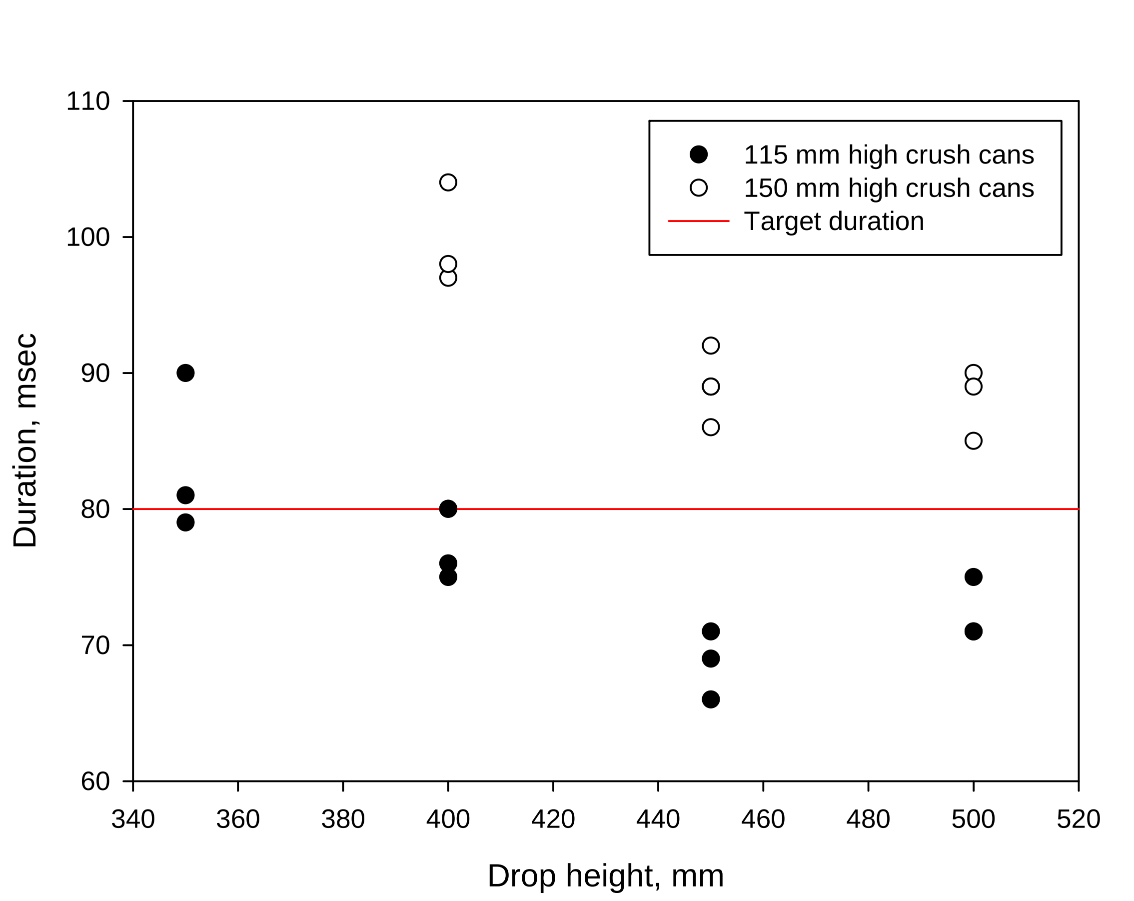


Figure 27. Graph showing the relationship between drop height and duration for fixed 300mm sample length

Figure 27 shows the relationship between the drop height in mm and the load duration in milliseconds for each height of energy absorber. The graph shows that as drop height increases, the load duration decreases up to a limiting drop height for each size of crush can. It appears that, beyond this drop height the performance of the energy absorption system changes, with increasing drop height increasing the test duration. The taller crush cans, which give longer deceleration times, result in longer load durations. The line on the graph shows the target duration of 80 milliseconds which is required in order to match the pulse from the dynamic sled testing.

Figure 28 shows how the peak load varies as a function of drop height for each height of energy absorber. The load attenuation of both heights of energy absorber were very similar. The line on the graph shows the target peak load which would match the pulse from the dynamic sled test.

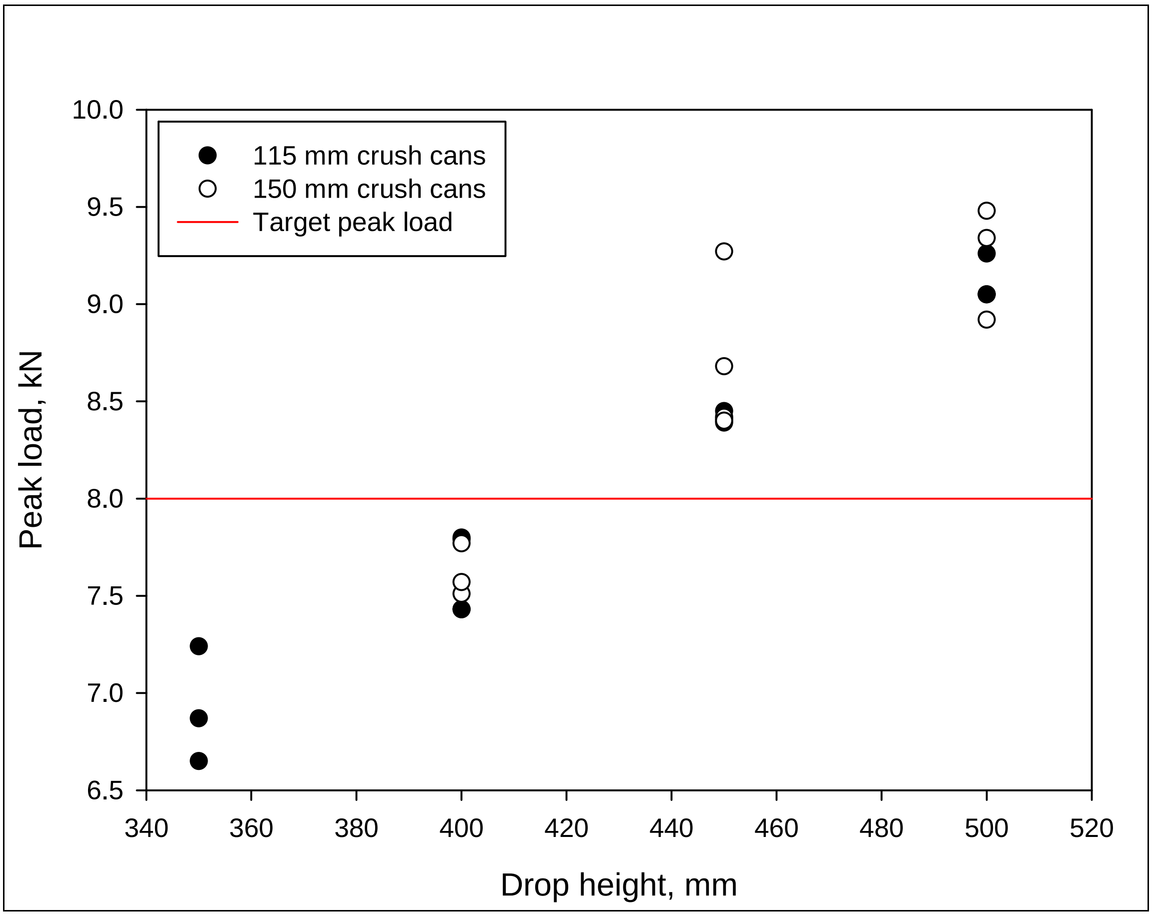


Figure 28. Graph showing how peak load varies as a function of drop height for a grip separation of 300mm

These graphs show how the properties of energy absorber systems can be characterised and, by using the two graphs above, the optimum system can be selected in order to give the required results. There is, however, a complex relationship between the load duration and the system performance, as shown in Figure 27. The data suggests that, after the decrease in duration with increasing drop height, a limiting point is reached beyond which other factors are contributing to increasing load duration. The reason for this is not known and is likely to be complex as the belt sample is also forming part of the load attenuation system. For this reason it would be sensible to avoid using the energy absorption system for drop heights beyond this limiting value.

The results of this series of tests show that, for the current configuration of the feasibility test rig with a fixed separation of 300 mm, the ideal set-up is to use 115mm tall crush cans, and a drop height of approximately 400mm in order to simulate the dynamic sled loading conditions.

7.3.2 Varying sample length tests

The results of the first series of tests showing the relationship between drop height and test rig separation, and therefore sample length, are shown in the figures below. These results are also summarised in Appendix C.3. As previously mentioned, the larger size of crush can was used in order to provide a wider range of drop heights within the valid region of performance based on the findings in the fixed separation tests. Only one test was performed at a separation of 350mm, as it was found to generate too high a peak force for the crush can to attenuate.

By trial and error it was found that the relationship between drop height and sample length to achieve the required load was linear, as can be seen from the data reported in Table C.3 in the Appendix. For increasing separations, however, this relationship no longer held true, as can be seen in Figure 29.

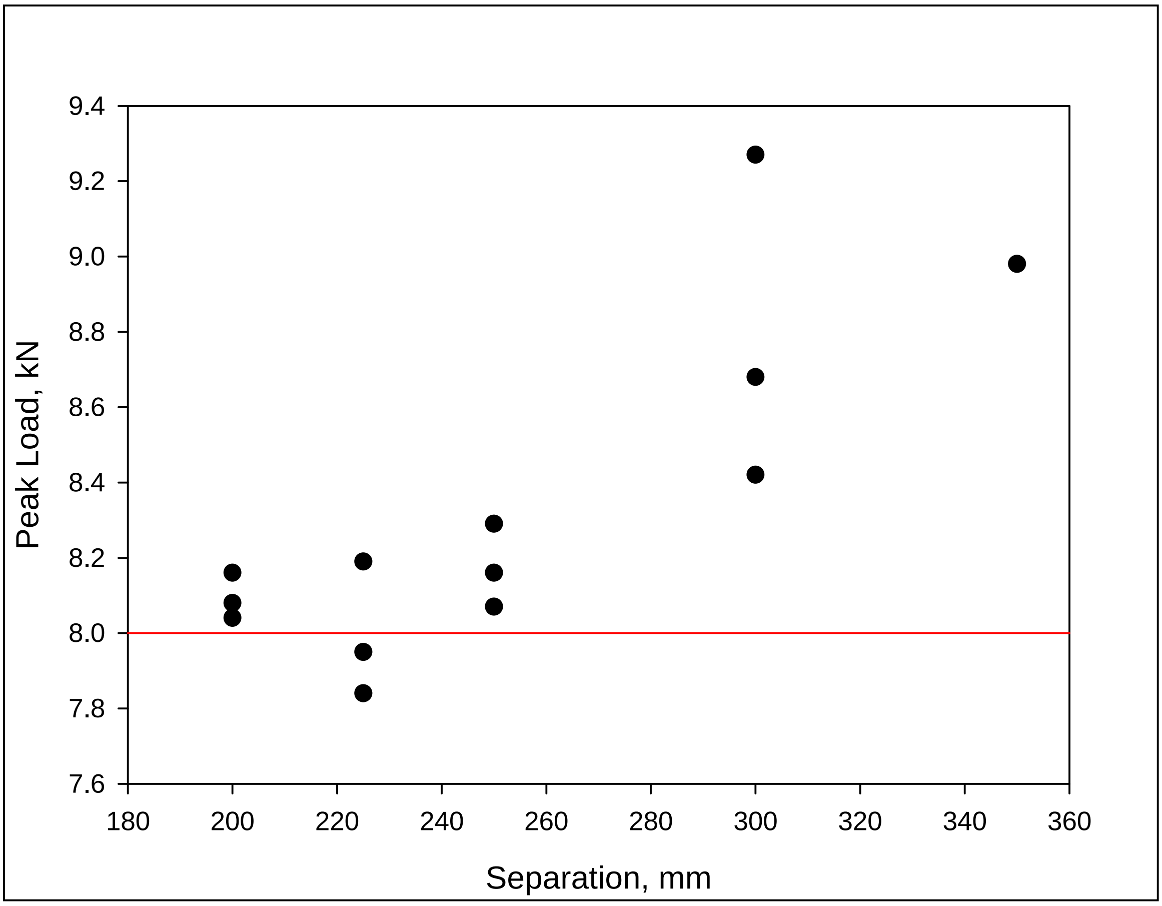


Figure 29. Variation of peak load with increasing separation

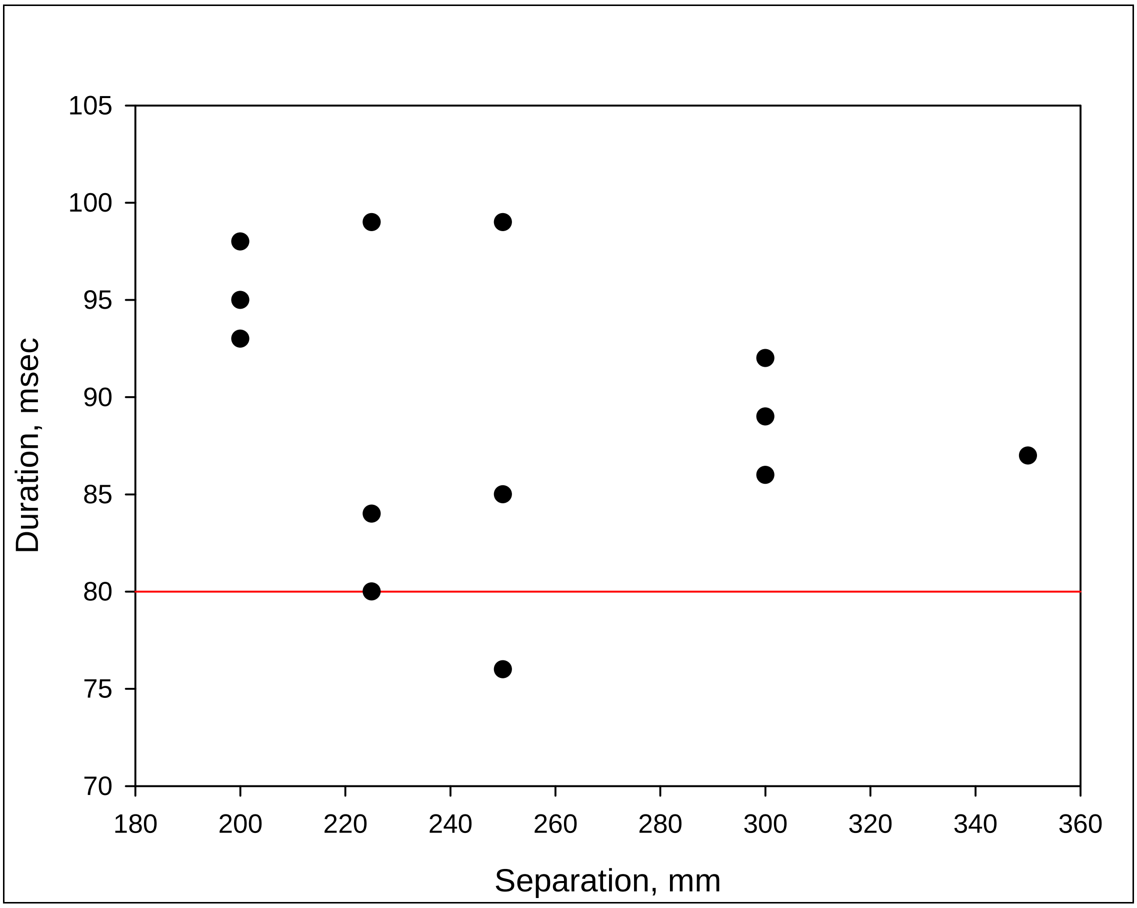


Figure 30 shows how the duration of the load varied according to separation. There appears to be a wide scatter in this data, making it difficult to draw conclusions from it, except that few tests achieved the correct duration.

These results show that it is difficult to control both parameters (peak load and duration) when sample length is varied. This is likely to be due to the fact that, as the separation is increased, the amount of the sample which is attenuating the load increases. While the relationship between the sample length and peak load appears to be predictable, its effect on the load duration is more complex and difficult to predict. In addition, the large amount of scatter may be due to the increased likelihood of variation in the belt samples under test.

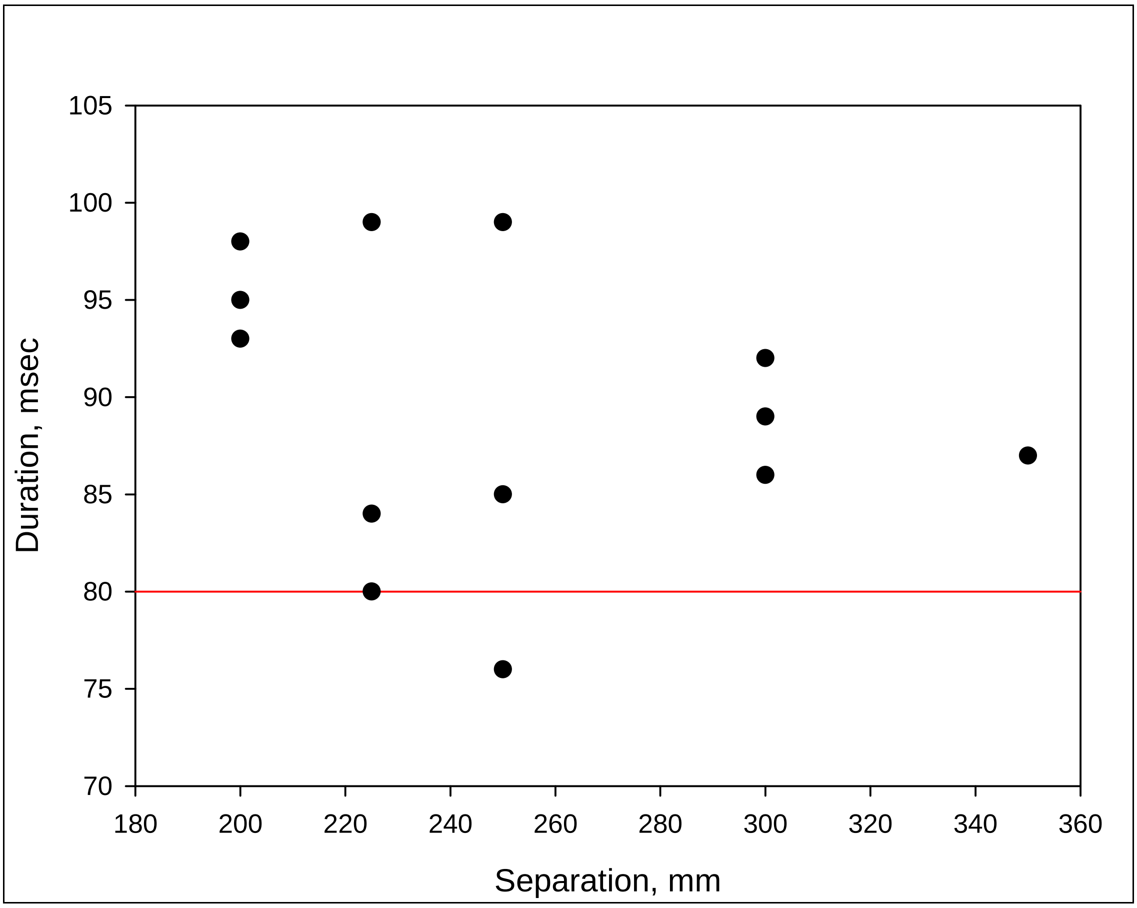


Figure 30. Variation of duration with increasing separation

7.3.3 Evaluation of results

The results of Phase 2 of the feasibility test show that it is possible to design and optimise a small-scale test rig to replicate the force pulse which the belt experiences. This only appears to be feasible for the HSL test rig, however, if fixed sample lengths are used.

Developing a test rig, which would accommodate varying sample lengths would require a large number of iterative tests with a highly adjustable energy absorber system in order to achieve the correct test conditions. This would be very time consuming and require a large number of test parameters to be able to generate performance graphs as shown here, which would enable the correct operating conditions to be chosen.

It would be more practical and less time consuming however, to specify a fixed sample length for testing purposes, around which a test rig could be fine tuned.

8 STATISTICAL ANALYSIS

8.1 STATIC TEST DATA

8.1.1 Methods

Linear regression was used to investigate the relationship between age and elongation, and also age and elongation per load. The different strengths and elongations were treated as separate analyses. Age was entered into the regression models as a continuous variable to investigate linear trend, the significance of which was tested using the Wald test. Factors for repair status (yes or no), material (nylon or polyester), manufacturer (A, B or C), colour (black, blue or other) and buckle type (A or B/C) were included in the regression models only if they altered the relationship between age and elongation.

The possibility of a non-linear relationship was investigated by including quadratic and cubic age terms (i.e. age squared and age cubed respectively), and also using a restricted cubic spline. The likelihood ratio test was used to compare linear models to non-linear models.

Whether or not the linear relationship with age was different for the different belt types was also investigated. For 3000 lb belts, this was achieved by entering the main effect of belt colour (if not already included) and the interaction between age and colour into the linear regression models defined above. The statistical significance of the interaction term was tested using the likelihood ratio test, which tests whether the linear relationship differed by belt colour. All of the 2000 lb belts fell in to the 'other' category and so could not be investigated.

Initial investigation of the data revealed that the residuals from the regression analyses were not normally distributed, indicating the assumptions of linear regression had been violated. Therefore standard errors were estimated using nonparametric bootstrapping, a technique that does not rely on the underlying distribution of the data. A p-value of 0.05 or below was used to indicate statistical significance throughout, and all statistical analyses were undertaken in Stata SE Version 12.1[5].

8.1.2 Results

Figure 31 and Figure 32 shows the distribution of the elongation and elongation per load, respectively, using box and whisker plots, which appeared to be symmetrically distributed.

Table 7 shows summary statistics for the elongation. The interquartile range is the upper quartile (75th percentile) minus the lower quartile (25th percentile), and so shows the spread of the data. There were fewer observations for the 2000 lb belts compared to the 3000 lb belts, and fewer observations for elongation at 26.6 kN compared to elongation at 18 kN.

Table 8 and Table 9 show the proportion of 3000 lb belts and 2000 lb belts (respectively) that slipped during testing at 26.6 kN. Just 12% (N=2) of the 2000 lb belts slipped at 26.6 kN compared to 35% (N=19) of the 3000 lb belts. There was weak evidence that the proportion of 3000 lb belts that slipped depended on the age of the belt, although this was of borderline statistical significance (Fisher's exact test, p=0.066; Table 8). New belts had the lowest risk of slippage (17%), and belts aged 4 to 5 years had the greatest (60%) (Table 8). All of the 3000 lb belts that slipped had the type A buckle design, and none of type B/C slipped. All of the 2000 lb belts that slipped were 8 years of age and had a type B/C buckle (Table 9).

[5] *Full reference: StataCorp,* Stata Statistical Software SE Version: Release 12.1. *2012, TX: StataCorp LP.*

8.1.2.1 3000 lb belts

There was strong evidence of increasing elongation at 18 kN with increasing age, such that elongation increased by an average of 9.2 mm for each 1 year increase in age (Figure 33; slope = 9.2, 95%CI=7.5-10.8, $p<0.001$), with no evidence of a non-linear relationship (all likelihood ratio tests $p>0.10$). There was also evidence of increasing elongation at 26.6 kN with increasing age, with a 1 year increase in age resulting in an increase in elongation of around 4.3 mm (Figure 34; slope = 4.3, 95%CI = 2.3-6.2, $p<0.001$), and no evidence of a non-linear relationship (all likelihood ratio tests $p>0.10$).

There was strong evidence that the linear age trend for elongation at 18 kN differed by belt colour (likelihood ratio test $p<0.001$). For black belts, elongation at 18 kN increased, on average, by 9.8 mm for each 1 year increase in age, which was a highly statistically significant result (Figure 35; slope = 9.8, 95%CI = 8.1-11.4, $p<0.001$). In contrast, there was strong evidence that elongation at 18 kN decreased with increasing age for blue belts (Figure 35; slope = -5.9, 95%CI = -10.3 – -1.5, p=0.009), and there was no evidence of a linear trend for other colours (p=0.109). There was no evidence that the linear age trend for elongation at 26.6 kN differed by belt colour (likelihood ratio test $p>0.10$).

The change in age trend from increasing elongation at 18 kN for black belts to decreasing elongation at 18 kN for blue belts does not seem plausible. In addition, the age trend for blue belts was based on a small number of data points, and the age range was severely restricted in comparison to that of black belts. Therefore it is possible that this finding is an artefact of the data rather than a true result, and further testing would be required to investigate this difference further

Results were similar when looking at elongation per load. There was strong evidence that elongation per load at 18 kN increased with increasing age (Figure 36; slope=0.9, 95%CI=0.8-1.1, $p<0.001$), with no evidence of a non-linear relationship (all likelihood ratio tests $p>0.10$). There was also strong evidence of increasing elongation per load at 26.6 kN (Figure 37; slope=0.3, 95%CI=0.1-0.4, $p<0.001$), with no evidence of a non-linear relationship (all likelihood ratio tests $p>0.10$). As for elongation at 18 kN, there was strong evidence that the linear age trend for elongation per load at 18 kN differed by belt colour (likelihood ratio test $p<0.001$). The different age trends are presented in Figure 38, and once again there was a change in the age trend from increasing elongation per load for black belts to decreasing elongation per load for blue belts. As described above, this could be an artefact of the data rather than a true result.

8.1.2.2 2000 lb belts

There was weak evidence of a linear relationship between age and elongation at 18 kN, such that elongation decreased by an average of 4.3 mm for each 1 year increase in age, but this was of borderline statistical significance (Figure 39; slope=-4.3, 95%CI=-8.8 – 0.1, p=0.056). There was some indication that a non-linear model (i.e. cubic) fit the data better than assuming a purely linear model (likelihood ratio test p=0.008). Although there was evidence that the fit was improved, the individual terms in the cubic regression model (i.e. age, age squared, and age cubed) were not statistically significant and the confidence intervals of the fitted values were large. This makes interpretation of the non-linear model extremely difficult, and so the results are not presented.

There was weak evidence of a linear relationship between age and elongation at 26.6 kN, with the estimated slope being of borderline statistical significance (Figure 40; slope=-6.7, 95% CI=-14.3 – 0.8, p=0.081). There was also no evidence of a non-linear relationship with age (all likelihood ratio tests p>0.10).

Once again the results were similar when looking at elongation per load. There was strong evidence of decreasing elongation per load at 18 kN with increasing age (Figure 41; slope=-0.7, 95%CI=-1.2 – -0.2, p=0.003). There was no evidence of a linear trend with age for elongation per load at 26.6 kN (Figure 42; slope=-0.3, 95%CI=-0.9 – 0.3, p=0.277). For both elongation per load at 18 kN and 26.6 kN, there was no evidence of non-linear trend with age (all likelihood ratio tests p>0.10).

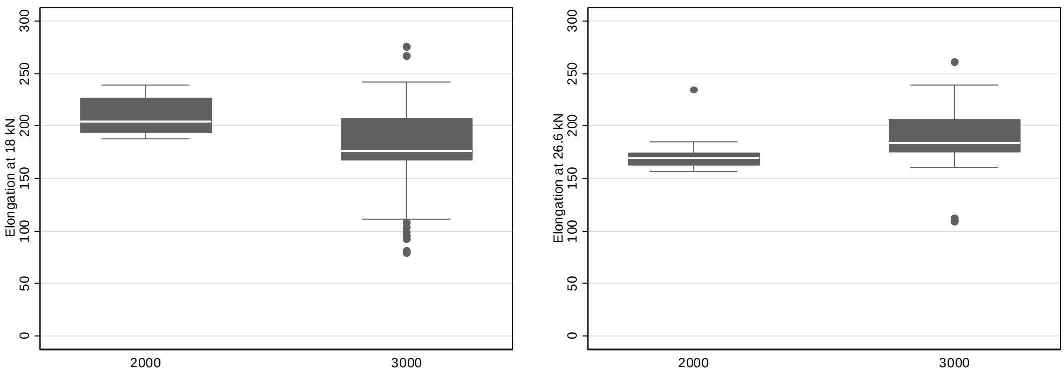


Figure 31 Box and whisker plot of elongation at 18 kN (left) and 26.6 kN (right) by strength

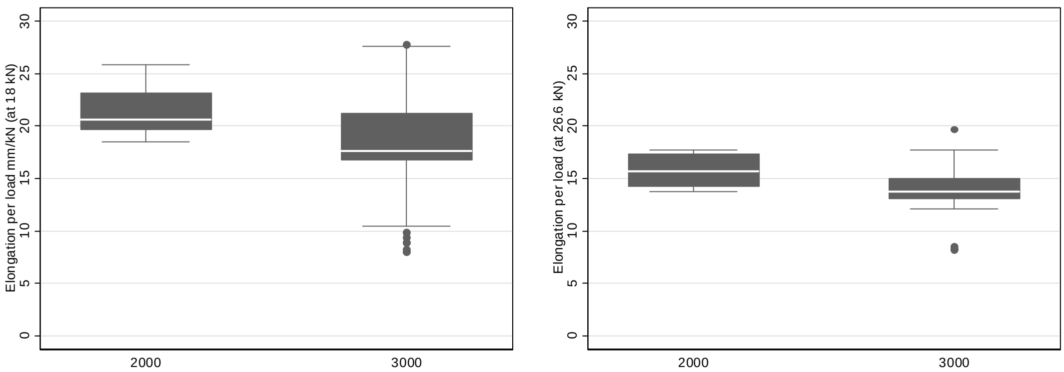


Figure 32 Box and whisker plot of elongation per load at 18 kN (left) and 26.6 kN (right) by strength

Table 7 Summary statistics for elongation by strength

Strength	*Outcome*	*Obs.*	*Mean*	*Standard deviation*	*Median*	*Interquartile range*
2000	Elongation at 18 kN	17	209.9	18.1	204.4	32.6
	Elongation per load at 18 kN	17	21.3	2.3	20.6	3.4
	Elongation at 26.6 kN	9	175.8	23.8	169.0	10.6
	Elongation per load at 26.6 kN	9	15.7	1.6	15.7	3.0
3000	Elongation at 18 kN	57	179.2	47.8	176.6	38.9
	Elongation per load at 18 kN	57	17.9	4.9	17.6	4.4
	Elongation at 26.6 kN	43	184.7	35.0	184.0	30.8
	Elongation per load at 26.6 kN	43	13.8	2.6	13.8	1.8

Table 8 Number of 3000 lb belts experiencing slippage during testing at 26.6 kN, by age and buckle design

Characteristic		***No slippage***		**Slippage**	
		N	***(%)***	***N***	***(%)***
Age (years)	0	19	(83)	4	(17)
	2-3	6	(50)	6	(50)
	4-5	4	(40)	6	(60)
	6-13	6	(67)	3	(33)
Buckle design	A	29	(60)	19	(40)
	B/C	6	(100)	0	(0)
Total		35	(65)	19	(35)

Note: 3 belts missing observations for slippage
Fisher's exact test for age, p=0.066

Table 9 Number of 2000 lb belts experiencing slippage during testing at 26.6 kN, by age and buckle design

Characteristic		***No slippage***		***Slippage***	
		N	***(%)***	***N***	***(%)***
Age (years)	5	2	(100)	0	(0)
	8	3	(60)	2	(40)
	9-13	10	(100)	0	(0)
Buckle design	A	0	(0)	0	(0)
	B/C	15	(88)	2	(12)
Total		15	(88)	2	(12)

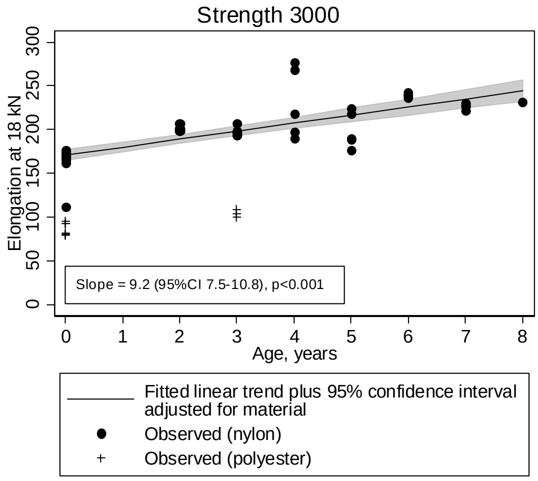


Figure 33 Fitted linear age trend for elongation at 18 kN and strength 3000

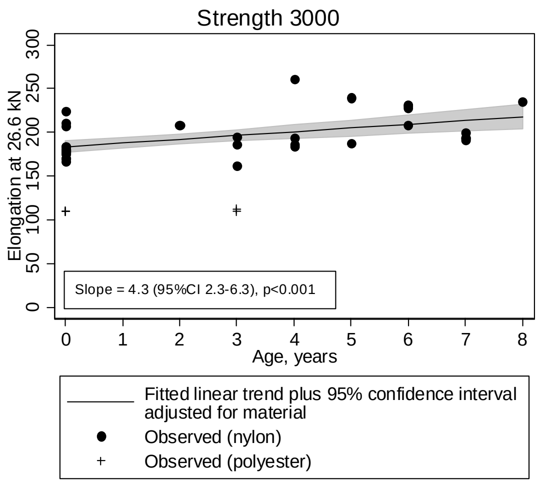


Figure 34 Fitted linear age trend for elongation at 26.6 kN and strength 3000

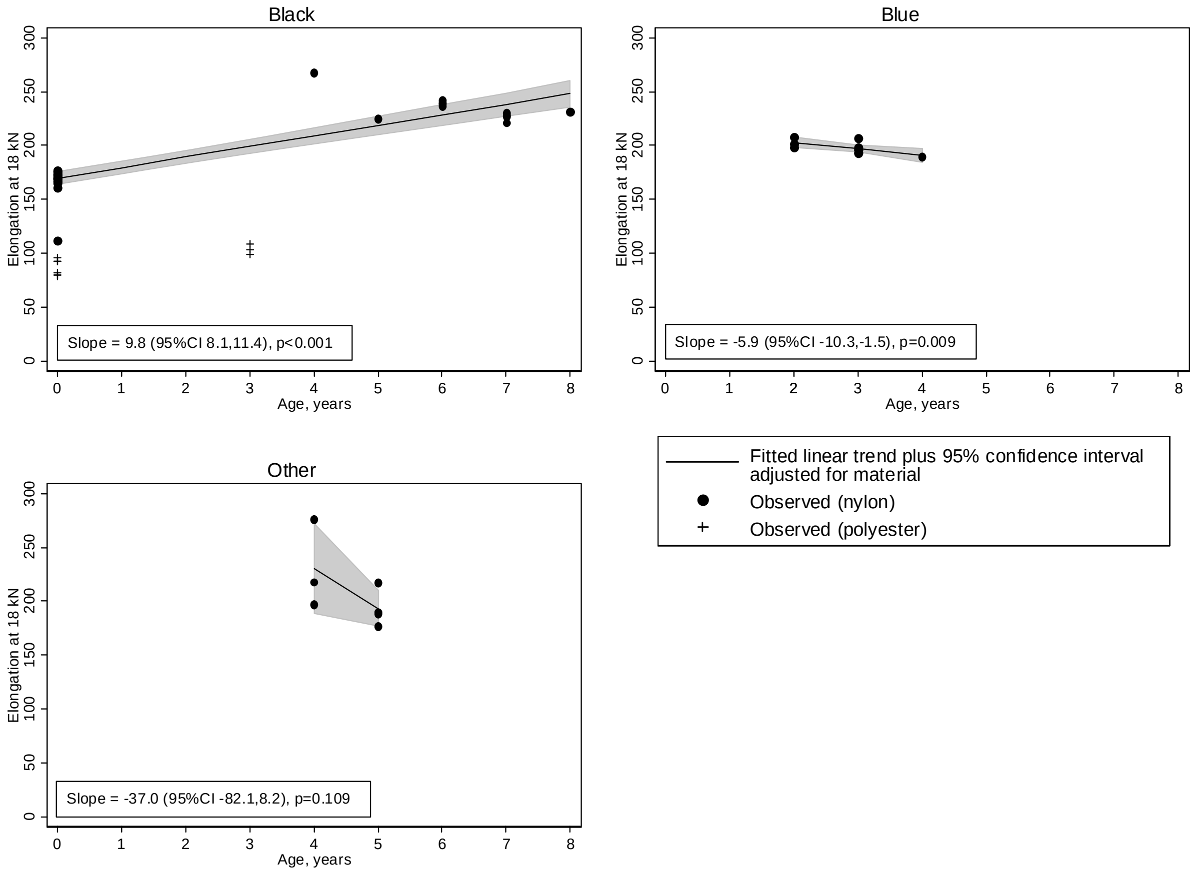


Figure 35 Fitted linear age trend for elongation at 18 kN and strength 3000, by belt colour

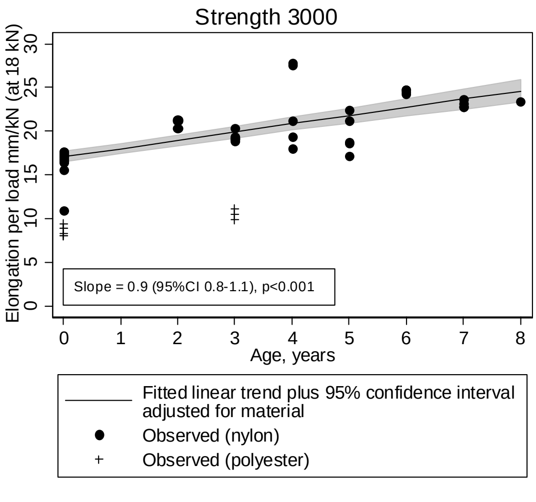


Figure 36 Fitted linear age trend for elongation per load at 18 kN and strength 3000

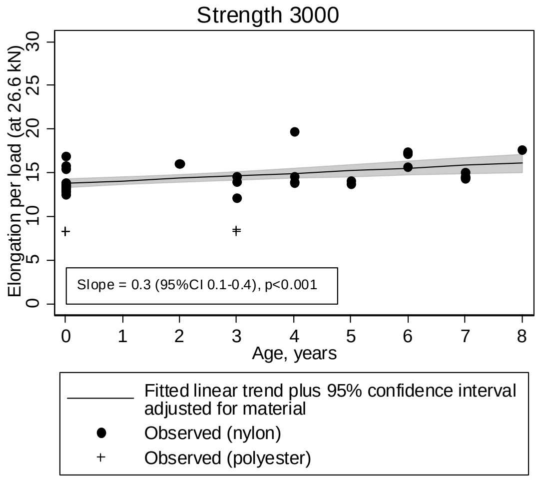


Figure 37 Fitted linear age trend for elongation per load at 26.6 kN and strength 3000

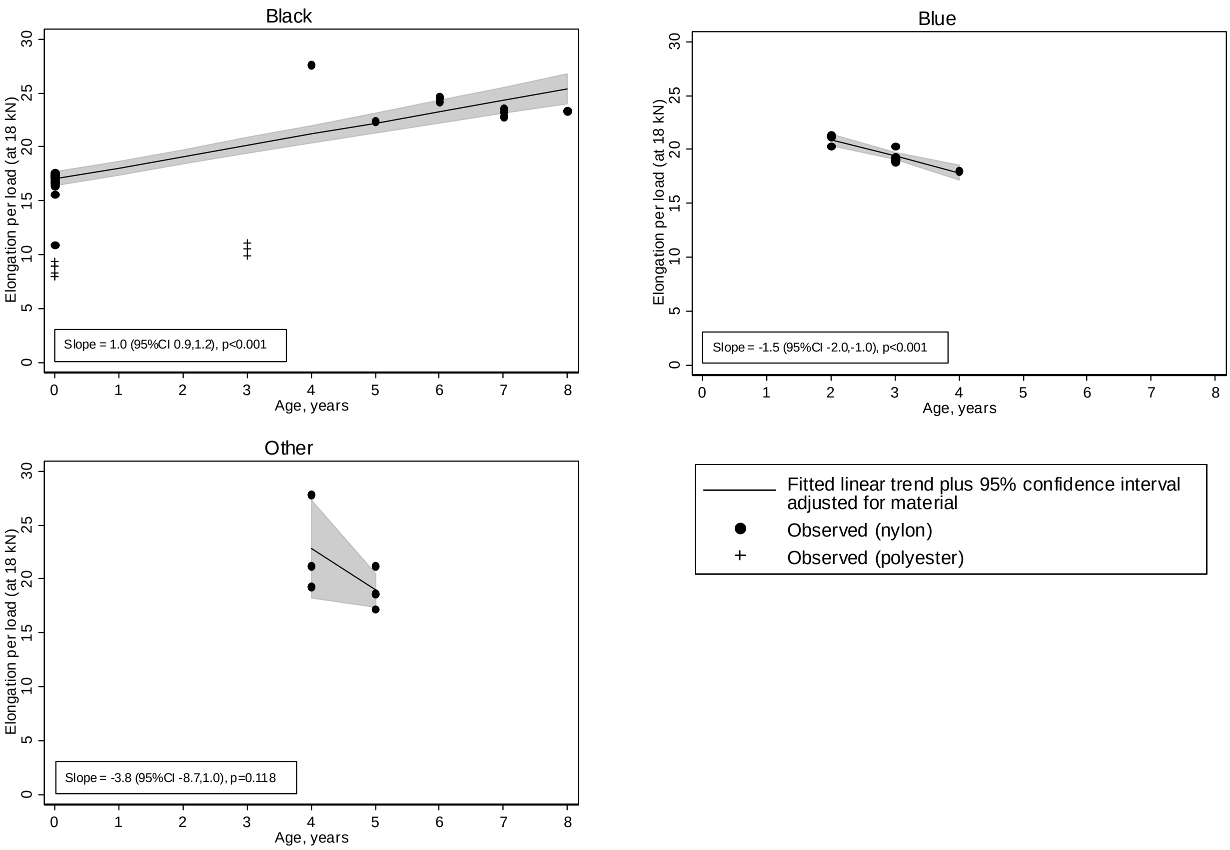


Figure 38 Fitted linear age trend for elongation per load at 18 kN and strength 3000, by belt colour

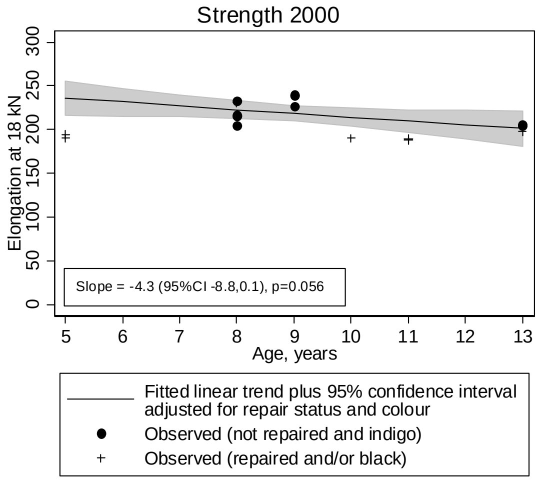


Figure 39 Fitted linear age trend for elongation at 18 kN and strength 2000

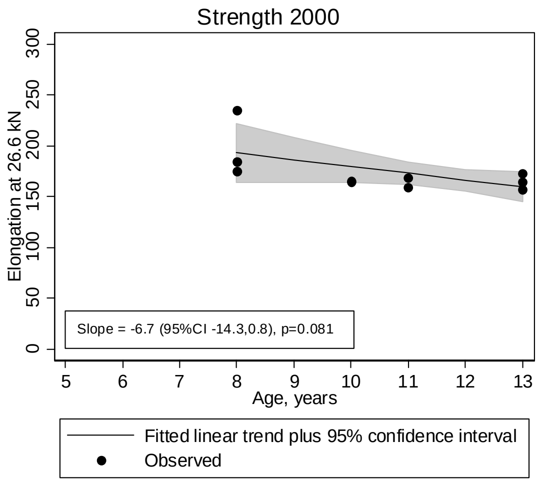


Figure 40 Fitted linear age trend for elongation at 26.6 kN and strength 2000

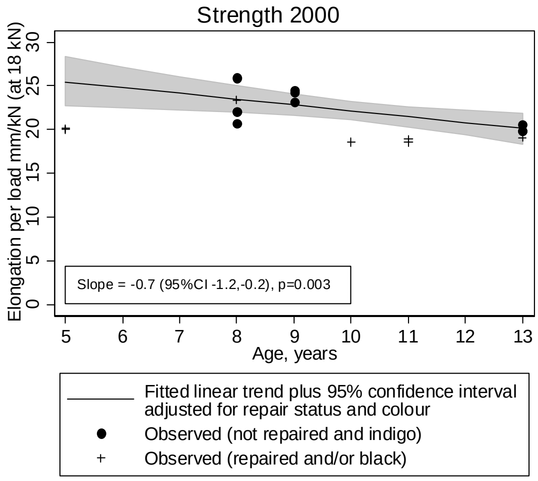


Figure 41 Fitted linear age trend for elongation per load at 18 kN and strength 2000

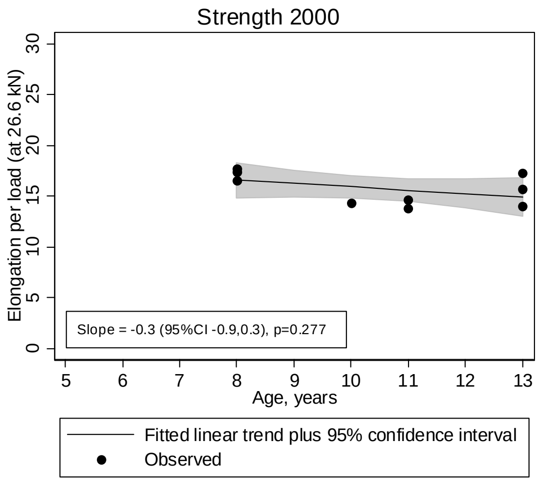


Figure 42 Fitted linear age trend for elongation per load at 26.6 kN and strength 2000

8.2 COMPARABILITY AND REPEATABILITY OF THE DYNAMIC AND FEASIBILITY TESTS

8.2.1 Statistical Methods

Both the dynamic test and feasibility tests are destructive, and so it was not possible to have both tests measure identical belts. Therefore belts were grouped to be as similar as possible (same part number, same ages, same material, etc), and the repeated tests within these groups were used to assess comparability and repeatability of the two test methods. The groups of main interest were those containing new belts (new nylon belts, new polyester belts, and newly refurbished belts). It was expected that age and use would introduce additional variability into the measured elongation within each group, and so new belts were considered to be more comparable. The outcome of interest was elongation.

Due to the small sample sizes within each belt grouping, the Wilcoxon rank-sum test was used to test for differences in measured elongation between the two methods (i.e. the comparability), and Levene's test was used to test for differences in the variability (or reliability) of measured elongation.

Although the above (non-parametric) tests are more robust for small sample sizes than their (parametric) alternatives, they are limited: they do not use all of the data available, they cannot adjust for different maximum loads, and they cannot estimate the size of the difference between the two methods. Therefore the comparability and variability was also assessed by pooling together all of the belt types.

Linear regression was used to test for differences in the measured elongation for the two methods. The estimated difference was adjusted for the belt type (entered as a categorical variable) and maximum load (entered as a continuous variable). All two-way interactions between method, belt type and maximum load were assessed for statistical significance. This would test whether the difference between methods depended on the belt type, and/or whether it depended on maximum load. The statistical significance of the difference between methods and all interactions was tested using the Wald test. This analysis was performed on all data, but also for all new belts and all old/used belts separately.

Linear mixed effects models were used to investigate the reliability (or variability) for each method separately. These statistical models can be used to separate the variability of the observed elongation due to differences between belt type, and the variability within belt type. Belt type was entered as a 'random effect', which would separate the variability into its different components, and maximum load was adjusted for by entering this as a 'fixed effect'. Separate models were used for each method, the results of which were then used to estimate the following parameters:

The *test-retest reliability* measures the consistency of a test, and can be quantified using the intraclass correlation coefficient (ICC) estimated as

$$\text{ICC} = \frac{\text{between belt type variance}}{\text{total variance}}.$$

A value of zero would indicate no correlation/reliability, and a value of one would indicate perfect correlation/reliability. A value of 0.7 is often used to indicate good reliability.

The *Standard Error of Measurement (SEM)* gives an indication of the precision of individual measurements, and is calculated from the known sample standard deviation (SD) and the test-retest reliability:

$$\mathrm{SEM} = \mathrm{SD}\sqrt{(1-\mathrm{ICC})}\,.$$

The SEM can be used to calculate a 95% confidence interval for a belt's true elongation as

$$E \pm 1.96 \times \mathrm{SEM}\,,\ \text{ where } E \text{ is the measured elongation.}$$

The *Smallest Detectable Difference (SDD)* is the difference needed between two separate measurements on two similar belts for the difference in measurements to be considered real, and is estimated as

$$\mathrm{SDD} = 1.96 \times \sqrt{2} \times \mathrm{SEM}\,.$$

That is, for a statistically significant difference between two separate measurements (within the same belt type), the difference must be at least the SDD.

Note that the number of groups (belt types) being included in the mixed effects models is small for this kind of analysis, and so the results will be subject to a high degree of uncertainty. For this reason, the analysis was not performed separately for new belts and other belts, which would reduce the number of belt types further.

Initial investigation of the data revealed that the residuals from the regression analyses were not normally distributed, indicating that the assumptions of linear regression had been violated. Standard errors were therefore estimated using nonparametric bootstrapping throughout, which is a technique that does not rely on the underlying distribution of the data. A p-value of 0.05 or below was used to indicate statistical significance throughout, and all statistical analyses were undertaken in Stata SE Version 12.1[6].

8.2.2 Results

Table 10 shows the mean, standard deviation, and standard error of the measured elongations by belt type and test method. The mean elongation for the dynamic test was greater than that for the feasibility test for all belt types (Table 10). However, the elongation was only statistically significantly different between test methods for the three 'new belt' groups (Wilcoxon rank-sum test, $p \leq 0.05$); there was no evidence that the measured elongation differed between tests for the old/used belts (Wilcoxon rank-sum test, $p > 0.05$ Table 10). The standard deviation (i.e. variability) tended to be greater for the dynamic test compared to the feasibility test, but these differences were not statistically significant among new belts (Levene's test, $p > 0.05$; Table 10). However, among old/used belts, there was evidence that the variability was different for the two test methods (Levene's test, $p \leq 0.05$), with the dynamic test observing greater variability than the

[6] *Full reference: StataCorp,* Stata Statistical Software SE Version: Release 12.1*. 2012, TX: StataCorp LP.*

feasibility test; although this difference was of borderline statistical significance for 6 year-old unused belts (Levene's test, p=0.068; Table 10).

Table 10. Summary measures for the observed elongation (mm) by test and belt type

Belt type	***Dynamic test***				***Feasibility test***				***Wilcoxon rank-sum test*** [a]	***Levene's Test*** [b]
	N	***Mean***	***SD***	***SE***	***N***	***Mean***	***SD***	***SE***		
New belts										
New nylon belts	6	64.84	4.68	1.91	5	53.22	3.43	1.53	**P=0.006**	P=0.688
New polyester belts	3	34.05	1.33	0.77	3	25.30	1.51	0.87	**P=0.050**	P=0.733
Refurbished belts - new	5	63.91	2.76	1.23	5	53.14	1.60	0.72	**P=0.009**	P=0.363
Old/used belts										
6 year old unused belts	3	47.15	15.62	9.02	3	36.13	1.02	0.59	P=0.513	P=0.068
3 year old belts	2	66.55	5.17	3.65	3	54.43	1.75	1.01	P=0.083	**P=0.024**
13 year old belts	3	60.67	10.41	6.01	3	53.53	1.55	0.90	P=0.127	**P=0.028**

Note: Bold font indicates a statistically significant result.

N, number of observations; SD, standard deviation; SE, standard error; a, Test of inequality of distributions; b, Test of inequality of variances.

Table 11 shows the results of the linear regression analyses quantifying the difference in elongation between the dynamic test and the feasibility test methods. After adjustment for belt type and maximum load, the difference between the two methods was, on average, 5.19 mm with the dynamic test measuring the greater elongation. However, this estimate was subject to large uncertainty and was not statistically significant at the 5% level (95%CI = -1.05 to11.43 mm; p=0.103; Table 11). As indicated by the non-parametric analysis in Table 10, the results were different for new belts and old/used belts. Among new belts, there was strong evidence of a difference in the elongations measured by the two test methods, with the dynamic test measuring the greater elongation (estimated difference = 7.79 mm; 95%CI = 3.80 to 11.79 mm; p<0.001). On the other hand, there was no evidence of a difference in the measured elongations for old/used belts (p=0.517), but the estimated difference was subject to large uncertainty (95%CI = -23.98 mm to +12.06 mm). There were no statistically significant two-way interactions, and so there was no evidence that the difference between test methods depended on the belt type or the maximum load.[7]

Table 11. Difference between elongation (mm) for the dynamic test and the feasibility test adjusted for belt type and maximum load, stratified by whether the belts were new or old/used

Belts included	***Adjusted difference***	***(95% confidence interval)***	***P-value***
New belts	7.79	(3.80, 11.79)	**<0.001**
Old/used belts	-5.96	(-23.98, 12.06)	0.517
All belts	5.19	(-1.05, 11.43)	0.103

Note: Bold font indicates a statistically significant result.

[7] *This analysis was repeated based on the percentage elongations for the belt samples. These results, which showed little difference to those presented here, are shown in Appendix D.*

Table 12 shows the results of the linear mixed effects models investigating the reliability of the two test methods. Both test methods achieved reasonable test-retest reliability, although the dynamic test was less reliable than the feasibility test (dynamic test = 0.778, feasibility test = 0.991). The limits of the 95% confidence interval for the feasibility test were both above 0.700 (95%CI = 0.829 to 1.153), providing evidence that the feasibility test achieved good reliability. However, the estimate of the test-retest reliability for the dynamic test was subject to a high degree of uncertainty, such that the 95% confidence interval included both zero and one. Note that Normal-based approximation was used to estimate the confidence intervals of the test-retest reliability from the bootstrapped standard errors, and so their limits can lie outside of the 0-1 range. The smallest detectable difference was greater for the dynamic test compared to the feasibility test (17.01 mm and 2.89 mm respectively; Table 12).

Table 12 Test-retest reliability for elongation by test

Measure	***Dynamic test***	***Feasibility test***
Test-retest reliability (95% confidence interval)	0.778 (-4.262, 5.819)	0.991 (0.829, 1.153)
Standard error of measurement, mm	6.14	1.04
95% confidence interval for the true elongation, mm	±12.03	±2.04
Smallest detectable difference, mm	17.01	2.89

8.2.3 Interpretation of results

There was evidence that the variability of the measured elongations was greater for the dynamic test than the feasibility test, but this was only for the old/used belts and not for the new belts. This finding was consistent among all three belt types, and so this is unlikely to be a chance finding. A potential explanation for this result could be that, for whatever reason, the old/used belts tested with the feasibility test were in fact more similar than those tested with the dynamic test, which would distort the comparison between test methods. If the possibility of this is low, then the finding could imply that the dynamic test is more sensitive to changes in the belts due to age than the feasibility test in terms of the variability of the result. The feasibility test may therefore provide a more reliable result when the belts are no longer new; however it may also be that it is less sensitive to changes in the belts with age. It should be remembered that there were low numbers of samples within each age group for used belts and so the results should be treated with caution. Therefore it is recommended that further testing should be undertaken to see if this result can be replicated before making strong conclusions.

There was strong evidence that the measured elongation for new belts was greater when measured by the dynamic test compared to the feasibility test. The best estimate of this difference based on the study sample was 7.79 mm, but the true difference could range from 3.80 to 11.79 mm. A difference of 3.80 mm would probably be small enough that the two methods could be considered equivalent, whereas a difference of 11.79 mm would be scientifically relevant. Additional testing would be required before a clear conclusion could be made about whether or not the two methods are equivalent. See below section ‘Sample size for further testing’ for an estimate of how many belts would be required for this.

There was no evidence of a difference between the measured elongations for the two test methods when comparing old/used belts. However, the estimated difference between the two test methods was subject to high uncertainty, which will be at least partially attributable to the larger variability for the dynamic test method for old/used belts described above. Further testing using old/used belts would be required to be confident that there truly is not a substantial difference for these belt types.

The best estimate of the overall test-retest reliability for the feasibility test was greater than that of the dynamic test (0.991 versus 0.778). The true reliability for the feasibility test could range from 0.829 to 1.000 and so, based on this study, we can be confident that the feasibility test provided good reliability. However, the estimate for the dynamic test was subject to a large degree of uncertainty such that the actual reliability of the test could lie anywhere from absolutely no reliability to perfect reliability. It would therefore be difficult to draw any conclusions about the reliability of the dynamic test from this study.

The test-retest reliability was used to provide estimates of the standard error of measurement, the confidence interval for the true measurement, and the smallest detectable difference. Based on this study, in order to be confident that two similar belts truly have different elongations, the difference between the two measured elongations must be at least 17.01 mm for the dynamic test and 2.89 mm for the feasibility test. The larger value for the dynamic test will be at least partially attributable to the larger variability in the measurements for the old/used belts.

8.2.4 Sample size for further testing

The question was posed regarding what sample size would be required if we wanted to state, with confidence, that the dynamic test and feasibility test were or were not equivalent.

To do this, a sample size analysis of a two-sample t-test for testing equivalence was performed. It was assumed that further testing would concentrate on one belt type only, and so the study data for new nylon belts were used to inform the calculations.

The following estimates were required for the sample size calculations:

- The power of the study – this is the probability of rejecting non-equivalence when the means are actually equivalent. It is desirable for power to be at least 0.80, and so this value was used in the sample size calculations.
- The significance level – this is typically set at 0.05.
- The upper and lower equivalence limits for the ratio of the two means – these are the ratios between which the two methods are equivalent. This was set at ±5%[8], so that if the ratio of the two means was between 0.95 and 1.05, then the two methods are said to be 'equivalent'.
- The coefficient of variation (COV) – this is the ratio of the standard deviation and the mean (SD/Mean), and is used to specify the variability. For new nylon belts, the COV was 0.072 for the dynamic test and 0.064 for the feasibility test. The midpoint of the two was used in the calculations (= 0.068).

Table 13 shows the results of the sample size analysis, using different ratios of the two tests. Note that estimated sample sizes have been increased by 20% (as a rough rule of thumb) to

[8] *This error was quoted by webbing manufacturers as the variability in elongation of their product, as supplied.*

account for adjusting for other factors such as maximum load. In order to obtain the necessary statistical power to test for equivalence of the two methods, 40 belts would need to be measured using the dynamic test and 40 using the feasibility test. Due to time/cost, it may be desirable to reduce the number of belts tested using the dynamic test; this can be done by increasing the number of belts tested using the feasibility test. Testing 60 belts using the feasibility test would reduce the number needed using the dynamic test to 30 belts, and testing 80 belts using the feasibility test would reduce the dynamic testing to 27 belts (Table 13).

Tests of equivalence generally require larger sample sizes than tests of inequality, and so the estimated sample size should also be sufficient to estimate the difference between the two methods. In fact, this sample size should provide sufficient power to produce a 95% confidence interval for the difference between the two means of width ±2.02 mm. This is equivalent to ±3.4%, using the mean of the new nylon belts over both methods (59.56 mm) as the reference.

Table 13. Sample size analysis of a two-sample t-test for testing equivalence using ratios

Allocation ratio	*Sample size*		
Dynamic:feasibility	***Dynamic test***	***Feasibility test***	***Total***
1:1	40	40	80
1:2	30	60	90
1:3	27	80	107

9 OUTCOMES AND CONCLUSIONS

- The results of the static tests in both Phase 1 and 2 showed that there was an increase in the elongation of the belts with age for the 3000lb nylon belts (no used polyester belts were available). Results for the 2000lb belts were less conclusive due to the low number of data points, but generally showed a decrease in elongation with age. Since there were belts with strength ratings of 2000lb and 3000lb, it was not possible to compare the two data sets directly. It was not possible to determine from the data whether performance of the belts will decline linearly after a critical age, or whether a sudden drop off will occur. No relationship between colour of belts and performance was found.

- The results of the dynamic tests showed that there was some evidence that elongation of the belts increased with age, and therefore length of time in service. The trend was less obvious than for the static test results, due to the lower number of results obtained.

- New polyester belts consistently exhibited lower elongations than the new nylon belts in both static and dynamic testing.

- Comparison of the static and dynamic test methods showed that static testing of seatbelts to 18kN load was similar to dynamic testing. The maximum loads in both tests were found to be the same, and comparison of the test results showed that similar elongations were recorded for both new and used belts when tested dynamically and statically. This correlation between the results suggests that there may be less need to test the belts dynamically, and that the information obtained by static testing may be sufficient. Static testing of the seatbelts to 26 kN, imparts 48% more load to the seatbelt than would be experienced during dynamic testing.

- It was found during testing that the belts which had been in storage for five years exhibited the same elongation characteristics as those which had been in service.

- The feasibility study in Phase 1 showed that it is possible to replicate the loading conditions to which a seatbelt is subjected in dynamic sled testing using a small-scale test rig. The test produced consistent force extension profiles, demonstrating a high repeatability. The force pulse generated was found to be dependant on the sample length. Since the samples used were the tongue side of the seatbelt assembly, they were manufactured to different lengths depending on the part number and manufacturer. This made the testing process more complex as the energy input had to be altered to accommodate the difference in length. Statistical analysis comparing the feasibility test results to the dynamic sled test results found that the feasibility test appeared to be better suited to testing new belts rather than used belts.

- The data obtained during the feasibility study in Phase 1 showed that the energy absorption system can be refined by the replacement of consumable energy absorbers with a manufactured shock absorber or dashpot with the same performance curve (load vs. displacement). Such a shock absorber or dashpot would, however, need some form of fine adjustment to its energy absorption characteristics in order to accommodate any variation in the length of sample being tested or the properties of the webbing from which the belt was manufactured (energy absorption capacity of the webbing).

- It was found during feasibility testing in Phase 1 that the length of the samples tested in the feasibility test rig affected the force pulse generated. Since the samples tested were the tongue side of the belt, which had been manufactured to different lengths, constant adjustment of the drop height was required in order to keep a consistent force input.

- A study of the performance of the feasibility rig in Phase 2 found that it was possible to generate rig performance curves for a fixed sample length which could be used to select the correct energy input (drop height) conditions for two different energy absorber set-ups. It was very difficult, however to predict the required energy input to achieve the correct load durations when sample lengths were varied. This was likely to be due to increasing sample lengths having an increased effect on the total load attenuation of the test rig. Based on this information the most sensible approach to small scale testing would be to specify a fixed sample length for testing purposes. The sample length would need to be sufficiently small so that large input energies are not required. This would then mean that smaller test masses and drop heights can be used, minimising the size of the small-scale test rig.

- It was apparent from discussions with aircraft operators that they had little knowledge of the history of the aircraft seatbelts between them going into service and being removed from service. Belts were replaced when they became obviously damaged, or when printed manufacturer's labels became too worn for the text to be legible. Very little information about the service history or maintenance of the belts was able to be obtained for this study.

- The component maintenance manual for belts made by manufacturer A states that their belts may remain in service until defects are found upon inspection or in use. No maximum lifespan is given as it is stated that this depends upon the amount of use and the environment in which it is used. Whilst to some extent this is the case, it is well known that polymer products will deteriorate with age when in storage, and as such will have a maximum lifetime even when not in use (explained in EASA report EASA.2008/2 [11]). For example, the current industry guidance for fall arrest equipment made from webbing is that the maximum lifespan for these products is 10 years. Many manufacturers of these products issue this guidance, which arose from industry working groups consulting polymer manufacturers about long-term deterioration of nylon and polyester fibres without exposure to any ageing effects such as abrasion, sunlight, contamination etc. The manufacturers advised that their products, when stored in ideal conditions (cool, dark and dry conditions), would begin to degrade after 10 years. It is recommended that polymer fibre manufacturers are approached again to determine whether more recent developments in polymer manufacture may have delayed the onset of this degradation.

- When gathering used belts for this study, it was found that several of the belts supplied as one assembly were in fact made up of a tongue side and buckle side of differing ages. Although the colours of the belts were the same, the ages were different. In one case, one part of the belt was repaired, the other part was original. This mis-matching of belts could not have occurred during manufacture and is unlikely to have occurred during repair of the belts, rather it is most likely to have occurred during cleaning and maintenance of the belts. In this study, the mismatched belts were all of the same standard and strength rating, however mismatches between two different types of belts may occur, with more serious consequences.

- It was observed during belt procurement that a large number of belts were obtained which had illegible labels. These belts must have been in service for some time with labels in poor condition prior to being removed from service in order for them to have become so worn that the text could no longer be read. These belts should clearly have been removed from service before deteriorating to this extent. It may be possible to improve the quality of printed labels to make them more durable and to prevent belts becoming non-compliant due to label wear when they are still otherwise serviceable.

- It was almost impossible to visually distinguish between the polyester and nylon belts used in this study. The only means of identifying different belts was by the manufacturer's part number on the belts, but this would require prior knowledge of which code applied to which material in order to identify them. Since belts and seats are tested together in order to achieve conformity to aviation standards, it is important to ensure that the correct belt is used with the correct seat set (i.e. nylon belts should not be used on seats tested only with polyester belts and vice versa). .

10 RECOMMENDATIONS

- It is recommended that the use of a small-scale rig is considered for the testing of seatbelts. The feasibility study showed that it is possible to replicate the loading conditions to which a seatbelt is subjected in dynamic sled testing using a small-scale test rig.

- It is recommended that a fixed sample length should be specified for testing in order to make testing in a small-scale rig practical. Sample sizes should be sufficiently small so that large energy inputs are not required, thus keeping the rig small.

- It is recommended that, in order to better determine when a belt should be removed from service, that service history of the belts should be recorded. It was found during this study that little or no information appears to be kept by the operators regarding the service history of belts. There appears to be little knowledge of the conditions in which the belts are used, the cleaning regimes to which they are exposed or the frequency of inspection.

- It is recommended that the date when a belt first goes into service is recorded. This would allow a more accurate assessment of the service history of the belt to be determined, and therefore allow a better assessment of the continued airworthiness of the belt during routine inspection.

- It is recommended that inspection of the seatbelts should be carried out at a maximum interval of every 12 months, or more frequently depending on the extent of use. This is consistent with the recommendations from the manufacturers. This approach would avoid situations where labels become illegible whilst belts are in service.

- It would be prudent to adopt a maximum lifespan for belts in service of 10 years from the date of manufacture (this would include both time in storage and service life) until further information can be gained about long-term performance. This lifetime is based on the natural deterioration of polymer fibres that occurs even when they are in storage in ideal conditions.

- It is recommended that guidance be issued to air operators about the importance of ensuring that belts are made up of matched parts. When gathering belts from various sources, it was common to find belts which were assembled from mismatched parts.

- It may be useful to issue each belt with its own unique serial number to enable records about individual belts to be kept. This would allow belts to be tracked throughout their service life. Belts are currently issued with part numbers and date of manufacture, but these details usually apply to large batches of belts and so are not unique, with no way of identifying or tracking an individual seat belt.

11 REFERENCES

[1] 2010-15R1: Improper Maintenance of Safety Belts / Torso Restraint Systems, European Aviation Safety Agency, 29/09/2010. http://ad.easa.europa.eu/ad/2010-15R1

[2] Aerospace Standard SAE AS8043, SAE International, 2008. http://www.sae.org

[3] European Technical Standard Order ETSO-C22g, European Aviation Safety Agency, 24/10/2003.

[4] "*Technical Standard Order TSO-C22g: Safety Belts*", US Department of Transportation, Federal Aviation Administration, Aircraft Certification Service, Washington DC, USA. Published 1993.

[5] CS25.561 Certification Specifications and Acceptable Means of Compliance for large Aeroplanes, Subpart C – Structure 'Emergency landing conditions- General', CS.25 Amendment 11. http://easa.europa.eu/agency-measures/docs/certification-specifications/CS-25/CS-25%20Amendment%2011.pdf

[6] CS25.785 Certification Specifications and Acceptable Means of Compliance for large Aeroplanes, Subpart D – Design and Construction 'Seats, berths, safety belts and harnesses', CS.25 Amendment 11. http://easa.europa.eu/agency-measures/docs/certification-specifications/CS-25/CS-25%20Amendment%2011.pdf

[7] CS25.562 Certification Specifications and Acceptable Means of Compliance for large Aeroplanes, Subpart C – Structure 'Emergency landing conditions- Emergency landing dynamic condition', CS.25 Amendment 11. http://easa.europa.eu/agency-measures/docs/certification-specifications/CS-25/CS-25%20Amendment%2011.pdf

[8] FAA Memorandum ANM-115-05-10 "Policy statement on an acceptable method of compliance with CS25.562 for replacing restraint systems on forward and aft facing seats". http://rgl.faa.gov/RegulatoryandGuidanceLibrary/rgPolicy.nsf/0/4667691dea8713f88625705e006437f9/$FILE/ANM-115-05-10.doc

[9] Parkin, R and Robinson, L. '*Factors affecting the strength of webbing materials used to manufacture energy absorbing lanyards*' HSL/02/04.

[10] Aerospace Standard SAE AS8049 Revision A, SAE International, 1997. http://www.sae.org

[11]Research project EASA.2008/2 "*Evaluation of strength degradation of fabric particularly used for cargo nets*". http://easa.europa.eu/safety-and-research/research-projects/docs/miscellaneous/EASA.2008_2.pdf

APPENDIX A

A.1. PHASE 1 BELT SERVICE HISTORY

Manufacture year	***Number of samples***	***Manufacturer/ repairer***	***Service history***	***Source***
2011	20	A	New	Manufacturer A
2011	15	A	New	Manufacturer A
2010	10	B	New	Manufacturer B
2006	25	A	New/stored	Repairer Z
2011	20	A/Y	Refurbished, new	Repairer Y
2008	9	A	European operator. Long haul service	UK air salvage company
2007	4	A	UK Operator, domestic and short haul flights in Europe.	UK air operator
2006	4	A	UK Operator, domestic and short haul flights in Europe.	UK air operator
2005	4	A	UK Operator, domestic and short haul flights in Europe.	UK air operator
2004	4	A	UK Operator, domestic and short haul flights in Europe.	UK air operator
2003	10	A	Russian Operator, flights within Russia/Baltic states.	UK air salvage company
2002	10	A	Russian Operator, flights within Russia/Baltic states.	UK air salvage company
1998	10	A	Russian Operator, flights within Russia/Baltic states.	UK air salvage company
2008	2	A/X	UK Operator, domestic and short haul flights in Europe.	UK air operator
2001	1	A/X	Unknown. Used repaired	UK air salvage company
2000	3	A/X	UK Operator, domestic and short haul flights in Europe.	UK air operator
1999	2	A/X	Unknown. Used, repaired	UK air salvage company

1998	1	A/X	Russian Operator, flights within Russia/Baltic states.	UK air salvage company
Mismatched	6	A	Used, short & long haul	UK air salvage company
Unusable	129	A	UK Operator, domestic and short haul flights in Europe.	UK air operator
TOTAL	**289**			

A.2. PHASE 2 BELT SERVICE HISTORY

Manufacture year	***Number of samples***	***Manufacturer/ repairer***	***Service history***	***Source***
2010	5	A/X	Refurbished. European operator. Long haul service	UK air salvage company
2010	2	A/X	Refurbished. European operator. Long haul service	UK air salvage company
2010	1	AX	Refurbished. European operator. Short haul service	UK air salvage company
2009	7	D/W	Refurbished. European operator. Short haul service	UK air salvage company
2007	6	A/X	Refurbished. Unknown.	UK air salvage company
2002	1	A/X	Refurbished. Unknown	UK air salvage company
1996	6	A/X	Refurbished. Unknown	UK air salvage company
1995	1	A/X	Refurbished. Unknown	UK air salvage company
Unusable	4	A	Refurbished. European operator. Short haul service.	Italian air operator
TOTAL	**33**			

A.3.1 AVERAGE LENGTHS OF BELTS BY YEAR OF MANUFACTURE PHASE 1

Manufacture year	***Manufacturer/repairer***	***Total length of belt (between attachment hooks) , mm***	***Length of tongue side (webbing only), mm***
2011	A (nylon)	1070	345
2011	A (polyester)	1135	345
2010	B	1135	342
2006	A	1015	200
2011	A/Y	1040	348
2008	A	1155	350
2007	A	996	300
2006	A	1005	292
2005	A	1026	284
2004	A	1028	286
2003	A	990	350
2002	A	1005	310
1998	A	1045	311
2008	A/X	1005	284
2001	A/X	1044	317
2000	A/X	1040	330
1999	A/X	1036	318
1998	A/X	1025	323

A.3.2 AVERAGE LENGTHS OF BELTS BY YEAR OF MANUFACTURE PHASE 2

Manufacture year	*Manufacturer/repairer*	*Total length of belt (between attachment hooks) , mm*	*Length of tongue side (webbing only), mm*
2010	A /X	1194	350
2010	A	1310	367
1996	A/X	1066	311
2007	A/X	1100	312
1995	A/X	1106	317
2002	A/X	1090	304
2009	C/W	1136	317
2010	C/W	1067	301

A.4.1 AGE WINDOWS – PHASE 1

Range of dates of manufacture	*Age, years*
February 2011 –October 2011	0
February 2010 –October 2010	1
February 2009 –October 2009	2
February 2008 –October 2008	3
February 2007 –October 2007	4
February 2006 –October 2006	5
February 2005 –October 2005	6
February 2004 –October 2004	7
February 2003 –October 2003	8
February 2002 –October 2002	9
February 2001 –October 2001	10
February 2000 –October 2000	11
February 1999 –October 1999	12
February 1998 –October 1998	13

A.4.2 AGE WINDOWS – PHASE 2

Range of dates of manufacture	***Age, years***
January 2011 – September 2011	1
January 2010 – September 2010	2
January 2009 –September 2009	3
January 2008 – September 2008	4
January 2007 – September 2007	5
January 2006 – September 2006	6
January 2005 – September 2005	7
January 2004 – September 2004	8
January 2003 – September 2003	9
January 2002 – September 2002	10
January 2001 – September 2001	11
January 2000 – September 2000	12
January 1999 – September 1999	13
January 1998 – September 1998	14
January 1997 – September 1997	15
January 1996 – September 1996	16

APPENDIX B

B.1. STATIC TEST PROCEDURE

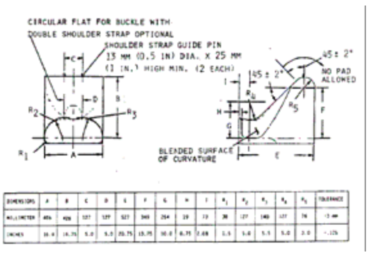
B.1.1 Test equipment

B.1.1.1 Test fixtures

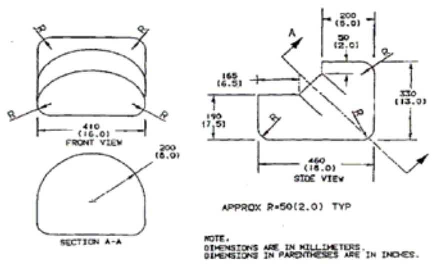
Pelvic Block

A modified test block, as described in ETSO- C22g was fabricated based on the pelvis section of the full wooden test block specified in AS8043B, as shown in Figure B.1.1. The pelvis block incorporates the first three inches of the AS8043B test block, resulting in a two-dimensional test fixture for testing of the seat belt assembly in a testing frame. The pelvis block was manufactured from solid aluminium to minimise the buckle indenting the block and therefore restrict the buckle movement around the block as the webbing elongates or slips through the buckle.

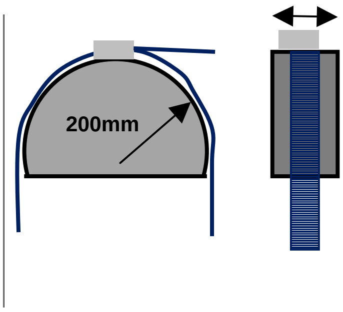
The pelvis block was mounted into the test frame with 4 supports to restrict rotation of the block. As a balance loading beam was used the loads on both sides of the belt were equal, so any uneven elongation or belt slippage was observed by a change in angle on the balance beam.



AS8043B Pelvis Block used for seat belt assembly static testing. Not specified in SEBED Project



AS8049A Pelvis Block used for seat integrity static testing. Specified in SEBED Project



Modified AS8049A Pelvis Block used for seat belt assembly static testing for the SEBED Project

Figure B.1.1 Pelvis blocks used in aircraft seat belt and seat static testing

Testing frame

The test fixture was assembled in a purpose built testing facility to enable better access for the installation of instrumentation and visibility for camera observation. A schematic of the purpose built testing frame is shown in Figures B.1.2. and B.1.4. Apart from the pelvis block the main components of the testing frame were:-

1) **Balance beam** - with 400mm long seat belt attachments; the pivoted balance beam was attached to the hydraulic ram via the control and recording load cell.

2) **Hydraulic Ram** - the hydraulic ram, which was floor mounted, was controlled by both load control from the load cell (specified loading rate and peak load) and displacement

control from the ram inbuilt potentiometer (specified as displacement rate and peak displacement).

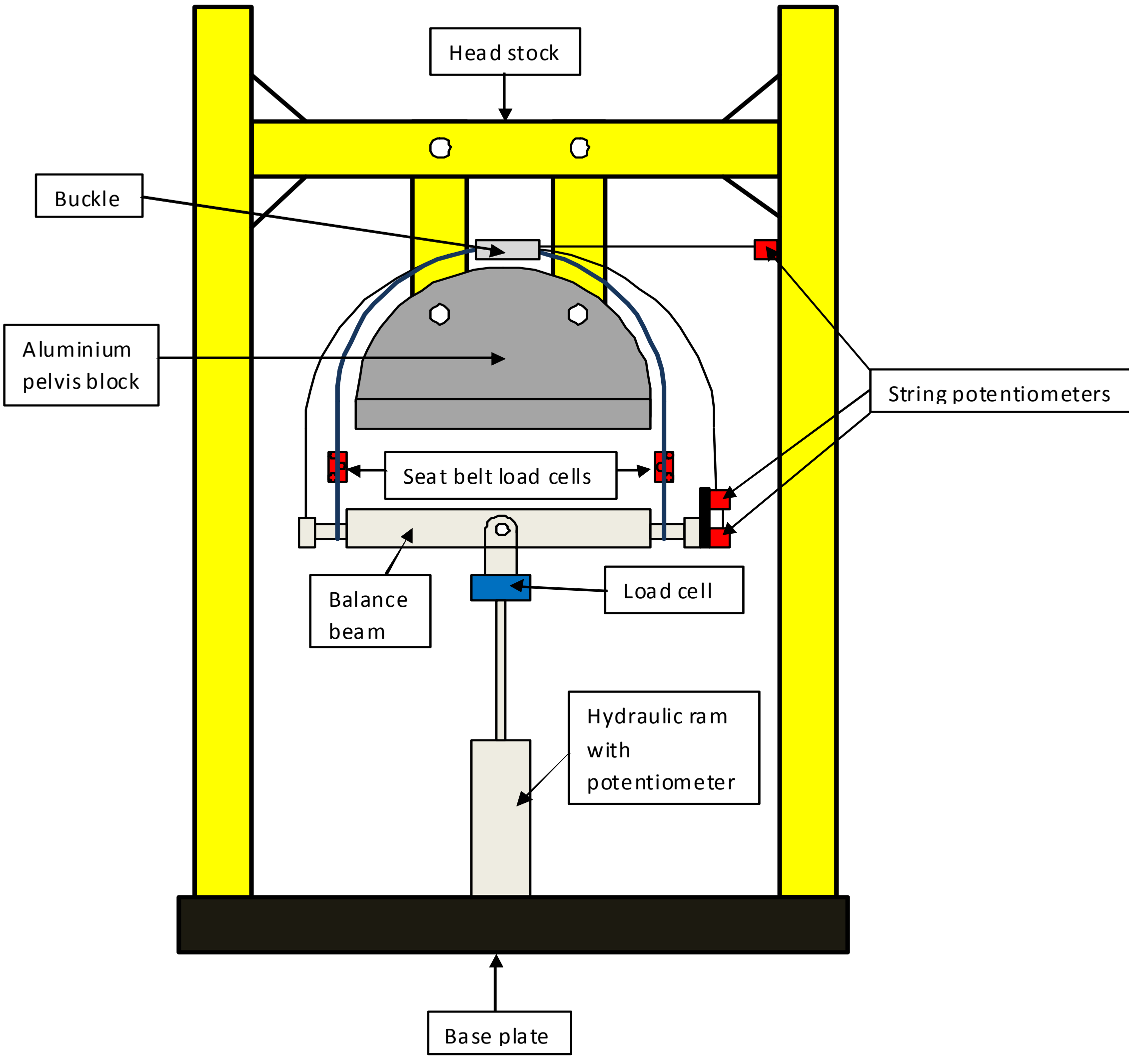


Figure B1.2. Schematic of static test rig

B.1.1.2 Test instrumentation

MIRA-calibrated instrumentation was used throughout the static test programme, with its the relevant Quality Assurance documentation presented in Appendix B.

Load Cells

Overall load was controlled and recorded using the main test fixture load cell. In the elongation tests, a 30kN capacity load cell was used to ensure a good resolution over the entire loading range. In the 26.6 kN elongation test, when the seat belt load cells were removed to avoid damage, the in-built ram load cell was used to monitor belt load.

Seat Belt Load Cells

For measurement of the loads in both sides of the aircraft seat belt, two seat belt load cells of 30kN capacity were installed on the belt approximately 50mm from the webbing (away from the attachment stitching) above the mounting points. Prior to testing, the seatbelt load cells were calibrated using AmSafe standard nylon aircraft seat belt webbing material. These load cells were removed in the 26.6 kN elongation tests to avoid damage if the belt suffered a catastrophic failure.

Ram Potentiometer

The ram position was continually recorded using the system potentiometer. The ram potentiometer was used to monitor belt elongation in the 26.6 kN elongation test to avoid damage to the string potentiometers

String Potentiometers

Three string potentiometers were used to measure belt elongation. Due to the potential for large belt elongations, large displacement string potentiometers were mounted to the test frame and not the balance beam. Using the three potentiometers it was possible to measure the elongation of the belt on the buckle side, tongue side and also movement of the buckle round the aluminium pelvis block (belt slippage).

Data Acquisition

All the instrumentation data was acquired using signal conditioning modules and recorded on a Instron 8800 hydraulic control tower with a sampling rate of 25Hz

B.1.1.3 Calibration of Seat Belt Loadcells

In both the static and dynamic testing programmes seat belt load cells have been used as shown in Figure B.1.3. The load cells used being specially calibrated for the test programmes using standard automotive webbing material. In the initial static test trails to optimise the test procedure, the seat belt load cell loads were compared with the hydraulic ram actuator load cell. With the seat belt maintained at a constant 18kN load by the actuator control system load cells the combined load from the 2 load cells gave a load of 21.5kN, as shown in figure B.1.3. Following an investigation into the load cell loading mechanism for the seat belt load cells were recalibrated using aircraft seat belt nylon webbing. The trail test was repeated, using a seat belt with the same webbing material as used in the calibration, and under the maintained 18kN load the combined load from the seat belt load cells was 18.9kN, which is also shown in Figure B.1.3. To ensure consistency throughout both the static and dynamic testing programmes all seat belt load cells used were calibrated to new seat belt nylon webbing.

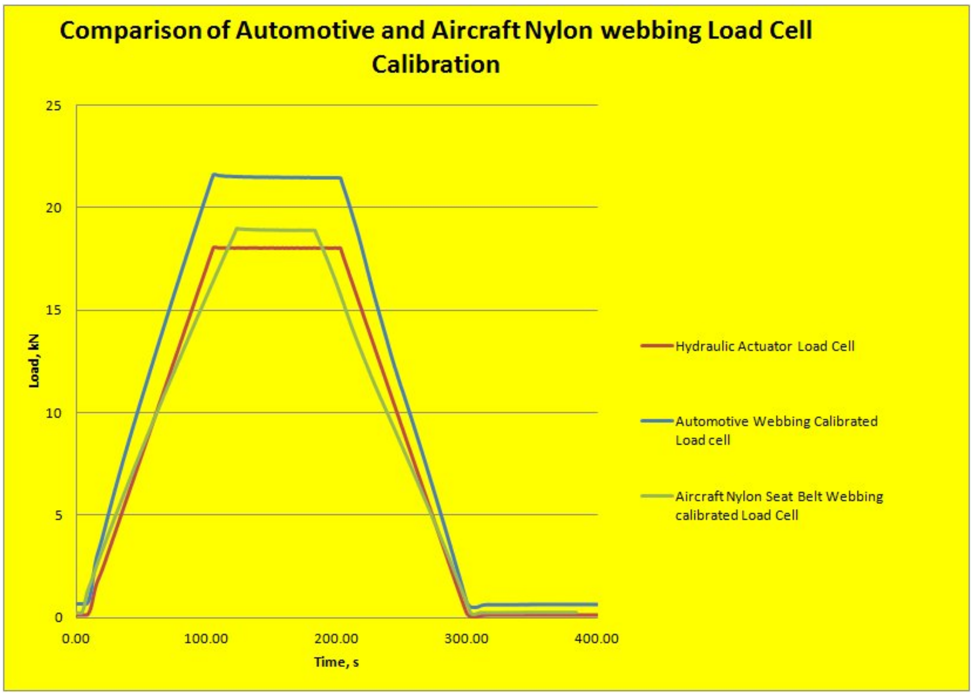


Figure B.1.3 Comparison of Seat Belt Load Cell loads calibrated with Automotive and aircraft seat belt webbing materials

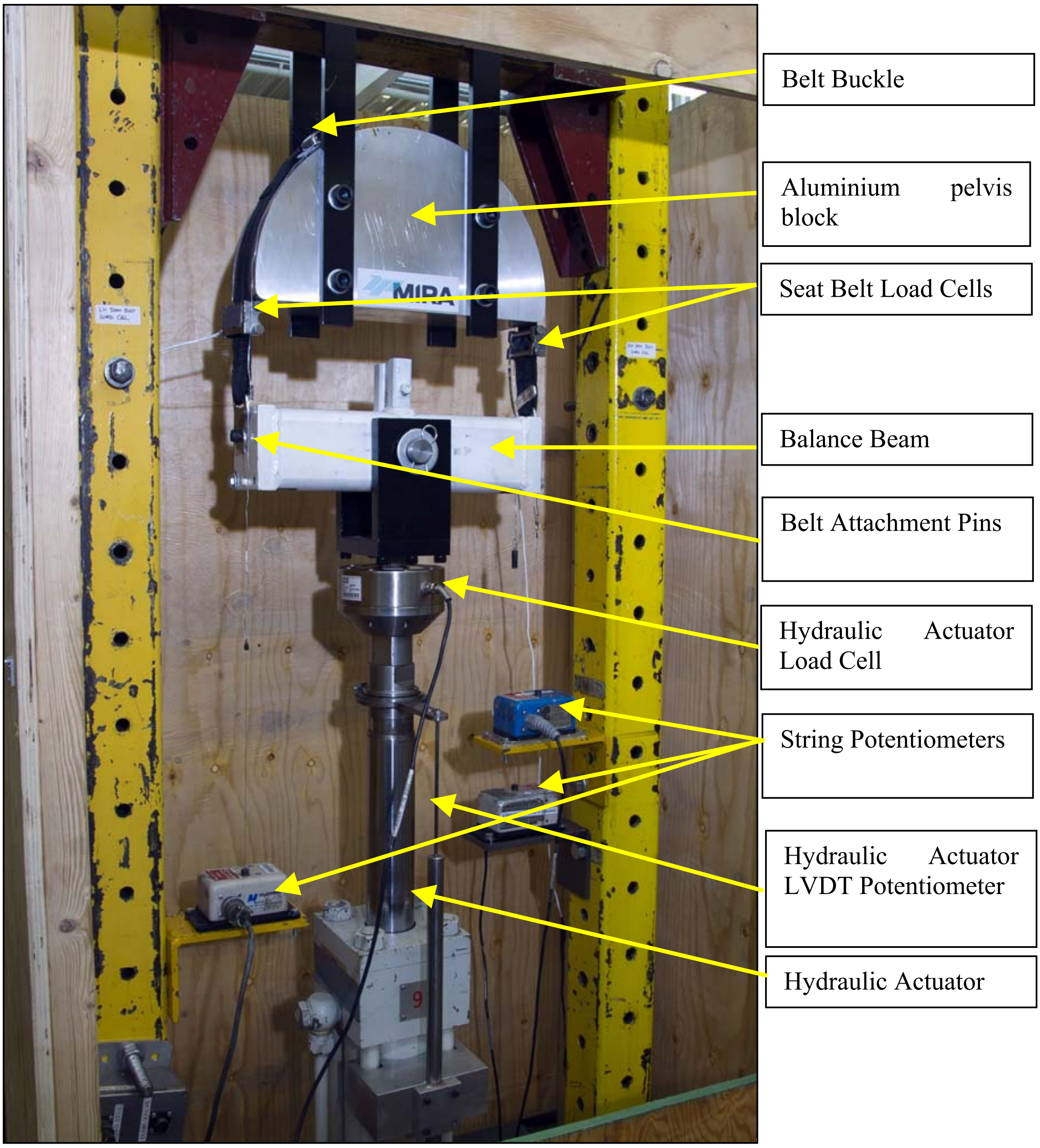


Figure B.1.4 . Annotated photograph showing the location of the static test components and instrumentation

B1.2 TEST PROTOCOL

B.1.2.1 Belt Installation

The protocol for installing the aircraft seat belts into the static test rig was developed to ensure repeatability in the static test and compatibility with the dynamic tests. During aircraft seat belt procurement it was discovered that the total belt length between the attachment points varied considerably from 1340mm to 1050mm. Using the 200mm diameter aluminium block, as prescribed in AS8043B, an adjusted belt length of 1000mm was selected as the total test length. This left 100mm of free webbing each side of the aluminium block for mounting the seat belt load cells (Figure B1.2). Using the 1050mm belt it would therefore leave only 50mm webbing through the belt for slippage under load.

To install the belts into the test fixture, the belt was initially set with a distance of 1000mm between the attachment points on a rigid template. The free end was pulled using a force gauge to approximately 150N (15.3 kgf). Without unbuckling the belt, it was then installed over the pelvis block and attached to the loading pins on both sides of the balance beam. The hydraulic ram was then used to load the belt to 150N before attaching the seat belt load cells at a distance of 100mm from the attachment end stitching. The string potentiometers were then attached to the buckle and the attachment loading pins on the balance beam.

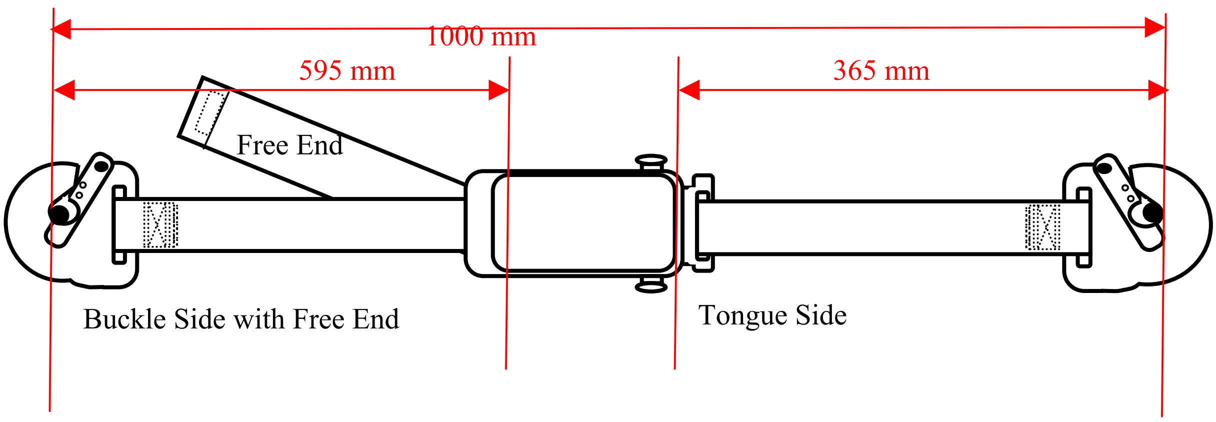


Figure B.1.5. Schematic of the belt dimensions in the Static Test Fixture

B.2. STATIC RESULTS OVERVIEW

Table B.2.1 Phase 1 Static Test Results Table with Observations

MIRA Test	*Ref.*	*Type*	*Material*	*Age, years*	*Rated*	*Elongation*		*Observation*	*Peak*	*Elongation*		*Observation*
					lbs	*mm*	*mm/kN*		*kN*	*mm*	*mm/kN*	
001	7743	New Baseline	Nylon	0	3000	166.5	17.6	Completed <5mm	26.6	210.6	15.8	Completed 22 mm
002	7744	New Baseline	Nylon	0	3000	169.1	17.3	Completed <5mm	26.6	206.8	15.5	Completed 9 mm
003	7745	New Baseline	Nylon	0	3000	165.0	16.6	Completed < 5mm	26.6	180.2	13.5	Massive Slip 58mm
004	7746	New Baseline	Nylon	0	3000	161.0	15.6	Completed <5mm	26.6	224.6	16.9	Completed 45mm
005	7747	New Baseline	Nylon	0	3000	166.8	16.4	Completed <5mm	26.6	166.4	12.5	Completed 4mm
006	7768	New	Polyester	0	3000	79.3	8.0	Completed <5mm	26.6	N/K	N/K	Massive slip 164mm
007	7769	New	Polyester	0	3000	80.0	8.0	Completed <5mm	26.6	N/K	N/K	Massive slip 180mm
008	7770	New	Polyester	0	3000	81.6	8.3	Completed <5mm	26.0	N/K	N/K	Massive slip 190mm
009	7898	Used	Nylon	13	2000	205.1	20.6	Completed <5mm	21.0	N/K	N/K	Attachment failure
010	7891	Used	Nylon	9	2000	226.9	23.2	Completed <5mm	23.8	N/K	N/K	Attachment failure
011	7863	Used	Nylon	9	2000	239.6	24.5	Completed <5mm	22.6	N/K	N/K	Attachment failure
012	7861	Used	Nylon	9	2000	238.5	24.2	Completed <5mm	23.0	N/K	N/K	Attachment failure
013	7878	Used	Nylon	8	3000	232.8*	25.9*	Completed < 5mm	26.6	N/K	N/K	Massive Slip 100mm

014	7869	Used	Nylon	3	3000	196.3	19.1	Completed < 5mm	26.6	186.4	14.0	Massive Slip 135mm
015	7880	Used	Nylon	13	2000	204.1	19.8	Completed < 5mm	20.0	173.0	17.3	Attachment failure
016	7866	Used	Nylon	8	2000	204.4	20.7	Completed < 5mm	20.1	174.6	17.4	Attachment failure
017	7887	Used	Nylon	8	2000	216.3	22.0	Completed < 5mm	22.3	184.9	16.6	Attachment failure
018	7868	Used	Nylon	3	3000	206.8	20.3	Completed < 5mm	26.6	194.8	14.6	Completed < 5mm
019	7886	Used	Nylon	13	2000	204.0	19.8	Completed < 5mm	20.0	157.3	15.7	Attachment failure
020	7883	Used	Nylon	3	3000	193.0	18.9	Completed < 5mm	26.6	N/K	N/K	Massive Slip 140mm
021	7748	New Baseline	Nylon	0	3000	169.4	17.2	Completed < 5mm	26.6	N/K	N/K	Slippage 47mm
022	7921	Used, repaired	Nylon	10	2000	190.2	18.6	Completed < 5mm	23.0	165.0	14.3	Attachment failure
023	7876	Used	Nylon	3	3000	198.4	19.1	Completed < 5mm	26.6	N/K	N/K	Slippage 165mm
024	7930	Used, repaired	Nylon	13	2000	197.9	19.1	Completed < 5mm	23.4	164.0	14.0	Attachment failure
025	7934	Used, repaired	Nylon	11	2000	189.5	18.9	Completed < 5mm	23.0	159.3	13.8	Attachment failure
026	7922	Used, repaired	Nylon	11	2000	187.7	18.5	Completed < 5mm	23.0	169.0	14.7	Attachment failure
027	7923	Used	Nylon	4	3000	218.0	21.2	Completed < 5mm	26.6	193.8	14.6	Completed < 5mm
028	7936	Used	Nylon	4	3000	196.8	19.3	Completed < 5mm	26.6	184.0	13.8	Completed < 5mm
029	7935	Used	Nylon	4	3000	189.8	18.0	Completed < 5mm	26.6	186.6	14.0	Completed < 5mm
030	7929	Used	Nylon	5	3000	224.5	22.4	Completed < 5mm	26.6	N/K	N/K	Slippage 47mm
031	7933	Used	Nylon	5	3000	217.8	21.2	Completed < 5mm	26.6	N/K	N/K	Slippage 65mm

*Elongation and Elongation Characteristic evaluated from ram load and displacement due to loss of instrumentation data

MIRA Test	Sample	Type	Material	D o M	Rated	Elongation		Observation	Peak	Elongation		Observation
					lbs	mm	mm/kN		kN	mm	mm/kN	
032	7895	Used	Nylon	8	2000	215.4	22.1	Completed <5mm	21.9	N/K	N/K	Attachment Failure
033	7718	Used	Nylon	7	3000	230.5	23.6	Completed <5mm	26.6	200.0	15.0	Completed <5mm
034	7712	Used	Nylon	7	3000	228.0	23.2	Completed <5mm	26.6	193.0	14.5	Completed <5mm
035	7707	Used	Nylon	7	3000	221.3	22.8	Completed <5mm	26.6	191.4	14.4	Completed <5mm
036	7721	Used	Nylon	7	3000	226.7	22.8	Completed <5mm	26.6	194.0	14.6	Completed <5mm
037	7692	Used	Nylon	3	3000	196.5	19.3	Completed <5mm	26.6	N/K	N/K	Massive Slip >105mm
038	7885	Used	Nylon	3	3000	193.4	19.2	Completed <5mm	26.6	161.0	12.1	Completed 7.5mm
039	8437	Used	Nylon	5	3000	176.7	17.2	Completed <5mm	24.9	N/K	N/K	Massive Slip >42mm
040	8435	Used	Nylon	5	3000	190.4	18.7	Completed <5 mm	26.6	187.0	14.1	Slip at peak load >57mm
041	8436	Used	Nylon	5	3000	188.9	18.6	Completed <5mm	26.6	239.6	13.7	Slip peak load >46mm
042	8418	New, repaired	Nylon	0	3000	170.1	16.8	Completed <5mm	26.6	170.8	12.8	Completed <5mm
043	8410	New, repaired	Nylon	0	3000	172.5	17.2	Completed <5mm	26.6	177.4	13.3	Completed <5mm
044	8417	New, repaired	Nylon	0	3000	173.5	17.1	Completed <5mm	26.6	184.0	13.8	Completed <5mm
045	8414	New, repaired	Nylon	0	3000	172.5	17.2	Completed <5mm	26.6	179.8	13.5	Completed <5mm
046	8416	New, repaired	Nylon	0	3000	173.4	17.3	Completed <5mm	26.6	179.0	13.5	Completed <5mm
047	8422	New, repaired	Nylon	0	3000	169.3	16.7	Completed <5mm	26.6	180.6	13.6	Completed <5mm

		Type	Material	Age	Rated	Elongation		Observation	Peak	Elongation		Observation
					lbs	mm	mm/kN		kN	mm	mm/kN	
048	8421	New, repaired	Nylon	0	3000	176.6	17.5	Completed <5mm	26.6	178.4	13.4	Completed <5mm
049	8419	New, repaired	Nylon	0	3000	171.6	17.0	Completed <5mm	26.6	183.8	13.8	Completed <5mm
050	8423	New, repaired	Nylon	0	3000	111.5	10.9	Completed <5mm	26.6	169.8	12.8	Completed <5mm
051	8423	New, repaired	Nylon	0	3000	175.8	17.4	Completed <5mm	26.6	176	13.2	Completed <5mm
052	7709	Used, repaired	Nylon	4	3000	276.4	27.8	Completed 12mm	23.7	N/K	N/K	Massive Slip >64 mm
053	7710	Used, repaired	Nylon	8	3000	231.0	23.4	Completed 3mm	26.6	235.0	17.7	Slip 20 mm
054	7719	Used, repaired	Nylon	4	3000	267.7	27.6	Completed 2 mm	26.6	261.4	19.7	Completed >5mm
055	7708	Unused, stored	Nylon	6	3000	240.2	24.7	Completed 3mm	26.6	227.6	17.1	Massive Slip >96mm
056	7717	Unused, stored	Nylon	6	3000	236.4	24.2	Completed <5mm	26.6	230.2	17.3	slip at peak 31mm
057	7720	Unused, stored	Nylon	6	3000	238.8	24.5	Completed <5mm	26.6	208.6	15.7	Completed <5mm
058	7711	Unused, stored	Nylon	6	3000	242.1	24.7	Completed 3mm	26.6	231.0	17.4	Massive Slip >91mm
059	7783	New	Polyester	0	3000	92.7	8.9	Completed<5mm	26.6	110.2	8.3	Completed <5mm
060	7784	New	Polyester	0	3000	95.5	9.4	Completed<5mm	26.6	109.4	8.2	Completed <5mm
061	7785	New	Polyester	0	3000	92.4	8.9	Completed<5mm	26.6	110.0	8.3	Completed <5mm
062	7754	New - Rpt Baseline	Nylon	0	3000	170.7	17.6	Completed <5mm	25.7	175.2	13.6	Slip 25.7 33 mm
063	7755	New - Rpt Baseline	Nylon	0	3000	168.9	17.3	Completed <5mm	25.7	179.0	13.4	Slip 25.7 33 mm

MIRA Test	*Sample*	*Type*	*Material*	*Age, years*	*Rated*	*Elongation*		*Observation*	*Peak*	*Elongation*		*Observation*
					lbs	*mm*	*mm/kN*		*kN*	*mm*	*mm/kN*	
064	**7756**	**New - Rpt Baseline**	**Nylon**	**0**	**3000**	**168.5**	**17.3**	**Completed <5mm**	**26.0**	**177.2**	**13.6**	**Slip 26.0 35 mm**

Table B.2.2 Phase 2 Static Test Results Table with Observations

MIRA Test	*Ref.*	*Type*	*Material*	*Age, years*	*Rated*	*Elongation*		*Observation*	*Peak*	*Elongation*		*Observation*
					lbs	*mm*	*mm/kN*		*kN*	*mm*	*mm/kN*	
065	**9356**	**Used Refurb**	**Nylon**	**2**	**3000**	**166.5**	**17.6**	**201.2**	**21.2**	**Completed <5mm**	**26.0**	**208.6**
066	**9357**	**Used refurb**	**Nylon**	**2**	**3000**	**169.1**	**17.3**	**207.4**	**21.3**	**Completed <5mm**	**25.2**	**N/K**
067	**9355**	**Used refurb**	**Nylon**	**2**	**3000**	**165.0**	**16.6**	**198.7**	**20.3**	**Completed <5mm**	**25.4**	**N/K**
068	**9348**	**Used refurb**	**Polyester**	**3**	**3000**	**161.0**	**15.6**	**103.7**	**10.5**	**Completed <5mm**	**26.6**	**112.6**
069	**9347**	**Used refurb**	**Polyester**	**3**	**3000**	**166.8**	**16.4**	**99.4**	**9.9**	**Completed <5mm**	**26.6**	**110.0**
070	**9349**	**Used refurb**	**Polyester**	**3**	**3000**	**79.3**	**8.0**	**108.3**	**11.1**	**Completed <5mm**	**25.0**	**N/K**
071	**9366**	**Used refurb**	**Nylon**	**5**	**2000**	**80.0**	**8.0**	**194.3**	**20.1**	**Completed <5mm**	**25.1**	**N/K**
072	**9370**	**Used refurb**	**Nylon**	**5**	**2000**	**81.6**	**8.3**	**N/K**	**N/K**	**Buckle failed at 14.2 kN**	**Not tested**	
073	**9371**	**Used refurb**	**Nylon**	**5**	**2000**	**205.1**	**20.6**	**190.3**	**20.0**	**Completed <5mm**	**23.9**	**N/K**

B.3. EXAMPLE STATIC TEST REPORT

Test Results Detail – Test 001

Belt Specification			
Sample Number	7743	Belt Type	New
Manufacturer		Part Number	
Material	Nylon	DoM Number	
Total Belt Length	1135mm	Proof Load	3000lbs
Pre-Test Observations	As new		

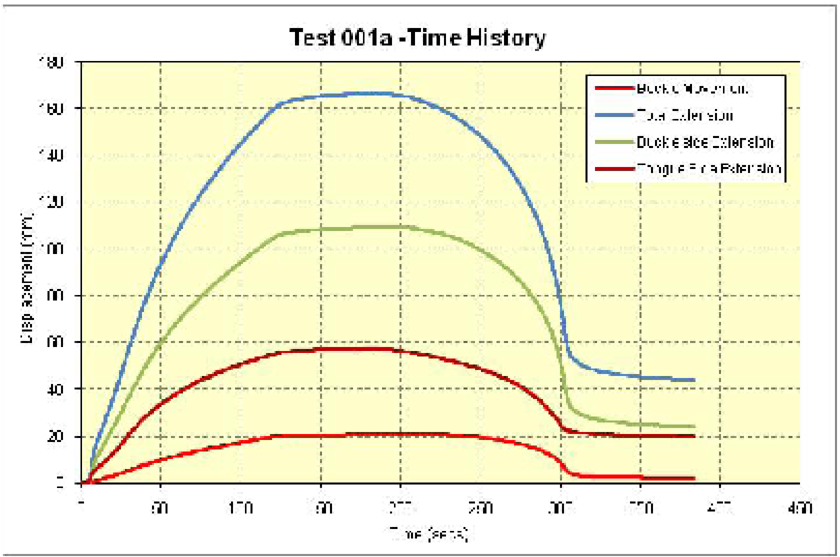
Test A - Elongation Characteristics to 18 kN

Test Set-Up Data			
Belts Lengths	Free End - 130mm	Buckle – 450mm	Tongue - 200mm
Belt Pre-Load 98.1N – 196.2N		115.3N	

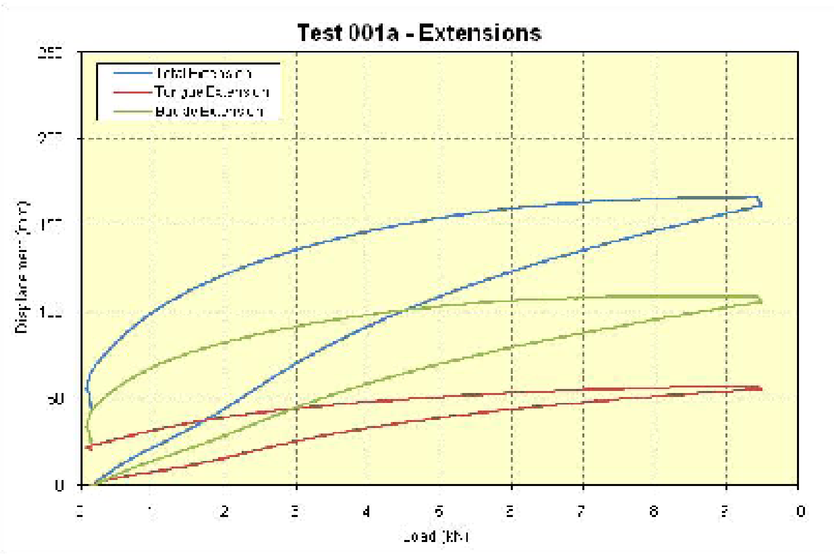
Test Recorded Data		
Ram Displacement at peak load (failure)		88.8 mm
Ram Displacement at end of test		26.5 mm
Peak Belt Loads	LH Load Cell	9.34 kN
	RH Load Cell	9.55 kN
	Average	9.45 kN
Peak Belt Elongations	Total Belt	166.5 mm
	Buckle Side	109.1 mm
	Tongue Side	57.4 mm
Belt Elongation at end of test	Total Belt	44.0 mm
Belt Elongation Characteristics	Total Belt	17.6 mm/kN (to 9.45 kN)
Test Observations Test Completed – No major belt slippage		

Post Test Observations	
Post Test belt Length	1033 mm
Belt Slippage	<5 mm
Buckle Rotation	20 mm
Failures / Damage / Abrasion	

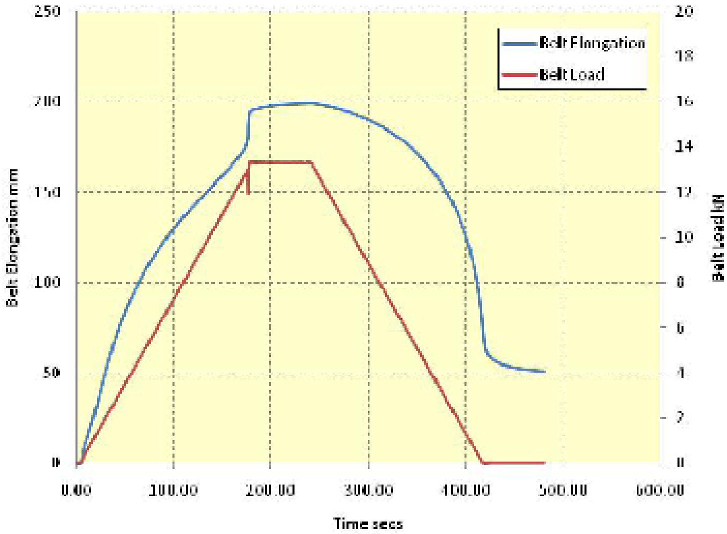
Graph 1 – Test 001A Displacement Time History



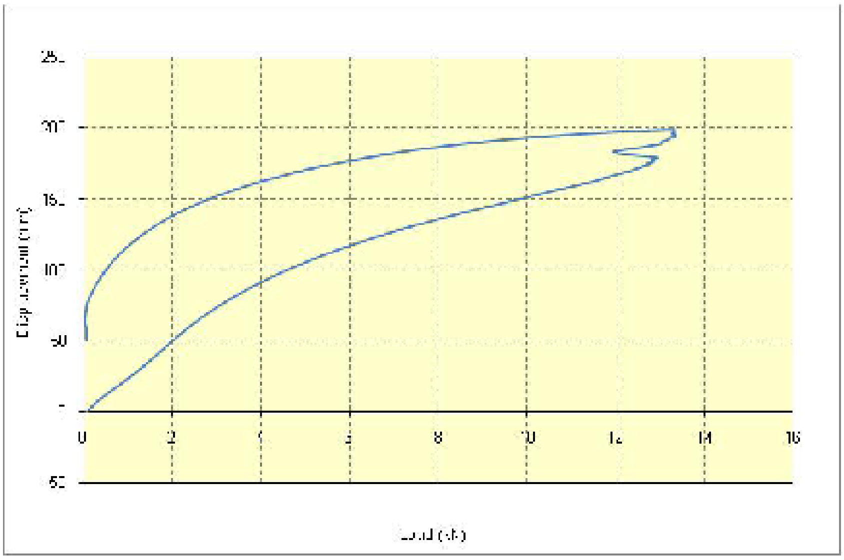
Graph 2 – Test 001A Elongation Characteristics



Graph 3 – Test 001B Displacement / Load Time History



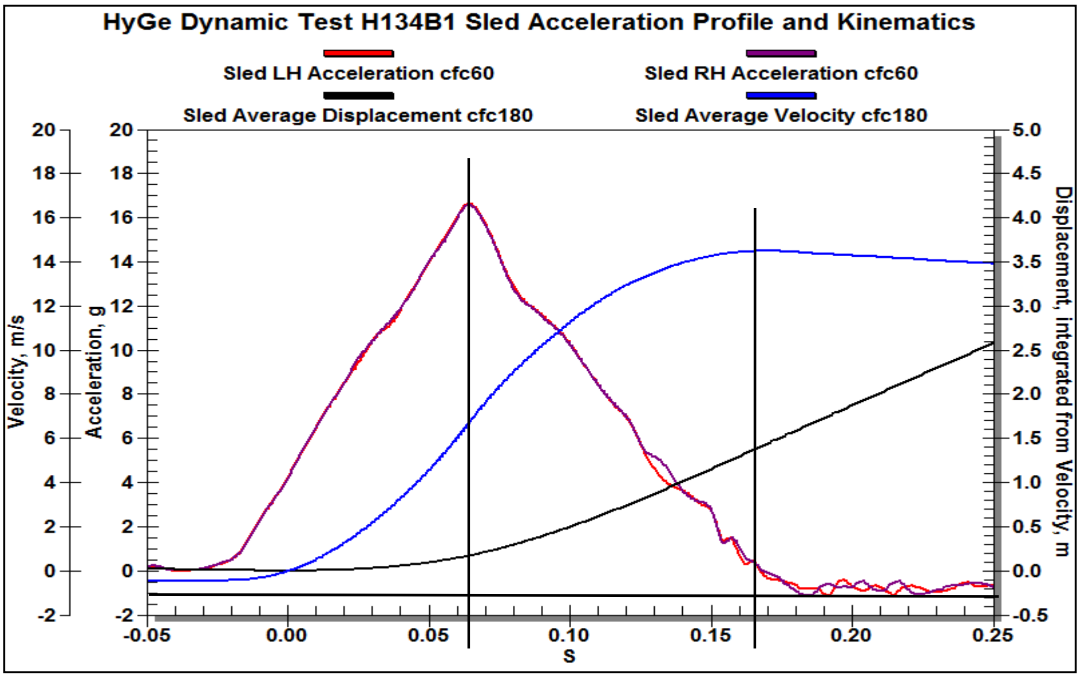
Graph 4 – Test 001B Elongation Characteristics



B.4 DYNAMIC TEST PROCEDURE

B.4.1. Test Equipment

The dynamic tests were conducted on the MIRA Hyge reverse accelerator sled using the 16g triangular acceleration profile as defined in the test protocol AS8049, to the profile validation procedure define in AS8049B. Figure B4.1 shows the sled acceleration profile and kinematics for test H134B1 while Figure B4.2 shows the acceleration profile produced in four of the 18 sled tests, showing pulse consistency



	Sled Acceleration (g)	Sled Velocity (ms^{-1})	Sled Displacement (m)
Peak Sled Acceleration (64msec)	16.6	6.65	0.17
End of Acceleration (g=0) (168mes)	0	14.5	1.40

Figure B4.1. Sled acceleration profile and kinematics table

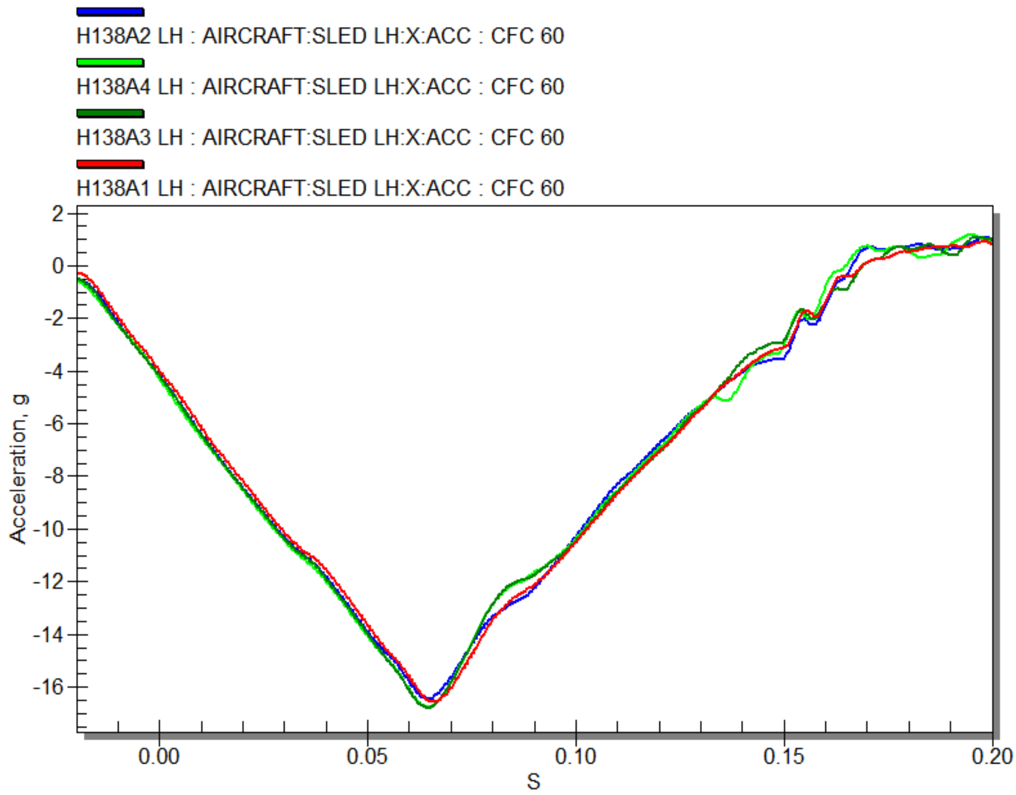


Figure B.4.2. Acceleration profiles from the HyGe reverse accelerator sled.

B.4.1.1 Test Instrumentation

Seat Belt Load Cells

The same seat belt loadcells were used for dynamic testing as for static testing. The details of these are given in Appendix B, section B.1.1.2. One seat belt load cell was positioned on the tongue side and one on the buckle side of the belt.

String Potentiometers

The same string potentiometers were used for dynamic testing and static testing. One was positioned on the tongue side and one on the buckle side of the belt. The total elongation was determined by summing the two elongation values obtained. To measure belt elongation the string potentiometers were mounted on the sled floor, on both sides behind the rigidised seat, with wires going round a pulley mounted close to the seat belt attachment point and then round the centre of the belt to the buckle (Figure B.4.3).

High Speed Video

High speed digital cameras were mounted on board the HyGe test sled, with one camera giving a general view of the each test seat and dummy to evaluate general dummy kinematics plus detailed film analysis of the dummy head trajectory, and two looking in detail at the belt and belt attachment points on both sides of the dummy. An offboard camera was mounted in front of the sled to record overall dummy kinematics.

B.4.2 TEST PROTOCOL

B.4.2.1 Belt Installation

The test sample was measured and photographed prior to the test and its general condition was noted. The test sample was attached to the seat and then both seat belt load cells were fitted. The dummy was installed in the seat to the protocol of AS8049 and the seat belt was fastened. The seat belt was tightened by pulling the free end through the buckle using a force gauge to ensure that the tightening force was approximately 150N. The length of the free end of the belt was recorded and a witness mark was made on the belt as it exited the buckle, this can be seen as a blue line on the belt in the photograph in Appendix B. Both string potentiometers were attached as shown in Figure B.2 and the wires routed along the lay of the belts, around the belt attachment stud and down to the potentiometer on the seat mounting plate.

B.4.2.2 Dummy Installation

Reference points on the dummy were measured with a 3-dimensional FARO machine and compared with a baseline dummy set-up to ensure a consistent position in each test (Figure B.4.3. A typical Test Data Sheet is shown in Appendix B.3, this details the FARO measurements made to confirm dummy position, the force applied to the free end of the belt and the free end length.

A typical instrumentation report is shown in Appendix B7; one of these was produced for every test. Each dummy was certified to the requirements of AS8049, the unique identification number can be used to trace the details of the certification. Prior to the test all the instrumentation was zeroed.

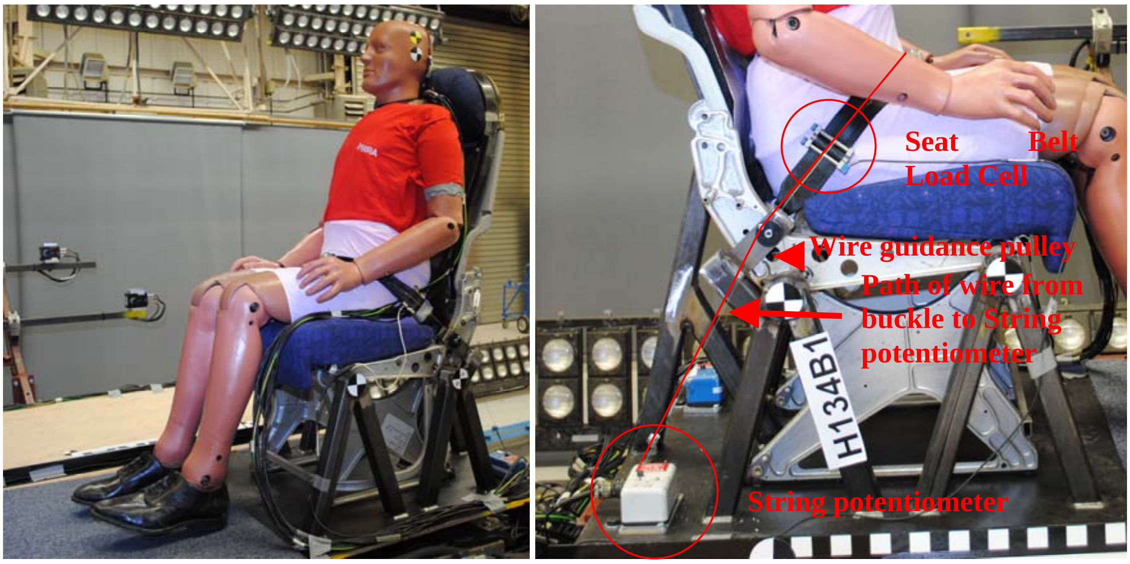


Figure B.4.3. Photograph of dummy installation into the rigidised seat and instrumentation location

B.4.2.3 Other data

The temperature and humidity were recorded during a four-hour period prior to the test.

After the test general observations were made before the string potentiometers and load cells were removed and the belt was marked on the free end to compare with the first witness mark, the belt was then un-buckled and removed for visual examination.

B 4.3. BELT ELONGATION ANALYSIS

In conducting the evaluation several belt and dummy load and kinematic have been calculated. The definition and method of evaluation is shown in the Glossary. The values for these parameters at the end of each phase is shown in Table B.4.1 and the definitive graphs plus high speed digital images are shown in Figure B.4.4.

Phase 1 – Loading mechanisms to the First Belt Peak Load – 80 msec

In the dynamic tests the sled on which the rigidised seat are mounted is given a triangular acceleration profile as defined in the aircraft seat dynamic longitudinal test protocol specified in AS8049.

In phase 1 the seat accelerates rapidly, peaking at, 16.6g at 64 msec. To accelerate the dummy, the seat belt load increases reaching the first peak of 7.75 kN at 80 msec immediately after the peak sled acceleration. The belt elongation also increases to the first peak. During this phase it is the dummy lower torso (pelvis) and upper legs, with a combined mass of 35kg, which predominantly produce the load. The dummy upper torso only starts to load at 60 msec and is responsible for only 30% at the peak. As shown in the high speed images the dummy is still upright with no upper torso rotation with no absolute movement of the head. At the end of the phase the dummy lower torso has attained the sled velocity and therefore requires no further acceleration or loading. In total the dummy has acquired 1.3kJ of kinetic energy, only 17% of the final amount.

As there have been no reduction in belt loads up to the first peak the seat belt elongation characteristic for the dynamic test is evaluated at the first peak

Phase 2 - Loading mechanisms to the Second Belt Peak Load – 129 msec

With the dummy pelvis at sled velocity and the peak sled acceleration now dropping the seat belt load reduces. However the upper torso, head, arms and lower legs, the remaining 43 kg of the dummy, now starts to significantly accelerate, with the loads passing through the dummy lumbar spine and upper legs to the pelvis and into the seat belt. So after an intial drop to 6.65kN at 98 msec, the upper torso loading continues to rise to produce the higher second peak of 9.86kN at 129 msec. During the phase the belt elongation initially remains constant as the pelvis is still being accelerated by the sled but as the upper torso load rises the belt stretchs again to 143mm at the second peak.

It is during this phase that the dummy rotates about the pelvis and lumbar spine to almost 20º at the second peak. Consequently the arms and lower legs flail out as they accelerate putting more load through the upper torso and lower legs. It is these arms effects which produce the rapid increases and decreases to the chest acceleration towards the end of the phase.

As the upper torso rotates the resultant force causes the pelvis to rise off the seat; the resulting rotation of the pelvis and pelvis accelerometers has produced a slight pelvis deceleration at the end of the phase.

At the end of the phase the sled acceleration and pelvis acceleration have significantly reduced with the 93% of the belt load being generated by the upper torso, head, arms and lower legs (the remaining dummy mass 43kg). The dummy has acquired nearly 75% of the final kinetic energy.

Phase 3 – Load Mechanism to the Peak Forward Trajectory – 145 msec

Although the upper torso has acheived the sled velocity at the second belt load peak, the upper torso, head and arms are still rotating until the peak head forward trajectory at 145msec when the dummy torso and head are at 0º. After the peak the belt loads start to reduce until 142 msec when the belt elongation peaks at before they both rapidly drop.

Unfortunately during this phase the head passes behind the flailing upper and lower arms so it is impossible to track the head trajectory until the head reappaears at 145msec. The maxiumum head trajectory probably occurred at 142ms with the peak belt elongation but for the evaluation it has been taken at 145 msec..Also all the arm and lower leg motion has disrupted both the chest and pelvis accelerations producing a rapidly changing or ‘spikey’ response making it difficult to estimate the loading coming from the upper or lower torso. However by 145msec all the dummy body parts have attained to sled velocity and the final dummy kinetic energy of 7.98 kJ.

Phase 4 – Belt unloading after the Peak Forward Trajectory

Following the peak forward trajectory the belt loads rapidly drop however the dummy continues to move downwards until the chest contacts the upper legs further forcing the dummy pelvis upwards. This causes a final belt loading peak at 190 msec with a load of 4.68kN and elongation 119mm.

The sled acceleration has now completely finished and with the dummy travelling at the same velocity as the sled the loads and elongation gradually reduce as the dummy now rotates upwards. The elastic energy in the belt being returned to the dummy which now rotates back into its original postion in the seat.

Glossary of terms used in kinematics analysis

Seat Belt

Belt Average Force kN - Average of the inboard and outboard seat belt load cells. Used for the calculation of the belt elongation characteristics as the would be the load in a static pull test.

Belt Total Force kN - Summation of the inboard and outboard seat belt load cells. The total force is the force restraining the dummy and transferred through the seat structure into the sled

Belt Buckle Elongation mm.- Elongation of the seat belt on the adjustable length of the belt from the seat attachment to the buckle.

Belt Tongue Elongation mm - Elongation of the seatbelt in the fixed length of the belt from the seat attachment to the tongue fixing into the buckle.

Belt Total Elongation mm - Summation of the buckle and tongue elongation producing the total elongation of the belt in a static pull test.

Belt Elongation Characteristic kN/mm - The total elongation in the belt divided by the average belt force producing the amount of elongation mm per kN of load applied in a static pull test. This is applied over different times and mechanisms. In the static tests to 18kN total belt load and in dynamic tests the first belt load peak.

Belt Energy kJ - The total belt load multiplied by the total belt elongation producing the total belt elastic and plastic energy in the belt. Caution – only elastic energy will be recovered on completion of the test. Used in comparison with the dummy kinetic energy in the dynamic tests.

Sled Kinematics

Sled Acceleration g - Average of the Sled LH and RH acceleration at channel filter class (CFC) 60 as defined in J211 and used in acceleration pulse analysis in AS8048

Sled Velocity ms^{-1} - Sled velocity produced from the integration of the average sled accelerations (converted in ms^{-2}) at cfc 180 as defined in J211. The velocity is relative to the stationary laboratory in the dynamic tests.

Sled Displacement m - Sled Displacement produced from the integration of the sled velocity at cfc180 as defined in J211. Displacement is relative to the stationary laboratory in the dynamic tests.

Dummy Pelvis Kinematics

Pelvis x Acceleration g - Acceleration of the dummy pelvis x direction (longitudinal) accelerometer at cfc1000. Can be directly compared with sled acceleration

Pelvis x Velocity ms^{-1} Pelvis X velocity produced from the integration of the pelvis x direction accelerometer at cfc180 as defined in J211. The velocity is relative to the

	stationary laboratory and therefore can be compared with the sled velocity. CAUTION only can be directly compared while the x accelerometer is within ±5º of the x or longitudinal direction. Therefore not to be used after approximately 130msec. The velocity is relative to the stationary laboratory in the dynamic tests.
Pelvis x displacement ms^{-1}	Pelvis X displacement produced from the double integration of the pelvis x direction accelerometer at cfc180 as defined in J211. The displacement is relative to the stationary laboratory and therefore can be compared with the sled velocity. CAUTION only can be directly compared while the x accelerometer is within ±5º of the x or longitudinal direction. Therefore not to be used after approximately 130msec. Displacement is relative to the stationary laboratory in the dynamic tests.
Pelvis Resultant Acceleration g-	Pelvis resultant acceleration calculated from the pelvis x,y and z triaxial accelerometers. Can be compared with chest resultant acceleration.
Pelvis Load kN-	Pelvis dynamic load or force is calculated from the pelvis x acceleration and pelvis and upper legs mass (35kg) (F=ma or Pelvis Load=Pelvis mass x Pelvis x-acceleration). CAUTION only can be used while the x accelerometer is within ±5º of the x or longitudinal direction. Therefore not to be used after approximately 130msec.

Dummy Chest Kinematics

Pelvis Resultant Acceleration g-	Pelvis resultant acceleration calculated from the pelvis x,y and z triaxial accelerometers. Can be compared with pelvis resultant acceleration.
Chest Resultant Velocity ms^{-2} -	As a rule resultant accelerations should NOT be used to calculate velocities and displacements. Has been used in this case to calculate chest load (see below)
Chest Load kN-	Chest dynamic load or force is calculated from the chest resultant acceleration and chest arms and lower legs mass (43kg) (F=ma or Chest Load=Chest mass x chest resultant acceleration). CAUTION a resultant acceleration should not be integrated to give velocities and displacements. Only used here to demonstrate that the loading mechanism for the chest occurs at a different time to the pelvis.
Total Dummy Load kN	Summation of Pelvis and chest load to give the total load from the dummy into the restraint system. Only to be used in comparison with the total belt load

Head Trajectory

Head Trajectory x Direction	Evaluated from the longitudinal or x direction motion of the Dummy Head Centre of Gravity marker, digitised using the Movias Pro tracking software
Head Trajectory z Direction	Evaluated from the vertical or z direction motion of the Dummy Head Centre of Gravity marker, digitised using the Movias Pro tracking software

Dummy Total Kinetic Energy

Dummy Kinetic Energy kJ	Calculated using the pelvis and chest velocities and masses. To be used with CAUTION as the chest velocity is integrated from the resultant acceleration and the pelvis x direction accelerometer goes out of the longitudinal direction after 130 msec

Table B.4.1 Belts Loads and Characteristics with Sled and Dummy Kinematics and Energies

		Phase 1 - 80msec	Phase 2 - 129msec	Phase 3 - 145msec
		First Belt Load Peak	Second Belt Load Peak	Head Maximum Forward Trajectory
Belt Characteristics				
Belt Average Force	kN	7.75	9.86	7.86
Belt Elongation	mm	133	143	141
Belt Elongation Characteristic	kN/mm	17.2	14.5	17.9
Sled Kinematics				
Acceleration	g	12.9 (peak 16.6 @ 64 msec)	5.0	3.0
Velocity	ms^{-1}	9.0	13.2	14.2
Displacement	m	0.300	0.860	1.130
Pelvis Kinematics				
Resultant Acceleration	g	33.5 (peak 34.2@78msec)	37.3	17.6 (-7.63g X- Direction)
Velocity (X Direction)	ms^{-1}	8.6	13.5	12.2
Displacement (X Direction)	m	0.160	0.740	0.990
Chest Kinematics				
Resultant Acceleration	g	6.2	37.3	44.7 (peak)
Chest Load (from res acceleration)	kN	3.8	9.4	Difficult to assess
Head Trajectory				
X - Direction (Forward)	m	0.008 (0.308 relative to sled))	0.109 (0.849 relative to sled)	0.261 (0.869 relative to sled)
Z – Direction (vertical)	m	0.001	0.311	0.543

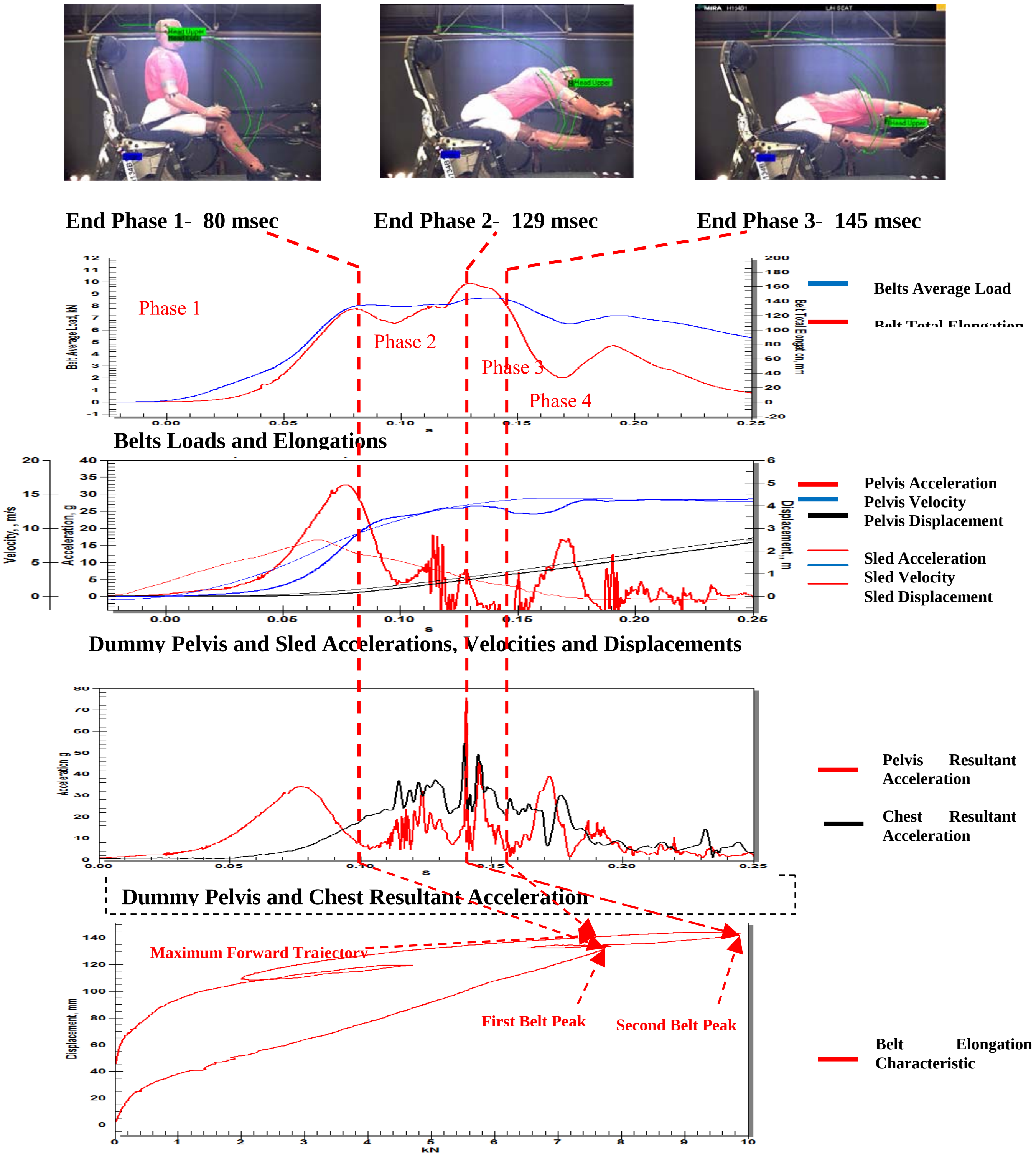


Figure B.4.4. Belt Loads with Dummy Kinematics and Loading Mechanisms

B.4.4. HEAD TRAJECTORY AND DUMMY KINEMATICS

In all the dynamic tests the dummy head trajectory was analysed from the high speed digital images. NAC Movias Pro film analysis system was used, using automatic film target tracking (Figure B.4.5.). As the head disappears behind the dummy's flailing arms immediately prior to peak head trajectory, at approximately 138msec, the peak head trajectory used in the comparisons and statistical analysis is the peak forward trajectory at 138msec to ensure consistency between tests. Figure B.4.6. shows the Head trajectory analysis with the head markers disappearing behind the flailing arms for both the RH and LH seating locations. Figure B.4.7. shows a typical graph which would be produced.

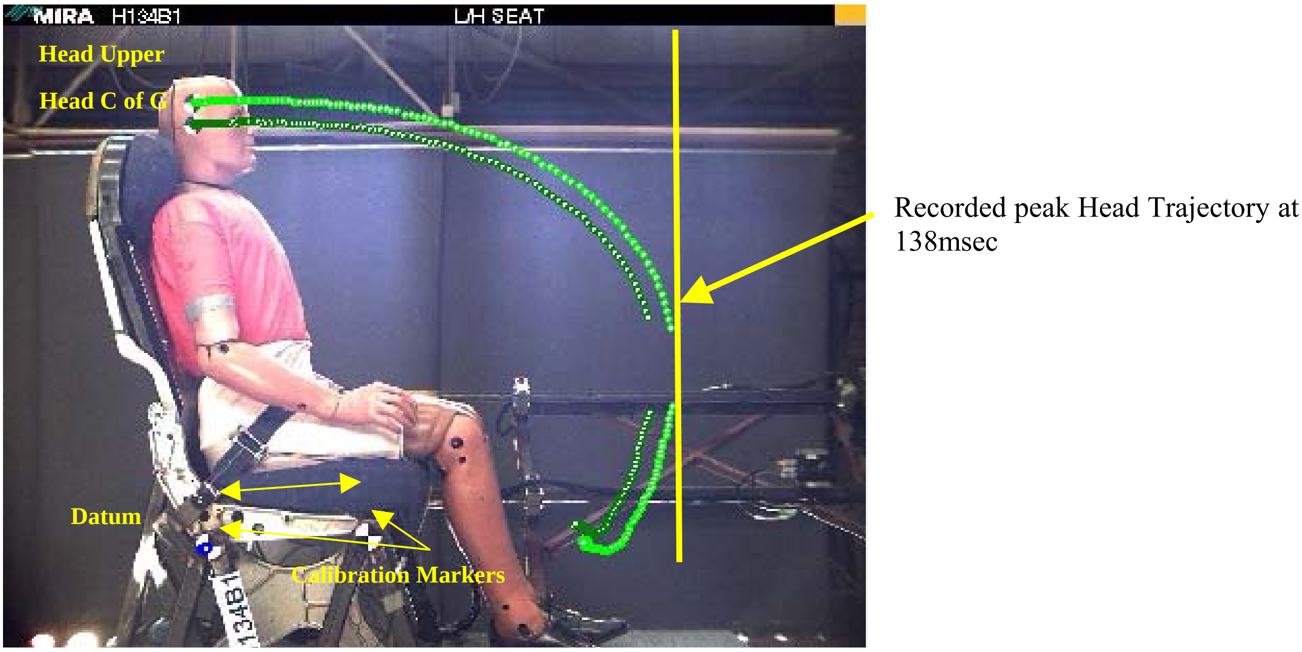


Figure B.4.5. Head Trajectory analysis showing Peak Trajectory location immediately prior head marker disappearing behind flailing arms

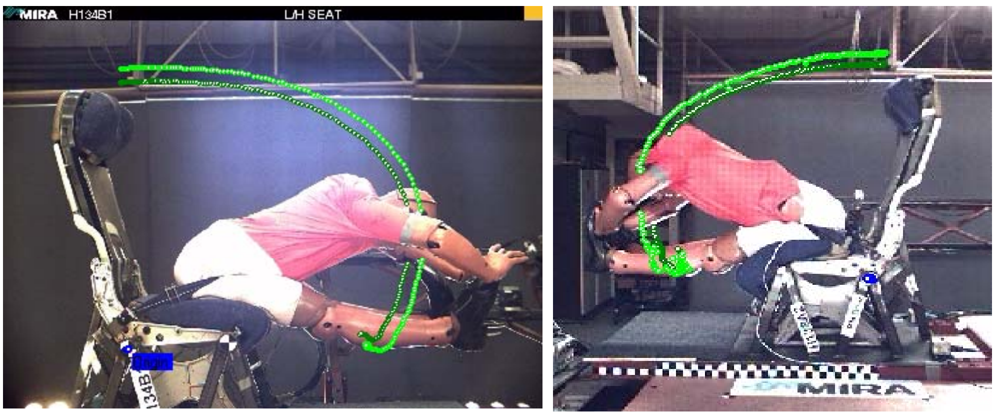


Figure B.4.6. Head disappearing behind flailing arms for the RH and LH seating locations

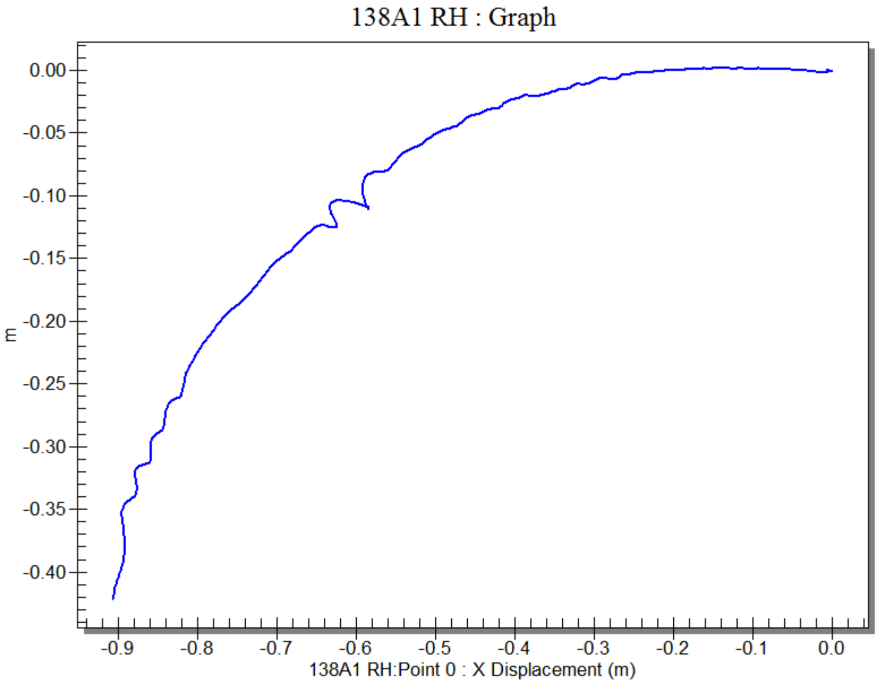


Figure B.4.7. Graph of upper head trajectory of dummy

B.4.5. COMPARISON OF NYLON AND POLYESTER SEAT BELTS

As part of the analysis of the dynamic tests a comparison was conducted between the baseline new Nylon Belt and new Polyester Belt.

B.4.5.1. Belt Loading and Elongations

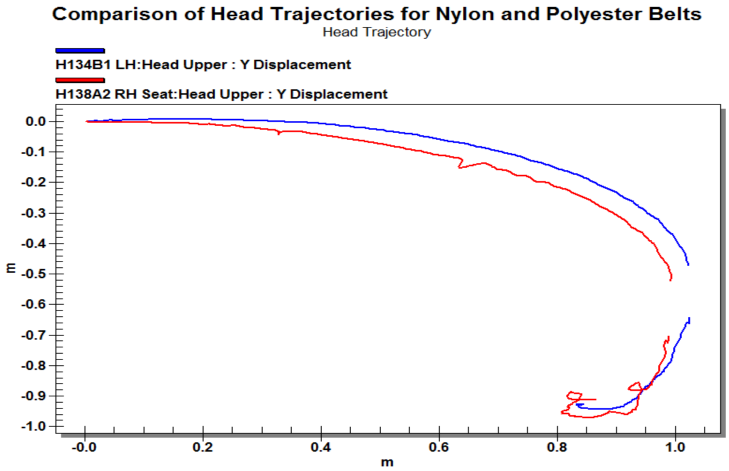
The average belt force and total belt elongations for a nylon and a polyester belt are shown in Figure B.4.8. with the elongation characteristics in Figure B.4.9, and the peaks in Table B.4.2. With the same loading mechanisms from the HII dummy, the four loading phases defined in section B.4.3., the belt loading profiles were shown to be similar with the 2 main loading peaks occurring at peak pelvis loading and peak forward occupant trajectory. However, as expected, the stiffer polyester belt produced approximately less elongation. The reduced elongation brought the first loading peak forward from 80 to 75 msec; the 5 msec offset being maintained for the rest of the test. The belt elongation characteristics showed the same phases of loading but with half the elongation.

B.4.5.2. Pelvis Kinematics

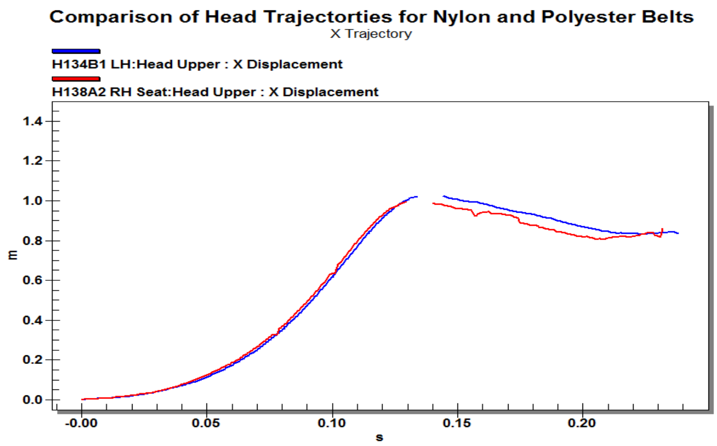
The increased stiffness of the polyester has only a marginal effect on the pelvis resultant acceleration velocity and displacement during phase 1 and phase 2. The increased pelvis resultant acceleration in phase 3, is produced by increased vertical acceleration as the pelvis upward motion is restricted by the increased belt stiffness.

B.4.5.3. Head Forward Trajectory

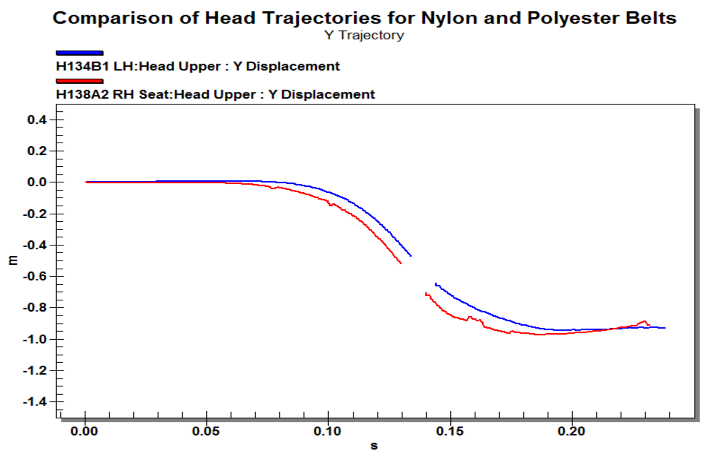
Head trajectory analysis is shown in Figure B.4.8 With the increased stiffness in the polyester belt head forward trajectory has be slightly reduced by 32mm at peak recorded head trajectory before the head targets disappear behind the flailing arms however the vertical displacement increased. The effect is seen in the Head X and Head Z time trajectory graphs. In the Head X graph the forward trajectories match with time while in the Head Z the polyester belt shows more vertical motion with time than the nylon belt. The stiffer belt reduces the amount of vertical upward motion of the pelvis in Phases 2 and 3; increasing the overall downward motion.



Head X and Z Trajectory



Head X Displacement with Time



Head Z Displacement with Time

Figure B.4.8. Belt Loads with Dummy Kinematics and Loading Mechanisms for nylon and polyester belts

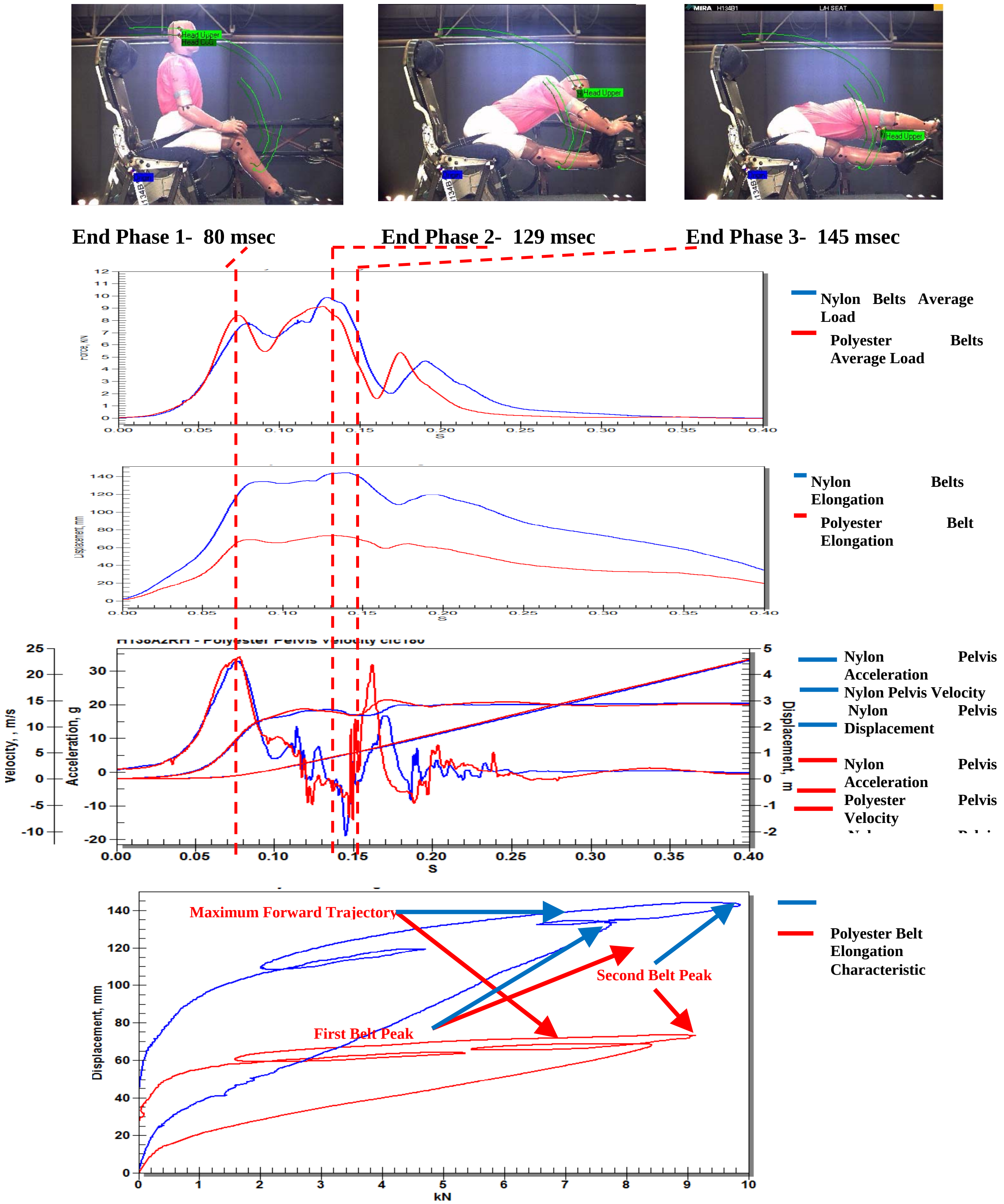


Figure B.4.9. Belt Loads with Dummy Kinematics and Loading Mechanisms

Table B.4.2. Belts Loads and Characteristics with Sled and Dummy Kinematics and Energies

Parameter	Units	Phase 1 - 80 / 75msec		Phase 2 - 129msec		Phase 3 (At peak trajectory or velocity)	
		First Belt Load Peak		Second Belt Load Peak		Head Maximum Forward Trajectory	
		Nylon	Polyester	Nylon	Polyester	Nylon	Polyester
Belt Characteristics							
Belt Average Force	kN	7.75	8.41	9.86	9.12	7.86	5.75
Belt Elongation	mm	133	68	143	73	141	71
Belt Elongation Characteristic	mm/kN	17.2	8.1	14.5	8.0	17.9	12.3
Energy in belt	kJ	1.031	0.572	1.410	0.668	1.108	1.115
Sled Kinematics							
Acceleration	g	12.9 (peak 16.6 @ 64 msec)		5.0		3.0	
Velocity	ms^{-1}	9.0		13.2		14.2	
Displacement	m	0.300		0.860		1.130	
Pelvis Kinematics							
Resultant Acceleration	g	33.5 (peak 34.2@78msec)	33.6 (peak 34.0@77msec)	37.3	43.1	17.6	18.0
Velocity (X Direction)	ms^{-1}	8.6	7.3	13.5	13.0	14.1	15.1
Displacement (X Direction)	m	0.160	0.120	0.740	0.74	1.260	1.290
Pelvis Load (from x acceleration)	kN	11.3	11.7	0.5	3.6	Difficult to assess	
Chest Kinematics							
Resultant Acceleration	g	6.2	6.6	37.3	30.9	44.7 (peak)	61.1 (peak)
Chest Load (from res acceleration)	kN	3.8	2.7	9.4	12.1	Difficult to assess	
Head Trajectory							
X - Direction (Forward)	m	0.370	0.308	0.989	0.948	1.023	0.991
Z – Direction (vertical)	m	0.001	0.035	0.311	0.330	0.521	0.543

B.5. DYNAMIC TEST RESULTS OVERVIEW

MIRA Test		*Sample*								
Test	***Seat***		***Type***	***Material***	***Age, years***	***Rating, lbs***	***Date / Time***	***Belt Observations***	***Maximum Elongation mm***	***Film Analysis* mm***
H134B1	**RH**	**7748**	**Baseline**	**Nylon**	**0**	**3000**	**25 Aug 14:30**	**No slippage, no damage**	**142**	**819**
	LH	**7749**	**Baseline**	**Nylon**	**0**	**3000**	**25 Aug 14:30**	**No slippage, no damage**	**142**	**832**
H138A1	**RH**	**7750**	**Baseline**	**Nylon**	**0**	**3000**	**20Sep 12:00**	**No slippage, no damage**	**156**	**829**
	LH	**7771**	**New**	**Polyester**	**0**	**3000**	**20Sep 12:00**	**No slippage, no damage**	**69**	**779**
H138A2	**RH**	**7772**	**New**	**Polyester**	**0**	**3000**	**20Sep 13:30**	**No slippage, no damage**	**73**	**874**
	LH	**7773**	**New**	**Polyester**	**0**	**3000**	**20Sep 13:30**	**No slippage, no damage**	**42**	**779**
H138A3	**RH**	**7691**	**Used**	**Nylon**	**13**	**2000**	**20Sep 15:00**	**No slippage, no damage**	**129**	**851**
	LH	**7871**	**Used**	**Nylon**	**8**	**2000**	**20Sep 15:00**	**No slippage, no damage**	**141**	**793**
H138A4	**RH**	**7689**	**Used**	**Nylon**	**2**	**2000**	**21 Sep 9:15**	**Belt Attach Failure**	**-**	**824**
	LH	**7889**	**Used**	**Nylon**	**13**	**2000**	**21 Sep. 9:15**	**No slippage, no damage**	**117**	**809**
H138A5	**LH**	**7780**	**New**	**Nylon**	**0**	**3000**	**21 sep 11:30**	**No slippage, no damage**	**85**	**757**
H138A6	**LH**	**7781**	**New**	**Nylon**	**0**	**3000**	**21 sep 1:00**	**No slippage, no damage**	**92**	**769**
H138A7	**LH**	**7782**	**New**	**Nylon**	**0**	**3000**	**21 Sep. 2:30**	**No slippage, no damage**	**82**	**794**

MIRA Test		*Sample*								
Test	*Seat*		*Type*	*Material*	*Age, years*	*Rating, lbs*	*Date / Time*	*Belt Observations*	*Maximum Elongation mm*	*Film Analysis mm*
H138A8	**LH**	**7865**	**Used**	**Nylon**	**13**	**2000**	**22 Sep 8:30**	**No slippage, no damage**	**122**	**800**
H138A9	**LH**	**7827**	**Used**	**Nylon**	**4**	**3000**	**22 Sep 9:30**	**No slippage, no damage**	**141**	**754**
H138AA	**LH**	**7828**	**Used**	**Nylon**	**4**	**3000**	**22 Sep 10:30**	**No slippage, no damage**	**130**	**822**
H138AB	**RH**	**7862**	**Used**	**Nylon**	**9**	**2000**	**22 Sep 12:00**	**No slippage, no damage**	**163**	**837**
	LH	**7884**	**Used**	**Nylon**	**9**	**2000**	**22 Sep 13:00**	**No slippage, no damage**	**133**	**760**
H138AC	**RH**	**7894**	**Used**	**Nylon**	**8**	**2000**	**22 Sep 14:30**	**No slippage, no damage**	**140**	**829**
	LH	**7875**	**Used**	**Nylon**	**9**	**2000**	**22 Sep 16:00**	**No slippage, no damage**	**132**	**813**
H139D1	**RH**	**7688**	**Used**	**Nylon**	**9**	**2000**	**30 Sept 10:00**	**No slippage, no damage**	**148**	**820**
	LH	**7925**	**Used**	**Nylon**	**12**	**2000**	**30 Sept 10:00**	**No slippage, no damage**	**133**	**867**
H139D2	**RH**	**7693**	**Used**	**Nylon**	**9**	**2000**	**30 Sept 12:00**	**No slippage, no damage**	**137**	**814**
	LH	**7931**	**Used**	**Nylon**	**4**	**3000**	**30 Sept 12:00**	**No slippage, no damage**	**135**	**850**
H139D3	**RH**	**7932**	**Used**	**Nylon**	**12**	**2000**	**30 Sept 16:00**	**No slippage, no damage**	**130**	**835**
	LH	**7790**	**New, stored**	**Nylon**	**5**	**3000**	**30 Sept 16:00**	**No slippage, no damage**	**136**	**848**
H140A1	**RH**	**7791**	**New, stored**	**Nylon**	**5**	**3000**	**3 0ct 09:30**	**No slippage, no damage**	**145**	**822**
	LH	**7792**	**New, stored**	**Nylon**	**5**	**3000**	**3 Oct 09:30**	**No slippage, no damage**	**163**	**852**

MIRA Test		*Sample*								
Test	*Seat*		*Type*	*Material*	*Age, years*	*Rating, lbs*	*Date / Time*	*Belt Observations*	*Maximum Elongation mm*	*Film Analysis mm*
H140A2	**RH**	**8409**	**Repaired**	**Nylon**	**0**	**3000**	**3 Oct 10:30**	**No slippage, no damage**	**137**	**831**
	LH	**8412**	**Repaired**	**Nylon**	**0**	**3000**	**3 Oct 10:30**	**No slippage, no damage**	**130**	**853**
H140A3	**RH**	**8415**	**Repaired**	**Nylon**	**0**	**3000**	**3 Oct 11:30**	**No slippage, no damage**	**129**	**819**
	LH	**8413**	**Repaired**	**Nylon**	**0**	**3000**	**3 Oct 11:30**	**No slippage, no damage**	**125**	**859**
H140A4	**RH**	**8411**	**Repaired**	**Nylon**	**0**	**3000**	**3 Oct 13:00**	**No slippage, no damage**	**135**	**842**
	LH	**7751**	**New**	**Nylon**	**0**	**3000**	**3 Oct 13:00**	**No slippage, no damage**	**130**	**798**
H140A5	**RH**	**7752**	**New**	**Nylon**	**0**	**3000**	**3 Oct 15:00**	**No slippage, no damage**	**121**	**833**
	LH	**7753**	**New**	**Nylon**	**0**	**3000**	**3 Oct 15:00**	**No slippage, no damage**	**118**	**866**

*Film analysis: upper head target X trajectory at 125th frame

B.6. EXAMPLE DYNAMIC TEST REPORT

Test Data Sheet – Test H138A3 RH – Sample 7691

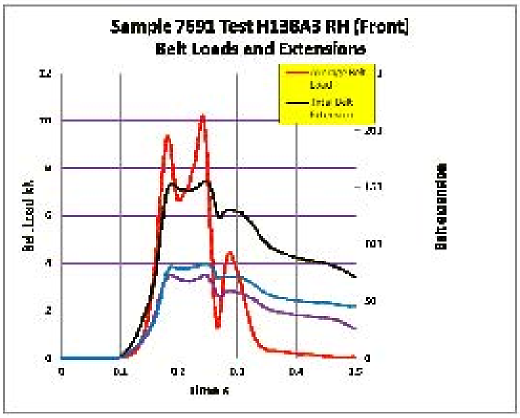
Belt Specification			
Sample Number	7691	Belt Type	Used
Manufacturer		Part Number	
Material	Nylon	DoM	0798
Total Belt Length	1068 mm	Proof Load	3000 lbs
Pre-Test Observations	Slight fraying on the edges. Wear on attachments.		

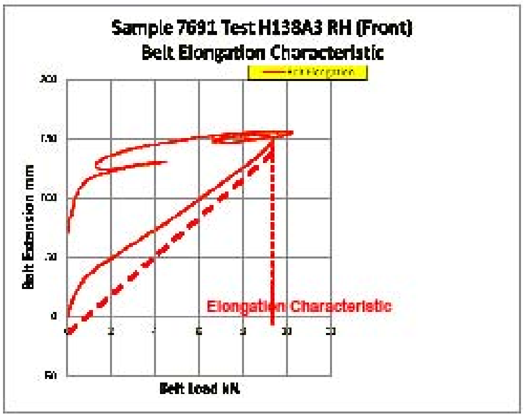
Dynamic Test

Test Set-Up Data			
Belts Lengths	Free End - 326 mm	Buckle –	Tongue –
Belt Pre-Load 98 – 196 N		152N	
Dummy QA Number		S/N 685	

Test Recorded Data		
Peak Sled Acceleration		16.8g – Compliant with AS8049B
Peak Dummy Pelvis Acceleration		37.8g
Peak Head Forward Trajectory		mm
Peak Belt Loads Seat Belt Load cells	LH Load Cell	10.44kN
	RH Load Cell	10.10kN
	Average	10.20kN
Peak Belt Elongations String Potentiometers	Total Belt	82.6mm
	Buckle Side	72.7mm
	Tongue Side	155.3mm
Peak Elongation at end of test	Total belt	mm
Belt Elongation Characteristics	First peak 9.3 kN	15.9 mm/kN
Test Observations Test Completed – No major belt slippage – Belt buckle released OK		

Post Test Observations	
Post Test belt Length (As Tested)	**787mm**
Belt Slippage	**< 5 mm**
Failures / Damage / Abrasion **No failures or increase in damage or abrasion**	





B.7 Dummy Instrumentation report

MIRA Crash/HyGe Test Instrumentation Report

MIRA Project Number	1029769	**Print Date**	25 August 2011 14:38:54
Customer Test Number	.	**Test Date**	25/Aug/11 14:38
Customer	EASA	**Test Number**	134B1
Test Configuration	Aircraft 16G	**MIRA Engineer**	Andy Haynes
Legislation	None	**Customer Engineer**	Dr A R Payne

Location	**Direc**	**Type**	**DAU**	**Chan**	**Q-No**	**CAC**	**Mu**	**Cal Due Date**
LH Seat Inboard	N/A	POTL	MD14	2	22197	380	mm	31/Aug/11
LH Seat Outboard	N/A	POTL	MD14	1	2067	254	mm	26/Aug/11
LHF Seat Belt Lap Inboard	N/A	LC	MD14	23	27303	16	kN	17/Aug/12
LHF Seat Belt Lap Outboard	N/A	LC	MD14	6	7713	30	kN	17/Aug/12
RH Seat Inboard	N/A	POTL	MD14	3	1251	762	mm	26/Aug/11
RH Seat Outboard	N/A	POTL	MD14	4	22105	508	mm	26/Aug/11
RHF Seat Belt Lap Inboard	N/A	LC	MD14	18	7528	30	kN	19/Jun/12
RHF Seat Belt Lap Outboard	N/A	LC	MD14	21	7527	30	kN	19/Jun/12
Sled LH	X	ACC	MD14	20	13908	200	g	16/Feb/12
Sled RH	X	ACC	MD14	16	5997	400	g	3/Feb/12
CHEST Hii 50% RH (Hybrid II t S-N 711)	X	ACC	MD14	14	20453	200	g	3/Jul/12
CHEST Hii 50% RH (Hybrid II S-N 711)	Y	ACC	MD14	12	122	200	g	3/Jul/12
CHEST Hii 50% RH (Hybrid II S-N 711)	Z	ACC	MD14	13	5	200	g	3/Jul/12
HEAD Hii 50% RH (Hybrid II S-N 711)	X	ACC	MD14	11	21685	200	g	16/Mar/12
HEAD Hii 50% RH (Hybrid II S-N 711)	Y	ACC	MD14	10	3310	200	g	16/Mar/12
HEAD Hii 50% RH (Hybrid II t S-N 711)	Z	ACC	MD14	9	6416	200	g	15/Mar/12
LUMBAR Hii 50% RH (Hybrid II S-N 711)	FZ	LC	MD14	7	38	20	kN	28/Mar/12
PELVIS Hii 50% RH (Hybrid II S-N 711)	X	ACC	MD14	15	11259	200	g	8/Aug/12
PELVIS Hii 50% RH (Hybrid II S-N 711)	Y	ACC	MD14	17	9635	200	g	8/Aug/12
PELVIS Hii 50% RH (Hybrid II S-N 711)	Z	ACC	MD14	19	12494	200	g	8/Aug/12
CHEST Hii 50% LH (Hybrid II S-N 685)	X	ACC	MD14	26	5459	200	g	26/Jul/12
CHEST Hii 50% LH (Hybrid II S-N 685)	Y	ACC	MD14	24	390	200	g	26/Jul/12
CHEST Hii 50% LH (Hybrid II S-N 685)	Z	ACC	MD14	22	433	200	g	26/Jul/12
HEAD Hii 50% LH (Hybrid II S-N 685)	X	ACC	MD14	27	2540	200	g	5/Jan/12
HEAD Hii 50% LH (Hybrid II S-N 685)	Y	ACC	MD14	28	590	200	g	4/Jul/12
HEAD Hii 50% LH (Hybrid II S-N 685)	Z	ACC	MD14	25	588	200	g	4/Jul/12

LUMBAR Hii 50% LH (Hybrid II S-N 685)	FZ	LC	MD14	30	3272	20	kN	23/Mar/12
PELVIS Hii 50% LH (Hybrid II S-N 685)	X	ACC	MD14	32	14661	200	g	26/Jul/12
PELVIS Hii 50% LH (Hybrid II S-N 685)	Y	ACC	MD14	29	6407	200	g	26/Jul/12
PELVIS Hii 50% LH (Hybrid II S-N 685)	Z	ACC	MD14	31	25248	200	g	26/Jul/12

B.8. Aircraft Seat Belt Failure Mechanisms

In the Static and Dynamic test programmes there were several belt loading failures, some gradual with slipping of webbing through the adjustable buckle and some catastrophic with lost of belt integrity. In the test programmes 4 different belt failure mechanisms were identified. Table B.8.1. shows the type of belt failure mechanisms and the type of belts and tests in which they occurred.

Massive Webbing Slippage
In assessing belt slippage in all static and dynamic tests, an indelible mark was drawn on the webbing, along the buckle edge, both and after the tests. The distance between the pre and post test marks being the belt slippage. In all tests a small amount of slippage will occur, to allow the buckle gripping mechanism to take load, and stretch of the belt within the buckle itself. Therefore any belt slippage less than 5mm was declared acceptable. In many of the higher load static tests, up to 26kN, the buckle gripping mechanism failed, leading to large, uncontrolled webbing slippage through the buckle, causing rapid reduction in loads, as the hydraulic actuator was unable to move fast enough to maintain load. In these tests, the test was aborted, with the failure mechanism declared as 'massive webbing slippage'; where possible this was measured using the marks on the belt.

Belt Attachment Failures
On both the buckle and tongue sides of the belt, the belt is attached by hooking a metal attachment plate around a pin mounted into the aircraft frame. A spring loaded clip ensures that the attachment remains on the pin, so the belt can only be removed by depressing the clip. In several of the higher load, 26kN static tests and one dynamic test the metal attachment plates fractured across the narrowest point of the plate, with the belt immediately loss integrity. This failure mechanism was confined to the older specification 2000lb belts.

Belt Webbing Cutting
In one higher load static test, the buckle gripping mechanism cut through the belt webbing, leading to catastrophic failure of the webbing.

Belt Buckle failure
The buckle release plate is attached to the buckle frame by a metal hinge pin, the pin held in place by metal retaining cap insert on either end of the pin, outside the buckle frame. In one test the cap insert appeared to have been forced out due to distortion of the buckle frame, leading to the pin becoming disengaged release of the buckle gripping mechanism and catastrophic failure of the buckle. In another test buckle integrity was maintained but one of the retaining cap inserts had been released.

Table B. 8.1. Summary of seatbelt failure mechanisms

	Static Tests (26 kN integrity tests)				Dynamic Tests			
	New (3000lb)	Used 3000lb	Used 2000lb	Refurbished	New (3000lb)	Used 3000lb	Used 2000lb	Refurbished
Massive Webbing Slippage	9	9	0	2	0	0	0	0
Attachment Failure	0	0	14	1	0	0	1	0
Belt webbing cutting	0	0	0	1	0	0	0	0-
Belt Buckle Failure	0	0	2 (1 in 18 kN Test)	0	0	0	0	0

APPENDIX C

C.1. FEASIBILITY STUDY TABLE OF RESULTS

HSL Test	Sample	Type	Material	Age	Rated	Elongation		Peak
					lbs	mm	mm/kN	kN
F35	7737	New	Nylon	0	3000	47.7	6.3	7.6
F36	7738	New	Nylon	0	3000	52.1	6.4	8.2
F37	7733	New	Nylon	0	3000	55.7	6.8	8.2
F38	7732	New	Nylon	0	3000	54.8	6.3	8.7
F39	7736	New	Nylon	0	3000	55.8	6.4	8.7
F40	8428	New, repaired	Nylon	0	3000	53.8	6.3	8.5
F41	8424	New, repaired	Nylon	0	3000	54.5	6.5	8.4
F42	8427	New, repaired	Nylon	0	3000	53.8	6.3	8.6
F43	8425	New, repaired	Nylon	0	3000	50.4	6.2	8.1
F44	8426	New, repaired	Nylon	0	3000	53.2	6.5	8.2
F45	7714	New	Polyester	0	3000	27.0	2.6	10.4
F46	7715	New	Polyester	0	3000	24.8	2.6	9.7
F47	7713	New	Polyester	0	3000	24.1	2.6	9.4

Table 1 Continued.

HSL Test	Sample	Type	Material	Age	Rated	Elongation		Peak
					lbs	mm	mm/kN	kN
F48	7896	Used	Nylon	3	3000	54.9	7.0	7.8
F49	7877	Used	Nylon	3	3000	52.5	6.4	8.2
F50	7864	Used	Nylon	3	3000	55.9	6.7	8.4
F51	7874	Used	Nylon	13	2000	51.8	6.6	7.8
F52	7873	Used	Nylon	13	2000	54	6.6	8.2
F53	7867	Used	Nylon	13	2000	54.8	6.5	8.4
F54	7882	Used	Nylon	8	2000	57.5	7.3	7.9
F55	7899	Used	Nylon	8	2000	60.9	7.2	8.5
F56	7793	Used	Nylon	8	2000	55.5	6.7	8.3
F57	8432	Used	Nylon	5	3000	35.4	4.4	8.1
F58	8433	Used	Nylon	5	3000	37.3	4.3	8.6
F59	8434	Used	Nylon	5	3000	35.7	4.3	8.3

C.2. COMPRESSIVE PROPERTIES OF ENERGY ABSORBING MATERIALS

Figure C.1. Static load-displacement profile for the energy absorber assembly used in the feasibility test rig Phase 1 and Phase 2 (115 mm crush can)

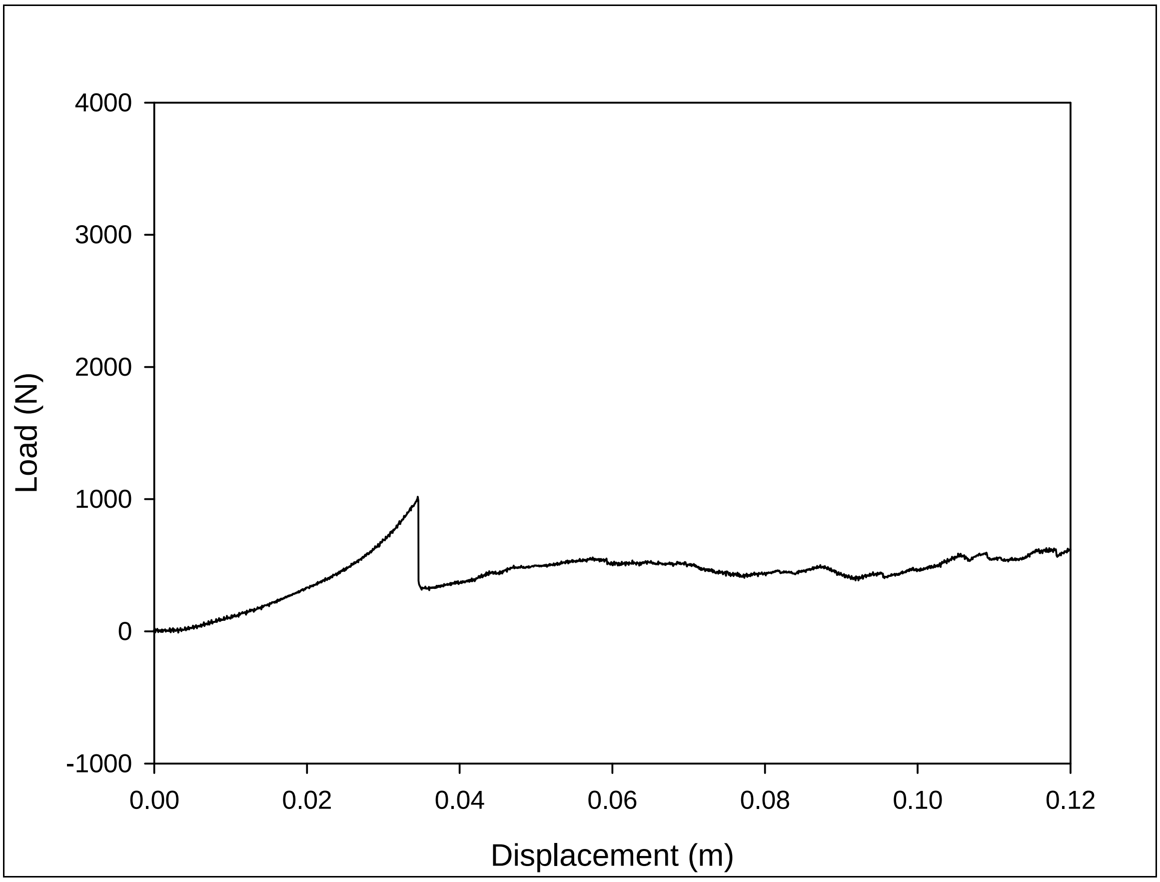


Figure C.2. Static load-displacement profile for the energy absorber assembly used in the feasibility test rig Phase 2 (150 mm crush can)

C.3. PHASE 2 TEST RESULTS

C.3.1. Fixed sample length tests - 115mm crush can

Test number	Drop height, mm	Duration, msec	Peak force, kN
86	350	79	6.87
95	350	81	6.65
88	350	90	7.24
87	400	76	7.43
89	400	80	7.80
90	400	80	7.43
65	400	75	7.79
91	450	69	8.45
92	450	66	8.39
66	450	71	8.41
93	500	71	9.26
67	500	75	9.05

C.3.2. Fixed sample length tests - 150mm crush can

Test number	Drop height, mm	Duration, msec	Peak force, kN
96	400	97	7.77
97	400	104	7.51
98	400	98	7.57
70	400	86	9.27
71	450	89	8.42
68	450	89	8.40
72	450	92	8.68
99	450	85	9.34
100	500	90	8.92
101	500	89	9.48

C3.3. Varying sample length tests

Test number	Separation, mm	Drop height, mm	Duration, msec	Peak force, kN
70	300	450	86	9.27
71	300	450	89	8.42
72	300	450	92	8.68
76	200	400	95	8.08
77	200	400	98	8.04
78	200	400	93	8.16
79	250	425	99	8.16
80	250	425	85	8.29
81	250	425	76	8.07
82	350	475	87	8.98
83	225	412.5	99	7.95
84	225	412.5	80	7.84
85	225	412.5	84	8.19

APPENDIX D

COMPARABILITY AND REPEATABILITY OF THE DYNAMIC AND FEASIBILITY TESTS - PERCENTAGE ELONGATION

There was very little variability in the belt lengths within the belt types (Table D1), and so it is unsurprising that using % elongation instead of absolute elongation did not substantially impact the results (Table D2). The one difference is that the variability for the dynamic test for 13 year old belts was no longer statistically significantly greater than that of the feasibility test (p=0.112, Table D2). This suggests that some of the additional variability for 13 year old belts when using the dynamic test compared to the feasibility test could have been due to variability in the belt lengths. However, the difference in variability between the two test methods remained statistically significant for 3 year old belts (p=0.029, Table D2) and of borderline statistical significance for 6 year old unused belts (p=0.069, Table D2), which suggests that different belt lengths did not account for all of the additional variability observed for the dynamic test when testing old/used belts.

To ensure that the different belt lengths did not affect results, the analyses quantifying the difference in elongation between the two test methods for old/used belts was repeated, but additionally adjusting for belt length. The results were not substantially different, and there remained no evidence of a difference in the measured elongations for old/used belts (estimated difference = -8.03 mm; 95%CI = -27.50 to 11.44 mm; p=0.419). The analyses for new belts and that quantifying the reliability of the tests were not repeated due to the lack of belt length data for two of the three new belt groups, which would have substantially affected these results.

Table D1. Summary of belt lengths (mm)

Belt type	***Dynamic test***				***Feasibility test***			
	N	***Mean***	***Min***	***Max***	***N***	***Mean***	***Min***	***Max***
New belts								
New nylon belts	Not available							
New polyester belts	Not available							
Repaired belts - new	5	348	347	350	5	347	346	348
Old/used belts								
6 year old unused belts	3	199	199	200	3	200	198	201
3 year old belts	2	351	350	351	3	351	350	353
13 year old belts	3	311	311	312	3	324	311	348

Table D2. Summary measures for percentage elongation by test and belt type

Belt type	***Dynamic test***				***Feasibility test***				***Wilcoxon rank-sum test*** [a]	***Levene's Test*** [b]
	N	***Mean***	***SD***	***SE***	***N***	***Mean***	***SD***	***SE***		
New belts										
New nylon belts	Not available									
New polyester belts	Not available									
Repaired belts - new	5	18.3	0.7	0.3	5	15.3	0.5	0.2	**P=0.009**	P=0.410
Old/used belts										
6 year old unused belts	3	23.6	7.8	4.5	3	18.1	0.5	0.3	P=0.513	P=0.069
3 year old belts	2	19.0	1.4	1.0	3	15.5	0.5	0.3	P=0.083	**P=0.029**
13 year old belts	3	19.5	3.4	1.9	3	16.6	1.5	0.9	P=0.127	P=0.112

Note: Bold font indicates a statistically significant result.
N, number of observations; SD, standard deviation; SE, standard error;
a, Test of inequality of distributions; b, Test of inequality of variances.

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