FOUR AND FIVE POINT GLIDER SEAT HARNESS STATIC AND DYNAMIC TESTS

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SUMMARY

Previous studies on aircraft seat harness have primarily dealt with an upright pilot seating position, and with a flat seat pan (Ref. 1). The present paper deals with the semi-recumbent seating position found in modern gliders, with a steeply raked thigh contact area as the front part of the seat pan.

The conclusion was reached in Germany that the 5th strap of a glider seat harness passing between the legs of a male pilot would cause injury in the crotch region in the event of an accident. Dipl.Ing. Martin Sperber of TüV Rheinland, Cologne, Germany, carried out an experimental study, following which he designed a glider seat pan and 4 point harness anchorage points that were stated to be as effective as a 5 point harness (Ref. 2 & 3).

A German glider manufacturer, DG Flugzeugbau, has ceased fitting 5 point harness in their gliders, and has also ceased fitting a hard point for retro-fitting a 5th strap. This was on the grounds of the presumed risk of legal liability for injury caused by a fifth strap (Ref. 4). This decision caused concern in the United Kingdom, leading to the undertaking of the present study.

The study was carried out using both 4 point and 5 point glider seat harness approaches. The tests were carried out with the harness tight and with the harness slack. Three test conditions were studied:

1) The angle of the lap strap relative to the vertical axis was noted when pilot dummies of three different sizes were placed in the seat. It was concluded that for very small and very large pilots, it would be a benefit if the lap strap anchorage points were moved forward. The forward angle of the lap strap may provide an explanation for the development of slack in the lap strap under certain conditions.

2) The effect of negative-g force was simulated by inverting the test rig and pilot dummy. The separation of the buttocks of the dummy from the horizontal portion of the seat pan was measured by a probe, and also by overlaying transparencies from a video film. A 5 point harness was more effective at reducing this separation than a 4 point harness. The separation was most marked with a slack 4 point harness - this could lead to the pilot loosing control of the glider. A test flight in a DG 300 was carried out.

3) The effect of a vertical impact in the longitudinal axis of the glider fuselage (the X axis) was simulated on a decelerator test track, with an impact velocity of 9-10 metres/sec. and at 15-16g. High speed video was used to record the effect of the impact from a side view and from a front view. Motion analysis was carried out on the film, and a transparency overlay study was carried out. The loads in the harness straps and in the crotch area were measured. With a 5 point harness, both tight and slack, the lap straps and the QRF remained in the correct position over the pelvic bones, with no risk of injury to the internal abdominal organs. With a 4 point harness, on impact, the lap straps moved upwards to a position under the lower rib margin, with the QRF in the epigastrium ("the pit of the stomach"). Serious injury to the internal abdominal organs could result.

The 5th strap, in the accident situation, caused a high injurious load in the crotch. It is recommended that the 5th strap be re-designed so as to avoid injury to the crotch region.

It is concluded that a 5 point harness should be fitted to gliders, with a re-design of the 5th strap being carried out.

DEFINITIONS

Glider: The term Glider and Sailplane are often used synonymously. On the Continent of Europe, "glider" refers to hang-gliders and para-gliders and sometimes for sailplane. The proper term used on the Continent is "sailplane." However, for the subject of this paper, the term glider is used in the present study as synonymous with the term sailplane.

QRF: This is an abbreviation for the "quick release fastening" or buckle.

H-point: This is defined as the point in a pilot seated in the cockpit which marks the theoretical axis of rotation between the thigh and the trunk (or torso). It is determined by the intersection of the centre lines of the thigh and the trunk. Martin Sperber has devised an apparatus for marking this point in the cockpit (Ref. 3).

INTRODUCTION

Dipl.Ing. Martin Sperber from TüV Rheinland, Cologne, Germany, published two papers on the behaviour of glider seat belts under accident conditions (Ref. 2 & 3). Following these reports, the OSTIV Airworthiness Standards (OSTIVAS) concerning "submarining" (the pilot sliding down and forward under the lap strap of the seat harness) were re-written to take account of this research. The relevant OSTIVAS are as follows (Ref. 5):

"Protection (against submarining) may be achieved by the use of (a) or (b)

(a) Crotch straps or straps.

(b) (1) Suitably shaped seat pans, in which the forward part under the occupant's thighs is adequately inclined, and the transition radius between the forward part and the part under the occupant's hips does not exceed approximately 15mm.

(2) Lap strap anchorage points located significantly below the H-point, (which is the intersection of the centre lines of the torso and thighs) in a sector centered on the latter extending from the vertical to 20° aft.

Diagram: The glider is assumed to be in a normal flight attitude. (Figure 1).

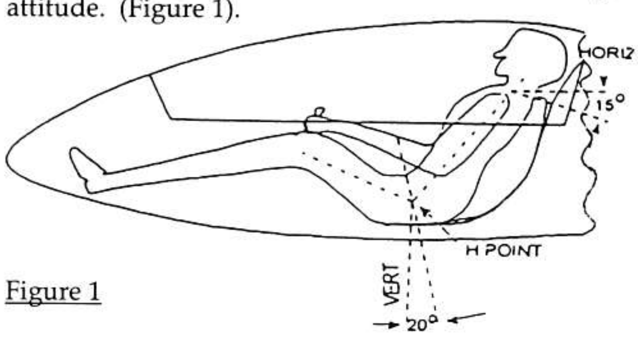


Figure 1

The German glider manufacturer DG Flugzeugbau has ceased fitting a fifth strap, or an attachment point for a fifth strap, to their gliders. This is on the grounds of the risk of injury to the male organs in the crotch by the fifth strap in an accident, and the consequent legal liability (Ref. 5). Concern was expressed in the United Kingdom following this decision, and Dr. Peter Saundby (Medical Advisor to the British Gliding Association) asked for an experimental study to be carried out.

Previous studies on aircraft seat harness have primarily dealt with an upright pilot seating position, and with a flat seat pan (Ref. 1). The present paper deals with the semi-recumbent seating position found in modern gliders, with a steeply raked thigh contact area as the front part of the seat pan.

The tests were carried out with both 4 point and 5 point glider seat harness, and with the harness tight and with the harness slack. Three test conditions were studied:

1) Three Pilot dummies of different sizes were seated in the test rig seat, and the angle of the lap straps noted.

2) The effect of negative-g was simulated by inverting the test rig and dummy. A test flight in a DG-300 glider was carried out to check harness in inverted flight.

3) The effect of a vertical impact in the longitudinal axis of the glider fuselage was simulated on a decelerator track.

The test reproduced conditions that occur in flight. The straps may slacken off in flight owing to micro-slip. The straps may also slacken off on ground impact with ovalling of the fuselage consequent on an accident. The condition of negative-g may be experienced by the pilot during the course of a normal flight.

Dipl.Ing. Martin Sperber and his colleague Dipl.Ing. Mattius Bancken visited DERA Farnborough before the test. They kindly gave most helpful advice about the test. The responsibility for the test is, of course, our own.

THE TEST RIG

The rig was built around a rigid metal girder sub-frame. A Nimbus 3 DM front seat (from Southern Sailplanes) was bolted to the sub-frame, with reinforcing plates under the bolt heads. The space under the front edge of the seat pan was packed with firm foam. Slots were cut in the seat pan to allow the lap straps and the 5th strap to be passed through and attached to fittings bolted directly to the sub-frame. The position of these slots corresponded to the areas on the seat pan demarcated by the manufacturer for the attachment of the lap straps and the 5th strap.

The seat back was constructed of metal sheet, bolted to the sub-frame. Three horizontal slots were cut in the seat back, corresponding to the shoulder height of the three dummies used in the test. The shoulder harness was passed through these slots to an adjustable metal anchoring bar. (It was not possible, due to lack of time, to carry out some proposed tests using different heights of shoulder harness attachment). The lateral spacing of the shoulder harness was 150mm to the centre line of the straps at the top of the shoulders. OSTIVAS (Ref. 5) quote a lateral spacing of 150mm - 200mm. The lesser figure was chosen to reduce the risk of the straps slipping off the shoulders of the dummy.

A study was carried out at the Lasham Gliding Centre of the seat back, angle of ten different types of glider. The range of values extended from 22° to 50° from the vertical. A seat back angle of 35 was chosen for the test. Coincidentally, this is the seat back angle of the F-16 aircraft.

Lugs were bolted to the four corners of the test rig sub-frame. Two slings connected to an electric hoist were used to lift and invert the rig for the negative-g tests.

A footrest was used for the impact tests.

Two small holes were drilled near the front of the horizontal portion of the seat pan, 60mm to each side of the midline. These were used to measure directly with a probe the displacement of the buttocks from the seat pan when the test rig was inverted for the negative-g test. This idea was suggested by Dipl.Ing. Mattius Bancken.

SEAT HARNESS

A seat harness supplied without charge by Willans Harness Manufacturing Ltd. was used for the initial installation of the test rig. During the visit of Martin Sperber to Farnborough, he recommended we use the same type of seat harness as used in his test in Germany. Several sets of seat harness were subsequently supplied without charge by Schroth Safety Products Gmbh. and used in our test. We are grateful to Willans (Cornwall, England), and to Schroth (Arnsberg, Germany) for their help.

The H-POINT

The importance of accurate positioning of the H-point and the associated lap strap attachment point was emphasised by Martin Sperber in his paper (Ref. 3). The German LBA kindly sent a special H-point device (Ref. 3), but due to e-mail delivery problems it did not arrive until several weeks after the test was completed. The H-point for our test was therefore determined by seating a 50th percentile male dummy in the seat of the test rig. The intersection of the centre line of the thigh and trunk was taken as the H-point. (It is of interest that the area of the seat pan indicated by the manufacturer for insertion of the lap strap was vertically below this H-point).

The centre of the attachment bolt for a lap strap was 110mm vertically below our H-point.

Following the arrival of the H-point device, the H-point was verified. It was 30mm below and 55mm forward of our H-point. Calculating by using the tangent, this gives an angle from the vertical of 34.5° to the attachment bolt. This was well outside Martin Sperber's required value of 0° to 20° to the vertical.

In our opinion, our H-point can be justified, and does not invalidate the test results. The photograph (Photograph 1) shows the two H-points, and the H-point apparatus.

ANTHROPOMORPHIC TEST DEVICES
(Manikins or Dummies)

General Motors Hybrid 111 Automotive dummies were used for both the initial seating test, and the negative-g test. These dummies are the standard type used in automotive occupant restraint testing. A 5th percentile female, a 50th percentile male and a 95th percentile male were used. For the impact tests, a 50th percentile male Aerospace variant of the Hybrid 111 dummy was used. This model has flexible hip joints, enabling the load exerted by the 5th strap in the crotch of the dummy to be measured.

For the static tests, the dummies were unclothed. For the dynamic impact test, the dummy wore Long Johns, to reduce friction between the surface of the dummy and the test rig seat.

Reflective patches were attached to the head, upper arm near the shoulder, and the knee of the dummy to assist in the analysis of the video of the test.

The dummy wore a back pack type parachute, and firm cushions were placed between the parachute and the seat back. This ensured the thighs of the dummy were firmly against the upward raked portion of the seat pan, as recommended by Martin Sperber. The parachute and cushions were kindly loaned by the Lasham Gliding Society.

SHAPE OF THE SEAT PAN

A Nimbus 3 DM front seat seat pan was used. This is typical of widely used modern seat pans, and may be used with 4 point or 5 point seat harness. The transition radius between the horizontal and thigh areas of the seat pan was greater than specified by Martin Sperber (15mm). We consider this does not invalidate our test results. Clearly, this is a matter for debate.

TYPE OF ACCIDENT

This was a vertical impact from a stall or a spin into a horizontal surface, or a horizontal impact into a vertical surface. This is the most severe situation as regards the pilot submarining. The impact was at a nominal velocity of 9-10 metres/sec. at 15g-16g.

The decelerator track at the Centre for Human Sciences, DERA, Farnborough is 50 metres long. A wheeled vehicle is propelled by elastic bungee cords. When the required velocity is attained, the vehicle is rapidly decelerated by a hydraulic arrestor system. Speeds of 15 m/s and deceleration levels of up to 55g may be attained. The track is human rated, and has been used in many impact assessment and accident investigation projects.

INSTRUMENTATION

Load cells were placed on one shoulder strap and one lap strap. A load cell was placed on the 5th strap, below the level of the seat pan, to measure the axial load in the 5th strap. A load cell was used on a pelvic plate, situated on the crotch of the dummy. This measured the load exerted by the 5th strap on the crotch. This load was exerted at right angles to the axial load in the 5th strap. An accelerometer was placed on the test vehicle.

Dynamic Impacts:

Outputs from each of the transducer strap load cells, the pelvic plate load cell and the vehicle accelerometer were fed to an on-board, ruggedised, Kayser K3600 Data Acquisition Unit (DAU). Data were collected and processed using DIA-DAGO software packages in accordance with SAE J211. Additionally each dynamic impact was recorded on a Memrecam High Speed Digital, 500 fps video camera and the video images were downloaded onto a conventional Super Video Home System (SVHS) video recorder. Hard copy prints were taken from these recordings to allow comparative dummy movements during the impacts to be assessed.

Static Inversion Tests:

Seat inversions were recorded on a conventional VHS video recorder and hard copy prints and transparencies were produced from each recording.

TEST RESULTS

(I) STATIC TEST, UPRIGHT TEST RIG

Three dummies, a 5th percentile female, a 50th percentile male and a 95th percentile male were seated in turn in the test rig. The dummies were seated with the thighs firmly against the thigh contact area of the seat pan, as specified by Martin Sperber. Firm cushions (made of chip foam) were placed between the parachute pack and the seat back as required.

The angle the lap strap made with the vertical, from the lateral aspect, was measured.

5th percentile female dummy, 5 point harness.

The small pilot was seated well forward in the seat, thus increasing the angle of the lap strap from the anchorage point of the lap strap. An angle of 25° from the vertical was recorded.

50th percentile male dummy, 5 point harness.

An angle of 15° from the vertical was measured. This value should be regarded as the reference value. It should be noted that this value was obtained despite the lap strap attachment point being vertically below the H-point position established with this particular dummy.

50th percentile male dummy, 4 point harness.

An angle to the vertical of 12° was recorded. This showed that the shoulder straps, acting unopposed due to the absence of a 5th strap, had pulled up the lap straps into the abdominal area.

95th percentile male dummy, 5 point harness.

An angle of 22° to the vertical was measured. The very large build of this pilot dummy had increased the angle of the lap strap from the attachment point.

It is suggested that moving the lap strap anchorage points forward may benefit very small and very large pilots.

With a 4 point harness, the forward angle of the lap strap to the vertical axis may provide a mechanism for slack to develop in the lap strap. For this to occur, it is necessary for the pilot to lose contact with the horizontal portion of the seat pan and with the seat back. (This may occur under conditions of negative-g, or in some types of accident impact situation). The lap strap may then rotate towards the vertical around the axis of the anchorage point. Geometric considerations, as shown in the diagram, mean that slack will ensue in the lap strap. (Figure 2).

When a 5 point harness is used, the rotation of the lap strap will be prevented by the 5th strap, slack will not develop, and the pilot will remain in close contact with the seat pan.

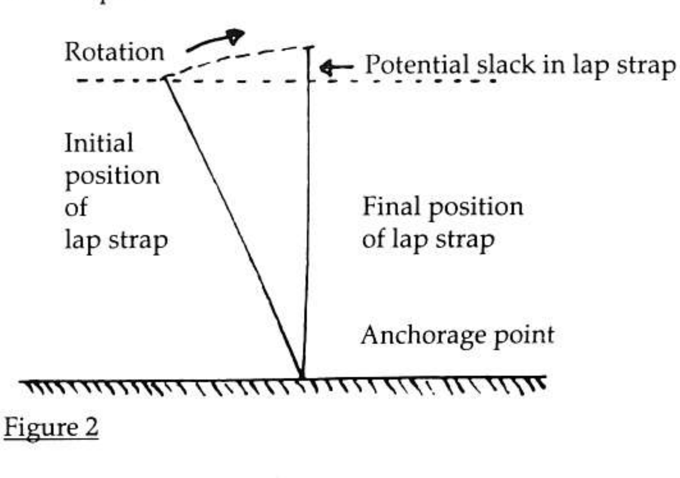


Figure 2

TEST RESULTS

(2) STATIC TEST, INVERTED TEST RIG SIMULATED NEGATIVE-G

The object of the test was to measure the separation of the buttocks of the pilot dummy from the horizontal surface of the seat pan when the test rig was inverted.

The experiment was carried out using a 50th percentile male dummy. For the test, the shoulder straps passed back horizontally to the attachment bar on the seat back.

Holes were burnt in the ends of the lap straps and the shoulder straps to take the hook of a force gauge. For the "harness tight" condition, the lap straps were loaded to 35 lb. f (approximately 160 N), and the shoulder straps to 25 lb f (approximately 110 N). For the "harness slack" condition, both hands of a member of the test team were placed flat under the harness which was then tightened onto them. (Hands were then withdrawn!). The 5th strap was tightened at the start of the test until it felt firm; it was not adjusted further during the course of the test.

Two methods were used to measure the displacement of the dummy.

1) Two small holes were drilled in the forward part of the horizontal portion of the seat pan, 60mm to either side of the midline. A probe was used to measure directly the distance to the surface of the buttocks . This was measured with the seat erect and with the seat inverted; subtraction gave the distance the dummy had dropped. Some error could occur due to the dummy moving other than strictly vertically.

2) Video recordings were made with the rig normal and inverted. Transparencies were then made from the video film. The transparencies were overlayed, being lined up by reference marks on the test rig. The distance the dummy had dropped when inverted could be measured against a reference grid. The test rig was placed immediately in front of the reference grid, so the error due to parallax was minimal.

The tests were carried out with 4 point and 5 point harness; with the harness tight and slack. Two tests were carried out for each experimental condition.

The test results are tabulated. (Table 1, Table 2).

The results of the probe test show that the dummy dropped a greater distance from the seat pan with 4 point harness than with 5 point harness. The distance was greatest when the 4 point harness was slack.

The results of the transparency overlay test again showed the distance of the buttocks from the seat pan was greater for a 4 point than for a 5 point harness,vertically. Again, it was greatest with a slack 4 point harness. With the 4 point harness, both tight and slack, there was significant horizontal movement as well as the vertical movement.

The results from the two measuring techniques were comparable.

The test showed clearly that a 5 point harness should be used for conditions of negative-g. Especially with a slack 4 point harness, the separation of the pilot from the seat pan is so great that control of the glider could be lost.

A test flight was carried out in a DG-300 glider to check the behaviour of the seat harness in inverted flight. With the harness very tight, control was satisfactory. With the harness slack, a less experienced pilot could have lost control of the glider. The DG-300 glider has a steep seat thigh ramp, and a 4 point harness.

Table 1
NEGATIVE-G: PROBE TEST METHOD (UNITS: mm)

DERA RUN NUMBER	TEST CONDITION	LEFT BUTTOCK INVERTED	LEFT BUTTOCK ERECT	DIFFERENCE	RIGHT BUTTOCK INVERTED	RIGHT BUTTOCK ERECT	DIFFERENCE
5274	5 point tight	37	9	28	27	2	25
5275	5 point tight	33	9	24	22	4	18
	Average			26			21.5
	Combined average-left & right			(24)			
5276	5 point slack	38	8	30	23	2	21
5277	5 point slack	51	13	38	37	3	34
	Average			34			27.5
	Combined average-left & right			(31)			
5278	4 point tight	66	3	63	53	2	51
5279	4 point tight	54	3	51	43	2	41
	Average			57			46
	Combined average-left & right			(51.5)			
5280	4 point slack	91	3	88	76	2	74
5281	4 point slack	97	6	91	82	3	79
	Average			89.5			76.5
	Combined average-left & right			(83)			

Conclusion:

The dummy dropped a greater distance from the seat pan under negative-g when a 4 point harness was used, than when a 5 point harness was used.

The distance was maximal when the 4 point harness was slack.

Table 2
NEGATIVE-G: VIDEO TRANSPARENCY OVERLAY METHOD (UNITS: mm)

DERA RUN NUMBER -TEST CONDITION	DISPLACEMENT OF DUMMY - first run			DISPLACEMENT OF DUMMY - second run		
		Vertical	Horizontal		Vertical	Horizontal
5274 5275 5 POINT TIGHT	Head	20	5	Head	30	0
	Shoulder	40	0	Shoulder	50	10
	Thigh	10	0	Thigh	30	10
	Average	23	2	Average	37	7
	Combined average-both runs	(30)	(5)			
5276 5277 5 POINT SLACK	Head	20	0	Head	30	0
	Shoulders	50	0	Shoulders	60	0
	Thigh	30	0	Thigh	40	10
	Average	33	0	Average	43	3
	Combined average-both runs	(38)	(1.5)			
5278 5279 4 POINT TIGHT	Head	60	20	Head	40	10
	Shoulders	70	20	Shoulders	60	10
	Thigh	10	30	Thigh	50	40
	Average	48	23	Average	50	20
	Combined average-both runs	(49)	(21.5)			
5280 5281 4 POINT SLACK	Head	70	20	Head	70	20
	Shoulders	70	20	Shoulders	80	20
	Thigh	20	50	Thigh	30	50
	Average	53	30	Average	70	30
	Combined average-both runs	(61.5)	(30)			

Conclusion:

The vertical displacement of the dummy from the seat pan was greater for a 4 point harness than for a 5 point harness. The vertical displacement was greatest with a slack 4 point harness.

With the 4 point harness, both tight and slack, there was significant horizontal movement as well as vertical movement.

The results from Table 1 and Table 2 are comparable.

NEGATIVE-G

DG-300 GLIDER - TEST FLIGHT

NOTE: This glider is equipped with a 4 point seat harness.
Test Pilot: Mr. Colin J. Short - BGA Full Cat. Instructor. Senior Regional Examiner for Glider Aerobatics.

Glider: DG-300 "Elan," No. 393.
Owned by the Surrey and Hampshire Gliding Club

Flight: Carried out at the Lasham Gliding Centre, Lasham Airfield, Hampshire, England.
Date of test flight: 30th June 1999.
Aerotow to 4500 ft on the QFE.

Test Conditions and Findings:

Four test conditions were considered, as follows, with the glider being rolled inverted.

1) The seat harness (lap straps and shoulder straps) were tightened very tightly indeed, to "aerobatic tightness." The vertical displacement of the pilot from the seat pan was approximately 20mm. The fore-and-aft body movement was minimal. This pilot displacement caused no adverse effect on pilot control of the glider.

2) The seat harness was tightened to the degree usually considered comfortable in local soaring and in cross-country flying. Two flat hands could be inserted under the lap straps, and similarly under the shoulder straps. The vertical displacement of the pilot from the seat pan was approximately 80mm. There was a rearward displacement of the pilot's body estimated to be between 25mm to 35mm. The test pilot compensated for the rearward movement, and let himself hang in the straps for the vertical displacement. He found no real adverse effects on the flying controls. However, he considered a less experienced pilot would almost certainly have begun to lose forward stick movement, and hence possibly lose control of the gllder.

3) The lap straps were tightened very tightly, to "aerobatic tightness." The shoulder harness was slackened right off. The results were similar to the first test situation. The vertical displacement was approximately 20mm, with minimal fore-and aft displacement. This showed that the lap straps were doing all the work of vertical restraint. The shoulder straps were providing little or no vertical restraint. The correct positioning and tensioning of the lap strap is thus of vital importance.

4) This time the harness, both lap straps and shoulder straps, were adjusted so they were very loose ("sloppy"). It was possible to get a fist under any strap. When inverted, noticeable rearward movement of the body occurred, between 60mm - 75mm. The vertical displacement was approximately 120mm. The effect on control was noticeable, the pilot having to reach forward stiffly to maintain the inverted flight attitude.

The following conclusions of the test pilot are based on the use of a 4 point seat harness:

" I certainly would not recommend a less experienced pilot to carry out any aerobatics with the seat harness other than very tight, but most importantly, the lap strap must be tightened fully prior to adjusting the shoulder straps. This enables the buckle to be kept in the correct position."

MEASUREMENT OF DISPLACEMENT OF PILOT

A simple "low tech." method was used. When flying inverted, the pilot slid his free hand between himself and the seat pan. Depending on the vertical displacement, he used either the flat of his hand or his clenched fist. On landing, the distance this represented was measured. The horizontal displacement was estimated by the pilot.

TEST RESULTS

(3) DYNAMIC TEST, UPRIGHT TEST RIG
IMPACT TEST ON THE DECELERATOR TRACK

The test will be considered under the following headings:

1. Test arrangements
2. Run nomenclature.
3. Test parameters - nominal and achieved.
4. Condition before test.
5. Observations and findings during and after test.
   a) Observation during test.
   b) Observation after test.
   c) Still photography.
   d) Video photography.
   e) Motion analysis - trajectory of knee, shoulder and head of dummy.
   f) Motion analysis and transparency overlay - maximum displacement of dummy.
   g) Motion analysis - end position of dummy.
   h) Load on 5th strap, crotch, lap straps and shoulder straps.

1. TEST ARRANGEMENTS

The dummy was a GM Hybrid 111 Aerospace Variant 50th percentile male. The dummy was clothed in Long Johns to reduce friction between the dummy and the seat pan. Reflective patches were placed on the knee, upper arm (shoulder), head and the QRF to assist in the interpretation of the video film. The hip was hidden by the test rig. A back pack type parachute was worn, and firm cushions were placed between the seat back and the parachute, so that the thighs of the dummy were firmly against the thigh contact area of the seat.

For the "harness tight"situation, the lap straps were tightened to 160 N (35 lb f), and the shoulder straps to 110 N (25 lb f). A force gauge, calibrated in lb f, was used to tighten the straps, a hook in the force gauge passing through holes burnt in the ends of the straps. For the "harness slack" situation, the harness was tightened against two hands placed flat between the harness and the dummy. Load cells were placed on the 5th strap, on a plate in the crotch area, one lap strap and one shoulder strap. An accelerometer was placed on the test vehicle. The shoulder harness passed back horizontally to the middle attachment point on the seat back.

2. RUN NOMENCLATURE.

The following nomenclature was used: (Table 3).

DERA TRACK RUN NUMBER	TEST CODE NUMBER	TEST CONDITION
5274	3.13	5 point tight
5275	3.13	5 point tight
5276	3.14	5 point slack
5277	3.14	5 point slack
5278	3.11	4 point tight
5279	3.11	4 point tight
5280	3.12	4 point slack
5281	3.12	4 point slack

3. Test Parameters

A Type 4 accident was simulated. (Ref. 2 & 3). This represented a vertical impact from a spin or a stall. It was the most severe situation as regards "submarining" under the lap strap. The dummy was seated erect, facing forward, on the test rig. This seating position limited the friction between the pilot dummy and the surface of the seat, as compared with the situation when the dummy is lying on its back.

The nominal parameters for the impact were a velocity of - 9-10 metres/sec and a peak g of l5g-16g. These required values were achieved in the test runs, as follows:

(Table 4)

DERA TRACK RUN NUMBER	VELOCITY CHANGE (m/s)	PEAK g
5274	10.31	15.80
5275	10.31	15.55
5276	10.31	16.15
5277	10.31	16.25
5278	10.31	16.24
5279	10.31	16.45
5280	10.26	15.85
5281	10.31	15.80

The slightly lower value for the impact velocity in Run 5280 was due to the run being held up for a few minutes with the bungees stretched.

The values achieved show little variation between themselves, so the test results that follow are comparable with each other.

4. Condition Before the Test

The angle of the lap strap from the vertical, viewed from the lateral aspect, was recorded. From the figures given below, it is clear that without a 5th strap to exert countertension in the case of a 4 point harness, the shoulder straps pull the lap straps and the QRF upwards into the abdomen. (Table 5).

DERA TRACK TEST NUMBER	TEST CONDITION	LAP STRAP ANGLE TO THE VERTICAL
5274	5 point tight	14°
5275	5 point tight	15°
5276	5 point slack	15°
5277	5 point slack	15°
5278	4 point tight	13°
5279	4 point tight	Not recorded
5280	4 point slack	12°
5281	4 point slack	12°

5. Observations and Findings During and After the Test

5 a). Observation During the Test

Excessive movement of the dummy was seen when the 4 point harness was being tested. This was especially so when the 4 point harness was slack.

5 b) Observations After the Impact Test

When a 5 point harness was being tested, both with the harness tight and with the harness slack, the lapstraps remained in the correct position over the hip bones. The QRF also stayed in the correct position.

When a 4 point harness was being tested, both with the harness tight and with the harness lose, the lap straps were seen to have moved up over the abdomen until they were jammed tightly under the lower rib margin. The QRF had moved upwards until it was in the epigastrium (the "pit of the stomach"). This is very serious as even fatal injury may be caused to the internal organs in the upper abdomen. I CONSIDER THIS TO BE THE MOST IMPORTANT FINDING OF THE ENTIRE TEST.

Following the impact test, with a 4 point harness, the shoulder straps were seen to be hanging loosely between the seat back and the pilot dummy's shoulders. This was due to the upward movement of the lap straps and the QRF.

5 c) Still Photography

The first photograph (Photograph 2) shows a 5 point harness after impact. The lap strap is in the correct position over the hip bones, and the QRF is safely over the lower abdomen.

The second photograph (Photograph 3) shows a 4 point harness after impact. The lap strap, and the metal fittings of the lap strap are digging into the soft tissues below the rib cage lower edge. The QRF is digging into the epigastrium (the "pit of the stomach"). The upper edge of the "Long Johns" gives a reference line to show the movement of the QRF.

5 d) Video Photography

A video camera was aimed at the area around the QRF. With a 5 point harness, on impact no significant upward movement of the lap straps or QRF occurred.

With a 4 point harness, both tight and slack, on impact the QRF could be seen moving upwards into the epigastric region (the "pit of the stomach"). The video film of this movement is very vivid.

5 e) Motion Analysis - Trajectory of Knee, Shoulder and Head

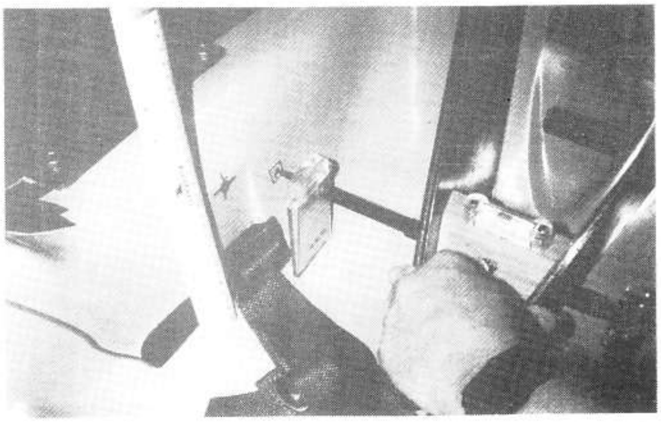
Reflective markers were placed on the knee, upper arm (shoulder) and the head of the dummy. A high speed video film was taken of the impact from a side view. The maximum forward movement (the horizontal x-coordinate, or abscissa), and the maximum vertical movement (the vertical Y-coordinate, or ordinate) were recorded. NOTE: The use of "Y" as the vertical axis in motion analysis, differs from the use of "Z" as the vertical axis in other studies with dummies.

KNEE TRAJECTORY - See Table 6.

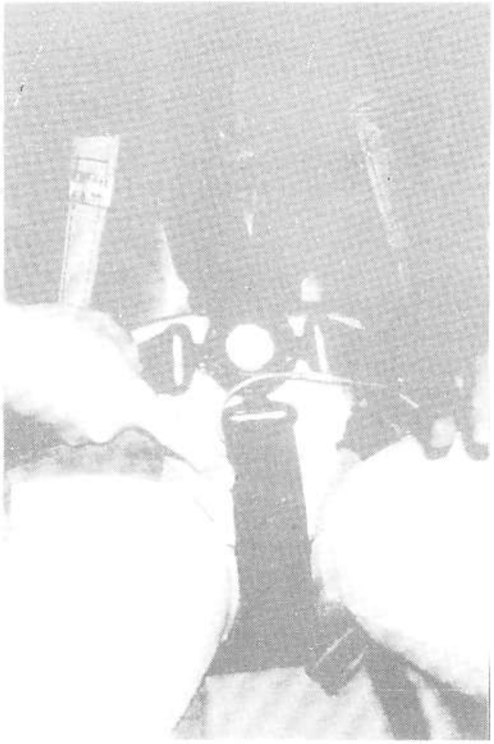
SHOULDER TRAJECTORY - See Table 7.

HEAD TRAJECTORY - See Table 8.

Photograph 1

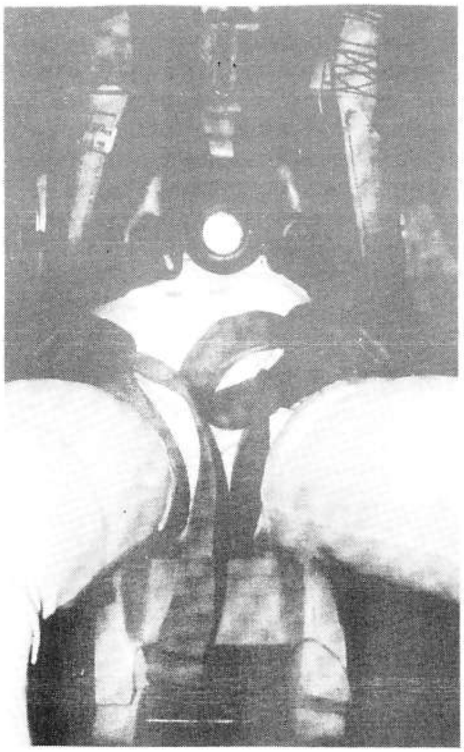


The "Test H-point" is marked by a cross. The H-point apparatus is in use, the H-point being marked by a rectangle. The slot for the 5th strap is to the right of the photograph.



Photograph 2

5 point harness after test impact. The lap straps and the QRF are in the correct position over the pelvic bones and the lower abdomen. Note the position of the QRF in relation to the upper edge of the "Long Johns."



Photograph 3

4 point harness after test impact. The lap strap and metal fittings are digging into the soft tissue below the lower rib cage. The QRF is in the epigastrium. Note the position of the QRF in relation to the upper edge of the "Long Johns."

KNEE TRAJECTORY

This is considered to be the most reliable indicator of relative body motion. The displacement of the dummy is increased with a 4 point harness as compared with a 5 point harness. The displacement is also increased when the seat harness is slack as compared with tight harness. These findings are as would be expected.

The figures for the displacement are given in Table 6:

Table 6 (UNITS: mm)

DERA RUN NUMBER	TEST CONDITION	HORIZONTAL DISPLACEMENT X-axis	VERTICAL DISPLACEMENT Y-axis	AVERAGE X Both runs	AVERAGE Y Both runs
5274	5 point tight	50	60	64	67.5
5275	5 point tight	77.5	75		
5276	5 point slack	82.5	75	84	76
5277	5 point slack	85	77.5		
5278	4 point tight	97.5	125	99	115
5279	4 point tight	100	105		
5280	4 point slack	97.5	120	104	110
5281	4 point slack	110	100		

SHOULDER TRAJECTORY

This is not as reliable a measurement as the knee trajectory, as the marker is placed on the upper arm. The marker is affected by any flailing movement of the arm on impact. The same basic findings are found as for the knee. However, the variation in the figures is less. One anomaly occurs in the Y-axis displacement in Run 5276, where the displacement is greater than expected. This result was checked on the motion analysis print out. It may be of significance that in this run the seat failed around the slot for the 5th strap.

The figures for the displacement are given in Table 7:

Table 7 (UNITS: mm)

DERA RUN NUMBER	TEST CONDITION	HORIZONTAL DISPLACEMENT X-axis	VERTICAL DISPLACEMENT Y-axis	AVERAGE X Both runs	AVERAGE Y Both runs
5274	5 point tight	100	37.5	111	34
5275	5 point tight	122.5	30		
5276	5 point slack	117.5	70	125	62.5
5277	5 point slack	132.5	55		
5278	4 point tight	127.5	45	126	42.5
5279	4 point tight	125	40		
5280	4 point slack	125	60	137.5	50
5281	4 point slack	150	40		

HEAD TRAJECTORY

In the X-axis there is little difference between 5 point and 4 point harness. The movement is slightly greater in both cases with the harness slack. In the Y-axis the movement is greater with 5 point harness than with 4 point harness. The movement is also slightly greater when the harness is slack. The explanation for this is as follows: The head moves in a ballistic fashion during the test impact (no headrest was provided). The 5 point harness restrained the torso more fully than a 4 point harness, so the ballistic response of the head was greater. An important point arises from this finding. The seat harness webbing should have some "give" to reduce the sudden load on the neck on impact.

The figures for the displacement are given in Table 8:

DERA RUN NUMBER	TEST CONDITION	HORIZONTAL DISPLACEMENT X-axis	VERTICAL DISPLACEMENT Y-axis	AVERAGE X Both runs	AVERAGE Y Both runs
5274	5 point tight	212.5	35	206	37.5
5275	5 point tight	200	40		
5276	5 point slack	225	45	225	45
5277	5 point slack	225	45		
5278	4 point tight	200	27.5	200	24
5279	4 point tight	200	20		
5280	4 point slack	225	37.5	225	29
5281	4 point slack	225	20		

5 f) Motion Analysis - transparency overlay, maximum displacement of dummy

A high speed video film was taken of the impact from a side view. Transparencies were made from the film to show the dummy at the time of maximum displacement. The reflective patch on the shoulder of the dummy was used as the reference point. The position of the shoulder was measured against a squared board behind the test track. There was a considerable parallax error, but as the error was the same for all the readings it was acceptable.

The minimum displacement of the shoulder was found to be with the 5 point harness tight. This position was therefore used as the reference point. Both 5 point harness tight runs gave identical results. A transparency from one of these runs was used, to be overlaid by the transparencies from the other test runs.

The maximum displacement of the dummy was increased with 4 point as against 5 point harness. The displacement was also increased when the harness was slack.

This is shown in Table 9

Table 9 (UNITS: mm)

The reference point is the position of the shoulder in runs 5274 and 5275, 5 point tight. The distance from this point, and the angle up and forward, is given in the table.

DERA RUN NUMBER	TEST CONDITION	DISTANCE FROM REF. POINT	ANGLE TO VERTICAL FROM REF. POINT
5276	5 point slack	10 mm	10°
5277	5 point slack	25 mm	30°
5278	4 point tight	25 mm	60°
5279	4 point tight	30 mm	10°
5280	4 point slack	40 mm	10°
5281	4 point slack	50 mm	40°

5 g) Motion Analysis - End Position of Dummy

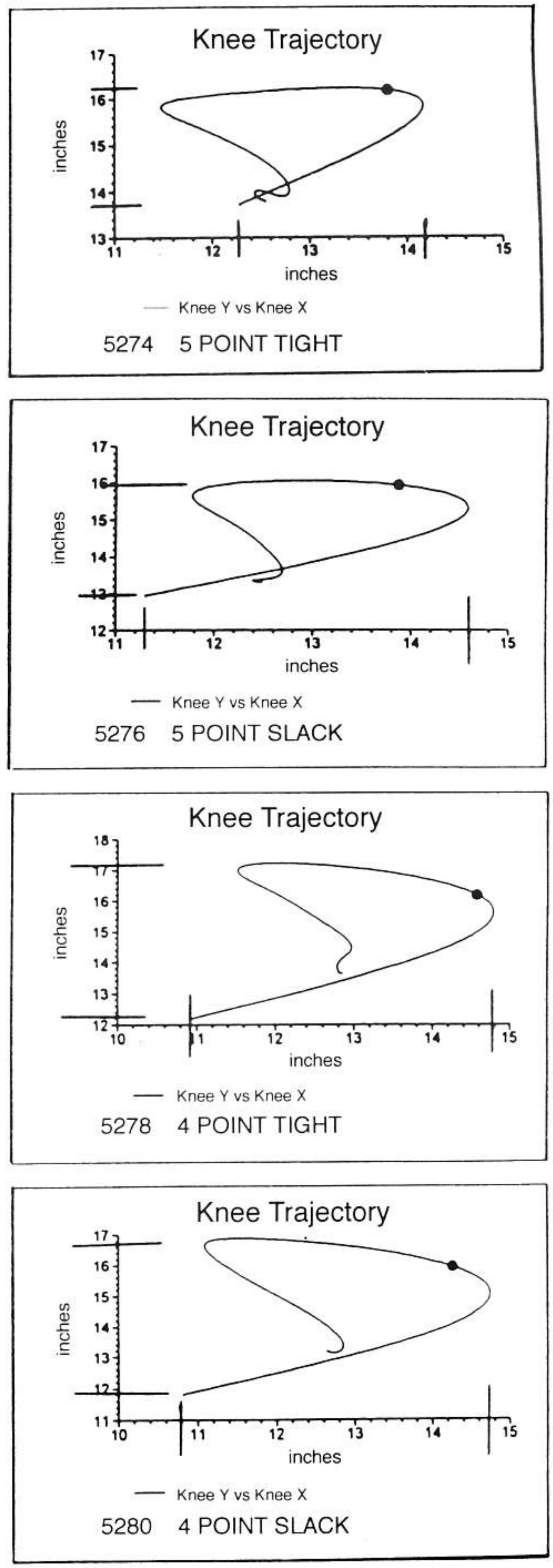
The starting position and the final position of the dummy, before and after the test impact, is shown in the motion analysis tracings. (Figure 3). It should be noted that the scale varies in the different tracings. The unit of measurement is in inches (one inch approximately equals 25 mm). The starting position is the smooth end of the tracing. The end position is marked by the jagged end of the tracing.

It will be seen that there is little difference between the starting position and the end position. This is especially so for Run 5274, the 5 point tight harness condition.

This could cause a misinterpretation of an experimental result if only the initial and final positions of the dummy are considered. The movement of the dummy during the course of the impact must also be considered.

A longitudinal section of the seat may be considered as forming an approximate "U" shape (the seat back, horizontal seat pan, and the thigh ramp). The dummy will have a tendency to settle into the base of the "U" after an impact.

Figure 3



5 h) Load on the 5th Strap and Crotch Strap; Lap Straps and Shoulder Straps

5th STRAP AND CROTCH STRAP LOADS

The most important finding was that the load in the crotch was approximately the same as the load in the 5th strap.(Table 10, andFigure 4). The load was high and would be injurious. It is suggested that if a strap is used it should be re-designed so as to avoid injury to the crotch area in an accident.

The load in the second run of each test condition was higher than in the first run. This was due to "bedding down."

The load with the harness slack was higher than with the harness tight. This was due to "snatch" occurring.

During Run 5276, there was a failure of the GRP seat pan at the slot for the 5th strap. This resulted in a jagged upstroke in the force tracing for the 5th strap. (It also caused a higher load in the lap strap). (Figure 5).

The values for the loads are given in Table 10:

DERA RUN NUMBER	TEST CONDITION	5th STRAP LOAD (N)	CROTCH STRAP LOAD (N)
5274	5 point tight	1440	1577
5275	5 point tight	2068	1965
5276	5 point slack	1844	1720
5277	5 point slack	2445	2738

Figure 4. The peak loads in the 5th Strap and in the crotch are comparable.

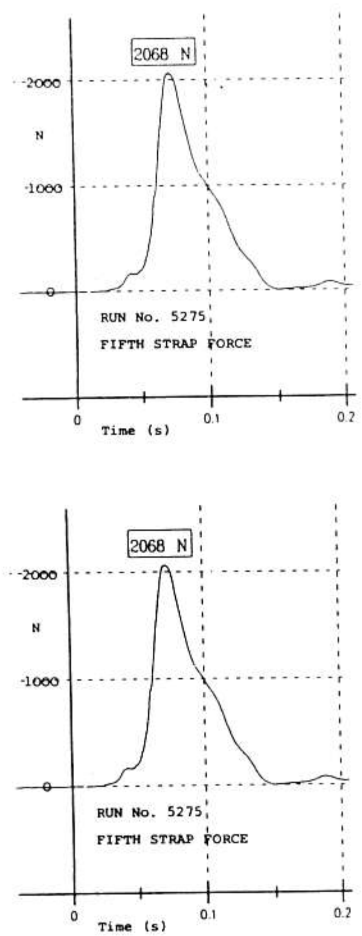
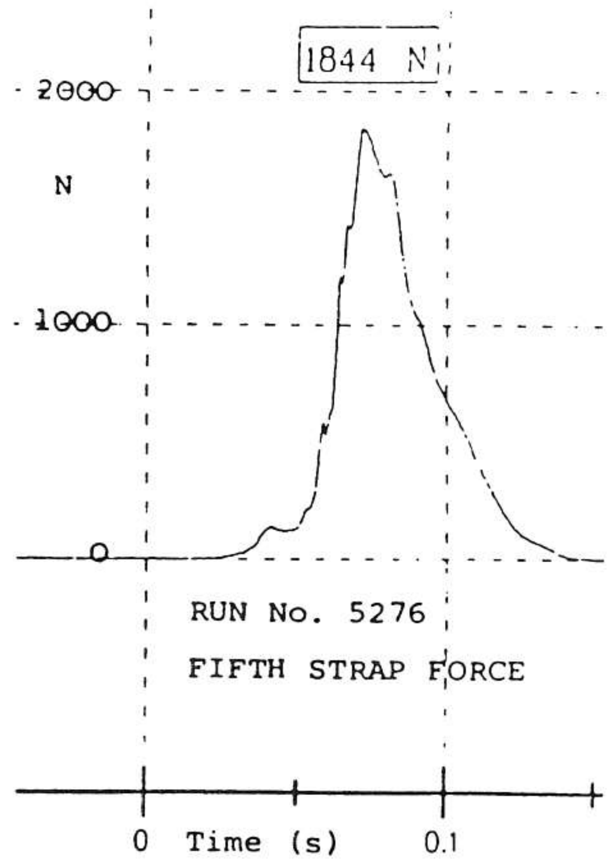


Figure 5

This shows the jagged upstroke in the load tracing for the 5th strap, caused by failure of the seat pan slot.



LAP STRAP LOADS

With a 5 point harness, the loads in the lap strap when tight and when slack were similar. The exception was a high load in Run 5376, consequent on the failure of the seat pan slot for the 5th strap.

With a 4 point harness, all the runs showed an increased load as compared with a 5 point harness, due to the loss of the share of the total load taken by the absent 5th strap. With the harness slack, there was a slight increase in the load, but this increase was probably not significant.

The lap straps had plastic adjustment buckles. During the second run (Run 5275), one of the buckles failed. Both buckles failed during each of the subsequent runs. The buckle locked onto the strap, so stopping any slip; the "failure" maytherefore have been an intentional part of the design. The displacement of the buckle adjusters may have assisted in energy attenuation in the lap strap, but the effect was not quantified.

The loads in the lap strap are shown in Table 11.

Table 11

DERA RUN NUMBER	TEST CONDITION	LAP STRAP LOAD (N)	AVERAGE LOAD (N) For both runs
5274	5 point tight	2443	2542
5275	5 point tight	2641	
5276	5 point slack	2967	2785
5277	5 point slack	2583	
5278	4 point tight	3118	3178
5279	4 point tight	3239	
5280	4 point slack	3302	3342
5281	4 point slack	3382	

SHOULDER STRAP LOADS

With a 4 point harness, the load on the shoulder straps was increased as compared to the load when a 5 point harness was in use.

In the case with a 5 point harness slack, the load was increased over that with the harness tight, probably due to "snatch."

In the first run (Run 5280) with the 4 point harness slack, the load in the shoulder straps was increased over that with the harness tight, again due to "snatch." However, the second run (Run 5281) was unduly low. This appears to be out of line with the rest of the results of the test. The value was confirmed by referral to the load tracing.

The shoulder strap loads are given in Table 12:

Table 12

DERA RUN NUMBER	TEST CONDITIONS	SHOULDER HARNESS LOAD (N)	AVERAGE LOAD (N) For both runs
5274	5 point tight	1499	1551
5275	5 point tight	1603	
5276	5 point slack	1854	1958
5277	5 point slack	2063	
5278	4 point tight	1841	1838
5279	4 point tight	1835	
5280	4 point slack	2146	1970
5281	4 point slack	1795	

CONCLUSION

A 5 point harness is superior to a 4 point harness in an accident impact situation, and under conditions of negative-g. This is especially so when the harness is slack. A high, injurious load is exerted on the crotch of the pilot by the 5th strap in an accident impact case.

It is recommended that the 5th strap be re-designed to avoid injury to the crotch of the pilot. The re-designed 5th strap should be fitted to new gliders, and be retro-fitted where structurally feasible to gliders in current use.

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