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CIVIL AVIATION AUTHORITY

CAA PAPER 93013

DUAL CHILD OCCUPANCY OF AN AIRCRAFT SEAT

CIVIL AVIATION AUTHORITY LONDON PRICE £12.00

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PREPARED BY CRANFIELD IMPACT CENTRE LTD
AND PUBLISHED BY
CIVIL AVIATION AUTHORITY LONDON JULY 1993

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ISBN 0 86039 556 1

Printed and distributed by Civil Aviation Authority, Greville House, 37 Gratton Road, Cheltenham, England

Summary

A series of tests was conducted to investigate the safety implications, during a crash, of a seating configuration where two children of similar or dissimilar ages occupied an aircraft seat designed for one adult passenger and were restrained under the same lap belt.

The tests were conducted on a HYGE (HYdraulically controlled Gas Energised) sled facility. An aircraft seat, modified for repeatable use, was mounted on the sled but yawed 10 degrees to the direction of motion of the sled. Anthropomorphic test devices (dummies), used to represent children, were positioned on the seat. The acceleration of the sled was according to the specification in Joint Aviation Requirement (JAR) 25.562, for a 16g longitudinal test.

During each test the accelerations measured by the accelerometers fitted in the head and chest of the dummies were monitored and the motion of the dummies was recorded by two high speed cine cameras.

The process of positioning the two dummies side by side on the seat for each test, showed that it was just possible to locate two dummies representing children of 3 years of age on a standard width Economy seat. However, it was impossible to locate any other combination of dummies representing children of 3 years of age or older. A convertible seat had been prepared for the tests and it was used in the wider configuration where necessary.

With two dummies positioned side by side, the lap belt could only provide restraining forces to one side of the pelvis of each dummy and could not effectively restrain both dummies until they were squeezed together in the middle of the loop of belt webbing. The interaction of the two dummies imposed forces on the pelvis of each that were absent during the tests with single dummies. These forces were not negligible since, in one test, the interaction forces between two dummies of different size, combined with the forces from the lap belt, were sufficient to cause the pelvis of the smaller dummy to crack in half. In addition, the forward excursions of the heads of the two dummies were greater than during the appropriate test with a single dummy and indicated an increased risk of head injuries due to contact with furniture within an aircraft interior.

With one dummy sat on the lap of a second dummy, the forces to restrain the motion of both dummies were imposed on the body of the lap held dummy and transmitted through its body to the second dummy.

Generally, the tests showed that neither seating configuration was likely to provide children with the same protection during an impact, as they would have received if they had been seated and restrained on separate seats. Both seating configurations were likely to increase the risk of injuries to children during an impact.

Contents

TABLES AND FIGURES

1 OBJECTIVE

To investigate the suitability of seating and restraining two children on an aircraft seat designed for one adult passenger, during a crash.

2 INTRODUCTION

The member countries of the Joint Aviation Authorities (JAA) each have their own national requirements, equivalent to those laid down in the United Kingdom's Air Navigation Order (ANO). In some cases particular national requirements may be in conflict with those in another country. Nevertheless, to arrive at a set of Joint Aviation Requirements (JAR) acceptable to all member countries, a re-examination of national regulations may be necessary.

A case in point concerns the seating of children in aircraft. The regulations of some member countries of the JAA allow more than one child to be occupy a seat designed for one adult passenger and be restrained under the same lap belt. The main guide-line governing the use of this seating configuration relates to the combined ages of the children. However, the combined age limit varies among those member countries of the JAA that allow this seating configuration. The combined age limit ranges from less than 7 years to less than 12 years. In addition, some countries also stipulate a combined weight limit for the children.

The United Kingdom (UK) Civil Aviation Authority does not currently permit this practise and felt that it was desirable to establish its effectiveness before a final JAA position is agreed.

To investigate this dual occupant seating configuration the Civil Aviation Authority (CAA) commissioned Cranfield Impact Centre Ltd. to conduct an experimental programme of research that would provide information relating to the safety of this configuration during an aircraft crash. For this purpose a series of tests was conducted on a HYGE accelerator with simulated crash conditions. Anthropomorphic test devices (dummies) were used to represent children.

3 TEST PROGRAMME

To fully evaluate this seating configuration, the following child combinations were chosen for the tests:

3 year sat next to 3 year;

3 year sat next to 6 year;

3 year sat next to 10 year;

6 year sat next to 6 year;

9 month sat on lap of 10 year.

These combinations fully exploited the range of child dummies that were available.

4 TEST FACILITY

The tests were conducted on a HYGE (HYdraulically controlled Gas Energised) accelerator device. Here, the sled and test components were propelled backwards by an acceleration pulse conforming to the requirements of JAR 25.562 – 16g longitudinal test. Having attained or exceeded the prescribed velocity, the sled was braked to a standstill. (The forces exerted on the sled and test components, during the acceleration phase of the sled movement, were the same as if the sled had started with the prescribed velocity and then been brought to a standstill by a pulse conforming to the requirements of JAR 25.562 – 16g longitudinal test).

Since there was no sled movement prior to the test pulse, the original positions/orientations of the dummies were not disturbed.

The aircraft seat on which the child dummies were positioned was bolted direct to the HYGE sled with the longitudinal axis yawed 10 degrees to the direction of motion of the sled. The test configurations of the 3 year dummy with 6 year dummy and the 3 year dummy with 10 year dummy were then set up so that the weight of the larger dummy was imposed on the smaller dummy during the test.

The seat was of twin spar construction with three seating positions and having 430mm between each pair of arm rests. However, it could be converted by raising the two middle arm rests and lowering a section of the centre seat back. This resulted in a double seat with a wide central arm rest, having 575mm between each outer arm rest and the centre arm rest.

The seat was modified for the tests to permit repeatable use. For this purpose the original legs were removed and replaced by 12mm steel plate aligned longitudinally. In addition, the left seating position was removed, leaving the right and centre positions. The cast aluminium framework components that supported the seat backs and diaphragms under each seat cushion were retained.

Since the construction of the seat restricted the break-forward capability of the seat backs, a strap was positioned around the seat backs (at the base of the head rests) and attached to a fixture behind the seat backs. This was done to prevent any damage to the framework components due to shock loads that might otherwise have occurred during a dynamic test, when further forward rotation of the seat backs was restricted.

The 3 year, 6 year and 10 year dummies used during the tests were manufactured by the TNO Road Vehicles Research Institute in Holland. All were instrumented with head and chest tri-axial accelerometers. The 9 month dummy was of 'bean-bag' type construction, as developed by the U.S. Civil Aeromedical Institute (CAMI), and was uninstrumentable.

5 TEST PROCEDURE

For the programme of tests the child dummies were located on the aircraft seat in an upright posture with shoulder to shoulder or shoulder to arm contact, depending on the size of the two dummies used. The shoulders were not overlapped, since the motion of one dummy may then have been dependant on the motion of the other dummy.

It was possible to position two dummies representing 3 year old children on the standard width seat, without converting it to the wider configuration. In subsequent tests the right dummy was located at a similar position, relative to the right arm rest, as the right 3 year dummy. The left dummy was positioned shoulder to shoulder or arm to shoulder against the right dummy. The wider seat configuration was used as required.

In the test with the 9 month dummy sat on the lap of the 10 year dummy, the 10 year dummy was located centrally in the right seating position of the standard width configuration.

The dummies were secured by one lap belt. Adjustment of the belt was achieved by positioning a 25mm thick board between the back of each dummy and the seat back and tightening the belt to a 'no slack/no tension' position. The boards were then removed and the dummies repositioned so that they were against the seat back. The slack introduced was thus the same in each test and also was felt to be representative of average passenger fitment.

A new lap belt was used for each test. The belt was marked so that stretch or slippage of the belt through the adjuster mechanism during the test could be measured.

When the seat was used in the standard width configuration, the quick release end fittings the lap belt were attached to the seat at a lateral spacing of 500mm. When the seat was used in the wider configuration the ends were attached at a lateral spacing of 520mm. The greater spacing was used to reduce the lateral distance by which the left anchorage lay within the longitudinal projections of the left dummy's hips.

In addition to the child seating combinations that were selected for testing (see Section 3), tests were also conducted with the 3 year, 6 year and 10 year dummies located singly on the right seating position of the standard width configuration. This provided data with which to assess any change in dummy performance in the tests where two dummies were used.

Initially, the dummies were calibrated according to the procedures described in ECE Regulation 44. During the programme of tests the joint settings were checked and, where necessary, adjusted to a 1g setting.

High speed cine films (1000 frames/second) were taken of each test by cameras positioned in front of and to the side of the aircraft seat. The direction of view of each camera was parallel to the longitudinal or lateral axes of the seat, rather than parallel or perpendicular to the axis of motion of the HYGE sled.

The position and orientation of the aircraft seat, each dummy, the direction of view of each camera and the direction of motion of the HYGE sled are shown by the diagram in Fig 1.

6 LOCATION OF THE CHILD DUMMIES ON THE AIRCRAFT SEAT

When tested singly the 3 year, 6 year and 10 year dummies were located centrally on the right seating position with the seat in the standard width configuration. The positions of these dummies prior to each test are shown by the photographs in Figs 2, 3 and 4 – this last photograph also shows the position and orientation of the aircraft seat on the HYGE sled.

It was just possible to position the two 3 year dummies on the standard width seat in a shoulder to shoulder position. However, this was only possible by positioning the non-adjacent arms of the dummies on the arm rests. The bodies of the two dummies completely filled the available space between the arm rests, as shown by the photograph in Fig 5. In addition, the buckle of the lap belt lay between the two dummies, in a position where, in the case of children, it could easily be tampered with.

Where one of the dummies was larger than a 3 year dummy, it was impossible to position both side by side on the standard width seat. Once the right dummy had been positioned against the right seat arm there was insufficient space available for the other dummy. Consequently the seat was converted to the wider configuration.

In the case of the test with the 3 year and 6 year dummies, with the wider seat configuration it was possible to position the left arm against the side of the left (6 year) dummy, as shown by the photograph in Fig 6. However, the left belt anchorage still lay within the longitudinal projections of the left dummy's hips. Consequently, the lap belt webbing was wrapped around the left hip of the dummy, as show by the photograph in Fig 7. In addition, the buckle of the lap belt lay between the two dummies, in a position where, in the case of children, it could easily be tampered with. The location of the (raised) arm rest used in the standard seat width configuration can be seen behind the left shoulder of the left (6 year) dummy in Fig 6.

In the case of the test with the 3 year and 10 year dummies, even with the wider seat configuration it was necessary to position the left arm of the larger dummy on the wide central arm rest, as shown by the photograph in Fig 8. The left belt anchorage again lay within the longitudinal projections of the larger dummy's hips. Consequently, the lap belt webbing was wrapped around the left hip of the dummy, as show by the photograph in Fig 9. Also, the buckle of the lap belt lay between the two dummies. The location of the (raised) arm rest used in the standard seat width configuration can just be seen behind the neck of the larger dummy in Fig 8.

In the case of the test with both 6 year dummies, even with the wider seat configuration it was necessary to position the left arm of the left dummy on the wide central arm rest, as shown by the photograph in Fig 10. In addition, the left belt anchorage still lay within the longitudinal projections of the left dummy's hips. Consequently, the lap belt webbing was wrapped around the left hip of the dummy, as show by the photograph in Fig 11. Again, the buckle of the lap belt lay between the two dummies. The location of the (raised) arm rest used in the standard seat width configuration can just be seen behind the head and left shoulder of the left dummy in Fig 10.

The standard width seating configuration was used for the test with the 9 month dummy sat on the lap of the 10 year dummy and allowed the arms to be positioned at the dummies' sides. However, the webbing and buckle of the lap belt lay wholly on the abdomen of the infant dummy, as shown by the photograph in Fig 12.

7 RESULTS

7.1 Sled Motions and Output from the Dummies

The average velocity change of the HYGE sled during the tests was 14.24m/s (51.25km/h) and the average peak HYGE acceleration was 16.2g. A graph showing a typical sled acceleration pulse is shown in Fig 13. The results from each test are given in Figs 14 to 21, in the form of photographs showing the post test dummy positions and graphs showing the accelerations of each dummy's head and chest. An index of tests is given in Table 1 and lists the Figure numbers for the results of each test. The results are summarised in Table 2, giving the dummy peak accelerations, and Table 3, giving the maximum excursions of each dummy's head.

To measure accelerations in the head and chest of each dummy during each test, accelerometers were moved from dummy to dummy between tests. Halfway through the programme of tests the accelerometer measuring the vertical component of acceleration in one of the tri-axial accelerometers was damaged. Off dummy static calibration checks between tests revealed no problems, but during a test this accelerometer would only measure accelerations to 30g. On an acceleration/time graph this problem was characterised by a trace rising to 30g, followed by a flat or slightly reducing portion and then a drop as the 'true' acceleration dropped below 30g. Subsequently, this damaged triaxial accelerometer was always located in the head of a dummy. Consequently, the calculated Head Injury Criteria (HIC) from the tests where this problem occurred are not given in Table 2. The measured peak resultant head acceleration from these tests is only given in the Table, if it was due to a maximum in one of the other measured component directions i.e. horizontal or lateral.

The chest accelerations given in Table 2 are 3 millisecond values i.e. the duration of the peak lasts for at least 3 milliseconds and therefore can be considered as significant for the chest. The head accelerations given in Table 2 are the maximum values without regard for time duration.

7.2 Tests with Single Dummies

During the tests with the 3 year, 6 year and 10 year dummies sat singly on the aircraft seat, all moved forward on the seat cushion until the slack in the lap belt was eliminated. Thereafter, the pelvis of each dummy was constrained from moving further due to the restraining forces applied by the lap belt. The torso of each dummy then rotated forward from the hips and ultimately the head struck one or both legs. By virtue of the fit of the lap belt across both hips, very little twisting motion was induced in any of the dummies – some was induced since the aircraft seat was yawed 10 degrees relative to the direction of motion of the HYGE sled.

The maximum displacements of the head of each dummy increased with increasing dummy size. The peak resultant chest and head accelerations also increased with increasing dummy size.

The peak resultant chest acceleration measured during each test was at an acceptable level (below 55g, as required in the European Standard for the approval of automotive child restraints – ECE Regulation 44) but the peak acceleration from the chest towards the head was high in the case of the 6 year and 10 year dummies (above 30g, as required by ECE Regulation 44). The peak resultant head accelerations were high for each dummy, giving rise to Head Injury Criterion values (HIC – a measure of the exposure to head acceleration) well in excess of 1000 – a level considered a threshold, beyond which there is an increasing likelihood of head injuries in adults exposed to direct head loading with blunt objects.

The plasticine located behind the abdomen insert in each dummy was generally unchanged in shape after the test, in the case of the 3 and 10 year dummies. However, in the case of the 6 year dummy distortion had occurred , indicating that significant forces had been imposed on the abdomen region by the lap belt and buckle – the initial belt buckle position is shown in Fig 3.

7.3 Test with Two 3 Year Dummies

In response to the motion of the sled both dummies initially moved forward on the aircraft seat as the slack in the lap belt was eliminated. However, as only one hip of each dummy was directly restrained by the lap belt, the dummies then twisted away from each other. That is the right dummy rotated clockwise about a vertical axis and the left dummy rotated anti-clockwise about a vertical axis. The dummies were pushed even closer together by the twisting motions and generated a hip to hip contact, in addition to the shoulder to shoulder contact. Lateral compression forces were imposed on the pelvis of each dummy by virtue of the hip contact, the inertias of each dummy and the constraint imposed by the lap belt. This type of loading was absent from the test with only one 3 year dummy, since both hips of that dummy were restrained by the lap belt.

Thereafter, each dummy rotated forward from the hips and ultimately struck the leg that was adjacent to the other dummy with its head.

The peak resultant chest acceleration measured from each dummy was not dissimilar to that measured during the single dummy test. The peak vertical component of chest acceleration from the right dummy was similar to that measured during the singly dummy test, but was higher from the left dummy (exceeding the 30g limit in ECE Regulation 44). The peak resultant head acceleration from each dummy was less than that measured during the single dummy test. However, the duration and average level of acceleration were greater than was the case during the single dummy test, as indicated by the greater HIC value for each dummy.

The plasticine located behind the abdomen insert of the left dummy was only slightly changed in shape after the test. However, in the case of the right dummy, the plasticine was badly distorted at the top left corner, see Fig 17b, indicating that, for a child, considerable force had been imposed on part of the abdomen region – probably by the belt buckle.

Analysis of the high speed cine film showed that the head excursions (forward, vertical and lateral movement) of each dummy were greater than those during the single dummy test. This can be attributed to the greater slack in the lap belt necessary for a fitment with two occupants.

7.4 **Test with 3 Year and 6 Year Dummies**

In response to the motion of the sled both dummies initially responded in a similar manner to the two 3 year dummies. That is, they moved forward on the aircraft seat and then twisted away from each other. However, in this test the distance between the non-adjacent hips of the two dummies was greater than the spacing of the belt anchorages. Consequently, once hip to hip contact occurred between the two dummies, the capability for movement within the loop of webbing was greater than if the anchorages had been more widely spaced. When hip to hip contact occurred, lateral compression forces were imposed on the pelvis of each dummy.

Subsequently, each dummy rotated forward from the hips and ultimately struck the leg that was nearest to the other dummy with its own head. This head contact was relatively minor in the case of the 3 year dummy, as indicated by the lack of a high, short duration spike on the resultant head acceleration graph (Fig 18b) during the period from 120 to 150 milliseconds.

The peak resultant chest acceleration measured from each dummy was lower than that measured in the tests with a single dummy, significantly so in the case of the 6 year dummy. The peak vertical component of chest acceleration was also significantly lower for the 6 year dummy when compared to the value from the test with a single dummy. In the case of the 3 year dummy, the vertical component of acceleration was unchanged from the test with a single dummy. The peak resultant head acceleration measured from each dummy was very significantly lower than that measured during the appropriate tests with a single dummy.

The pieces of plasticine located behind the abdomen insert of each dummy were slightly changed in shape after the test and indicated that some loading of each abdomen had occurred.

High speed film analysis showed that the head excursions of each dummy were greater than those during the appropriate test with a single dummy. This can be attributed to the greater slack in the lap belt necessary for a fitment with two occupants. In the case of the 6 year dummy, the greater horizontal excursion indicates an increased probability of head contact with the seat in front in an aircraft cabin environment.

7.5 **Test with 3 Year and 10 Year Dummies**

In response to the motion of the sled both dummies initially moved forward on the aircraft seat. The use of the wider seat configuration caused the lap belt to be wrapped around the left hip of the 10 year dummy (due to the position of the belt anchorage within the longitudinal projections of the dummy's hips) so that the 10 year dummy was pushed towards the 3 year dummy. Consequently, the motion of the 10 year dummy across the seat combined with the twisting motion of each dummy produced a hip to hip contact. The pelvis of the 3 year dummy was then squeezed between the 10 year dummy, on the left, and the lap belt on the right. As the dummies rotated forward from the hips and about the time of head to leg contact, the compression forces on the pelvis of the 3 year dummy became too great and the pelvis broke apart. The connection between the legs and torso of the dummy was thus severed. Inspection of the pelvis after the test suggested that the failure was initiated at the right wing of the pelvis structure where it was loaded by the lap belt.

The accelerations from the dummies, where they can be safely interpreted, were generally higher than those measured in the appropriate test with a single dummy.

The plasticine behind the abdomen insert of the 10 year dummy was only slightly changed in shape after the test.

A matter of concern after this test related to the lap belt buckle, since the release lever was open about 45 degrees, see lower photograph of Fig 19. The position of the buckle between the two dummies allowed this situation to occur.

7.6 Test with Two 6 Year Dummies

In response to the motion of the sled both dummies initially moved forward on the aircraft seat. The left dummy was also pushed towards the right dummy due to the wrapping of the lap belt around the left hip. Hip to hip contact occurred as the dummies continued to move forward and twist away from each other. For reasons given in paragraph 1 of section 7.4, once hip to hip contact occurred there was an increased capability for movement of the dummies within the loop of webbing.

Subsequently, each dummy rotated forward from the hips, bending double over the lap belt. The left dummy struck its leg nearest the right dummy with its head, whilst the right dummy's head made no contact with either of its legs.

All the chest and head accelerations were less than those measured during the single dummy test. The change was most marked in the case of the right dummy, in particular at the head, where the peak acceleration was less than half the single dummy test value because no head to leg contact occurred.

The pieces of plasticine behind the abdomen insert of each dummy were changed in shape after the test indicating that loading of each abdomen had occurred.

High speed film analysis showed that the head excursions of each dummy were greater than those during the test with a single dummy. This can be attributed to the greater slack in the lap belt necessary for a fitment with two occupants. The greater horizontal excursion indicates an increased probability of head contact with the seat in front in an aircraft cabin environment.

7.7 Test with 9 Month and 10 Year Dummies

In response to the motion of the sled the 10 year dummy moved forward on the aircraft seat with the 9 month (infant) dummy on its lap. As all slack was eliminated from the lap belt restraining forces were applied to the 9 month dummy (by the lap belt). However, restraint forces were not applied directly to the 10 year dummy. Consequently, the 10 year dummy continued to move forward on the seat, crushing the abdomen of the 9 month against the lap belt and buckle. With the rapidly increasing constraint at pelvis level, the torso of each dummy rotated forward from the hips. Ultimately, the head of the infant dummy struck its own legs, whilst the body of the dummy was crushed between the legs and torso of the 10 year dummy. The head of the 10 year dummy then struck the head of the infant dummy.

The chest and head accelerations from the 10 year dummy were substantially less than those measured in the single 10 year dummy test, since the crushing of the 9 month dummy cushioned the 10 year dummy from the test forces.

The plasticine behind the abdomen insert of the 10 year dummy was significantly distorted after the test, indicating that quite high forces were applied to the abdomen region, having been transmitted through the infant dummy.

Analysis of the high speed film indicated that the horizontal head excursion of the 10 year dummy was greater than in the test with a single 10 year dummy, but the vertical excursion was less. This can be attributed to the compliance of the 9 month dummy allowing forward movement but limiting vertical movement by being trapped between the legs and torso of the 10 year dummy.

8 DISCUSSION

8.1 The Practicality of Dual Child Occupancy of an Aircraft Seat

When considering the practicality of seating two children on an aircraft seat designed for one adult, there are only two feasible configurations by which they can be positioned on the seat. These are:

(a) side by side;

(b) one on the lap of the other.

Both were evaluated by the programme of tests and shown to have practical and operational limitations. It was clear from setting up the various combinations of dummies that, with a maximum space between each pair of arm rests of 430mm (almost 17in), it was only possible to position two 3 year dummies within one seating location. It was necessary to position the non-adjacent arms of both dummies on the arm rests to fit the dummies between the arm rests. Consequently, it would appear highly unlikely that any two children with combined ages over 6 years could be seated side by side on an Economy Class seat.

It would be possible for two children with combined ages up to 9 years to fit side by side on one Business Class seat, provided there was a space of 500mm (19.7in) between the seat arms. With a First Class or Convertible seat having 575mm (22.6in) between the seat arms, it would be possible for two children with combined ages up to 13 years to fit side by side on one seat. The only concern with the wider seats relates to the position of the lap belt anchorages and whether they would be beyond the extremities of the children's hips.

The second seating configuration would appear most likely to be used for, but not confined to, the carrying of an infant or younger child on the lap of an older child. Ignoring comfort, there are no practical limitations on the sizes of children who could be carried in this way – since they would fit on one seat. A maximum allowed weight at each seat position, specified by the manufacturer, and the length of the lap belt webbing may be the only limitations – although children with combined ages up to 20 years are unlikely to exceed the weight limit.

8.2 The Safety of Dual Child Occupancy of an Aircraft Seat

During the tests with two dummies in a side by side configuration the restraint forces from the lap belt acted on the dummies in a different manner than during the tests with a single dummy. In each of the latter tests the pelvis of each dummy was fully restrained since the lap belt passed across the front of the dummy's pelvis and lower abdomen, over both hips and then to the anchorages on the seat frame. In each of the former tests, the pelvis of each dummy was only partially restrained since the lap belt passed across the front of each dummy's pelvis but only over one hip of each pelvis. Due to the incomplete restraint, the dummies reacted against each other during the test. This interaction caused compression loading of the body of each dummy, particularly at pelvis level where the restraint forces from the lap belt were concentrated.

The potential consequences of the interaction of the two dummies were highlighted in the test with the 3 year and 10 year dummies, when the pelvis of the 3 year dummy broke apart. The mismatch in dummy sizes undoubtedly contributed to this failure. Nevertheless, the failure clearly illustrated that the forces generated by the interaction of the dummies were not negligible.

During the tests with two 3 year dummies, the 3 year and 6 year dummies and the two 6 year dummies the peak and average accelerations measured in each dummy were generally lower than during the appropriate test with a single dummy. However, after each of these tests the plasticine behind the abdomen insert of at least one of the dummies was distorted, indicating that significant loading had occurred. In effect, the packing together of two dummies of not too dissimilar weight (the 3 year dummy weighed 15kg, the 6 year dummy weighed 22kg) appeared to reduce the accelerations measured in each dummy but increase the loading on the abdomen of one or both dummies.

To position both dummies on the aircraft seat it was necessary to allow enough slack in the lap belt to represent a fitment which would be comfortable for two children. In addition, positioning the two dummies shoulder to shoulder automatically introduced a gap between the adjacent hips of the dummies – typically 50mm. Consequently, the capability for forward movement of the dummies was greater in these tests than those with a single dummy. Analysis of the high speed cine films indicated that the head of the left dummy moved further forward during these tests than those with a single dummy of the same size. The right dummy was also likely to have moved more, but this could not be verified since the right dummy was obscured by the left dummy. These greater excursions indicate the increased risk of a child's head striking items of furniture in an aircraft interior.

In addition, these greater excursions suggest that the reduced accelerations could in part be attributed to the greater time available for the dummies to undergo the same velocity change as the aircraft seat/HYGE sled.

The size and weight of the 10 year dummy compared to the sizes and weights of the 3 year and 9 month dummies undoubtedly influenced the results of the tests with these smaller dummies. In the test with the 3 year and 10 year dummies, the failure of the pelvis of the smaller dummy did not protect the larger dummy from the test forces. The accelerations in the larger dummy were greater than those measured during the test with a single 10 year dummy. The difference was most evident at the head of the dummy.

In the test with the 9 month and 10 year dummies, the 9 month dummy cushioned the larger dummy from the test forces and the chest and head accelerations were less than those measured during the test with a single 10 year dummy. However, since the lap belt did not lay on the pelvis of the larger dummy, restraint forces passed through the 9 month dummy to the abdomen of the larger dummy – thereby loading it more heavily than during the test with a single 10 year dummy. If the 9 month dummy could have been instrumented it would probably have registered forces and accelerations that were extremely high and likely to cause debilitating or fatal injuries to an infant.

The position of the lap belt buckle and the interaction between the dummies and the buckle were a cause for concern in several tests. With the belt buckle positioned between the two dummies it may drag against the legs or torsos of either dummy in a manner which might cause the release lever to be lifted, as happened during one test. In that test the lever was lifted/opened about 45 degrees, however, because belts with a 90 degree lift release angle were used (as required by the CAA) the lap belt did not come undone. If a belt with a buckle having a 35 degree lift release angle had been used (as allowed by the FAA), the belt would have come undone allowing the dummies to be thrown off the seat.

8.3 The Consequences for Children

The consequences for children seated side by side on an aircraft seat during an impact can be summarised thus:

(a) a lap belt will not effectively restrain two children until hip to hip contact is achieved and they are squeezed together in the middle of the loop of webbing between the two anchorages;

(b) positioning two children together under one lap belt will result in forces being imposed on their bodies which they would not experience if they were seated on separate seats;

(c) the greater the difference in ages of the two children, the greater the risk that the younger child will be injured due to the forces imposed on it by the older child;

(d) in general, the forward motion of the two children during an impact will be greater than for a single child and may increase the risk of their heads striking items of furniture within an aircraft interior, thereby causing injuries;

(e) the position of the belt buckle between two children will expose it to a greater risk of being tampered with and also to inadvertent release due to interaction with the children during an impact.

The consequences for children sat one on the lap of another on an aircraft seat during an impact can be summarised thus:

(a) regardless of the ages of the two children, the forces from the lap belt, to restrain the motion of both children, will be applied to the lap carried child and must be transmitted through their body to the body of the second child;

(b) the lap carried child will be at much greater risk of incurring serious or fatal injuries during an impact than if seated on a separate seat;

(c) the second child (sat on the aircraft seat) will be at greater risk of incurring serious or fatal abdominal injuries than if seated on a separate seat.

9 CONCLUSIONS

(a) Seating two children on the same seat and restraining both under one lap belt will provide neither with the same protection they would have received if they had sat on separate seats.

(b) Seating two children side by side on a seat and restraining both under the same lap belt will increase the risk of both sustaining head injuries during an impact.

(c) Seating two children side by side on a seat and restraining both under the same lap belt will increase the risk of both sustaining bodily injuries during an impact, due to their interaction with each other.

(d) Seating two children side by side on a seat and restraining both under the same lap belt will increase the loading on and consequently the injuries to the abdomen of one or both children during an impact.

(e) Carrying one child on the lap of another and restraining both under the same lap belt will greatly increase the risk of both sustaining serious or fatal injuries during an impact.

Table 1 Index of Tests

Dummy Configuration	*Test Number Shown in Photographs*	*Figure Numbers For Results*
3 yr	S2839	14
6 yr	S2844	15
10 yr	S2841	16
3 yr + 3 yr	S2840	17
3 yr + 6 yr	S2845	18
3 yr + 10 yr	S2842	19
6 yr + 6 yr	S2846	20
9 mth + 10 yr	S2843	21

Table 2 Summary of Dummy and Sled Instrumentation Results

RIGHT DUMMY					LEFT DUMMY					SLED	
Type	*Peak Resultant Chest Accel ('g')*	*Peak Vertical Accel. Chest To Head ('g')*	*Peak Resultant Head Accel ('g')*	*Head Injury Criterion (HIC)*	*Type*	*Peak Resultant Chest Accel ('g')*	*Peak Vertical Accel. Chest To Head ('g')*	*Peak Resultant Head Accel ('g')*	*Head Injury Criterion (HIC)*	*Peak Sled Accel ('g')*	*Sled Velocity Change (m/s)*
3 yr	35	23	144+	1727						16.0	14.2
6 yr	44	38	172+	*						16.1	14.2
10 yr	47	36	237+	2083						16.0	14.2
3 yr	34	25	118+	1921	3 yr	33	33	140+	2030	16.1	14.2
3 yr	31	23	84+	1056	6 yr	34	28	117+	*	16.3	14.3
3 yr	40	27	137+	*	10 yr	53	39	250+	2613	16.5	14.3
6 yr	36	25	63	1076	6 yr	40	30	144+	*	16.3	14.2
9 mth	–	–	–	–	10 yr	28	24	70	514	16.3	14.4

Note: Accel = Acceleration
* = Vertical component of acceleration suspect, therefore value not included
+ = Head of dummy struck own legs

Table 3 Maximum Displacements of Right and Left Dummies' Heads

RIGHT DUMMY				*LEFT DUMMY*			
Type	*Horizontal (mm)*	*Vertical (mm)*	*Lateral (mm)*	*Type*	*Horizontal (mm)*	*Vertical (mm)*	*Lateral (mm)*
3 yr	502	441	111				
6 yr	611	458	118				
10 yr	715	677	132				
3 yr	*	*	172	3 yr	641	543	132
3 yr	*	*	203	6 yr	757	652	47
3 yr	*	*	211	10 yr	698	904	105
6 yr	*	*	222	6 yr	771	739	25
9 mth	551	476	109	10 yr	783	547	281

Note: * = Right dummy obscured by left dummy

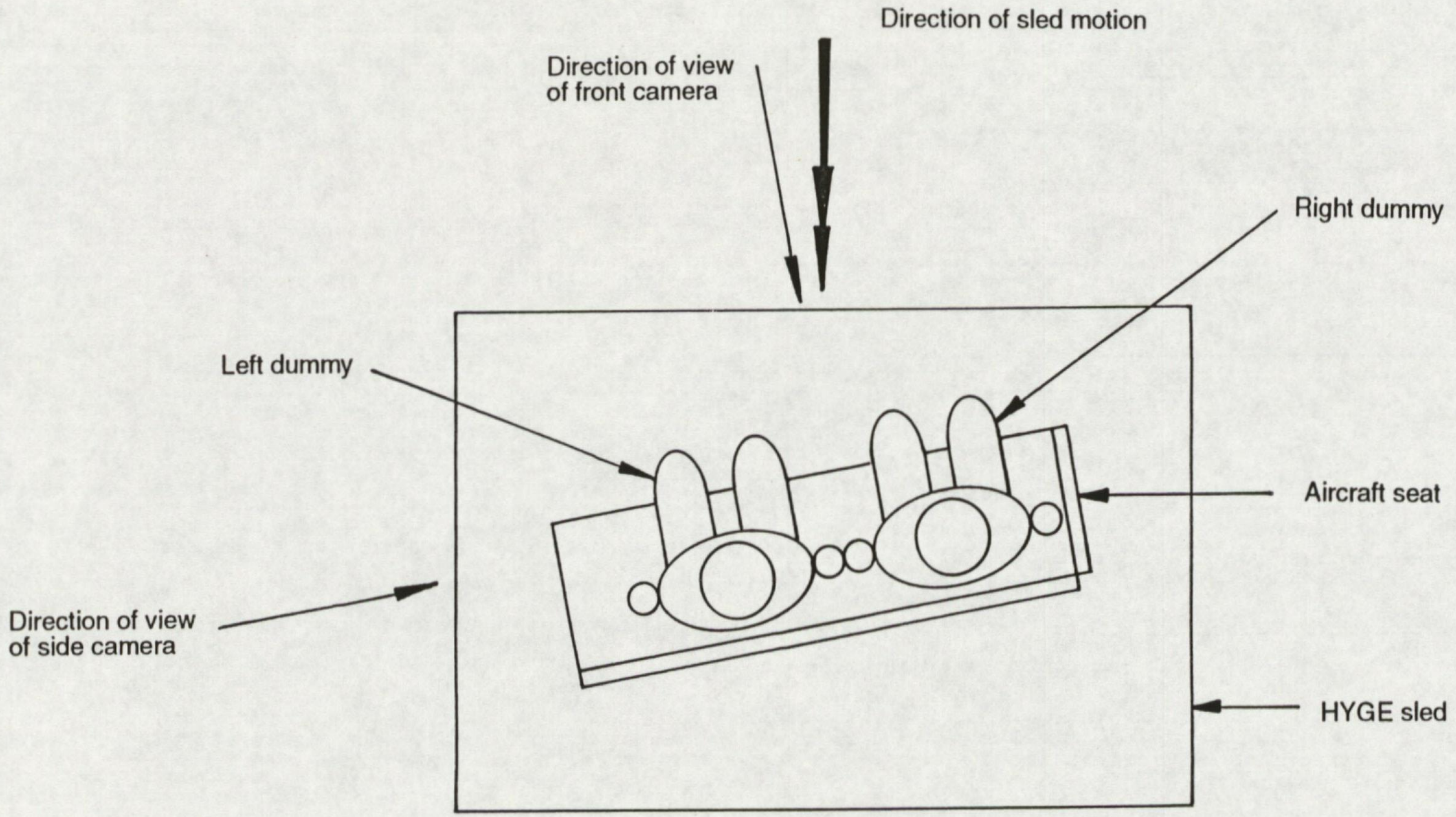


Figure 1 **Positions and Orientations of Aircraft Seat and Test Dummies on the HYGE Sled and Cine Camera View Directions**

Figure 2 Position of the 3 year dummy on the aircraft seat

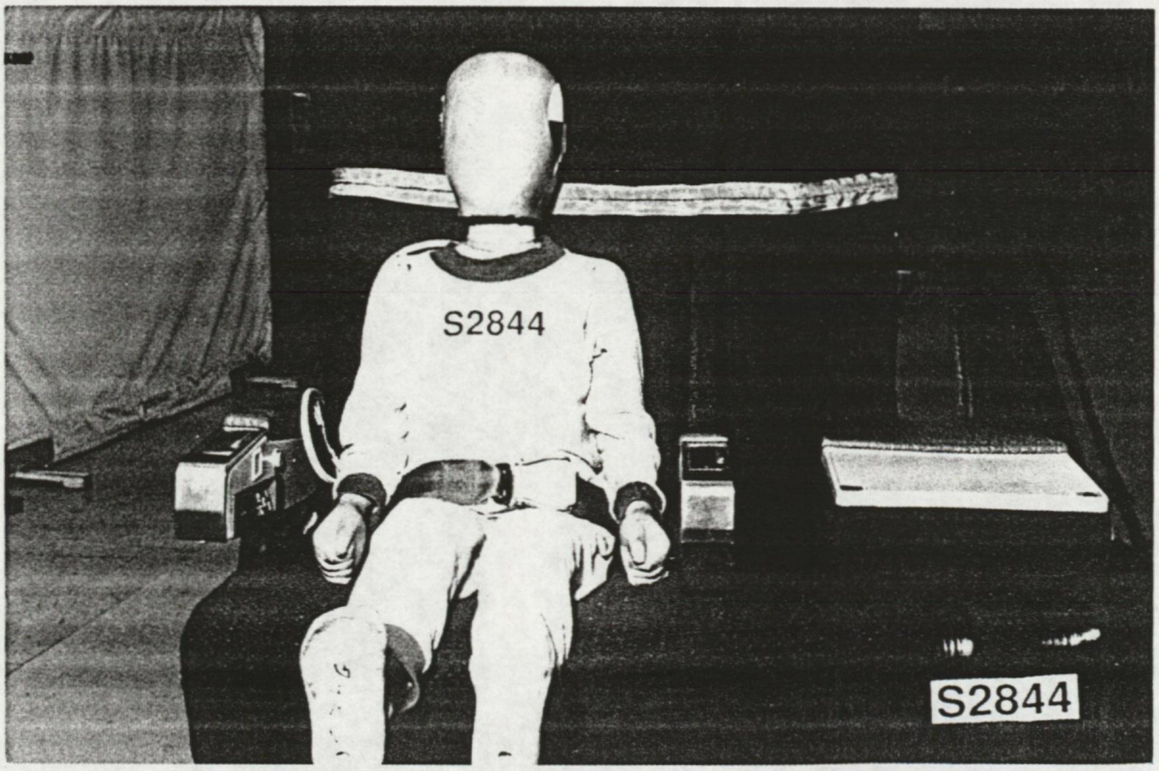


Figure 3 Position of the 6 year dummy on the aircraft seat

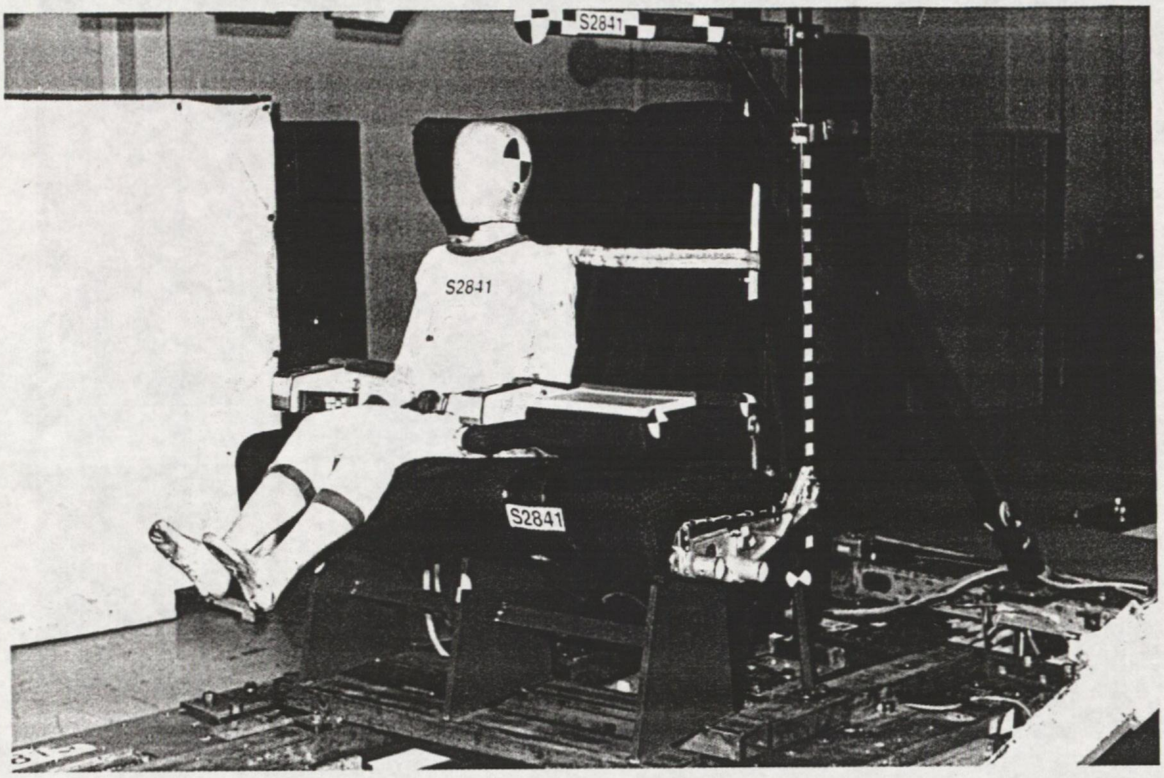


Figure 4 Position of the 10 year dummy on the aircraft seat

Figure 5 Positions of the two 3 year dummies on the aircraft seat

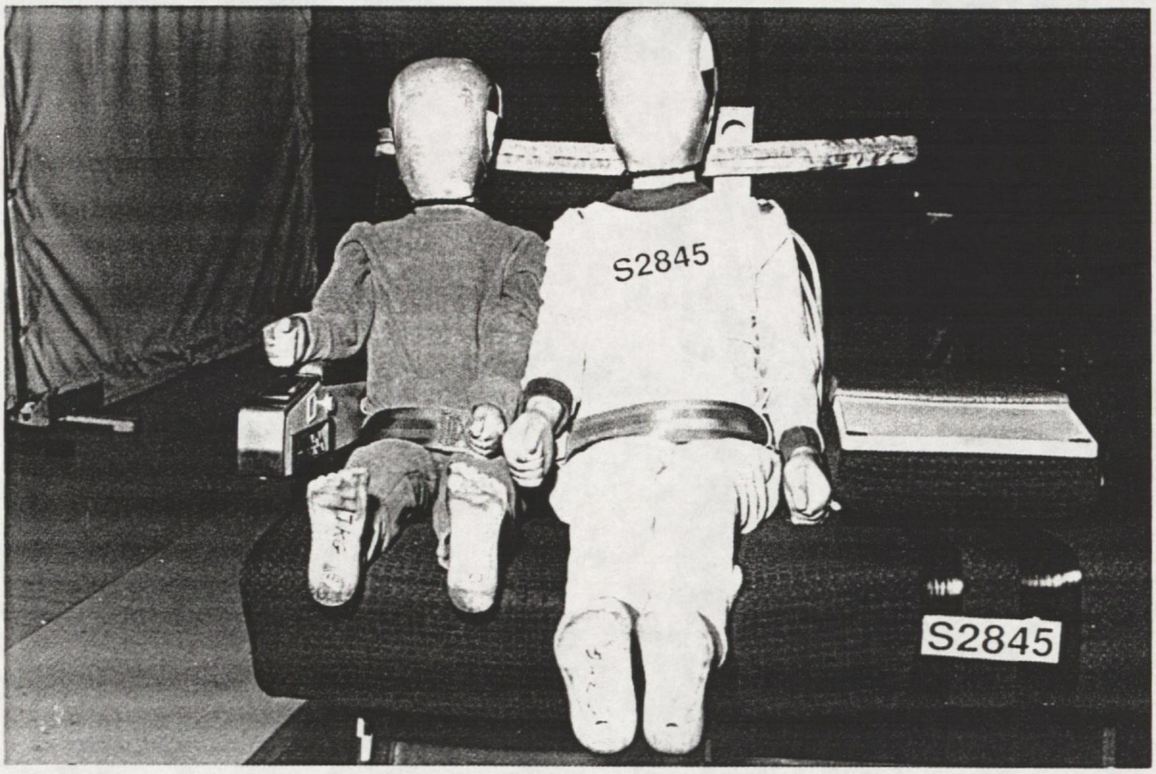


Figure 6   Positions of the 3 year and 6 year dummies on the aircraft seat

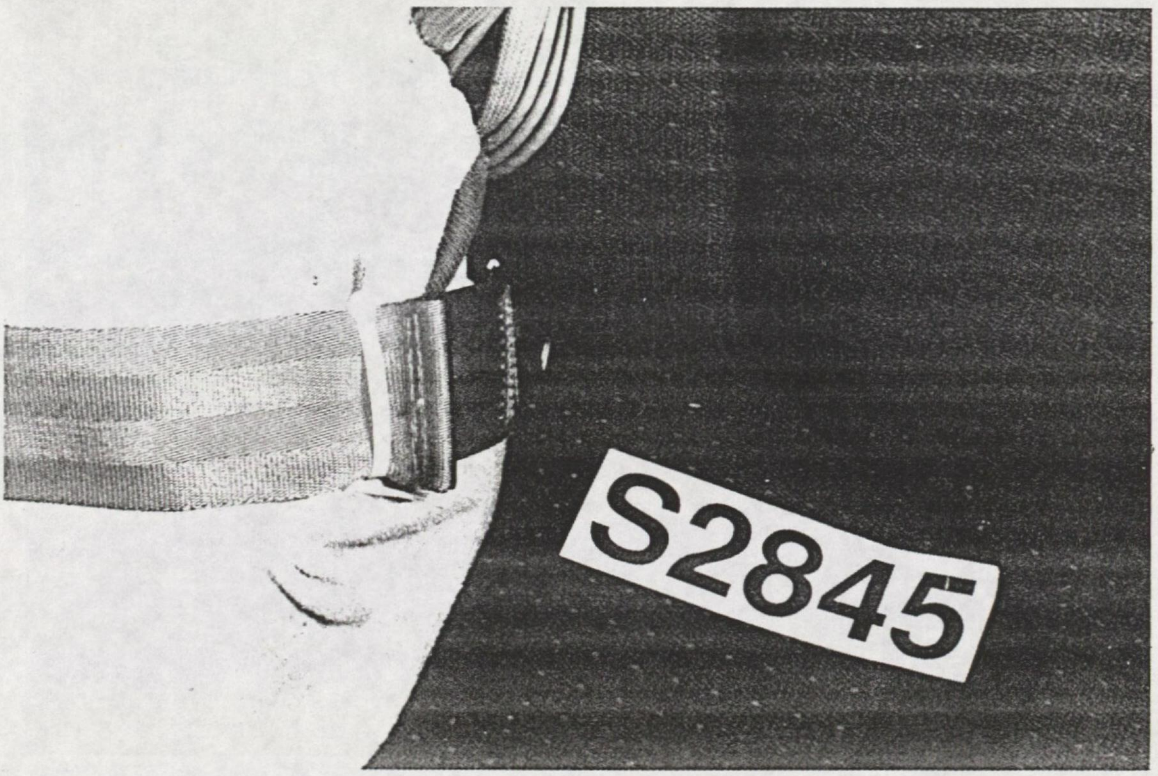


Figure 7   Wrapping of the lap belt around the left hip of the 6 year dummy

Figure 8 Positions of the 3 year and 10 year dummies on the aircraft seat

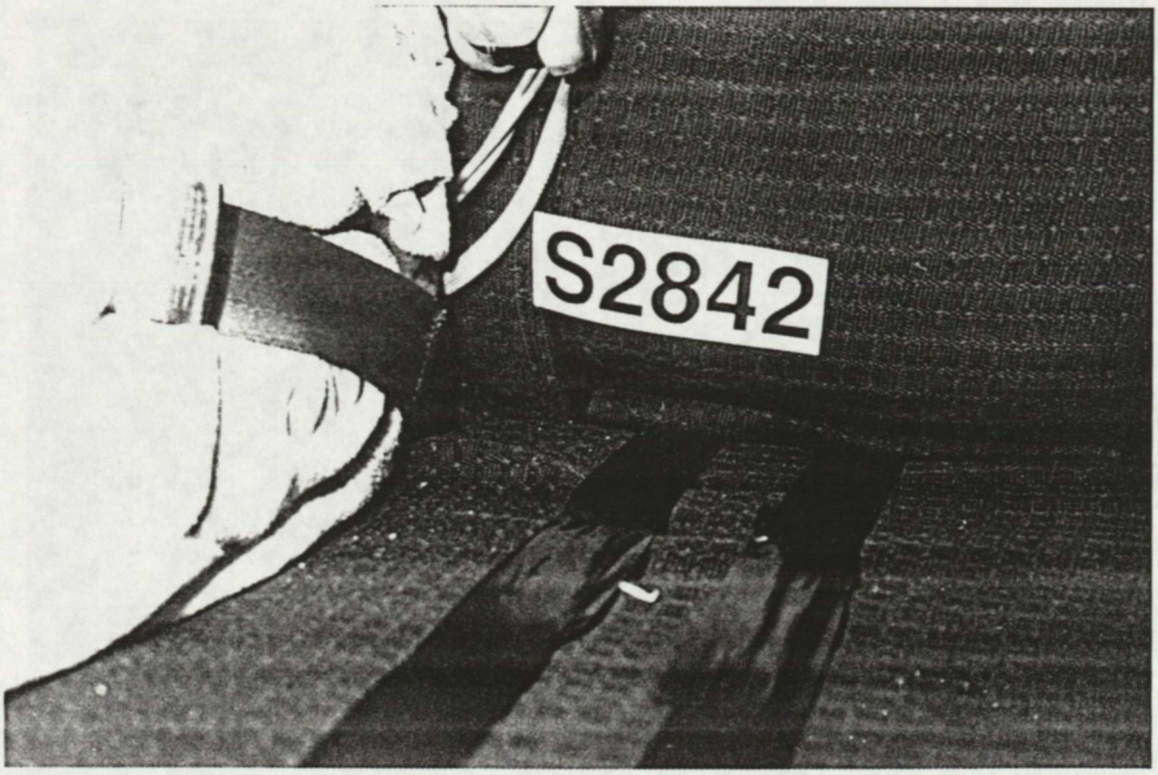


Figure 9 Wrapping of the lap belt around the left hip of the 10 year dummy

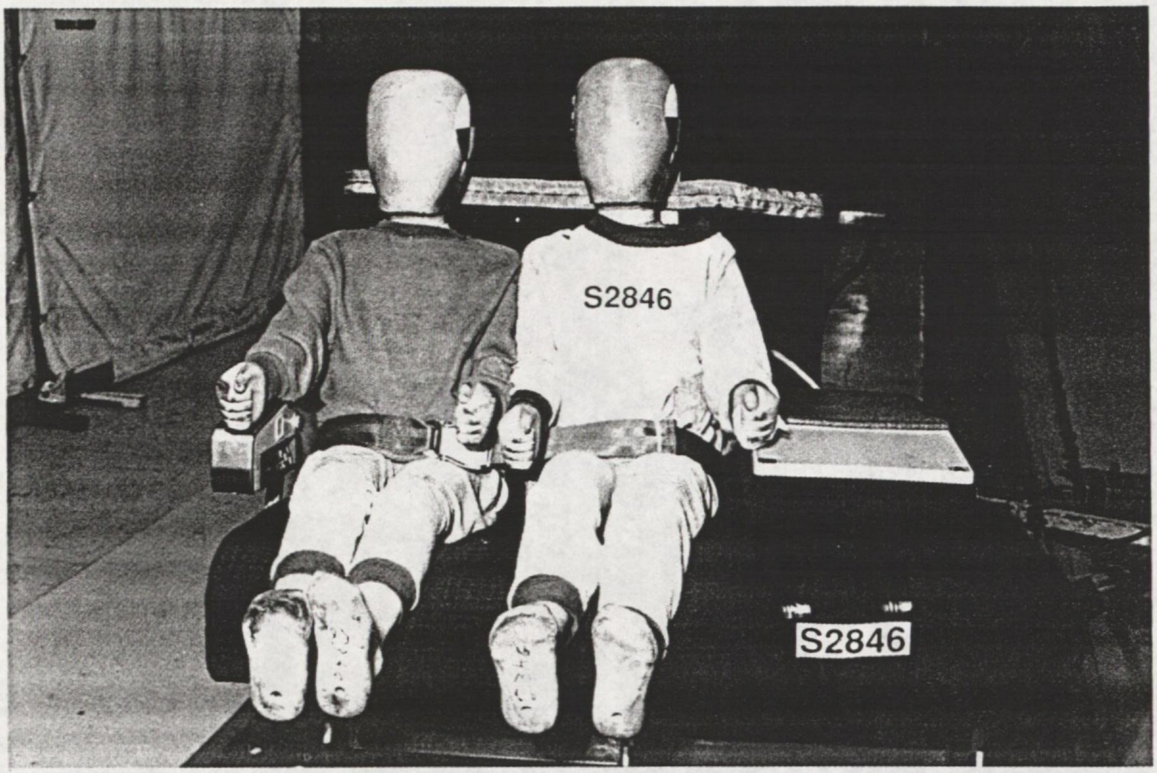


Figure 10 Positions of the two 6 year dummies on the aircraft seat

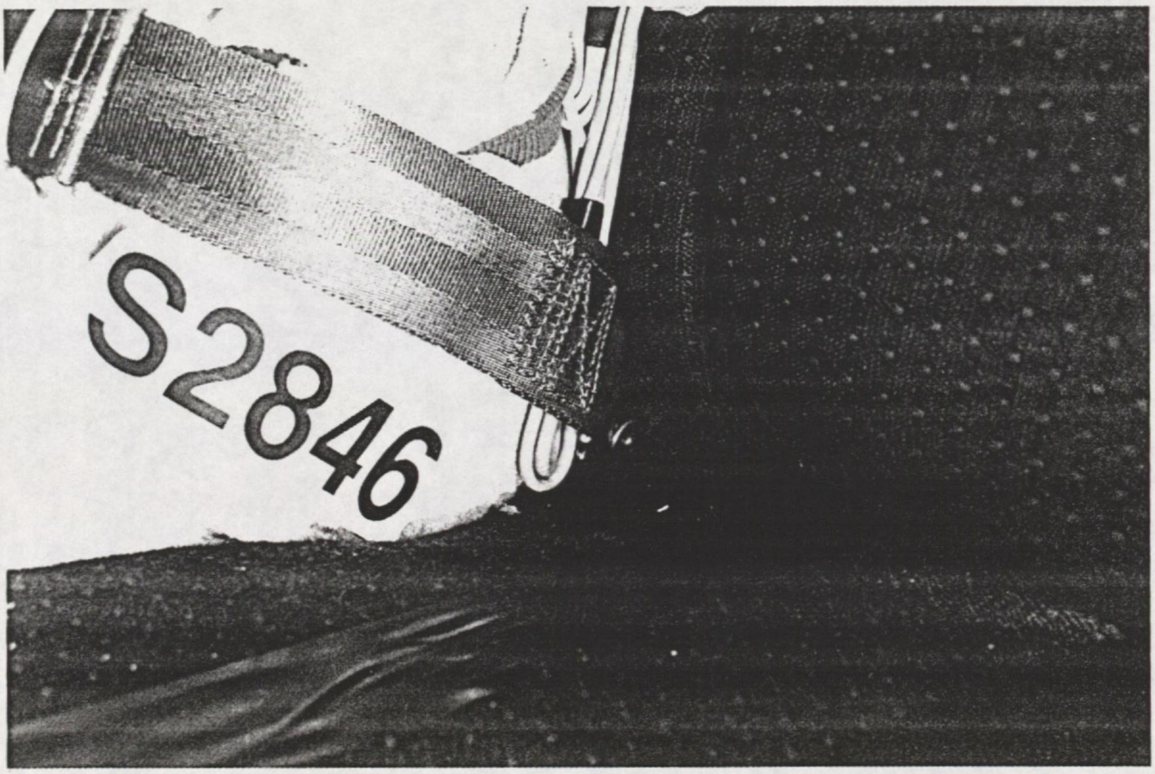


Figure 11 Wrapping of the lap belt around the left hip of the left dummy

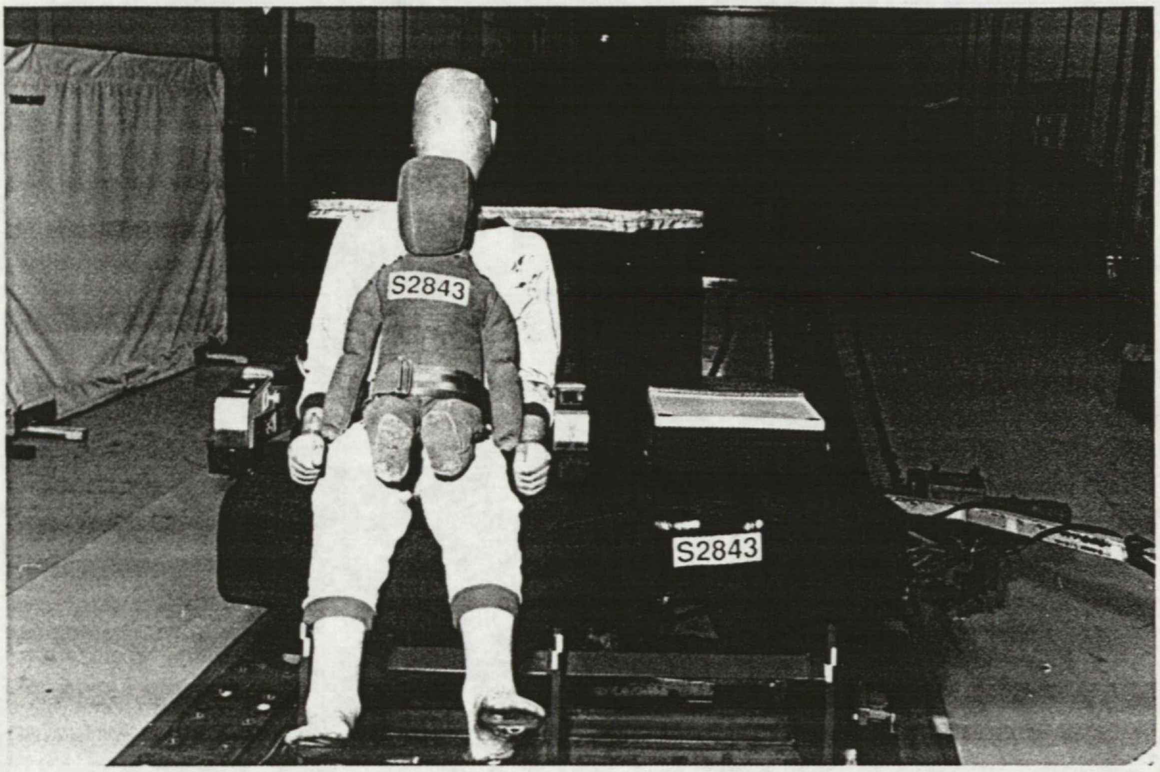


Figure 12 Positions of the 9 month and 10 year dummies on the aircraft seat

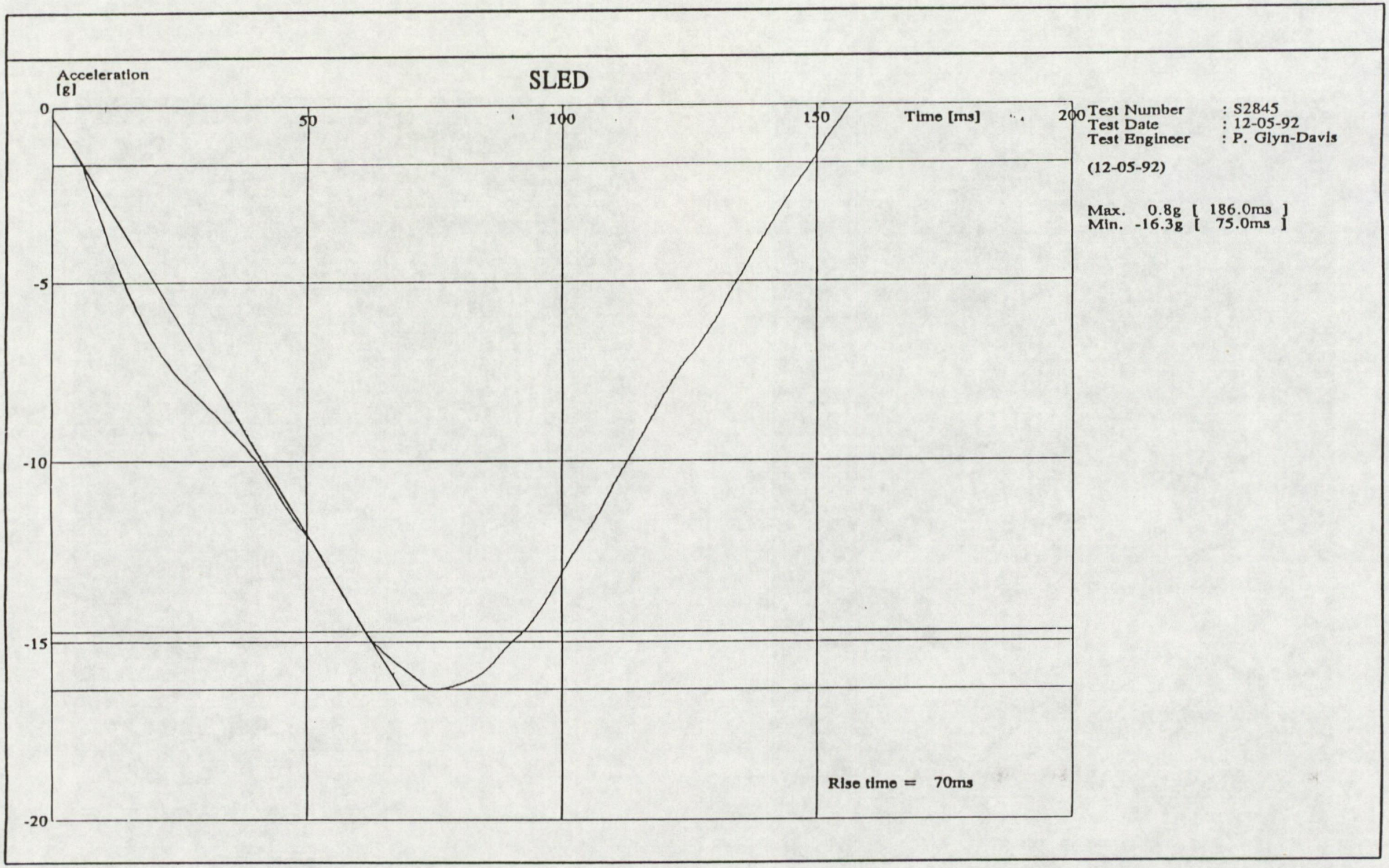


Figure 13 Typical HYGE sled acceleration pulse

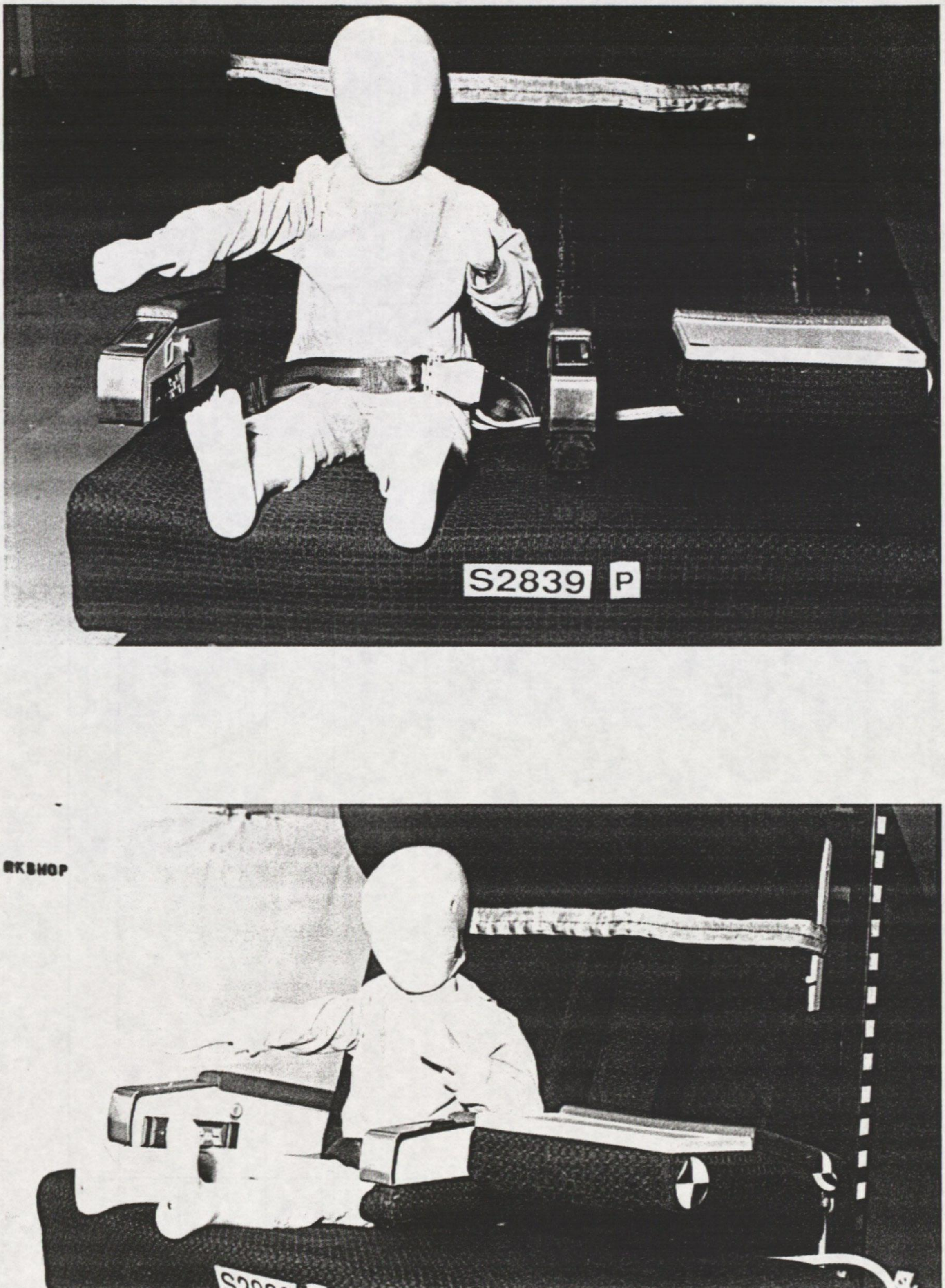


Figure 14a Position of the 3 year dummy after test

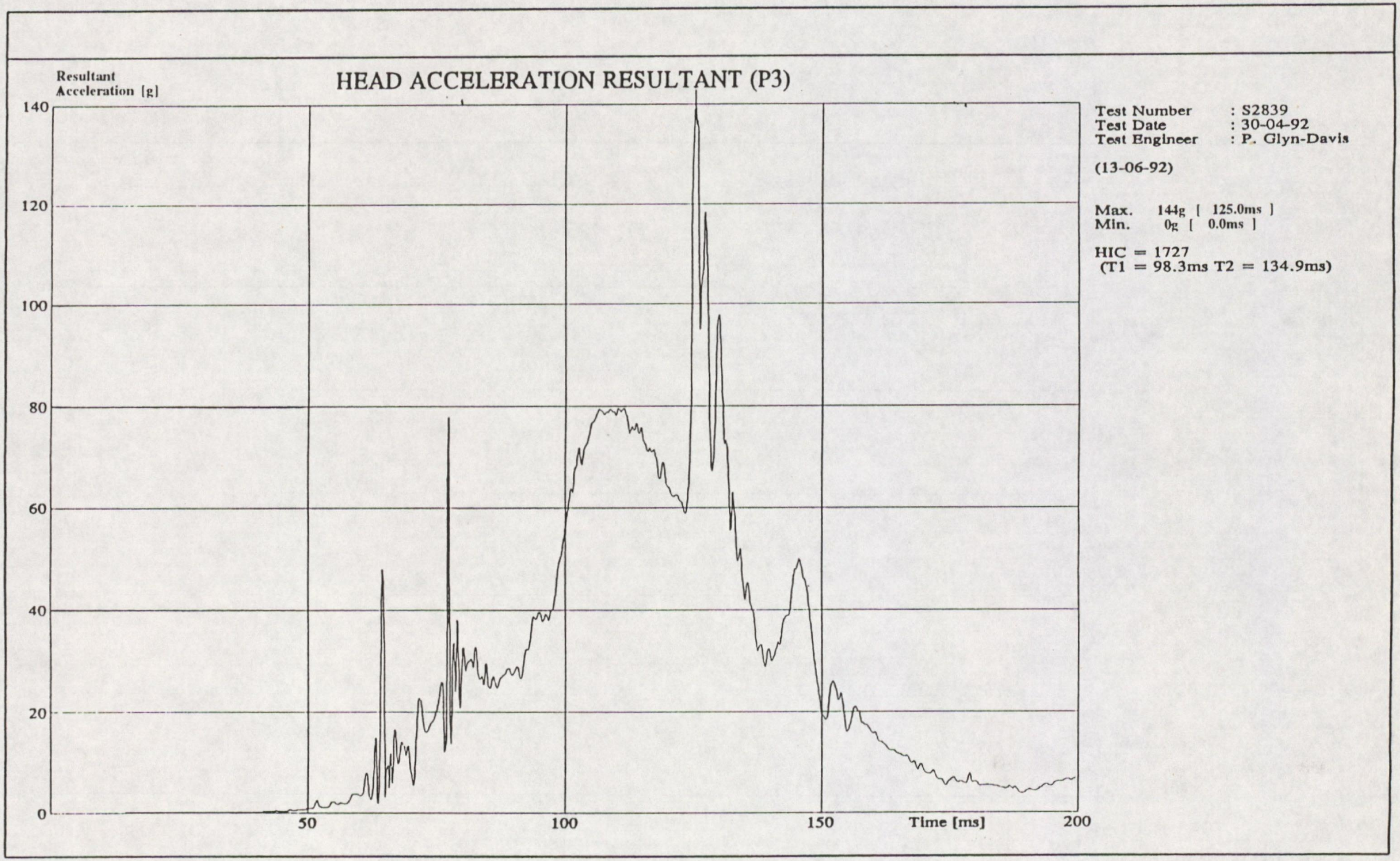
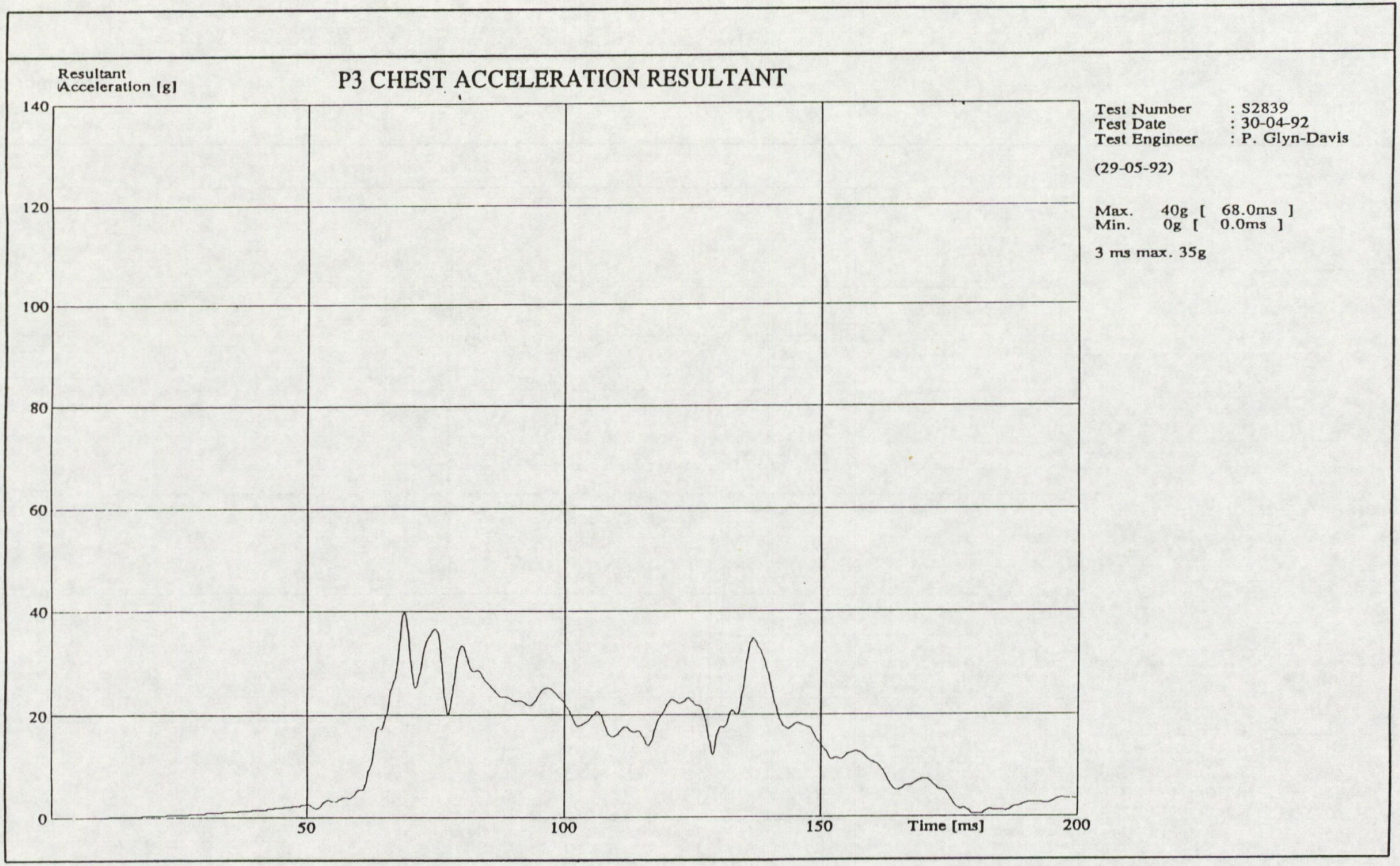

HEAD ACCELERATION RESULTANT (P3)
Resultant Acceleration [g]
140
120
100
80
60
40
20
0
50
100
150
200
Time [ms]
Test Number : S2839
Test Date : 30-04-92
Test Engineer : P. Glyn-Davis
(13-06-92)
Max. 144g [125.0ms]
Min. 0g [0.0ms]
HIC = 1727
(T1 = 98.3ms T2 = 134.9ms)

Figure 14b



P3 CHEST ACCELERATION RESULTANT
Resultant
Acceleration [g]
140
120
100
80
60
40
20
0
50
100
150
200
Time [ms]
Test Number : S2839
Test Date : 30-04-92
Test Engineer : P. Glyn-Davis
(29-05-92)
Max. 40g [68.0ms]
Min. 0g [0.0ms]
3 ms max. 35g

Figure 14c

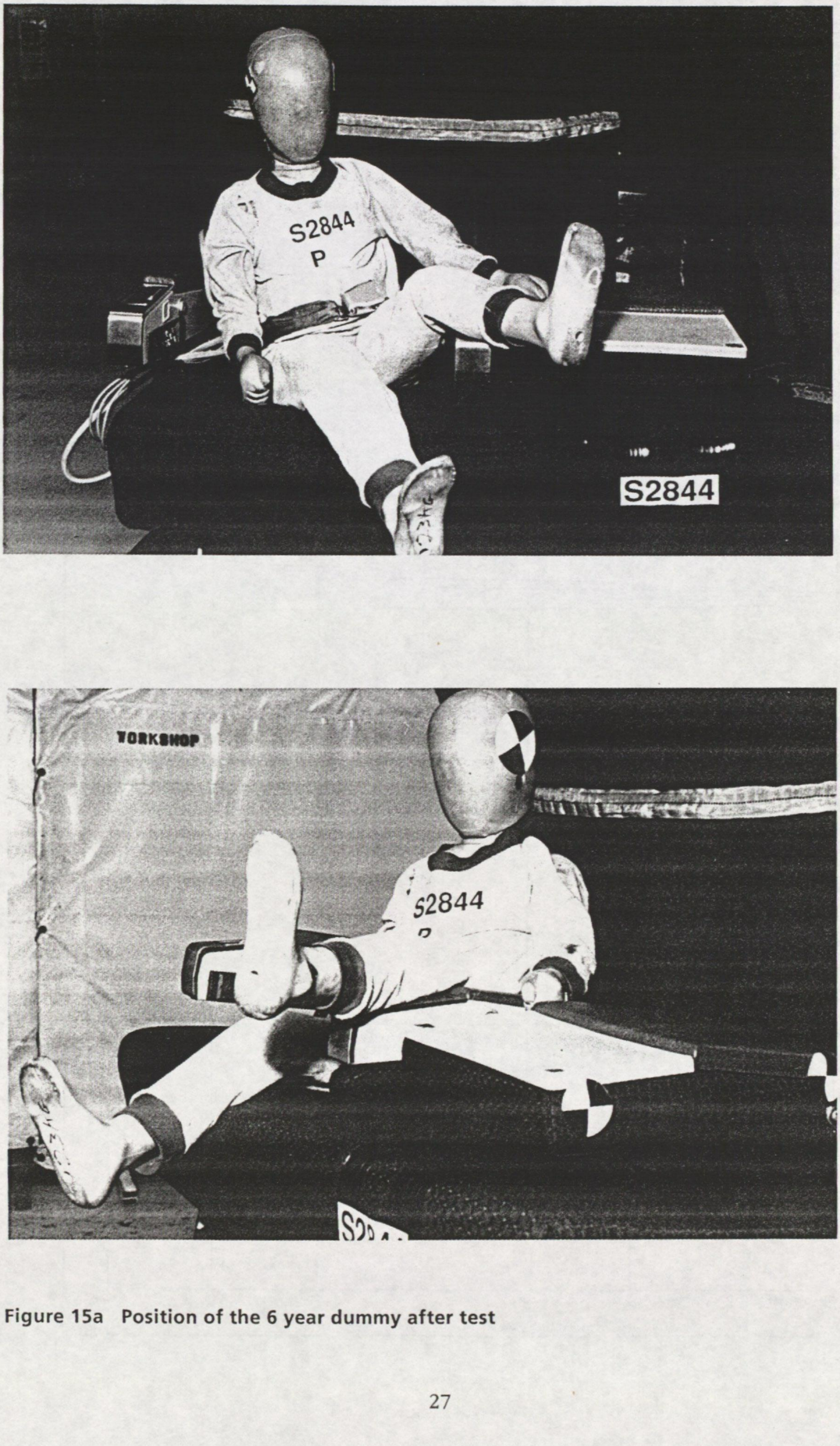
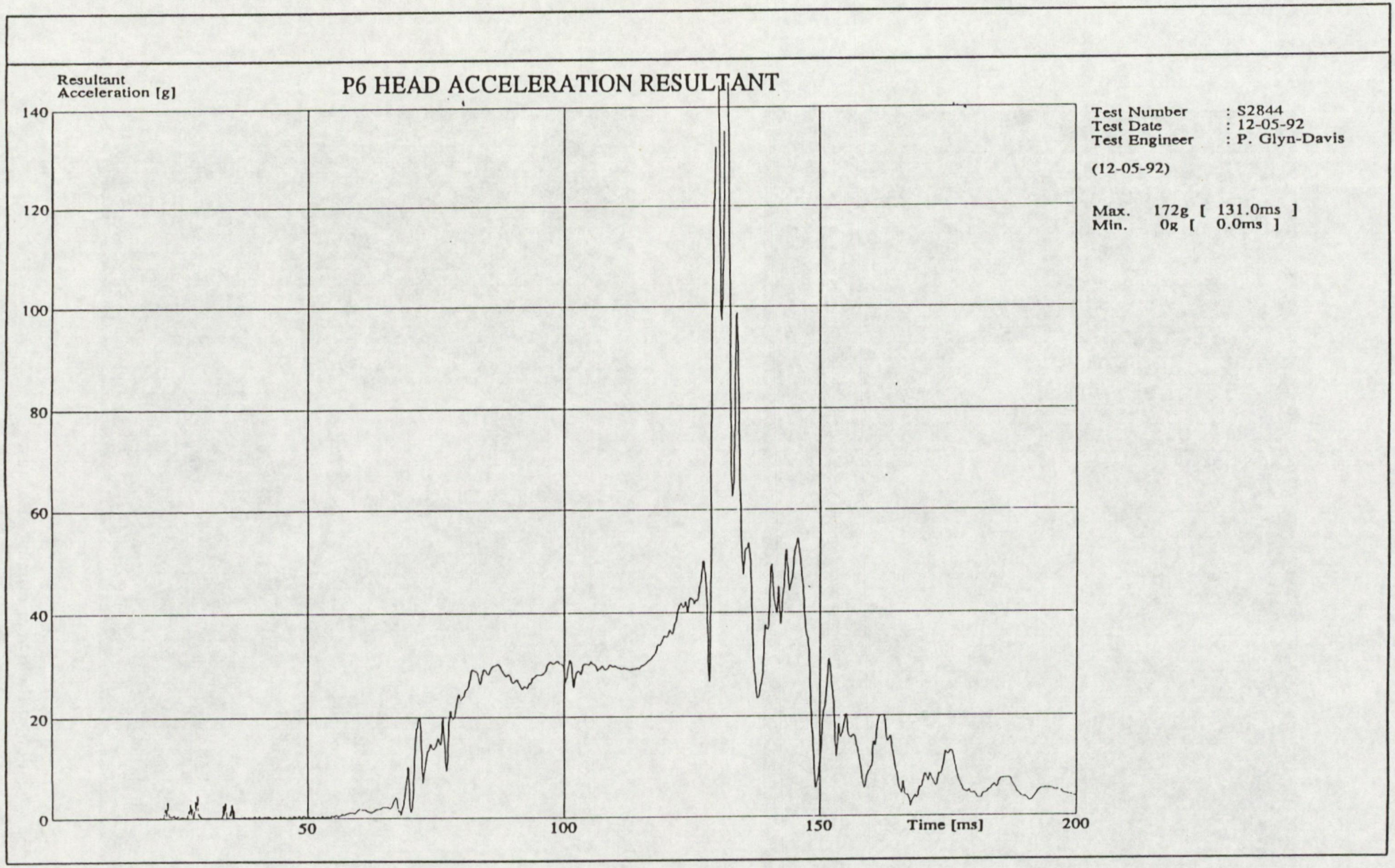


Figure 15a Position of the 6 year dummy after test



P6 HEAD ACCELERATION RESULTANT
Resultant
Acceleration [g]
140
120
100
80
60
40
20
0
50
100
150
200
Time [ms]
Test Number : S2844
Test Date : 12-05-92
Test Engineer : P. Glyn-Davis
(12-05-92)
Max. 172g [131.0ms]
Min. 0g [0.0ms]

Figure 15b

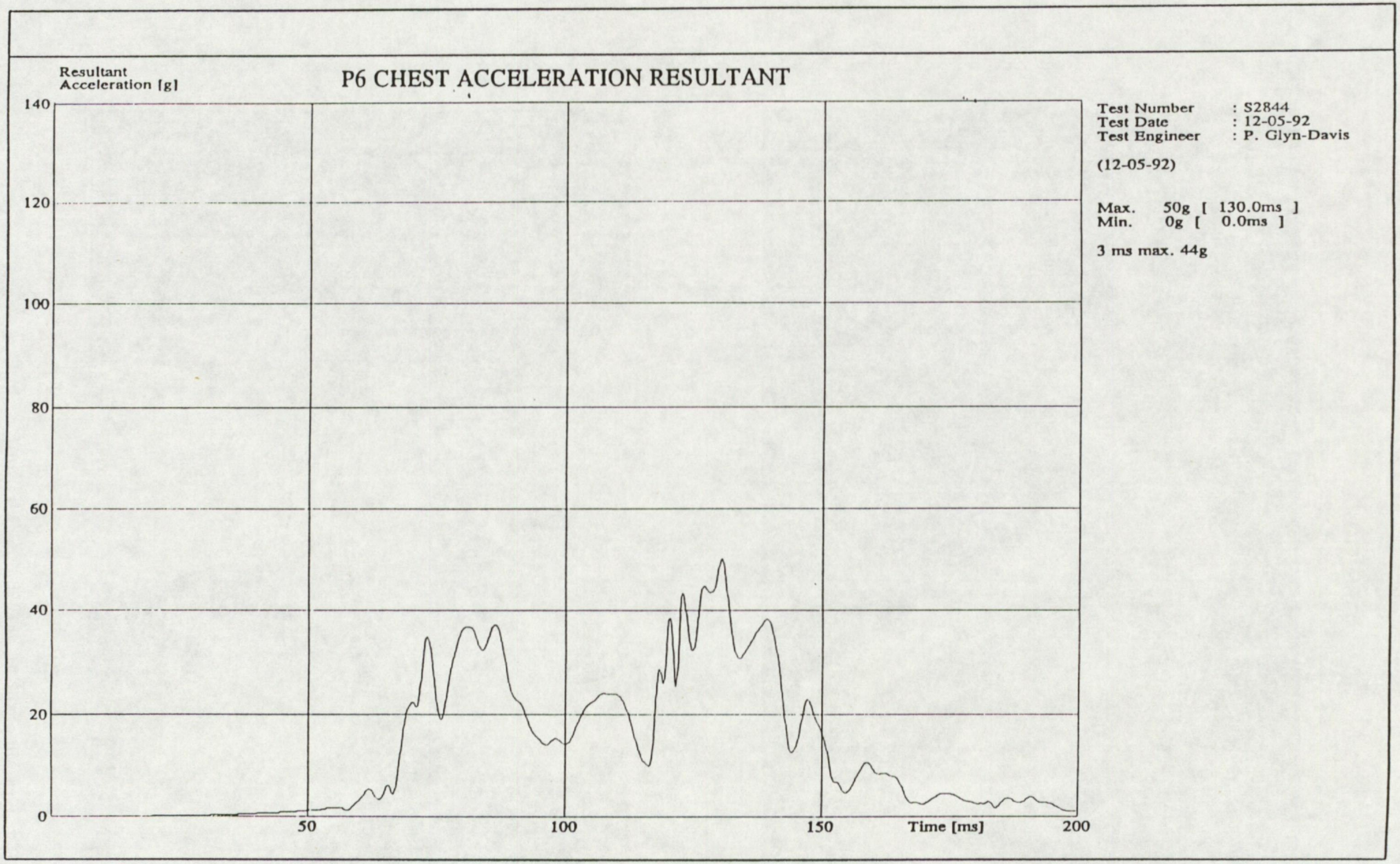

Resultant
Acceleration [g]
P6 CHEST ACCELERATION RESULTANT
140
120
100
80
60
40
20
0
50
100
150
Time [ms]
200
Test Number : S2844
Test Date : 12-05-92
Test Engineer : P. Glyn-Davis
(12-05-92)
Max. 50g [130.0ms]
Min. 0g [0.0ms]
3 ms max. 44g

Figure 15c

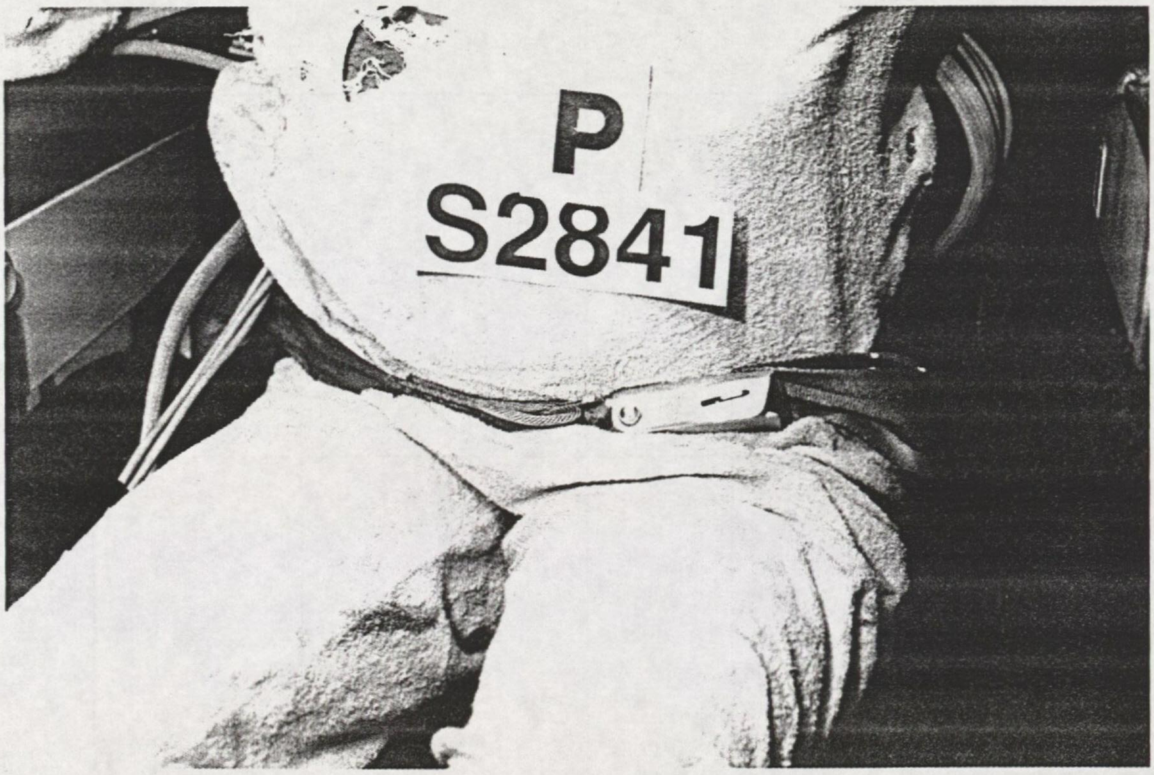


Figure 16a Position of the 10 year dummy after test

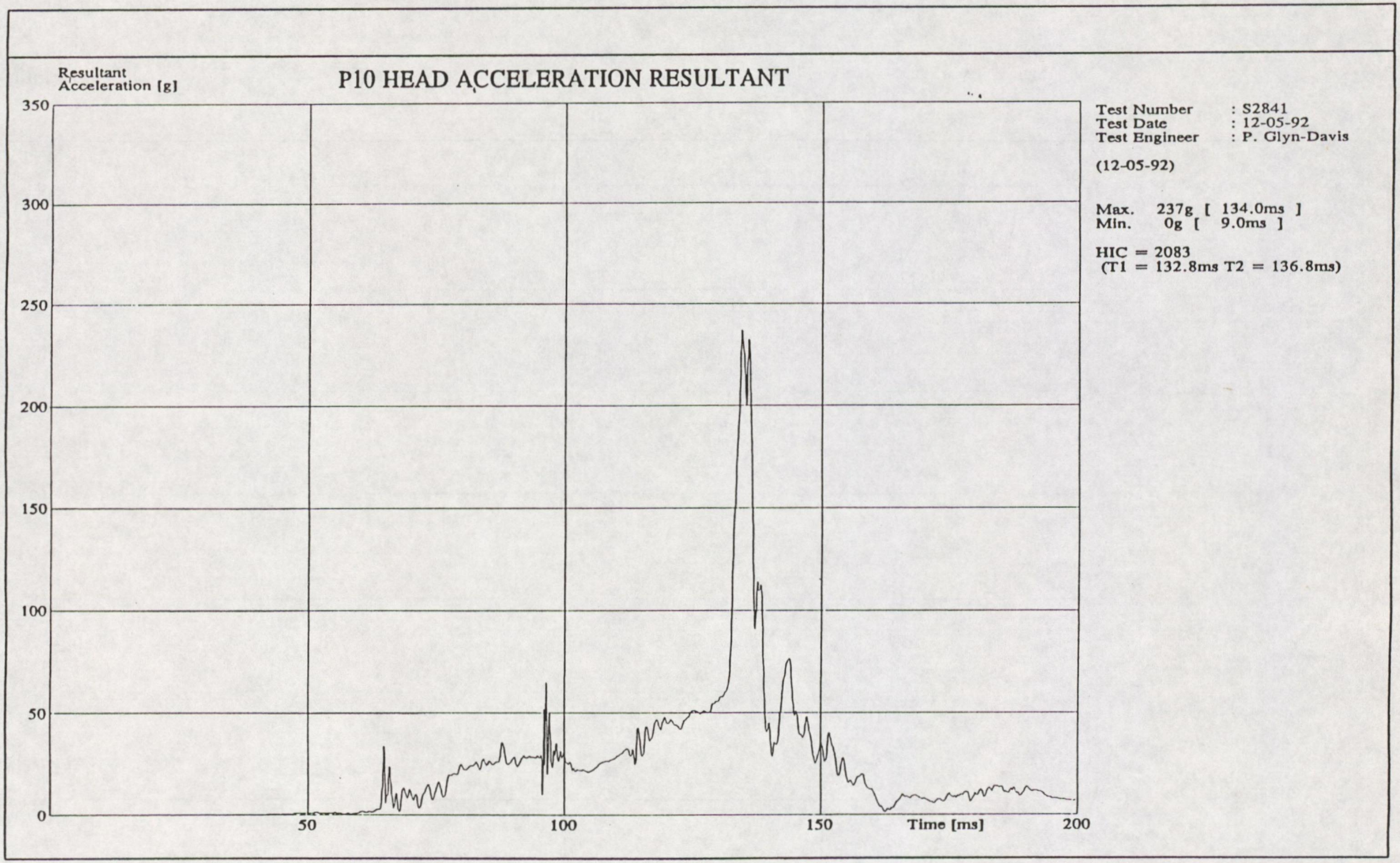

P10 HEAD ACCELERATION RESULTANT
Resultant Acceleration [g]
350
300
250
200
150
100
50
0
50
100
150
200
Time [ms]
Test Number : S2841
Test Date : 12-05-92
Test Engineer : P. Glyn-Davis
(12-05-92)
Max. 237g [134.0ms]
Min. 0g [9.0ms]
HIC = 2083
(T1 = 132.8ms T2 = 136.8ms)

Figure 16b

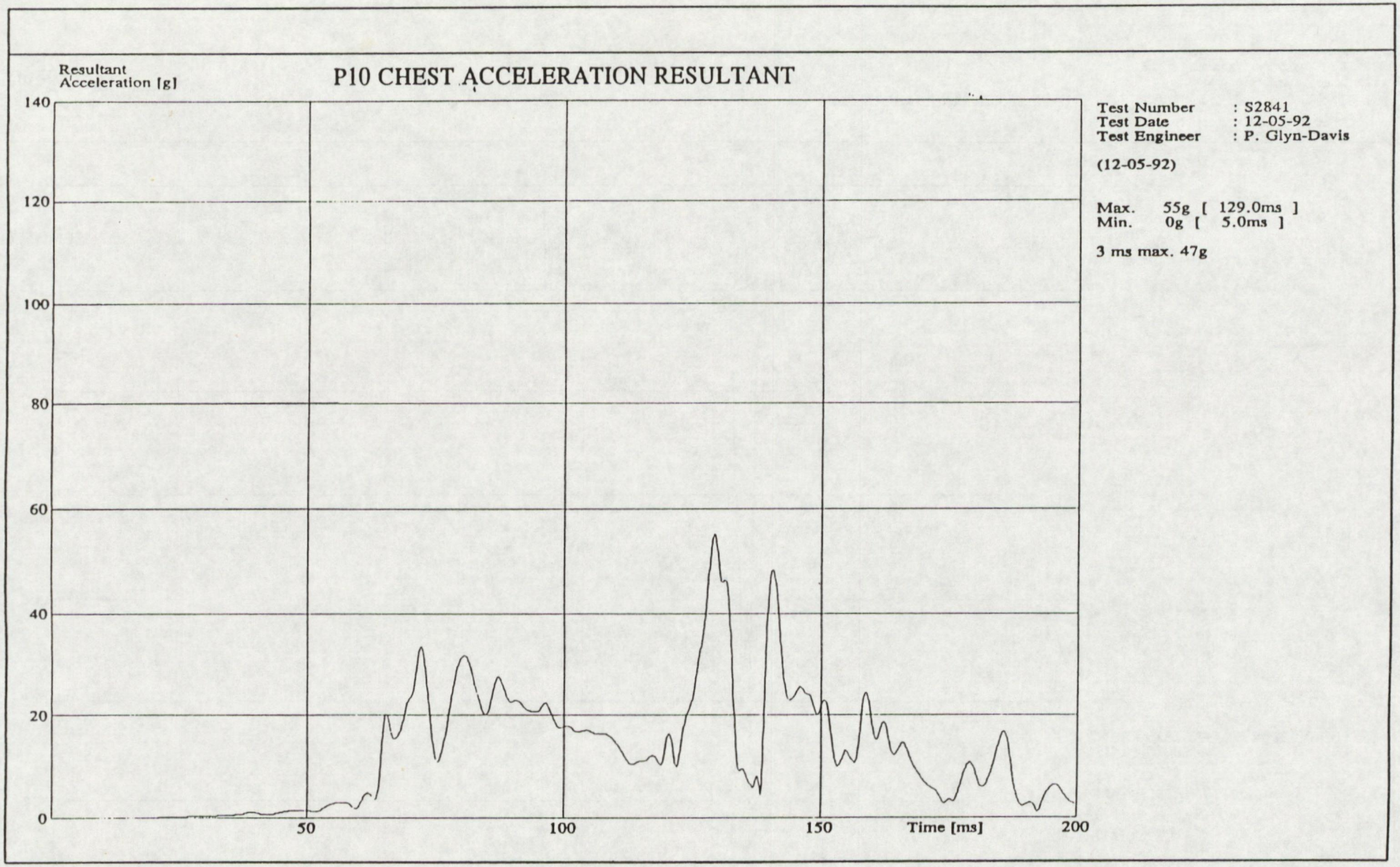

P10 CHEST ACCELERATION RESULTANT
Resultant
Acceleration [g]
140
120
100
80
60
40
20
0
50
100
150
200
Time [ms]
Test Number : S2841
Test Date : 12-05-92
Test Engineer : P. Glyn-Davis
(12-05-92)
Max. 55g [129.0ms]
Min. 0g [5.0ms]
3 ms max. 47g

Figure 16c

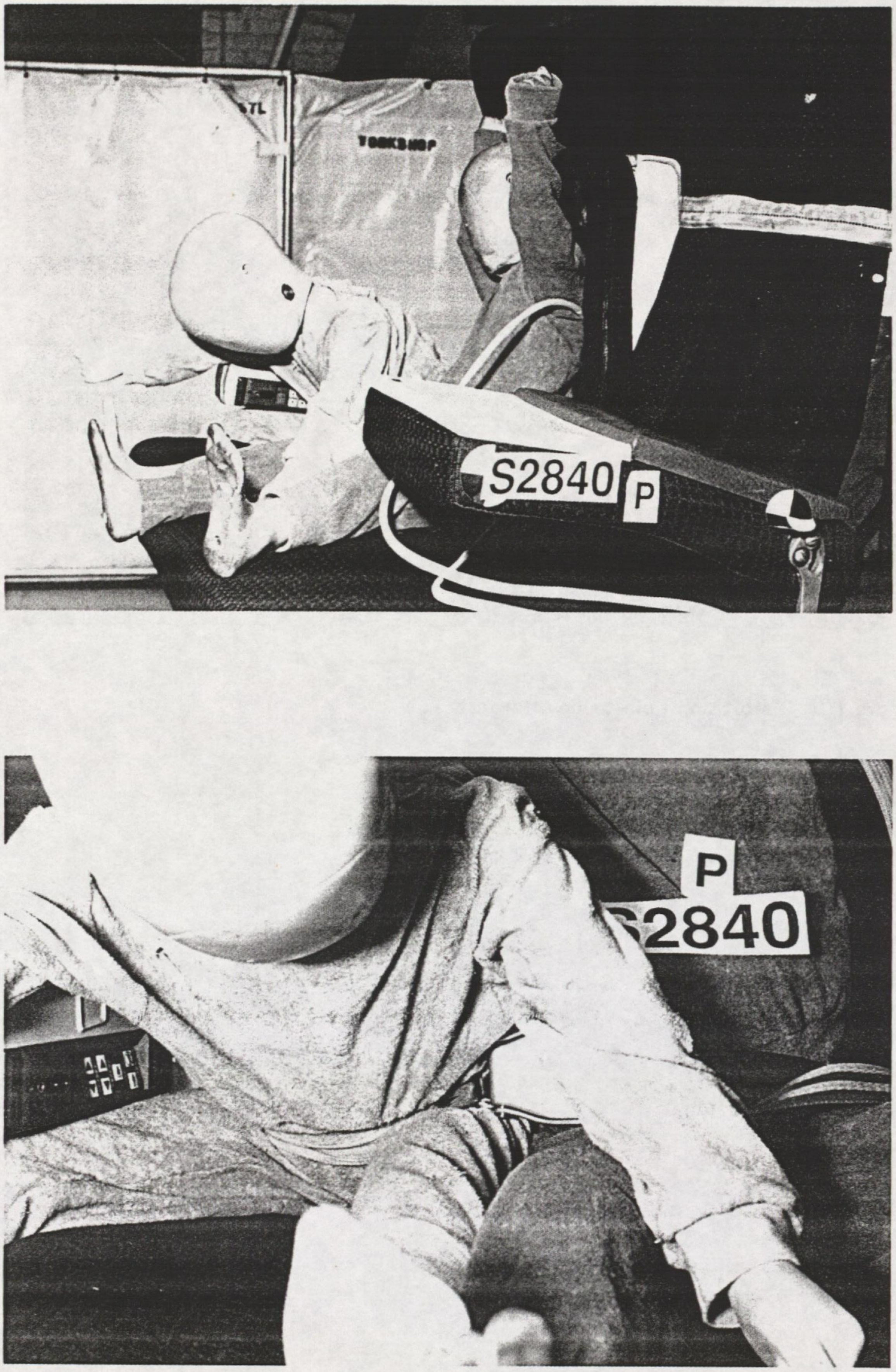


Figure 17a Positions of the 3 year dummies after test

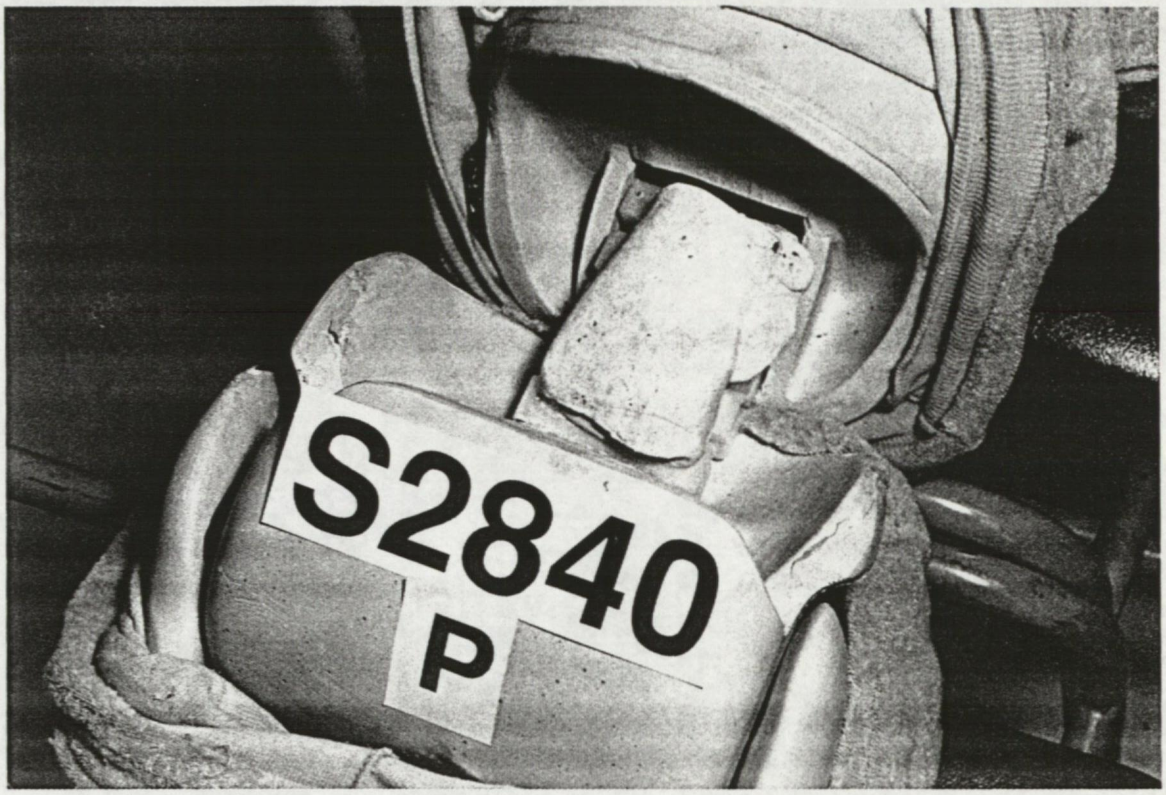


Figure 17b Distortion of plasticine after test

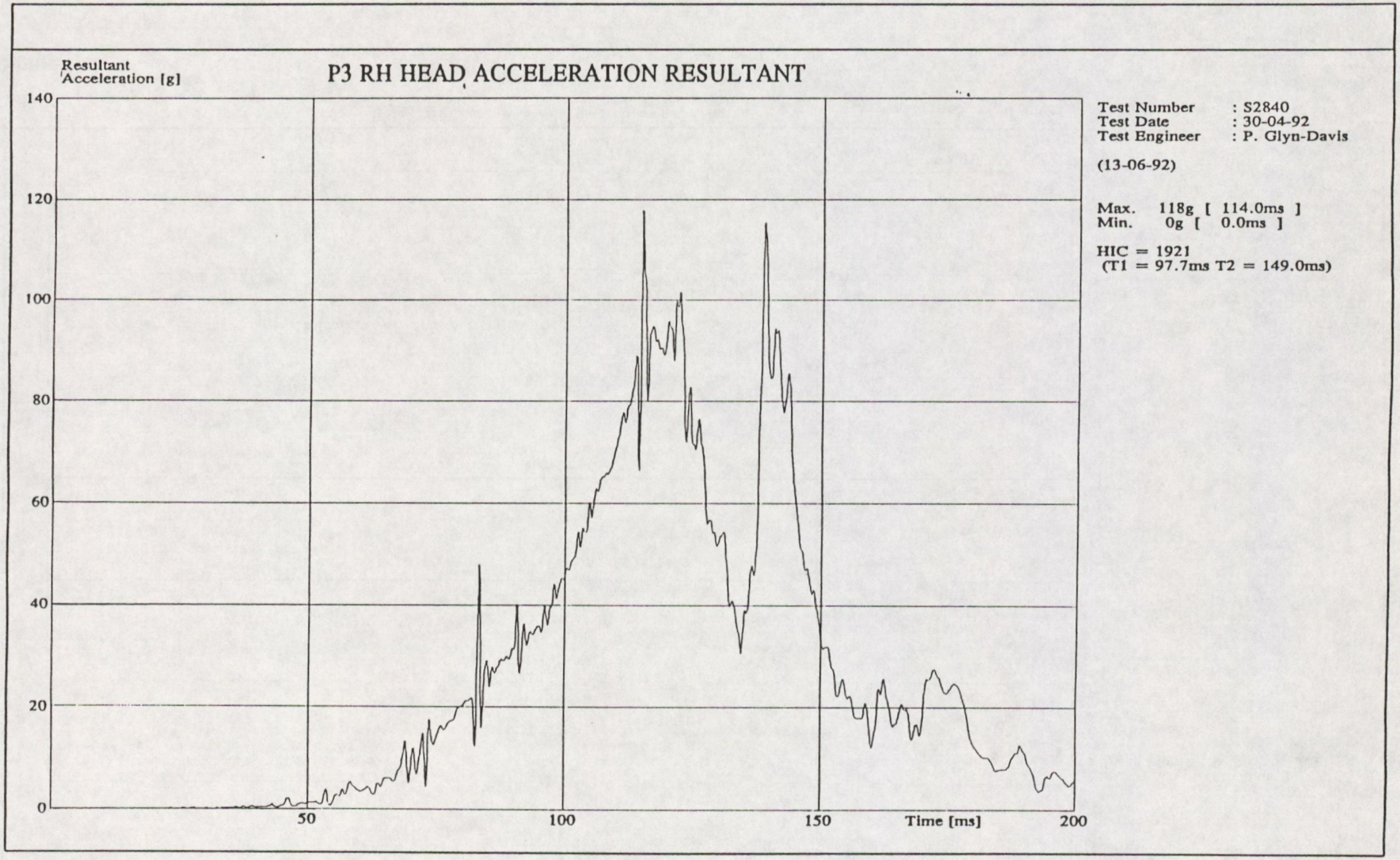

P3 RH HEAD ACCELERATION RESULTANT
Resultant Acceleration [g]
140
120
100
80
60
40
20
0
50
100
150
200
Time [ms]
Test Number : S2840
Test Date : 30-04-92
Test Engineer : P. Glyn-Davis
(13-06-92)
Max. 118g [114.0ms]
Min. 0g [0.0ms]
HIC = 1921
(T1 = 97.7ms T2 = 149.0ms)

Figure 17c

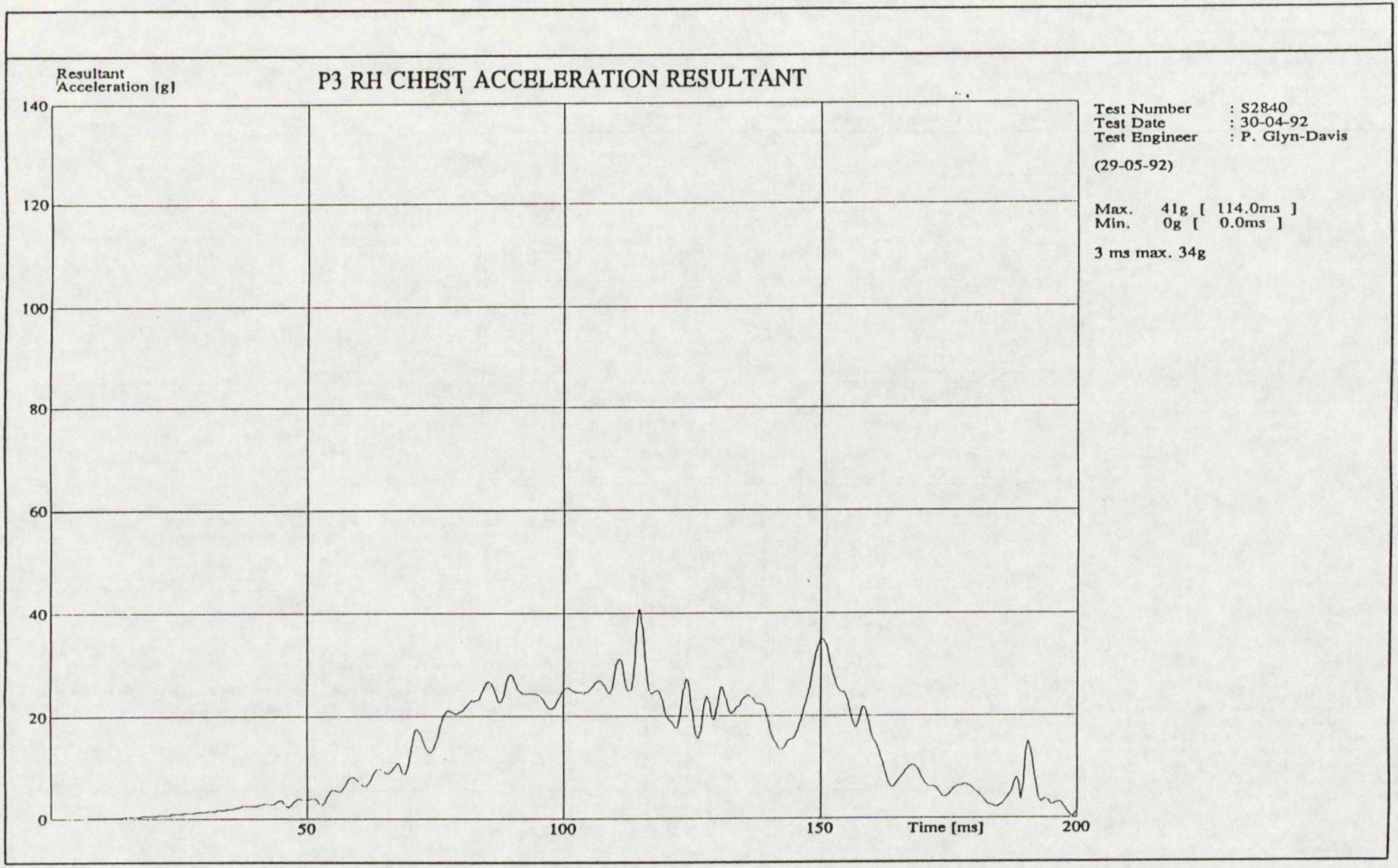

P3 RH CHEST ACCELERATION RESULTANT
Resultant
Acceleration [g]
140
120
100
80
60
40
20
0
50
100
150
Time [ms]
200
Test Number : S2840
Test Date : 30-04-92
Test Engineer : P. Glyn-Davis
(29-05-92)
Max. 41g [114.0ms]
Min. 0g [0.0ms]
3 ms max. 34g

Figure 17d

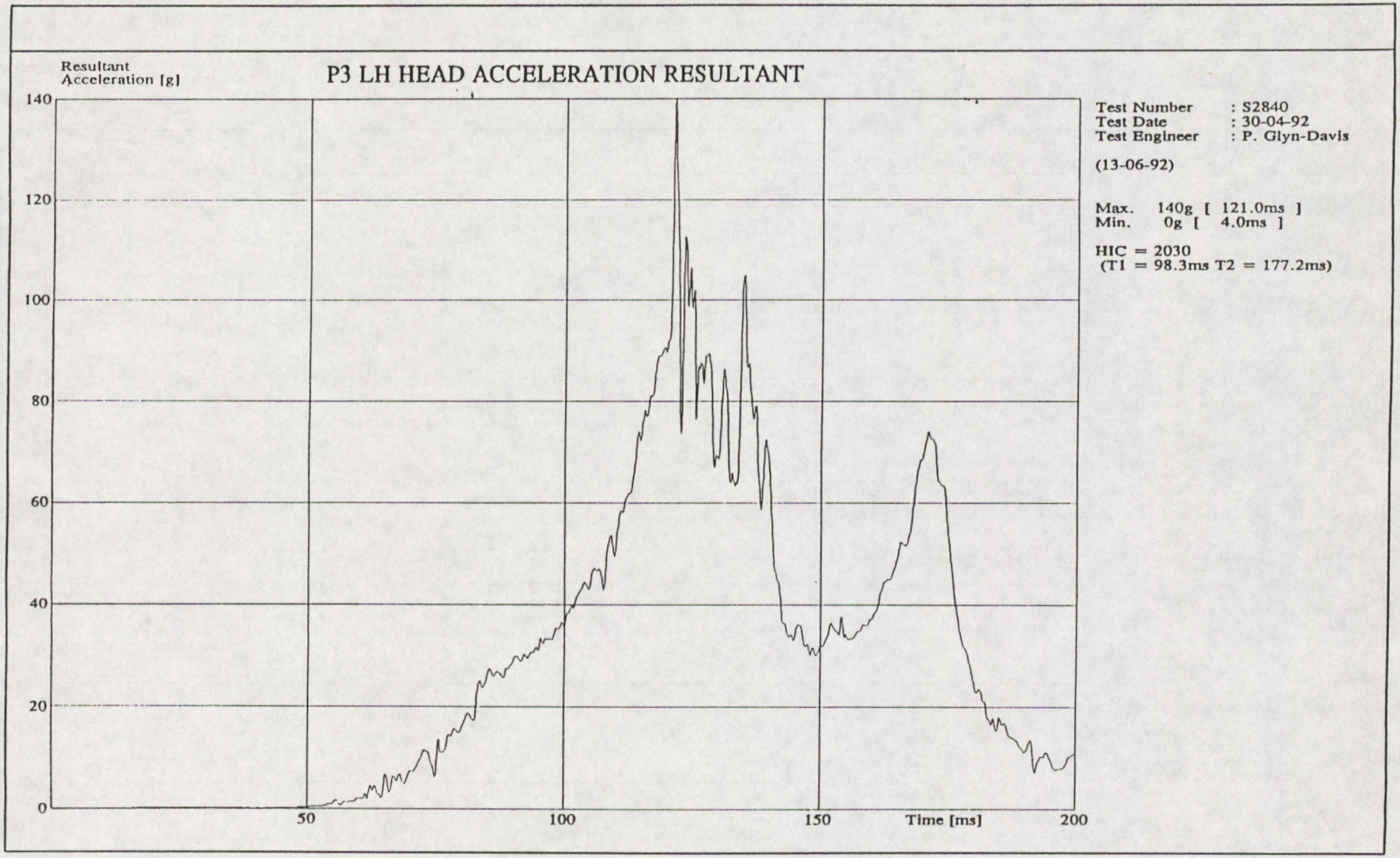

Resultant
Acceleration [g]
P3 LH HEAD ACCELERATION RESULTANT
140
120
100
80
60
40
20
0
50
100
150
200
Time [ms]
Test Number : S2840
Test Date : 30-04-92
Test Engineer : P. Glyn-Davis
(13-06-92)
Max. 140g [121.0ms]
Min. 0g [4.0ms]
HIC = 2030
(T1 = 98.3ms T2 = 177.2ms)

Figure 17e

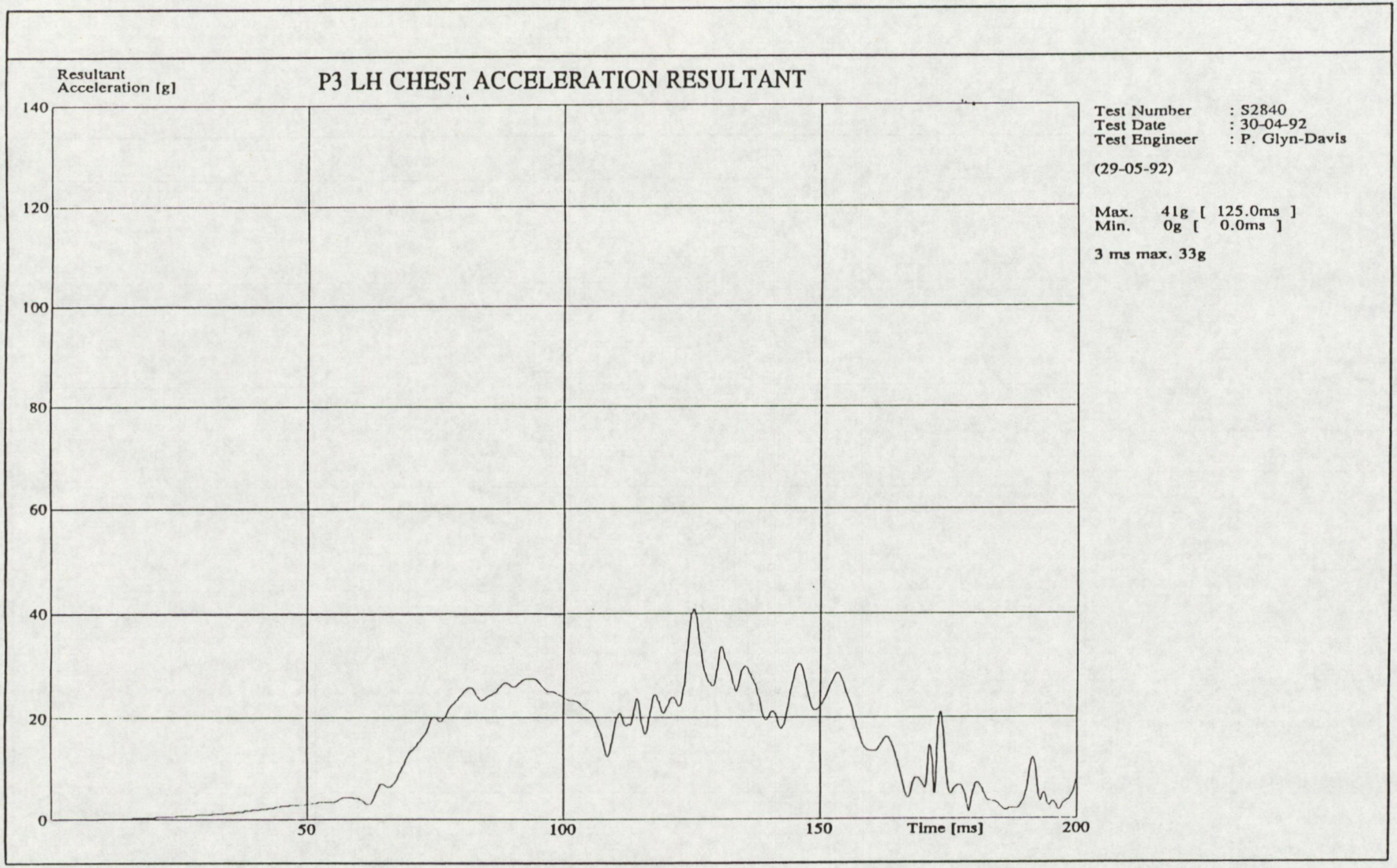

Resultant
Acceleration [g]
P3 LH CHEST ACCELERATION RESULTANT
140
120
100
80
60
40
20
0
50
100
150
200
Time [ms]
Test Number : S2840
Test Date : 30-04-92
Test Engineer : P. Glyn-Davis
(29-05-92)
Max. 41g [125.0ms]
Min. 0g [0.0ms]
3 ms max. 33g

Figure 17f

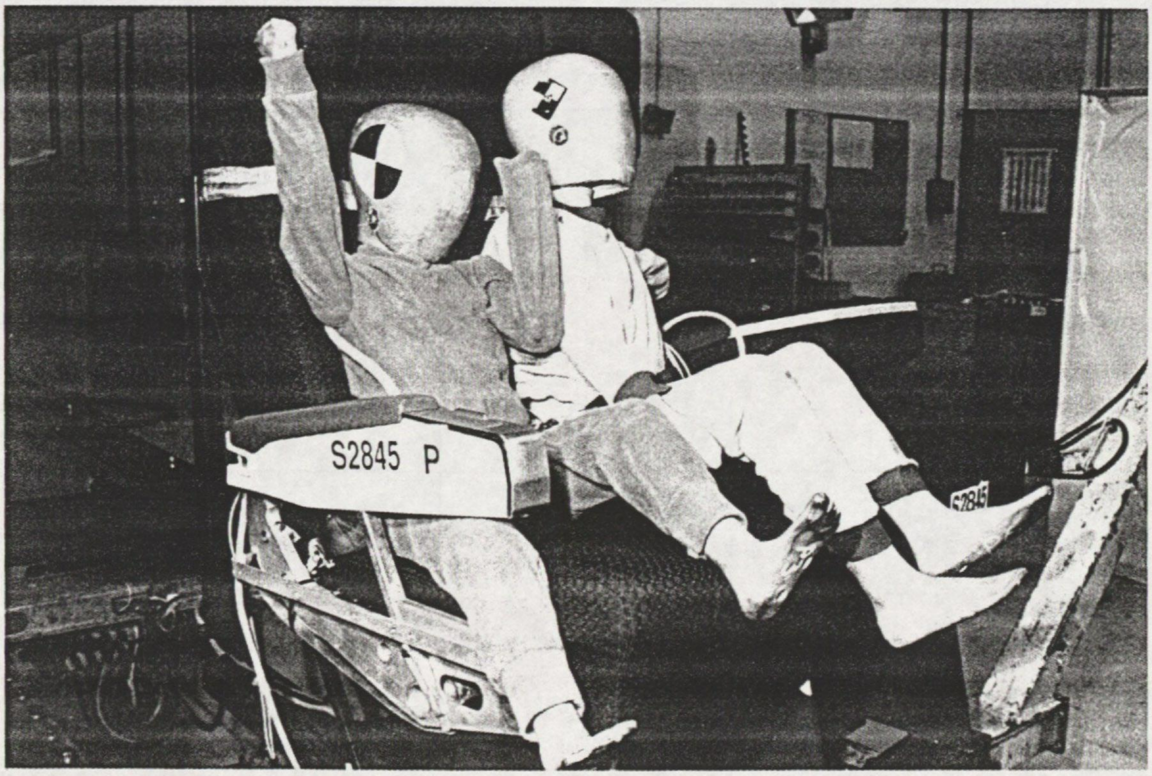
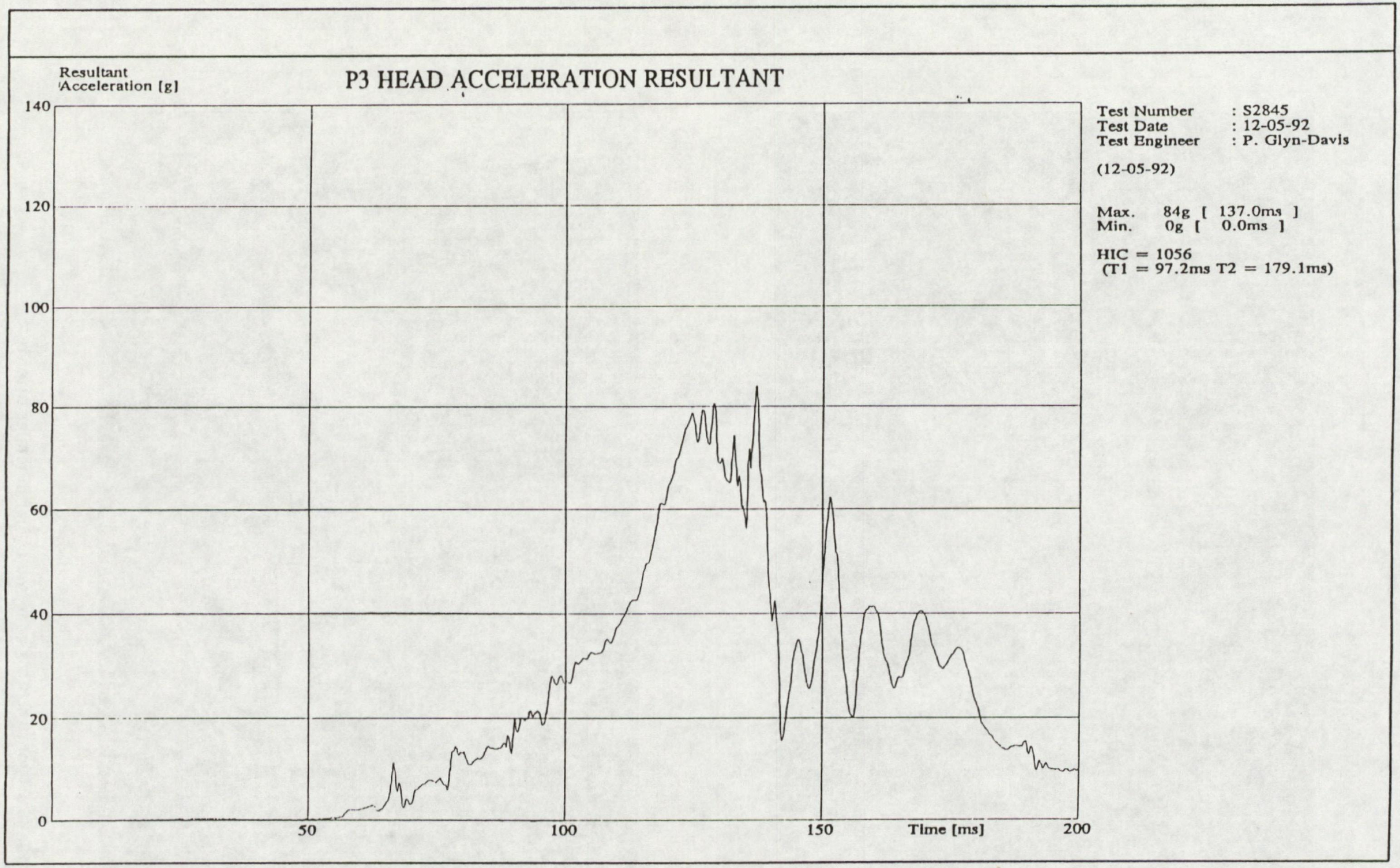
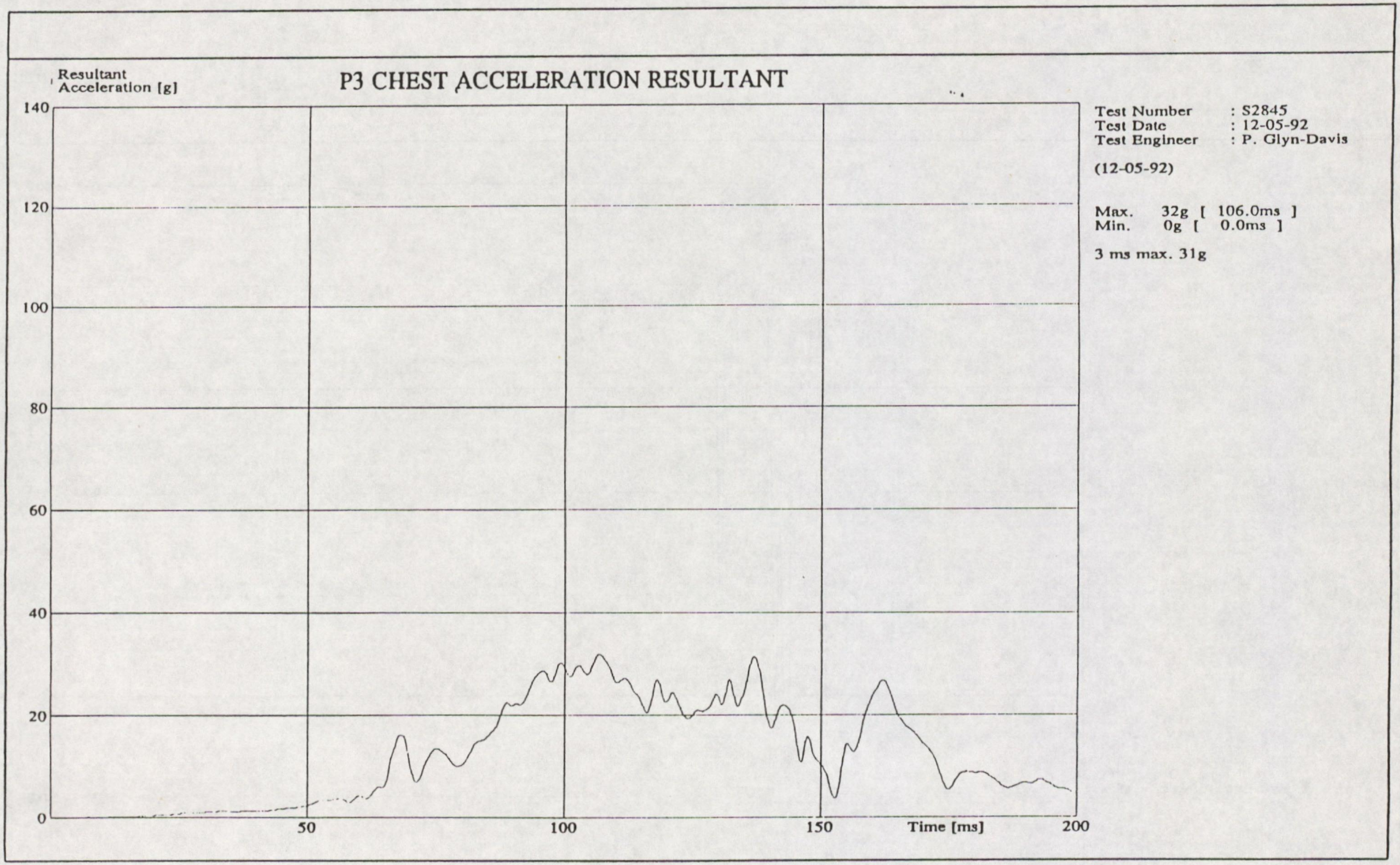


Figure 18a Positions of the 3 year and 6 year dummies after test



P3 HEAD ACCELERATION RESULTANT
Resultant
Acceleration [g]
140
120
100
80
60
40
20
0
50
100
150
Time [ms]
200
Test Number : S2845
Test Date : 12-05-92
Test Engineer : P. Glyn-Davis
(12-05-92)
Max. 84g [137.0ms]
Min. 0g [0.0ms]
HIC = 1056
(T1 = 97.2ms T2 = 179.1ms)

Figure 18b



Resultant Acceleration [g]
P3 CHEST ACCELERATION RESULTANT
140
120
100
80
60
40
20
0
50
100
150
200
Time [ms]
Test Number : S2845
Test Date : 12-05-92
Test Engineer : P. Glyn-Davis
(12-05-92)
Max. 32g [106.0ms]
Min. 0g [0.0ms]
3 ms max. 31g

Figure 18c

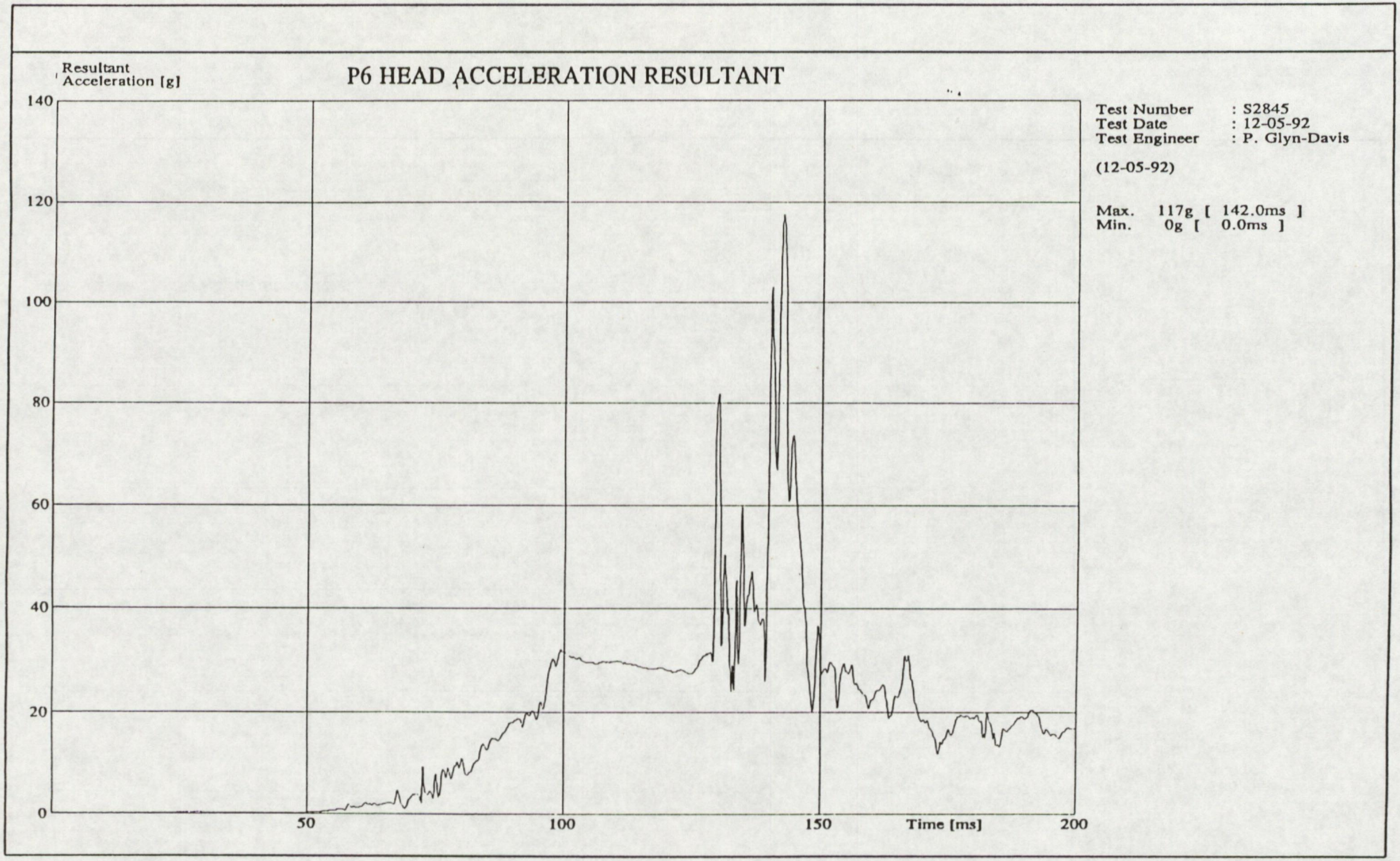
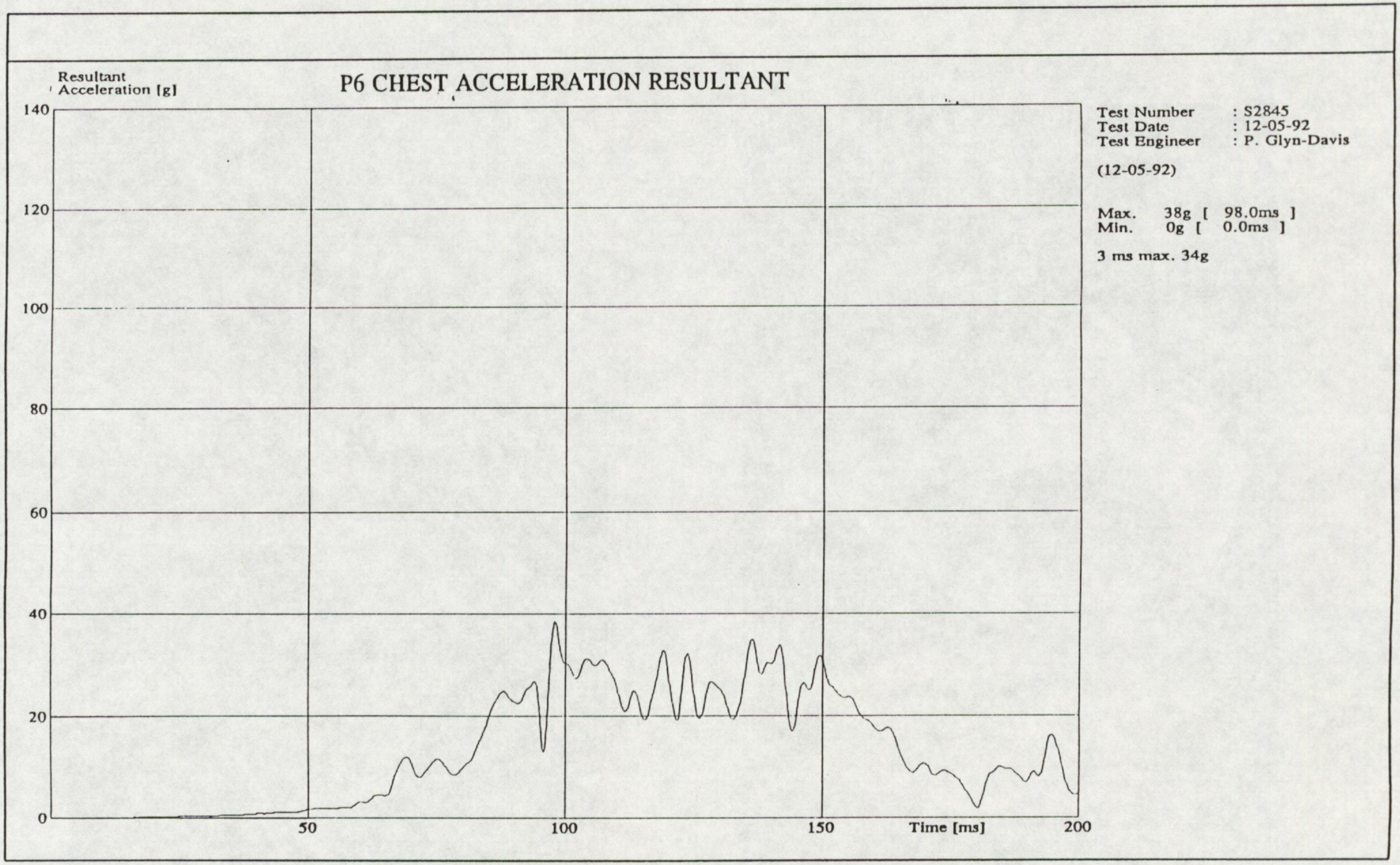

P6 HEAD ACCELERATION RESULTANT
Resultant Acceleration [g]
140
120
100
80
60
40
20
0
50
100
150
200
Time [ms]
Test Number : S2845
Test Date : 12-05-92
Test Engineer : P. Glyn-Davis
(12-05-92)
Max. 117g [142.0ms]
Min. 0g [0.0ms]

Figure 18d



P6 CHEST ACCELERATION RESULTANT
Resultant Acceleration [g]
140
120
100
80
60
40
20
0
50
100
150
Time [ms]
200
Test Number : S2845
Test Date : 12-05-92
Test Engineer : P. Glyn-Davis
(12-05-92)
Max. 38g [98.0ms]
Min. 0g [0.0ms]
3 ms max. 34g

Figure 18e

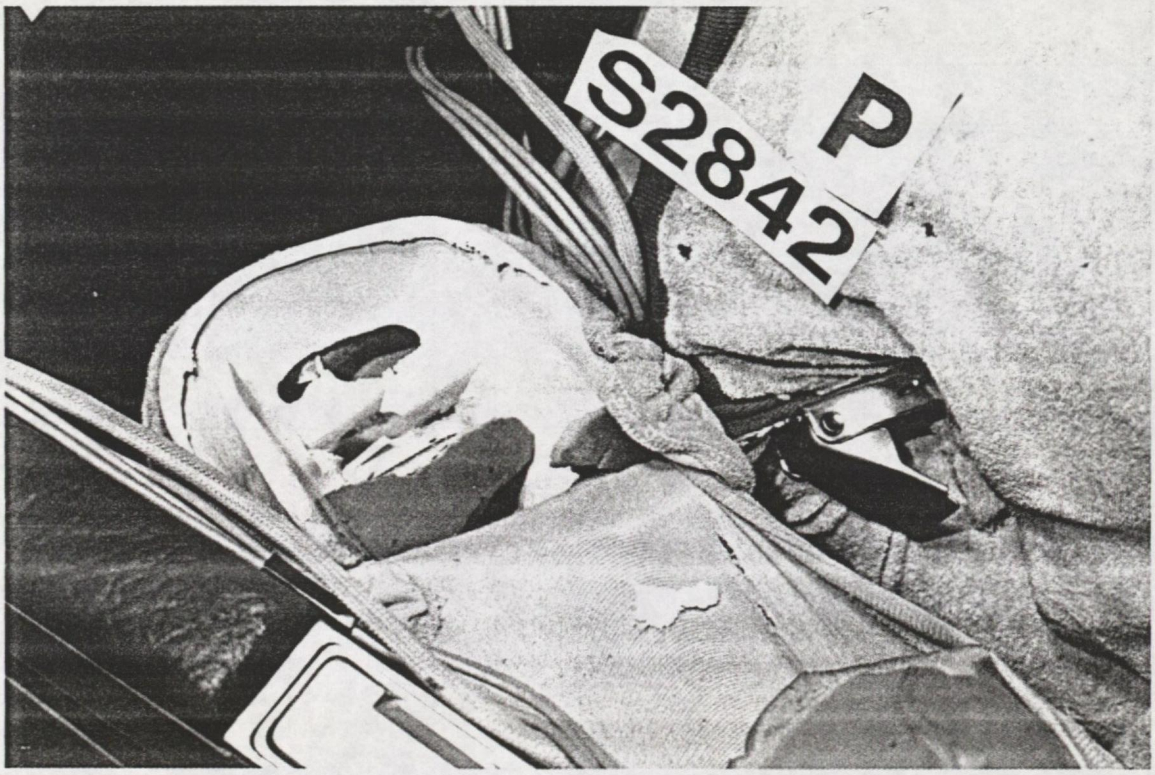
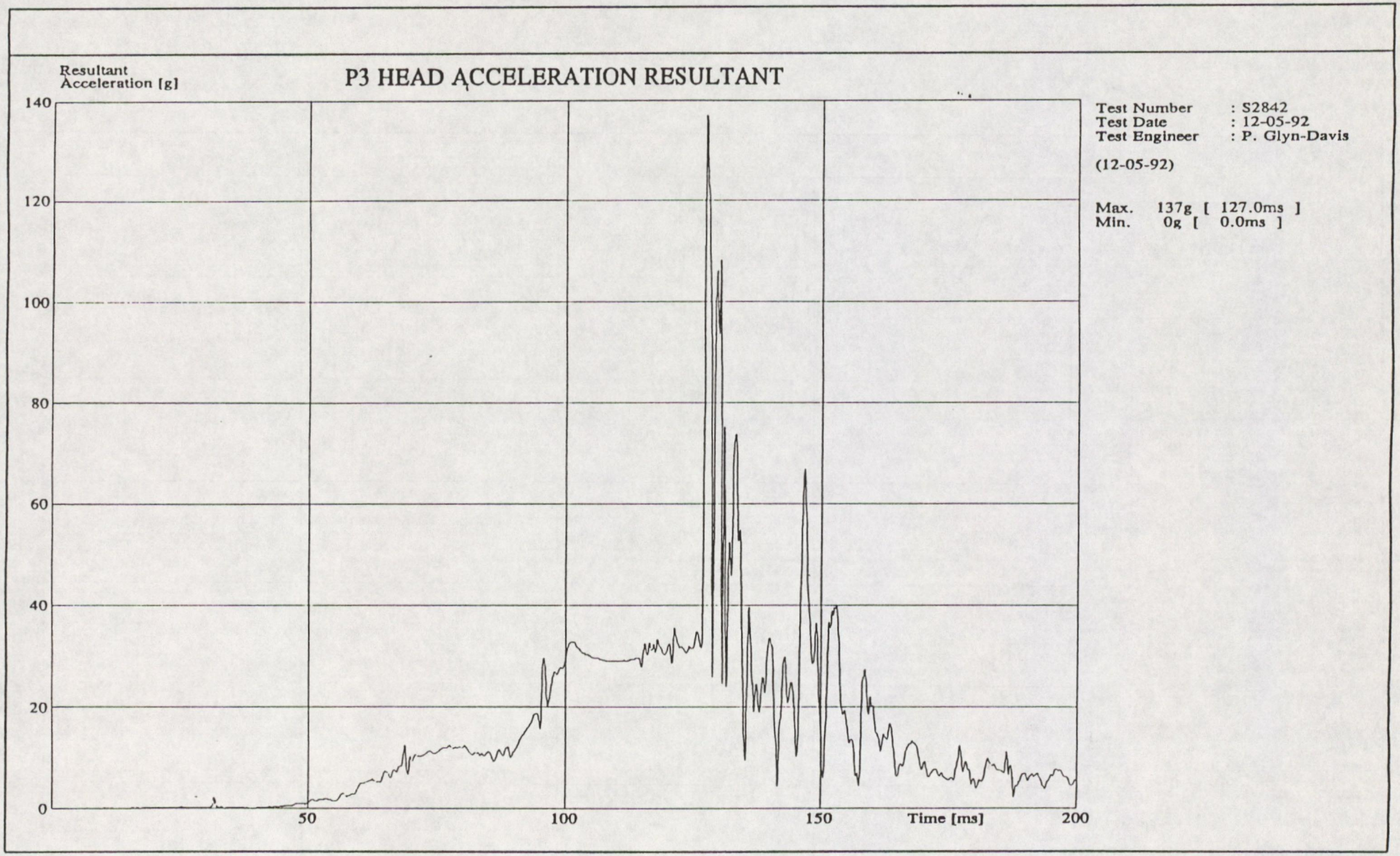
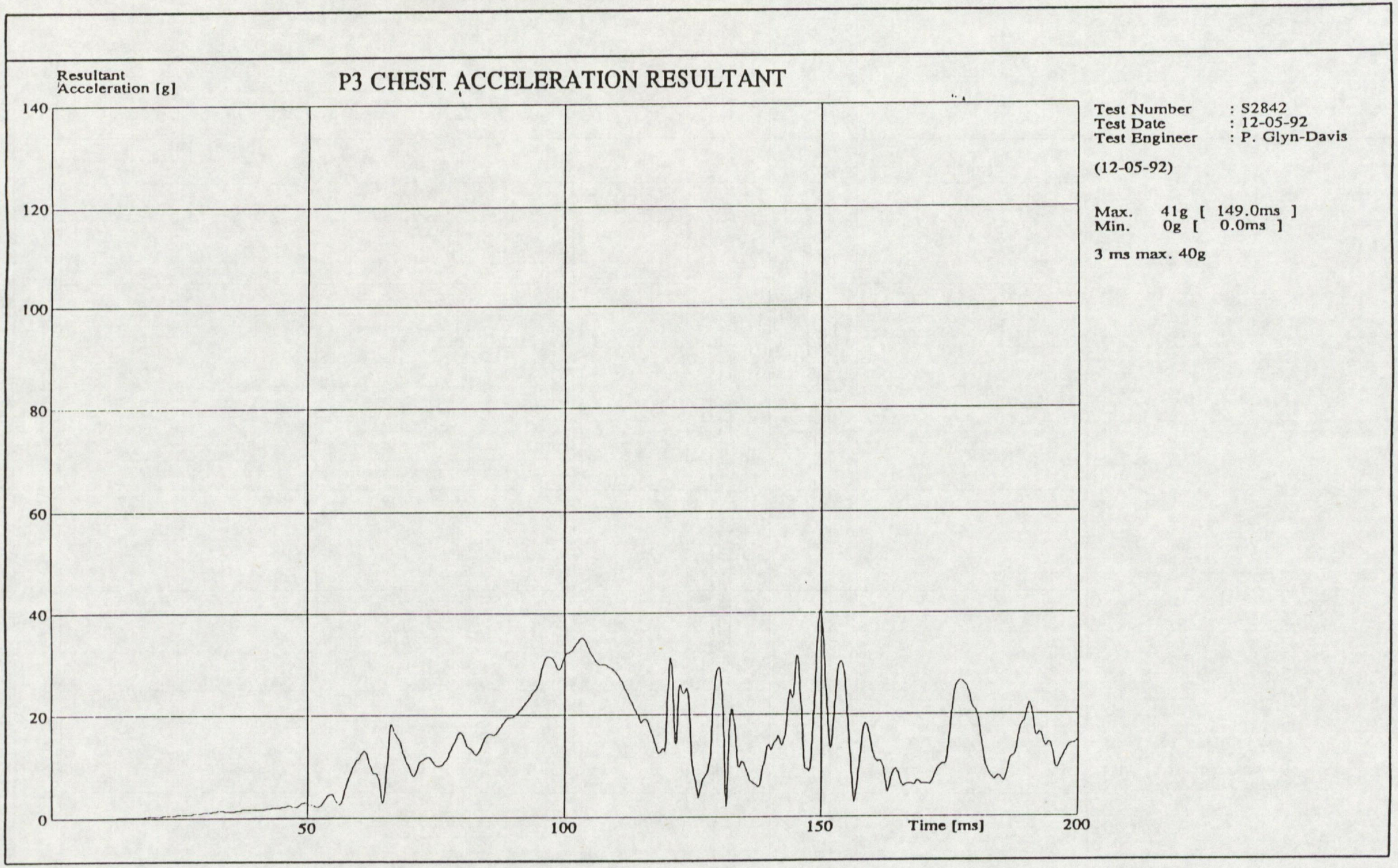


Figure 19a Positions of the 3 year and 10 year dummies after test



P3 HEAD ACCELERATION RESULTANT
Resultant Acceleration [g]
140
120
100
80
60
40
20
0
50
100
150
200
Time [ms]
Test Number : S2842
Test Date : 12-05-92
Test Engineer : P. Glyn-Davis
(12-05-92)
Max. 137g [127.0ms]
Min. 0g [0.0ms]

Figure 19b



P3 CHEST ACCELERATION RESULTANT
Resultant
Acceleration [g]
140
120
100
80
60
40
20
0
50
100
150
Time [ms]
200
Test Number : S2842
Test Date : 12-05-92
Test Engineer : P. Glyn-Davis
(12-05-92)
Max. 41g [149.0ms]
Min. 0g [0.0ms]
3 ms max. 40g

Figure 19c

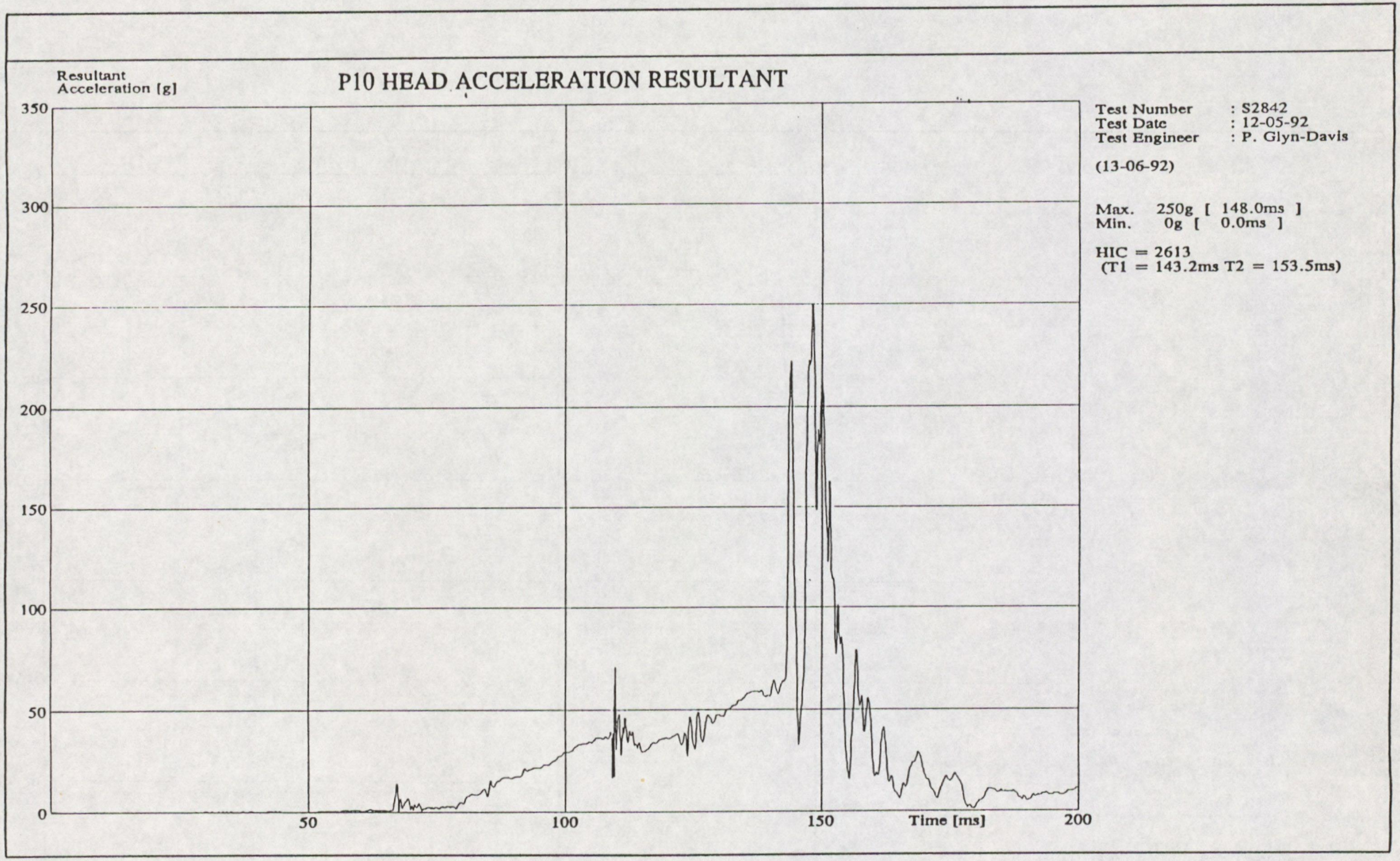

P10 HEAD ACCELERATION RESULTANT
Resultant
Acceleration [g]
350
300
250
200
150
100
50
0
50
100
150
Time [ms]
200
Test Number : S2842
Test Date : 12-05-92
Test Engineer : P. Glyn-Davis
(13-06-92)
Max. 250g [148.0ms]
Min. 0g [0.0ms]
HIC = 2613
(T1 = 143.2ms T2 = 153.5ms)

Figure 19d

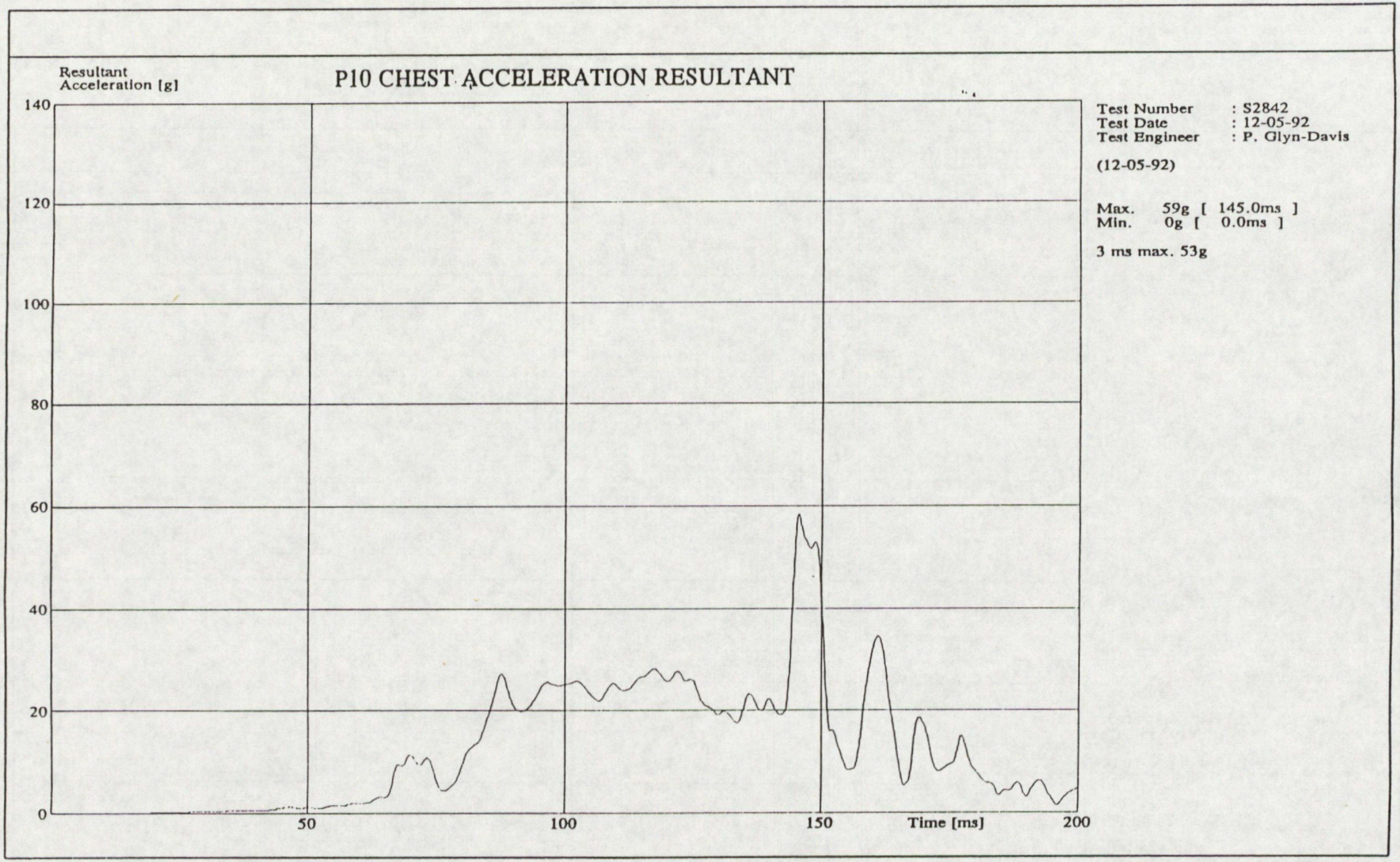

P10 CHEST ACCELERATION RESULTANT
Resultant
Acceleration [g]
140
120
100
80
60
40
20
0
50
100
150
Time [ms]
200
Test Number : S2842
Test Date : 12-05-92
Test Engineer : P. Glyn-Davis
(12-05-92)
Max. 59g [145.0ms]
Min. 0g [0.0ms]
3 ms max. 53g

Figure 19e

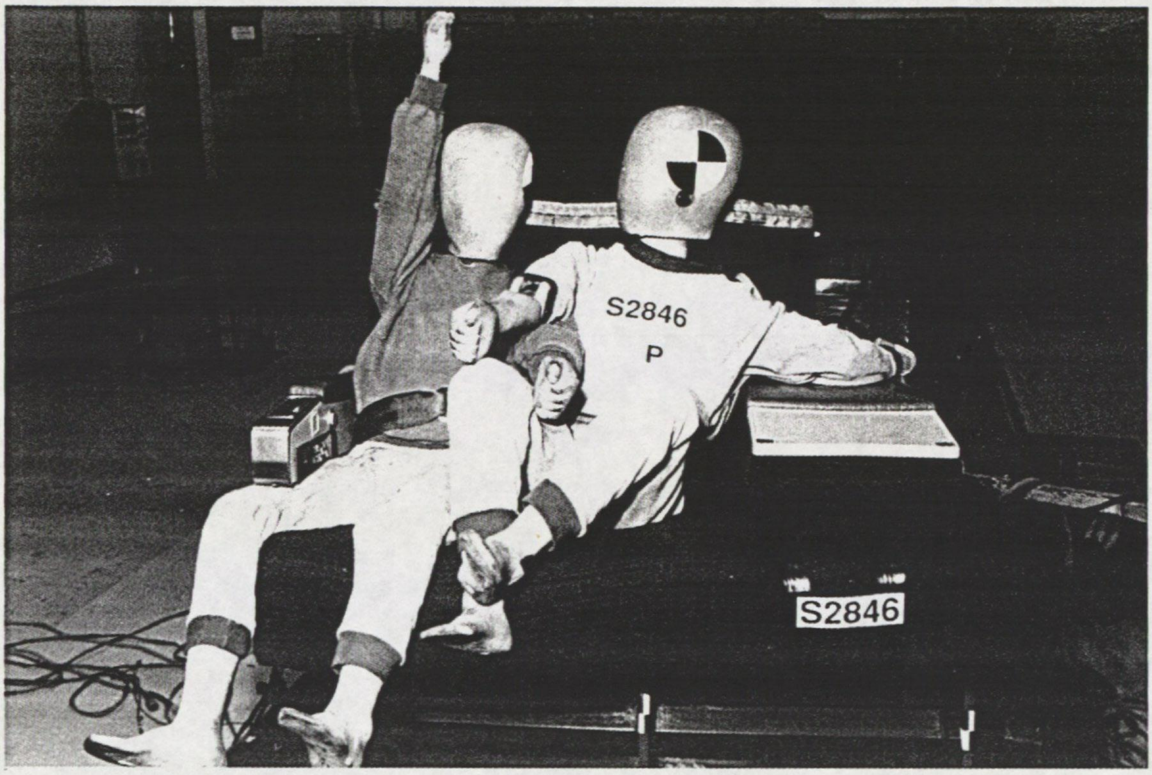


Figure 20a Positions of the 6 year dummies after test

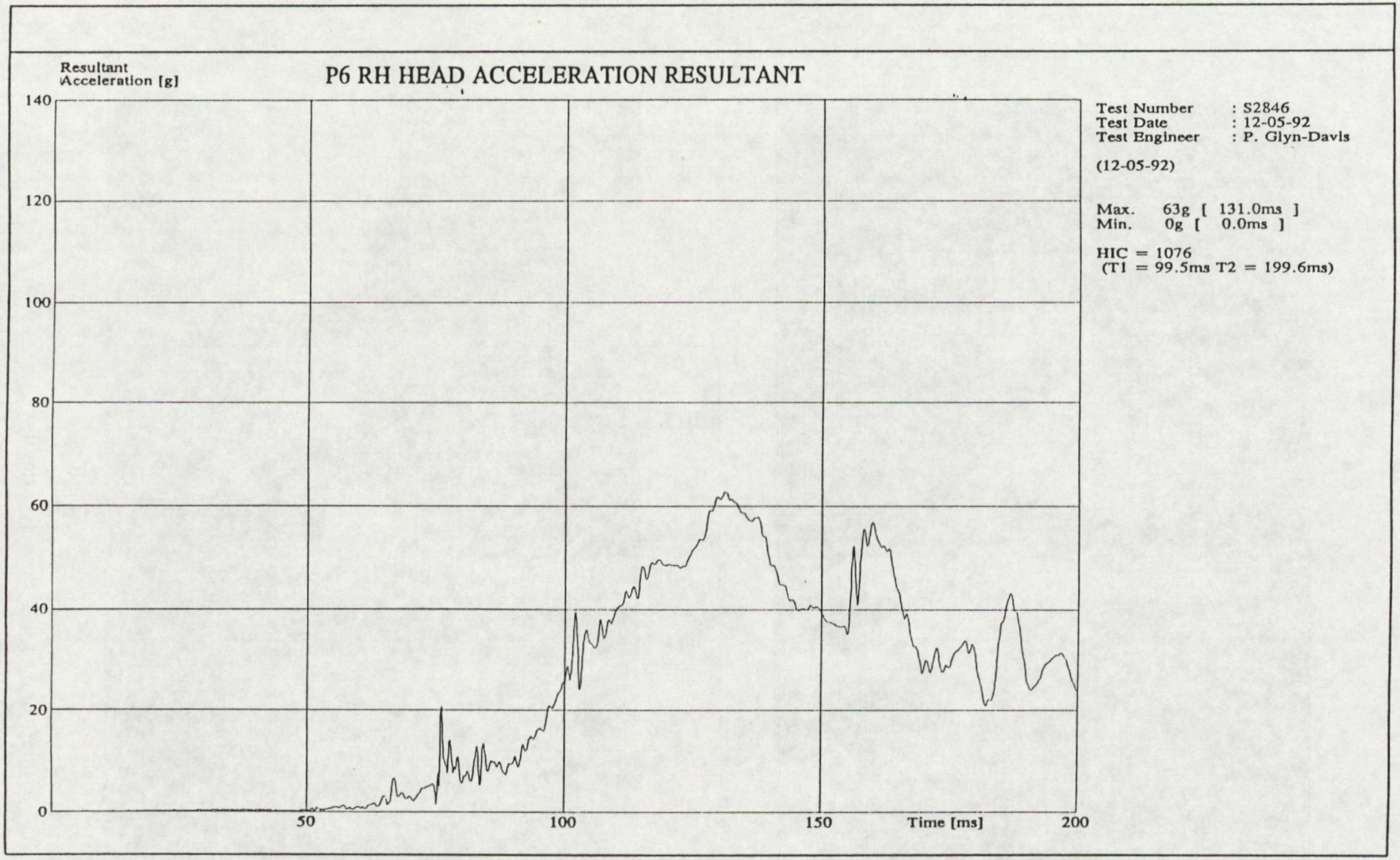

P6 RH HEAD ACCELERATION RESULTANT
Resultant
Acceleration [g]
140
120
100
80
60
40
20
0
50
100
150
Time [ms]
200
Test Number : S2846
Test Date : 12-05-92
Test Engineer : P. Glyn-Davis
(12-05-92)
Max. 63g [131.0ms]
Min. 0g [0.0ms]
HIC = 1076
(T1 = 99.5ms T2 = 199.6ms)

Figure 20b

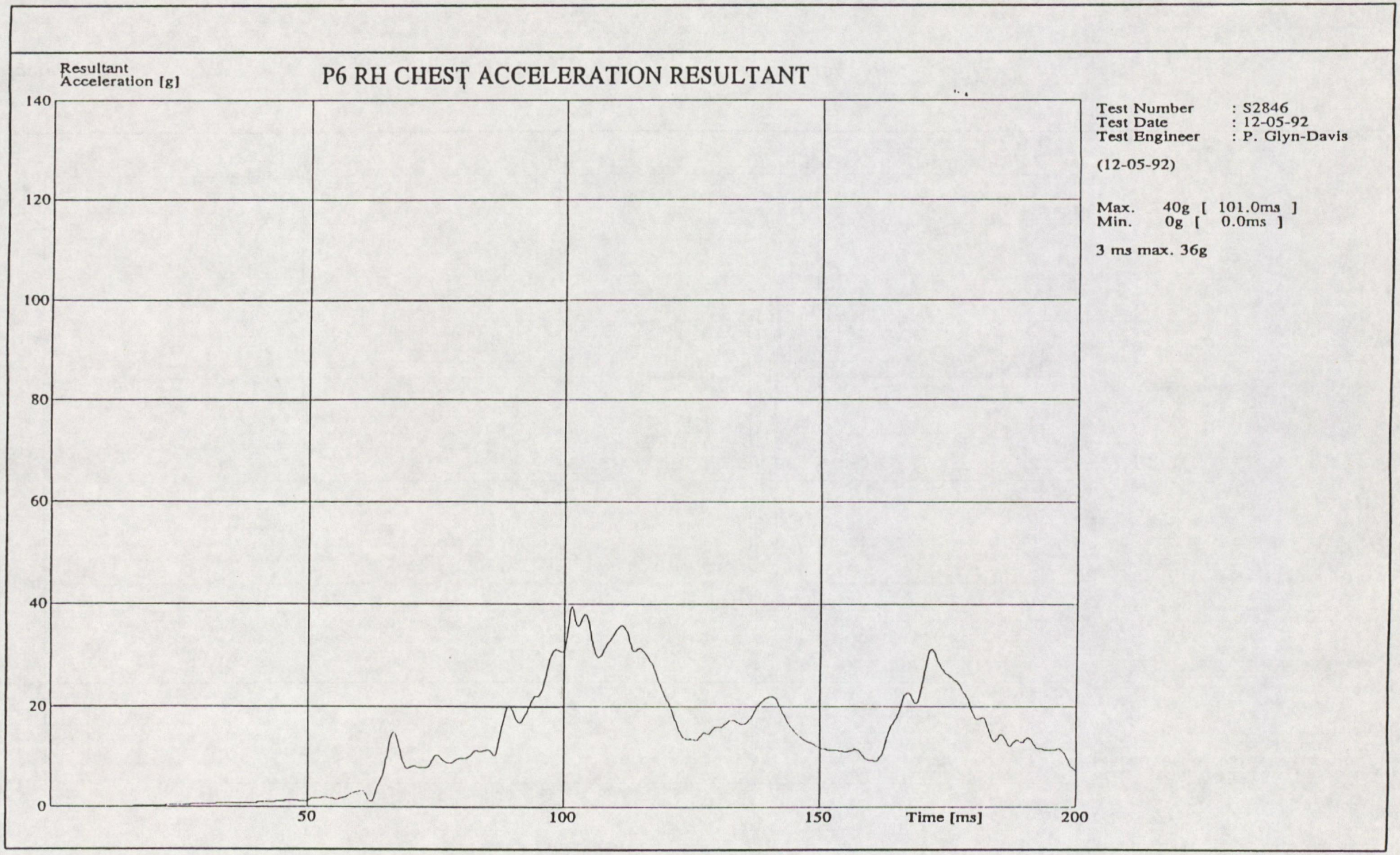

P6 RH CHEST ACCELERATION RESULTANT
Resultant Acceleration [g]
140
120
100
80
60
40
20
0
50
100
150
200
Time [ms]
Test Number : S2846
Test Date : 12-05-92
Test Engineer : P. Glyn-Davis
(12-05-92)
Max. 40g [101.0ms]
Min. 0g [0.0ms]
3 ms max. 36g

Figure 20c

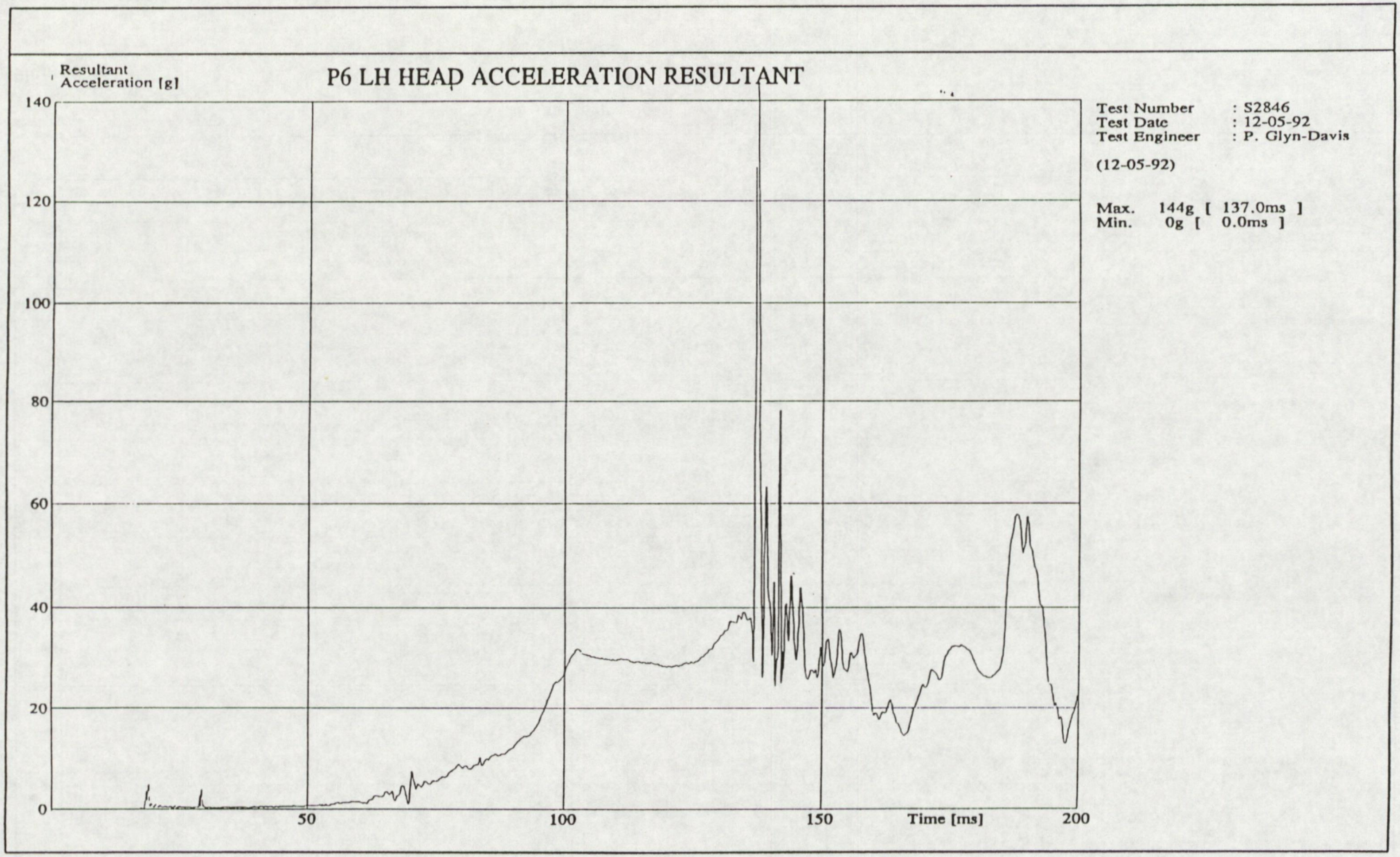

P6 LH HEAD ACCELERATION RESULTANT
Resultant Acceleration [g]
140
120
100
80
60
40
20
0
50
100
150
200
Time [ms]
Test Number : S2846
Test Date : 12-05-92
Test Engineer : P. Glyn-Davis
(12-05-92)
Max. 144g [137.0ms]
Min. 0g [0.0ms]

Figure 20d

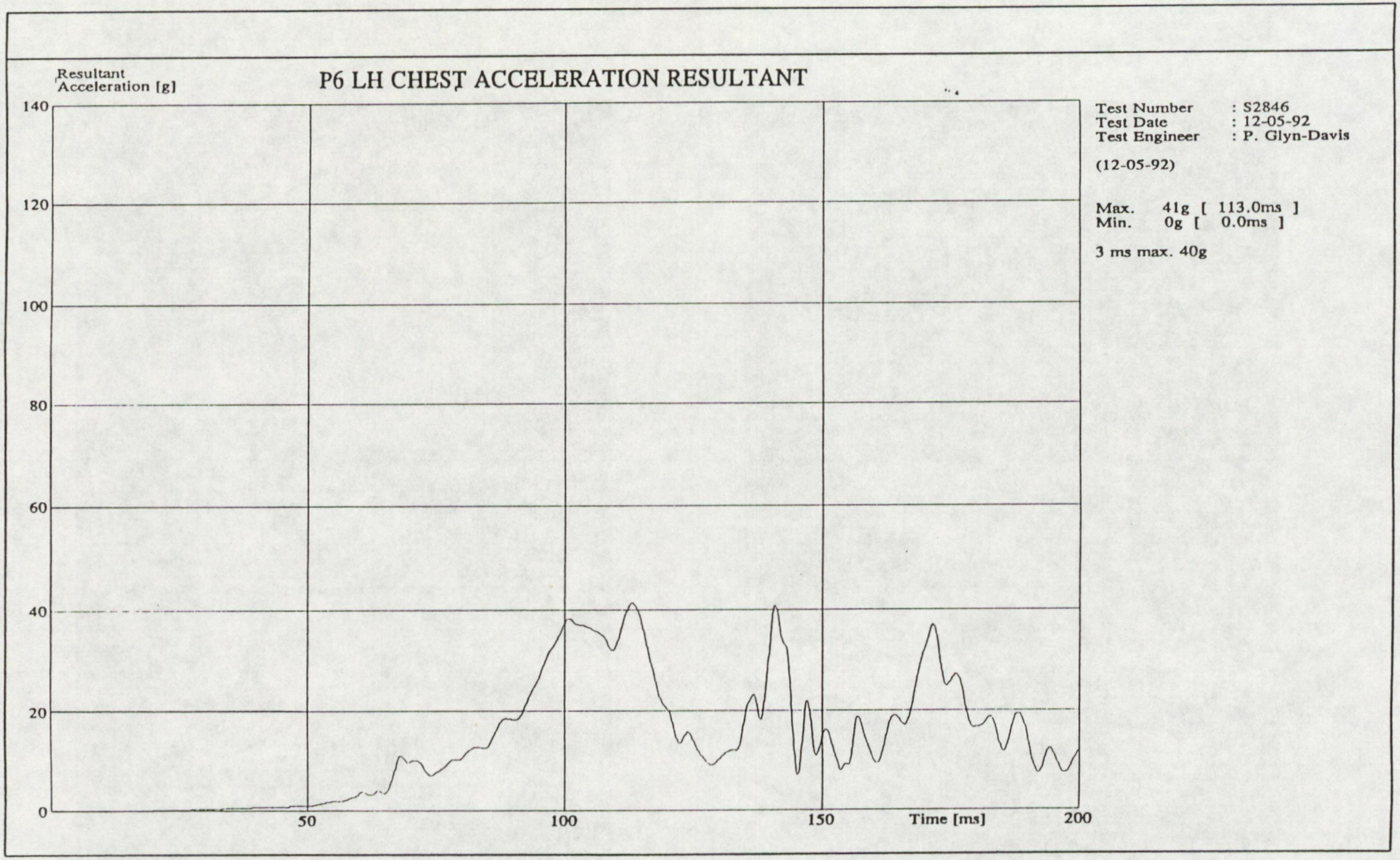
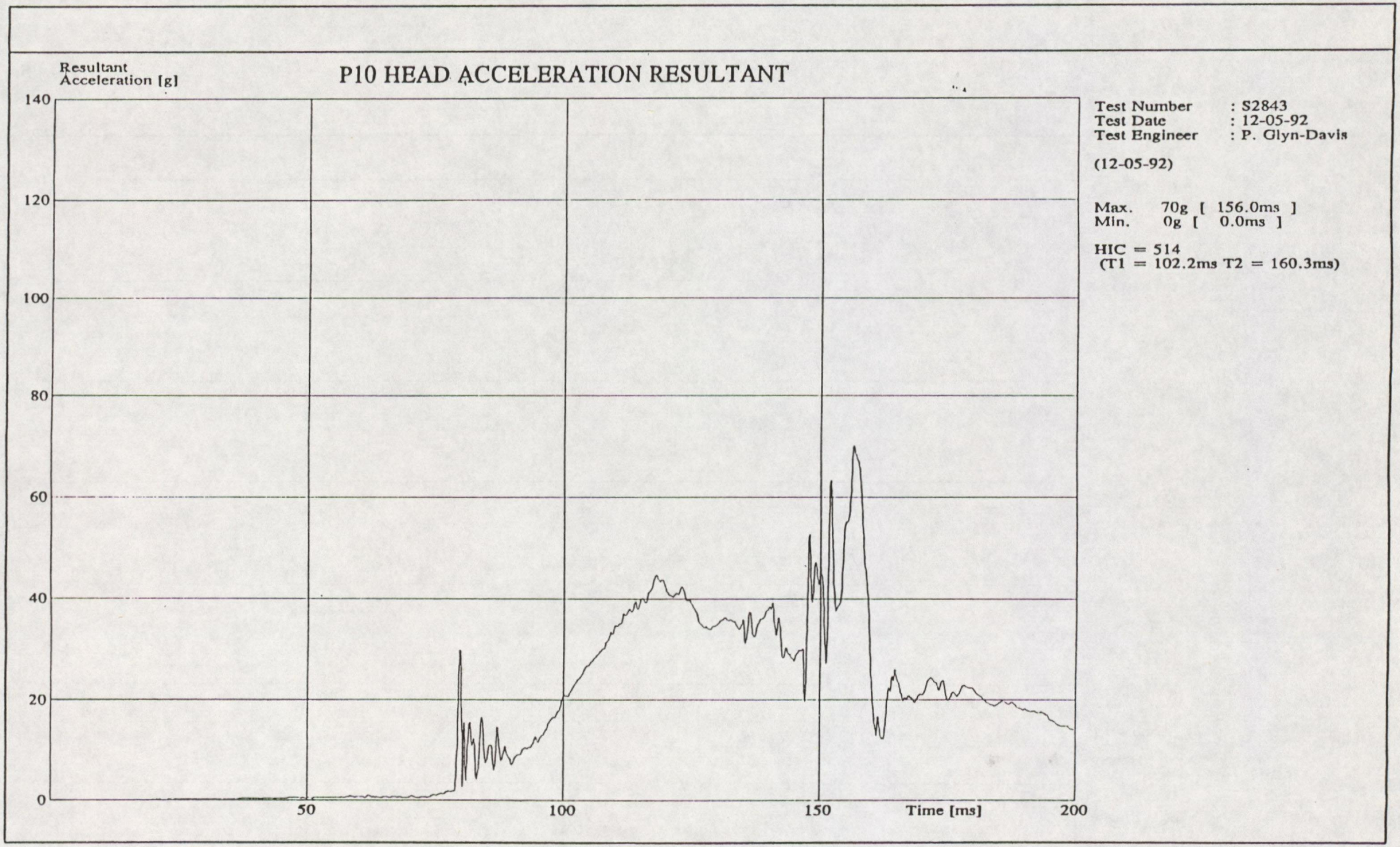

Resultant
Acceleration [g]
P6 LH CHEST ACCELERATION RESULTANT
140
120
100
80
60
40
20
0
50
100
150
Time [ms]
200
Test Number : S2846
Test Date : 12-05-92
Test Engineer : P. Glyn-Davis
(12-05-92)
Max. 41g [113.0ms]
Min. 0g [0.0ms]
3 ms max. 40g

Figure 20e

Figure 21a Positions of the 9 month and 10 year dummies after test



Resultant
Acceleration [g]
P10 HEAD ACCELERATION RESULTANT
140
120
100
80
60
40
20
0
50
100
150
Time [ms]
200
Test Number : S2843
Test Date : 12-05-92
Test Engineer : P. Glyn-Davis
(12-05-92)
Max. 70g [156.0ms]
Min. 0g [0.0ms]
HIC = 514
(T1 = 102.2ms T2 = 160.3ms)

Figure 21b

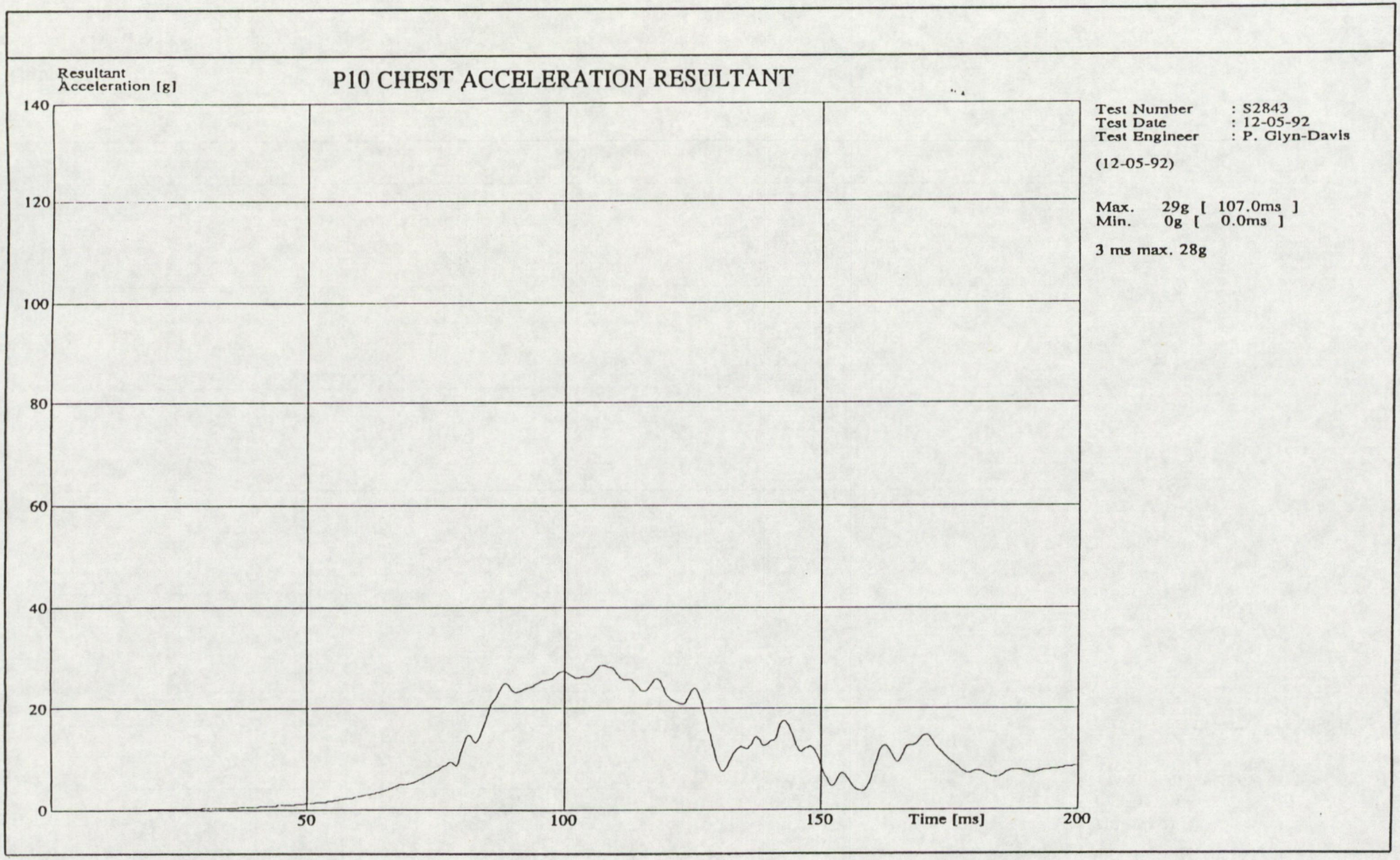

P10 CHEST ACCELERATION RESULTANT
Resultant
Acceleration [g]
140
120
100
80
60
40
20
0
50
100
150
200
Time [ms]
Test Number : S2843
Test Date : 12-05-92
Test Engineer : P. Glyn-Davis
(12-05-92)
Max. 29g [107.0ms]
Min. 0g [0.0ms]
3 ms max. 28g

Figure 21c