Homage to the work of Dr. Antony M. Segal.

This double issue of the OSTIV Journal, *Technical Soaring,* is completely devoted to the work of Dr. Tony Segal as homage for his very valuable contributions to the safety of gliding.

For his work Dr. Segal as been honoured with the:

OSTIV Prize 1989 and OSTIV Diploma in 1999,
Bill Scull Safety Award,
Diploma of the British Gliding Association,
Certificate of Merit of the Royal Aero Club,
FAI H.R.H. Prince Alvaro de Orleans-Borbon Award 2002.

Dr. Segal started gliding in 1956, the year he qualified in medicine, and worked as a family doctor in UK for 30 years. After retirement he started to work on safety in gliding and managed to get the help, technical support and facilities of the Centre for Human Sciences QinetiQ at Farnborough. Dr. Segal is a member of OSTIV's Sailplane Development Panel.

In addition to the articles published in this double issue of *Technical Soaring*, the following articles by Dr. Segal have been published previously:

- Pilot safety and spinal injury. *Technical Soaring* (TS) Vol 12, No. 4.
- Aircraft (full-size glider) crashworthiness impact test. TS Vol 14, No. 2.
- A study of the use in aviation of energy absorbing seating foam (partly in TS Vol 14, No. 4).
- Anthropometry and glider cockpit design. TS Vol 18, No. 1.
- Dynamic testing of highly damped seating foam. TS Vol. 19, No. 4
- Four and five point glider seat harness - Static and dynamic tests. TS Vol. 24, No. 3

The sailplane community is very much indebted to Dr. Tony Segal for his many years of very valuable contributions to safety of soaring.

Loek Boermans
OSTIV President

Energy Absorbing Seat Cushions for use in Gliders

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Abstract

Energy absorbing cushions are used to reduce the incidence and the severity of spinal injury in the event of a heavy landing or an accident in a glider. The special properties of the polyurethane material used in the cushions is due to their molecular structure. The seating foam is an open cell material. The mechanism of energy absorption is discussed. Impact experiments on a test track using Hybrid 111 anthropometric test devices showed a significant reduction in spinal load when energy absorbing seat cushions were used. Technical methods for testing the foam are described. The result of these test methods in relation to energy absorbing properties is discussed, but it is not possible to give a permissible range of numerical values for the test results. Advice is given as to the fitting of energy absorbing seat cushions in gliders.

Nomenclature

There has been discussion as to whether the foam should be called energy absorbing foam or energy attenuating foam. Definitions are as follows. (Ref. 1)

Absorb: 'To reduce the effect or intensity of (sound or an impact)'.
Attenuate: 'To reduce the strength, effect, or value of'.

It is seen that both words have the same meaning. I therefore consider the foam should be called energy absorbing foam as this is a well known and understandable term.

Introduction

This paper discusses the molecular and physical structure of polyurethane foam, and the effect of the environment on the foam. The three phases of compression loading are described. The mechanism of energy absorption is discussed. Technical test methods for the properties of foam are described, and the significance of the results discussed in relation to energy absorption. It has not been possible to assign specific numerical values to the test results. The relation between seating comfort and the risk of spinal injury is discussed. Advice is given on fitting energy absorbing cushions into gliders.

Duration of the Applied Acceleration

The duration of the applied acceleration is of significance. (Ref. 2)

Short duration acceleration lasts from 0.1s - 0.5s and is the time course for an impact event.

Intermediate duration acceleration lasts from 0.5s - 2.0s and is experienced during ejection from an aircraft, catapult launches and deck landings.

Long duration acceleration lasts longer than 2.0s, may last for minutes, and is experienced during aircraft manoevres. This is not relevant to the present study into impact.

Many experiments on seat cushions have been carried out in regard to ejection from aircraft due to the importance of ejection in regard to military aircrew. However, the findings may not be applicable to impact events owing to the different time scale.

The Molecular Structure

The molecular structure of polyurethane materials explains their special properties. (Ref. 3) Polyurethane is an elastomer. (An elastomer is defined as a natural or synthetic polymer having elastic properties.) Polyurethane consists of long flexible molecular chains with some degree of mechanical entanglement, containing large numbers of polar groups. (A polar group has an electrical or a magnetic field.) The polar groups form strong physical-chemical bonds, preventing the chains sliding easily over each other. This results in an elastomer of high modulus. (Modulus is defined as a constant factor or ratio relating a physical effect to the producing force.) Reinforcing fillers are not needed, so an elastic material can be obtained with a level of hardness not possible with conventional rubbers. At elevated temperature, the polar crosslinks are relatively easily broken, so the properties of polyurethanes decrease more rapidly at high temperature than is the case with other elastomers.

The Physical Structure

An open cell foam should be used for energy absorbing cushions. Care is required in the manufacturing process as variation in density and large air voids will adversely affect the energy absorbing properties. (Ref. 4, 7)

The Effect of the Environment

(Ref. 3)

High Temperature. All properties are adversely affected. For many applications, 80°C represents a maximum temperature. Below 80°C, polyurethanes are regarded as stable for continuous service.

Low Temperature. The properties are affected but no degradation occurs and the effect is completely reversible. There is only a small increase in torsional stiffness as the temperature falls from +20°C to -25°C, then there is a rapid increase in stiffness. Polyurethanes only become brittle at temperatures of -60°C to -80°C.

Hydrolytic Stability. Polyurethanes degrade over time due to attack by water, either by being immersed in water or by being exposed to moist air. This is due to the chemical composition of the main molecular chain.

Light Resistance. The resistance to ultraviolet light and to outdoor weather is good. On exposure to sunlight the surface darkens. On exposure to very bright sunlight some surface deterioration can occur, although this does not spread through the mass of the material.

The Effect of Compression Loading

This has three phases, as follows. (Ref. 7)

The first phase. This is a phase of high compression modulus, the material behaving like a stiff spring during which the cell walls remain largely undistorted.

The second phase. This is a phase of low modulus where small increments of pressure produce large compressions due to the collapse of the cell walls.

The third phase. This is a return to a high modulus when most of the air has been expelled and it behaves like a solid.

During recovery. During recovery from compression loading the foam shows marked hysteresis. The hysteresis is greater in polyester polyurethanes than in polyether polyurethanes. (Hysteresis is defined as a phenomenon in which the value of a physical property lags behind the changes in the effecting property causing the change.)

Energy Absorbing Properties

There are several mechanisms of action. These are quantified by measurements of resilience, hysteresis energy and damping properties. (Ref. 3)

The resilience. The resilience alone of the foam is not a sufficient measure of its energy absorbing properties. The energy absorbed is greater than the effective crush distance alone would indicate. It is probable that tensile stresses and shear stresses around the periphery of the compressed zone play a large role in the total forces resisting compression. (Ref. 5)

Hysteresis energy. When a stress is applied to an elastomeric material there is a small time lag before the material takes up the corresponding strain. This time lag is caused by the need for the intermolecular attractions to be overcome by the vibrational energy of the atoms.

The result is that the stress-strain curve in recovery does not follow the same path as when the stress was applied. There is consequently a loss of energy from the foam material, which is converted into heat energy.

Damping. An oscillation is induced in the foam and a measurement made of the first and second compressive wave. The ratio of the height of the second wave to that of the first wave provides a measure of the degree of damping. The lower the height of the second wave and the shorter its duration the more effective the damping.

Impact Test Results

This test (Ref. 6) used three Hybrid 111 anthropometric test devices (manikins) - 5th percentile female, 50th percentile male and 95th percentile male. The impact parameters were 17g and 9.4m/s. The manikin was strapped onto the seat of the test sledge in the vertical position. The seat was then rotated through 90°. This resulted in a load on the cushion that was being tested of 1g. Different thicknesses of foam cushions were used. The test results for the loads on the lumbar spines of the test manikins when using energy absorbing foam cushions follow.

The test showed there was a significant reduction in the spinal load of the pilot manikin, on impact, with increasing thickness of the energy absorbing foam cushion. The following figures show the thickness of the test cushion and the resulting spinal load on the test manikin.

5th Percentile Female Manikin

No cushion		1249 lb.f.	5.558 kN
1/2 inch	1.25 cm	1083 lb.f.	4.819 kN
1 inch	2.5 cm	1038 lb.f.	4.619 kN
2 inches	5.0 cm	823 lb.f.	3.662 kN
4 inches	10.0 cm	767 lb.f.	3.413 kN

50th Percentile Male Manikin

No cushion		2195 lb.f.	9.767 kN
1/2 inch	1.25 cm	1981 lb.f.	8.817 kN
1 inch	2.5 cm	1823 lb.f.	8.110 kN
2 inches	5.0 cm	1512 lb.f.	6.729 kN
4 inches	10.0 cm	1276 lb.f.	5.677 kN

95th Percentile Male Manikin

No cushion		1851 lb.f.	8.235 kN
1/2 inch	1.25 cm	1608 lb.f.	7.156 kN
1 inch	2.5 cm	1451 lb.f.	6.445 kN
2 inches	5.0 cm	1338 lb.f.	5.961 kN
4 inches	10.0 cm	1139 lb.f.	5.068 kN

Technical Test Methods (A)

The following information was taken from Ref. 7:

Density. This is a routine measurement.

Tensile Strength. The tensile strength increases with denisty. It is not of great significance, although the material will be more durable.

Elongation at Break. This varies greatly, and is not of significance.

Compressibility. Sequential loading is carried out, allowing for 30 seconds between each additional weight. As already described, a sigmoid-shaped curve is obtained with a hysteresis effect on the return curve. The *Percentage Compression* is defined as the percentage reduction in thickness from its original thickness. To give protection from an impact event, foam should only compress slightly under the resting weight of the pilot.

Elastic Memory. Rate of Recovery Following Compression. This describes the rate of recovery of a material after deformation. The test commences at 75% compression and the time to recover to 10% compression is taken. The recovery time for a period of compression of 5 seconds, 15 seconds, 30 seconds and 60 seconds is taken. A short recovery time would result in a cushion able to bounce too much. The rate of recovery depends on the resilience of the foam material, and the resistance to airflow of the communication between air cells.

Compression Set. This is the permanent deformation resulting from prolonged compression, expressed as a percentage reduction of the original thickness. The test is carried out for a period of twenty four hours and also for seven days. After release from compression the measurement is taken after thirty minutes. It is important that the compression set is small so that the foam will suffer as little permanent deformation as possible in normal use.

Dynamic Properties of Foam. The following two methods are used:

1) *Coefficient of Restitution.* A steel ball is dropped onto the foam from a known height. The height of the first bounce is measured and expressed as a decimal fraction of the initial drop height, giving the coefficient of restitution. If no energy were to be absorbed by the foam, the ball or the air, the coefficient of restitution would be one. The lower the figure, the greater the energy absorbed by the foam. This is a simple test to carry out. However, the foam is tested in an unloaded condition.

2) *Damping Under Load. Persistence Ratio.* The foam sample supports a lead mass, which is then set into oscillation by dropping onto it a further lead mass. Most of the air is expelled from the foam so there will be little further change in its properties. Oscillation recordings are made. The ratio of the height of the second wave to the first is termed the persistence ratio, and is a measure of the damping properties of the foam. The more the foam is damped, the more rapidly the oscillations die away and the lower the persistence ratio. As the foam is tested in a loaded condition, this is a more representative and realistic test.

Technical Test Methods (B)

The following information was taken from Ref. 5.

Compression Set Test. The foam is compressed between two flat plates larger than the specimen, under specified conditions of time and temperature. The reduction of thickness of the specimen is noted after removal of the load.

Load Deflection Tests. The following two methods are used:

1) *Indentation Load Deflection (ILD).* This is the load necessary to produce a specified 25% or 65% indentation under a circular indenter foot of 50 square inches area (322.6 sq.cm)

2) *Indentation Residual Gage Load (IRGL).* Using the same indenter foot, the deflections under loadings of 4.45 N, 111 N, and 222 N are obtained, and of 111 N during unloading.

Dynamic Drop Test. This more closely simulates impact conditions, although the foam is unloaded initially. An acceleration-time curve is obtained from a transducer on the impactor. The test parameters are the drop height (giving the impact velocity), the weight and the surface area of the impactor, and the thickness of the foam.

Load Deflection Testing of Urethane Foams forAutomtive Seating. This records the thickness of the cushion under an average passenger load, the initial softness, and the resiliency. A further test determines the thickness of the cushion under loads of 1 pound, 25 pounds and 50 pounds, with a circular indentor foot.

Temperature Sensitivity. A curve is drawn plotting Strain (percent) against Stress (pounds per square inch) under conditions of different temperature. Different types of foam vary in their response to temperature difference. Temperature sensitivity must therefore be considered as a selection criterion.

Notes on Test Methods

1) Some of the above papers quote recommended values for seating cushions for aircraft ejection seats. These values may not be applicable to the impact situation, owing to the different time scales of the impact and ejection situations.

2) Both the above reference documents present a mathematical analysis of the response of energy absorbing foam to impact and aircraft ejection seat conditions.

Seating Comfort and Protection from Spinal Injury

The following quotation (Ref. 8) is of relevance: "Aircrew member comfort is essential for operational effectiveness in high-performance aircraft, particularly during long-duration missions lasting several hours".

Glider pilots experience considerable discomfort after flying for several hours on a firm grade of energy absorbing foam cushion. This is due to pressure on the ischial tuberosities of the pelvic bones. A thin layer of a soft grade of energy absorbing foam, on top of a thicker layer of a firm grade of energy absorbing foam, would provide seating comfort while still providing spinal protection on impact. The contact pressure at the ischial tuberosities would be decreased, and the load of the pilot's body would be distributed more evenly across the buttocks.

However, a possible problem arises from the requirement for a thicker seat cushion. If there is restricted headroom under a low cockpit canopy there may not be room to fit such a cushion.

An impact test was carried out using a layered seat cushion (Ref. 9). A ½ inch (1.25 cm) thick firm grade energy absorbing foam layer, was placed on top of a 1 inch (2.5 cm) thick hard grade energy absorbing foam layer. A pilot manikin was fitted with an accelerometer at the base of the spine. The manikin was strapped firmly onto the seat on the test sledge. The seat was then rotated through 90°, so the foam was loaded to 1g. The impact velocity for the test was 8.1 m/s. The following peak g readings were recorded.

Bare seat	35g
Ordinary soft foam cushion	45g
Energy absorbing layered foam cushion	26g

These test results showed that the layered energy absorbing foam cushion absorbed considerable impact energy, as well as providing pilot seating comfort.

A further point of considerable interest and importance was the demonstration of the increased acceleration experienced by the spine on impact when ordinary soft foam was used as a seat cushion.

Advice on Fitting Energy Absorbing Foam Cushions

The cushion cover should be made of a material that is porous to air. The upper surface of the cushion should not be covered by an airtight structure. In the case of a motor glider, the material should be fire retardent. The cushion should be attached firmly to the underlying seat pan, but should be removable. The foam is firm, and if it were to slip forward it could prevent full movement of the control column. Energy absorbing foam may also be used for padding sharp edges and corners in areas within the strike envelope of the pilot (Ref. 5). The edges and corners to be padded should have a minimum radius of 1/2 inch (1.25 cm) to prevent the foam being cut or broken away.

Conclusions

Energy absorbing seat cushions have been shown on testing to absorb considerable impact energy, thus having the effect of reducing the severity of spinal injury in gliding accidents. If a layered cushion is used consisting of a softer grade of energy absorbing foam placed on top of a harder grade of energy absorbing foam, pilot comfort can be improved while retaining the protective effect of the cushion on the spine. The material is of low cost, and can be retro-fitted to existing gliders. The use of energy absorbing foam cushions is recommended.

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Jump or Bump

Part 1

Dr. Antony M. Segal

Introduction

The first meeting of the OSTIV Crashworthiness Sub-committee, under the chairmanship of Alan Patching (Australia), was held in Uvalde, Texas, in July. A great deal of information was exchanged in the meetings, the restaurant, and in the beer tent late into the evening. This article, giving my own personal view, discusses some of the points raised. I have been told a gliding competition was taking place at the same time in Uvalde.

Types of injury

Injury may be classified as minor, including for example a crush fracture of a vertebra, such that the ability of the pilot to extricate himself from the crashed glider is not impaired. Then there is severe injury, followed lastly by fatal injuries. The object of crashworthiness studies is to reduce the severity of injury and reduce the fatality rate.

Mechanism of injury

Primary injury is caused by the deceleration of the pilot's body on impact, and the effect of the resulting inertia loads on the pilot.

Secondary injury is due to missiles, such as batteries, cameras, and barographs that have not been firmly fastened, striking the pilot.

Tertiary injury is caused by violent contact between some part of the pilot's body and the cockpit, or with objects that have penetrated the cockpit shell.

Human tolerance to abrupt impact deceleration

The figures that follow are only approximate. Specifically, they refer to young fit males, quite unlike most glider pilots! Also, different expert sources give different values. The following values are taken from a paper by Professor (Gp. Capt.) David Glaister, RAF Institute of Aviation Medicine, Famborough.

A seated pilot, with the impact forces acting along the axis of the spine (+Gz) can withstand 20G for 0.18sec, with lap and shoulder restraint. (The accepted limit for ejection seats is 25G.)

A seated pilot, with the forces acting between his back and his chest (-Gx), can withstand an incredible 40G for 0.06sec, with full restraint of torso, head and limbs. This degree of restraint is impractical in most situations. With the more usual lap and shoulder restraint, 20G can be withstood for 0.04sec.

A seated pilot, with the impact forces acting in a direction across the shoulders (Gy), can withstand 8G for 0.06sec, with lap and shoulder restraint. The limiting factor is due to injurious loads on the neck. Full restraint of the neck would impair the mobility of the head, and hence adversely affect pilot look-out.

The direction of the applied forces in an actual accident will depend on the pilot's seating position, and on the attitude of the glider on impact.

Generally, impacts along the axis of the pilot's spine are less well tolerated than those from front to back, because of the greater mobility of the organs of the body in the direction of the spinal axis.

Types of accident

An analysis of glider accident statistics in Germany has been carried out at TüV Rheinland, Cologne, by Dipl. Ing. Martin Sperber, under the guidance of Dipl. Ing. Detlef Pusch. German accident statistics are especially comprehensive, because the unfortunate pilots involved have to complete a very full investigation form before they receive their insurance payment!

Two studies have been carried out, covering the periods 1982-1986 and 1987-1989. In the latter study, four types of accident caused 90% of the accidents.

Type 1. Caused by a high round-out in the late landing phase, or by premature release or a cable break in the initial phase of a winch launch. This caused 29% of the accidents.

Type 2. Due to the glider flying into the ground in the landing phase, by failure to round-out. This caused 33% of the accidents.

Type 3. A wing made contact with the ground, causing rotation of the glider around a vertical axis. This caused 7% of the accidents.

Type 4. This is a serious accident, due to stalling or spinning from a considerable height. This caused 21 % of the accidents.

The study, covering the period from 1987-1989, analysed 558 accidents. No injury was incurred in 72.4% of these accidents. Slight injury was shown in 6.5%. Severe injury occurred in 16.1 %. Sadly, 5% of the accidents were fatal.

Martin Sperber has analysed the forces acting on the glider, the seat harness, and a pilot manikin in these four types of accident. The experiments were carried out on the decelerator track at TüV Rheinland, Cologne - the same track is used for the crashworthiness tests on the Volvo car!

Cockpit strength

The Crashworthiness Sub-committee considered that the design load for head-on landings should be increased to 15G acting rearward and upward at an angle of 45° to the longitudinal axis of the glider. This brought the figure more into line with the impact tolerance of the pilot. Deformation and partial failure of the structure was considered acceptable, provided the pilot (securely strapped in place) did not receive fatal injuries.

However, mere strength is not sufficient. The cockpit structure must also help absorb some of the energy of the impact.

Fuselage crush length and depth

At the present time, spinning accidents are usually fatal. By providing a suitable crush length in front of the pilot, and a crush depth below the pilot, a spinning accident could be made survivable.

The acceleration, G, arising from an impact (in multiples of the acceleration due to gravity, g), is related to the initial velocity of impact of the glider (v), and to the stopping distance(s) by:

$$G=\frac{v^2}{2gs}$$

However, lengthening and deepening the fuselage would severely impair the performance of the glider to such a degree that it would not be acceptable to pilots.

Frank Irving (Imperial College), has kindly calculated the effect on the performance of a typical Standard Class glider of changing the fuselage dimensions. The following table gives his conclusions:

With			
Increase in nose length (m)	1	1	0.5
Increase in fuselage depth (m)	1	0.5	0.50
% decrease in L/D MAX	13	8	5
% decrease in L/D AT 80KTS	21	14	10

Surviving a Spin Accident

I should like to put forward for discussion a controversial proposal, giving the pilot a fair chance of survival in the event of a spinning accident.

At present, the toes of the pilot are a few inches from the nose cone of the glider. The nose of the glider is a relatively weak aerodynamic fairing. I suggest the nose structure, back as far as the plane of the control column, be designed to collapse progressively on severe impact, giving a metre length of crush distance. There would be no alteration to the external lines of the fuselage and no change in glider performance. The pilot's seat harness would have to hold him securely in place. The fuselage behind the plane of the control column would need to be sufficiently strong not to collapse into the pilot's space.

Assuming a crush distance of 1 m, and an impact velocity of 50kt on to an unyielding surface, a rough calculation gives a loading of 34G. If the impact was not vertical, and on to soft earth, the impact should be survivable.

The legs and pelvis of the pilot would inevitably be severely injured, with the resulting medical complications. The pilot would be trapped in his cockpit, so a LOCAT beacon would be required, and precautions taken against fire in the case of motor gliders.

However, his head and trunk should be uninjured, giving him a chance of living.

Canard configuration

Pilots often mention that a canard configuration would allow more of the fuselage length to be placed ahead of the pilot, where it would absorb the impact energy. Oliver Carl, and his fellow students of Akaflieg Aachen, Germany, have almost completed a canard glider. He told me at Uvalde that the nose region was a very light fairing that would absorb little impact. A heavier fairing would upset the CG of the glider. Frank Irving has pointed out that a canard is fundamentally unsuitable for a glider. For efficient thermailing flight, the glider wing must fly very near the stall. This is not possible with a canard configuration, since the foreplane is designed to stall well before the main wing approaches the stall.

A cockpit pod has also been suggested, the pod passing intact, backwards into the rear fuselage on impact. I consider the presence of the main spar, just behind the pilot, makes this idea impractical.

Tony started gliding at Lasham in 1956 and recently retired as a senior partner from general medical practice. He has completed a six month's training course at the RAF Institute of Aviation Medicine, Farnborough and carried out two experimental studies on pilot safety, one on spinal injury, and one a crash-worthiness test on a Libelle, see the S&G June 1989 issue, p130.

Jump or Bump

Part 2

Dr. Antony M. Segal

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Bad backs, or the "big B".

If you go to the canteen of any gliding club, you will soon realise that injured and strained backs are a major problem among the pilots. Ullrich Kopp, a member of the German LBA (equivalent to our CAA) in Braunschweig, has analysed accident figures in Germany for the period 1973-1990. He found that while the total number of accidents has decreased, the number of heavy landing accidents has increased. An amazing 94% of these heavy landing injuries affected the spine. A large number of heavy landings involved training two-seaters and early solo type of gliders.

Undercarriage.

Both Ullrich, and Gerhard Waibel (Gerhard is the glider manufacturer's representative on the OSTIV Crashworthiness Sub-committee) were concerned that present design requirements for undercarriages were actually increasing the risk of back injury. At the present time, as a sprung undercarriage reaches the limit of its stroke in a heavy landing, it comes to a sudden stop. A heavy load is thus imposed on the pilot's spine. It was suggested that at the extreme of undercarriage stroke the surrounding structure should break in a controlled manner, thus reducing the shock to the pilot's back.

Undercarriages have been steadily improved, with bigger wheels and tyres, longer stroke and improved shock absorption. It was proposed that a dangerous area was being entered, where the resonant frequency of the system was close to the natural resonant frequency of the human spine. However, I feel this is not so, and the information has been misunderstood. It is clear a lot more work needs to be carried out on undercarriage design.

The cockpit.

The requirements in the cockpit to help safeguard the pilot's back are well established and draft OSTIV Airworthiness Standards were drawn up at Uvalde to cover these points.

First, *the back must be fully supported* by the seat back and the parachute pack. A parachute pack ending half way down the spine will give a stress concentration at that level, at which a spinal fracture may occur.

Next, *the natural curve of the lower (lumbar) spine* must be maintained by the use of a small firm lumbar pad, placed between the pilot's back and the parachute. The original experiment showed that the spine fractured at 10g (under the conditions of the experiment), but 18g was required to cause fracture when a lumbar pad was used. This simple pad must be the most cost-effective measure ever! Incidentally, do not use an air inflated bladder for this purpose. It will cause rebound on impact, and will get harder at altitude.

Last of all, the pilot should never sit on soft *seat cushions,* as they amplify the crash acceleration. It is quite all right to sit directly on the seat, although it may get uncomfortable.

Special seat cushions are recommended; the foam involved is called by a variety of names - energy absorbing foam, long-memory foam, high hysteresis foam, low resilience foam. I carried out tests using a full size pilot manikin on the test track at the RAF Institute of Aviation Medicine, on Dunlopillo low resilience foam. On impact, there was a low rate of rise of g, a low peak of g and an absence of rebound. This foam was obviously good stuff - unfortunately, glider pilots at the time could not be bothered to buy it, so it has gone out of production.

An experiment on seat cushions was carried out in the USA at the Wright-Patterson Air Force Base. They concluded that soft foam cushions should not be used. They tested an American type of foam, and found it neither decreased nor increased the input acceleration, but it greatly increased seating comfort on long missions. The use of the foam was recommended for operational use in the A-10, the F-15, and the FB-111.

Further research is under way at the present time, by Martin Sperber at TüV Rheinland and Jeff Lewis at the Schweizer Aircraft Corporation, USA, on energy absorbing seat cushions.

It is vital the seat cushions are firmly attached - if they slide forward they could prevent full movement of the control column.

Martin Sperber is also working on the design of an energy absorbing seat pan.

Head rests.

Tests on a pilot manikin by Martin Sperber showed that on impact the head jerked forward until the chin met the chest and then jerked violently backwards. The head experienced 40g, but because of the very short duration this need cause no injury to the skull or to the brain. The Crashworthiness Sub-Committee drew up draft OSTIVAS to cover a suitably strong head rest to be faced by energy absorbing foam. Where possible, the head rest supporting structure should be integral with the seat back. There must also be no possibility of the parachute catching the head rest during an emergency exit.

Seat harness and "submarining".

The seat harness is a neglected but vitally important part of the glider. It has two functions - to hold the pilot in place against in-flight loads (including negative g), and against crash impact loads. For gliders with an upright seating position, such as the K-13, a four point harness (two shoulder straps and two lap or pelvic straps) is adequate. However, for a low profile glider, with the pilot in a semi-recumbent position, something more is needed to prevent submarining.

Submarining is the term used to describe the motion of the pilot if he slides down and forward under his seat harness. This is a thoroughly bad thing to occur, for the following reasons:

The feet and legs may be injured.

The groin may be injured on the control column.

The lap (pelvic) straps will rise up on to the abdomen and may damage the organs. (The lap straps should press on the hard bony pelvis.)

The harness quick release fastening (hereafter called the QRF) will rise up, causing the shoulder harness to slacken off.

The slack shoulder harness allows the spine to bend forward, so increasing the risk of spinal injury.

The classic and simplest method of preventing submarining is to have a fifth strap, the negative g strap, passing between the legs and anchoring the QRF in position. This is used in military and aerobatic aircraft. This makes a five point harness. There are some objections to this harness. Inevitably, it is more complicated to put on and remove. Passing urine during the course of a long flight may be difficult. The groin region may be injured on impact, but surely far less so than by striking the control column. Gerhard Waibel has pointed out that the fifth strap is fastened to the relatively weak join between the left and right halves of the fuselage. Also, if the fuselage becomes oval in shape on impact, the fifth strap will become slack.

An alternative is to use a six point harness, with two negative g straps passing between the legs. The two negative g straps can be joined by a common yoke, to simplify attachment to the QRF.

The *adjustment buckles* should have minimum "micro-slip", so that the harness does not become slack in flight. The buckles should tighten the harness by a pulling action towards the pilot.

The *QRF* should have the following properties:

A double-action operation, to prevent inadvertent opening.

It should not open under shock load. (Some types of fastenings do so!)

It should be operated one-handed. It should be possible to operate while under g load.

Once opened, it should remain locked open. Otherwise, the pilot may be trapped in a partially released harness.

The *attachment points* of the belt should be strong enough to take the design load.

The *shoulder straps* should pass backwards either horizontally, or at a slight downwards angle. This may be difficult to achieve with pilots of different size. The two straps should be a suitable distance apart horizontally.

The *lap (pelvic) straps* should pass vertically downward, or backwards as far as 20° from the vertical, from the H point. The H point (the hinge point) is the pivot between the torso middle line and the thigh middle line of the pilot.

Martin Sperber has demonstrated an entirely different method of preventing submarining, by using a steeply raked seat pan with a correctly positioned four point harness. I feel this needs further investigation, namely, checking with small and large pilot manikins, checking under conditions of negative g and checking with the seat harness slack. I am also concerned in case the steep rake of the seat pan increases the risk of deep vein thrombosis developing in the legs of the pilot.

Loose objects.

Thanks to the efforts of Alan Patching (Australia), new OSTIV Airworthiness Standards have been approved to cover the secure fastening of batteries, barographs and similar objects. It is clear that radios and cameras that are frequently placed loose in the cockpit present a serious hazard to the pilot in the event of severe mid-air turbulence or a crash landing.

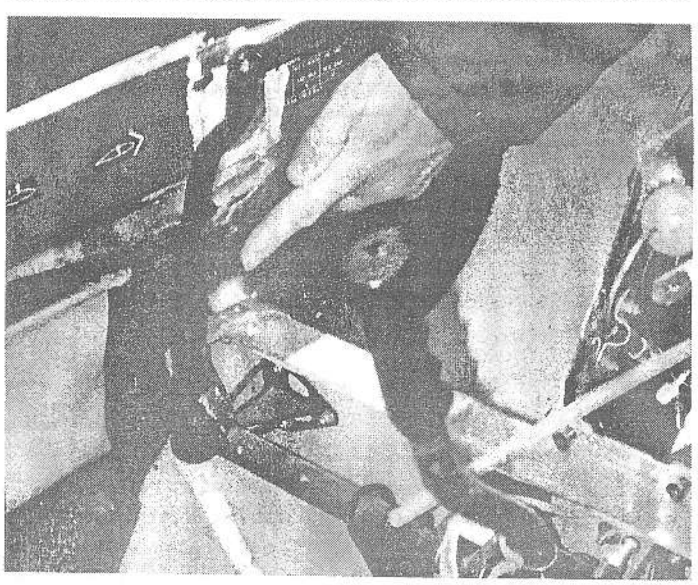
Delethalisation of the cockpit.

Sharp edges or protrusions in the cockpit area should be avoided if possible, or else covered with firm foam.

The effect of a heavy landing.

The photographs show the typical effects of a very heavy landing, when the impact is on the nose of the glider. The cockpit bends upwards, causing a failure in compression of the cockpit sill. The fuselage cross-section becomes oval in shape, causing a failure in tension of the join between the transverse bulkhead and the cockpit wall. These controlled failures absorb energy, so helping to protect the pilot. The pilot, who was wearing a five-point seat harness, had only minor injuries.

Falure of Grob 103 cockpit sill in compression. Note: the tail broke off.



Failure in tension of transverse bulkhead attachment to the cockpit side wall.

Jump or Bump

Part 3

Dr. Antony M. Segal

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Mid air collision and the subsequent escape of the pilot from the glider cockpit is a very emotional subject. Before he can use his parachute, the pilot has to get clear of his glider. Professor Dr. Ing. Wolf Roger of the Technical College, Aachen, has analysed German accident figures and carried out experiments on the factors affecting successful escape from the cockpit.

Damage to the glider.

Serious damage to the gliders involved the fuselage being broken into two, damage to part of the wing or damage to part of the tail. Damage of this severity was followed by a total loss of control and a very high rate of descent. The glider either entered a vertical dive, a spiral dive, or rotated around one or more of the three glider axes. The time between collision and ground impact was very short. The pilot experienced g loads that in some cases helped him escape, and in others prevented escape.

Pilot's psychological state.

Following a mid air collision with subsequent complete loss of control, the pilot must bail out immediately. The pilot will be highly aroused, with impairment of his thinking ability and memory. A standardised emergency system is therefore of great importance.

Fact and figures.

Wolf Roger has prepared a full report analysing all the mid air accidents in Germany from 1975 to 1988. From this report I have extracted the information that is relevant to the present discussion.

There were 34 mid air accidents, involving 58 gliders. Six of these gliders were two-seaters. Many of the accidents were between two gliders that collided while circling in thermals.

Of the total of 64 aircrew involved, 36 survived and 28 died. Thirty-two were known to have tried to jettison their canopy and bail out. (In some cases there were no witnesses and no evidence as to whether an attempt was made to jettison the canopy.) Of the 32 pilots who attempted to bail out, 19 lived and 13 died. This gives a success rate of 60%. This can be compared with the 90% success rate in military aircraft. Military aircraft have ejection seats, of course, but their escape envelope is far more stringent than that of gliders.

The height at which an escape was attempted had a great effect on the chance of survival. Most of the accidents occurred below 4000ft (1200m). Below 4000ft there were many accidents in which the pilot was killed because the time was too short to jettison the canopy and leave the cockpit. Above 4000ft, there was only one such fatal accident.

The lowest height at which aircrew survived an attempted escape was 650ft (200m). This involved a two-seater glider equipped with automatic parachutes operated by a static line. Without an automatic parachute, the lowest height at which anyone survived was 1600ft (500m). Clearly, this is a cause for great concern.

In four accidents, the pilots had difficulty operating the 3-lever canopy jettison system. The percentage of pilots killed in gliders equipped with a 3-lever system was higher than for those equipped with a 1 or 2-lever system.

Canopy jettisoning systems.

These systems vary greatly in different glider types, as the following list shows:

Shape. Some systems used operating levers, some used knobs.

Situation. The control could be above, on, or below the instrument panel. It could be on the right or the left side of the canopy, or the cockpit wall.

Number. 1-, 2-, or 3-lever systems may be found.

Operation. This may be one or two handed. The levers may need to be pulled or pushed. Unbelievably, in one 2-lever system, one lever must be pulled and one pushed!

Instrument panels.

In the case of a fixed instrument panel passing between the cockpit walls, the pilot will have to draw up his legs before he can bail out.

With a mushroom shaped panel, in the centre line of the cockpit, the pilot can easily swing his legs over the panel when escaping. This clearly is the preferable shape.

A further problem is that the cockpit sill may contain protruding pins or levers that may hamper rapid escape.

Experimental studies - factors affecting escape time.

An LS-4 cockpit was used in this study, which involved 25 pilots aged between 20 and 60 years. In the experiments, the time taken to jettison the canopy and open the seat harness was measured.

Number of levers:

1-lever system took 1-2/3sec.
2-lever system took 1-3/4sec.
3-lever system took 2-1/2sec.

Canopy.

If this was pulled clear by the airstream, and the canopy did not have to be pushed clear by the pilot, 1 sec was saved.

Pilot's age.

This had no effect on the time taken to release the canopy and seat harness.

Time taken to leave the cockpit.

In the next experiment, the time taken to leave the cockpit after release of the seat harness was measured. The time was recorded under two conditions, under 1 g and under 1-1/2*g*. The condition of 1-1/2g was simulated by attaching lead weights to the pilot's body.

A well trained, fit young pilot	- at 1 g	2.6sec
	at 1-1/2g	3.5sec
A pilot over 40 years	- at 1 g	4.5sec
	- at 1-1/2g	7.2sec

Some older pilots were unable to get out of the cockpit at all under conditions of 1-1/2g.

Instrument panel. Only fit young pilots were involved in this study. The time taken to leave the cockpit after release of the seat harness was measured:

With no instrument panel	2.4sec
Mushroom type panel	not tested
Fixed panel across the cockpit wall	3.4sec

(The pilot had to bend and then withdraw his legs.)

Height of the cockpit wall. This test also used fit young pilots. The time taken to leave the cockpit after release of the seat harness was as follows:

Low cockpit wall	8-1/2in (22cms)	2.7sec
High cockpit wall	20-1/2in (52cms)	4.5sec

(Presumably, these are heights above the seat pan.)

Experimental studies - behaviour of the canopy following release. Two series of tests were carried out by Wolf Roger. One used a wind tunnel. In the other, a glider fuselage was mounted on the roof rack of a powerful car which was driven at speed down a runway. A chase car filmed the behaviour of the canopy. A forward opening canopy was used.

With the canopy closed, but the canopy release open, the aerodynamic forces resulted in the canopy experiencing a nose down moment. As a result, the canopy was pressed firmly down on to the fuselage. If side-slip was used, the canopy lifted off the fuselage, but at a risk of striking the pilot or getting caught by the instrument panel.

With the canopy opened slightly, by less than 6cms, a sequence of four events occurred. The front of the canopy lifted up off the fuselage. Owing to the nose down moment, the rear of the canopy then lifted off the fuselage. Due to a tangential force, the whole canopy then moved forward.

Finally, the canopy pressed down firmly on the cockpit, preventing exit of the pilot.

With the forward opening between the front of the canopy and the fuselage greater than 6cms, the effect of the aerodynamic forces on the canopy changed. The canopy lifted off the fuselage, and moved backwards. If the rear of the canopy was attached to the fuselage by a hinge that disengaged at a canopy angle of between 30° to 40°, the canopy then flew off clear of the pilot and the tailplane. Wolf Roger suggested that for a successful escape, with the canopy hinge fitted, the pilot should raise the front of the canopy to the full extent of his outstretched arms.

In the absence of these measures, the canopy frequently struck the pilot and the tail of the glider.

A point of practical importance shown by the tests was that if the cockpit ventilation was open, and the clear vision panel closed, the pressure inside the cockpit was increased, so assisting the jettisoning of the canopy.

Recommendations

To increase the likelihood of successful escape of the pilot from the cockpit in an emergency, I suggest the following features should be incorporated in new glider designs:

The cockpit sill should be as low and as long as possible, consistent of course with the strength and crashworthiness of the fuselage. The cockpit sill should be free of protruding pins and levers.

The instrument panel should be of the mushroom type, situated on the centre line of the fuselage. Alternately, it could be replaced entirely by a Head Up Display.

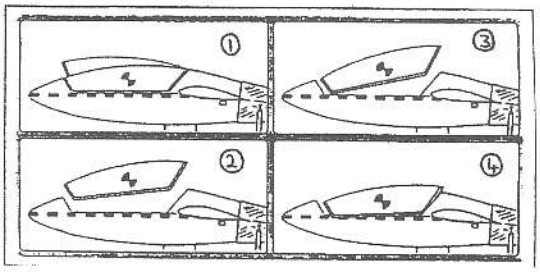
The canopy should be attached at its rear end to the fuselage by a hinge that disengages at an angle of 30° to 40°. When the emergency release is operated, a system of gas filled struts or springs should raise the front of the canopy as high as possible into the airstream.

The emergency activating handle should be situated between the pilot's legs, as in military aircraft. This position should be standardised in all gliders. In this position, it will be easy for the pilot to reach the handle under conditions of g loading. The handle should require a double'action, to prevent inadvertent operation.

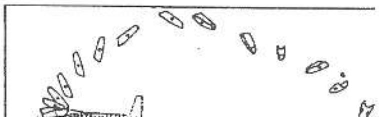
On operation of the handle, the canopy should release. After a short time delay (to allow the canopy to clear the cockpit), the seat harness should automatically release, possibly at the attachment point of the harness to the fuselage. The pilot would then be free to roll out over the cockpit sill and escape from the glider.

Further research.

Wolf Roger has commenced a study as to the value and practical problems involved in the lowering of the entire glider by parachute in an emergency.



Film sequence with the front of the canopy lifted by less than 6cms.



Jettisoning the canopy with a hinge at the rear of the canopy. The canopy Is flying clear of the pilot and tailplane.

OSTIV Sailplane Development Panel

Oerlinghausen, Germany; September 1992 Chairman -

Prof. Piero Morelli

Aviation Medicine Notes

Note 1. Proposed Emergency Unassisted Escape System.

Note 2. The Risk of Deep Vein Thrombosis in Glider Pilots, Especially as Related to a Steeply Raked Seatpan Angle.

Note 3. Resonance Frequency of the Glider Undercarriage, and the Pilot's Body.

Dr. Antony M. Segal
September 1992

Note 1: Proposed Emergency Unassisted Escape System

Professor Dr. Ing. Wolf Roger and his colleagues from Fachhochschule Aachen, Germany, have carried out a numerical survey and experimental studies on the factors involved in pilot emergency escape from the present generation of gliders.

The success rate of pilots attempting to escape was 60 per cent; the remaining 40 per cent died. Without an automatic parachute, the lowest height at which anyone survived was 500 metres (1600 feet). Using a parachute operated by a static line, the lowest height for survival was 200 metres (650 feet). The use of a static line is controversial, as it may become tangled with the glider structure.

Because of these findings, the SDP will be considering the possibility of lowering the glider airframe on a parachute, the pilot remaining in the cockpit. My proposal discusses an improved method of unassisted pilot escape from the cockpit.

Two factors, not mentioned in Wolf Rogers report, may make escape more difficult. Following severe damage to the glider, it may enter a vertical dive, a spiral dive, or rotate around one or more of the three glider axes in an irregular manner. The resulting G loading on the arms may make movement of the unsupported arm progressively more difficult; this problem begins above 3G. Rapid irregular rotation in any axis will cause degradation of vision for objects both inside and outside the cockpit. This is due to the semicircular canals of the vestibular system in the ear signalling inappropriate information to the external muscles of the eye. This results in "smearing" of the visual image on the retina. The canopy emergency jettison handles may therefore ndt be clearly seen. (This mechanism is called the vestibular-ocular reflex.)

The following suggested escape system is based on Wolf Roger's study, and also on the techniques used in military ejection seats.

1) The cockpit still should be as low and as long as possible, consistent of course with the strength and crashworthiness of the fuselage. The cockpit sill should be free of protruding pins and levers.

2) The instrument panel should be of the mushroom type, situated on the centre line of the fuselage. Alternately, it could be replaced entirely by a Head Up Display.

3) The canopy should be attached at its aft (rear) end to the fuselage by a hinge that disengages at an angle of 30° to 40°.

4) When the emergency release is operated, a system of gas filled struts or springs should raise the front of the canopy as high as possible into the airstream.

5) The emergency activating handle should be situated between the pilot's legs, as in military aircraft. This position should be standardised in all gliders. In this position, it will be easy for the pilot to locate and reach the handle under conditions of G loading. The handle should require a double action, to prevent inadvertent operation.

6) On operation of the emergency activating handle, the canopy should release and fly clear of the cockpit. From my study of the diagrams in Wolf Roger's report, I consider 1.5 seconds should be allowed for the canopy to clear the cockpit. This figure will need to be checked by Wolf Roger.

7) Immediately after this time delay, the seat harness should automatically release. The release of the harness could take place at the attachment point of the harness to the fuselage.

8) The pilot would then be free to roll out over the cockpit sill and escape from the glider.

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Colour Coding of Canopy Emergency Release Handle

In aircraft, emergency controls are coloured black with yellow stripes - this is the most easily seen colour combination.

In gliders, the emergency handle is coloured red, and the launch-cable release knob is coloured yellow. In the general population, 1/50 is red colour blind. A further 1/100 only recognise red with difficulty.

The Farnborough Gliding Club have placed a small plate on the glider structure behind the emergency handle (the emergency handle remains coloured red). The small plate is coloured black with yellow stripes. I consider this measure is to be recommended.

Dr. Antony M. Segal
20/8/92

Note 2: The Risk of Deep Vein Thrombosis in Glider Pilots, Especially as Related to a Steeply Raked Seatpan Angle

Modern low-profile gliders commonly have a very steeply raked seatpan. The attached diagram, (Bild 10) copied from a report by Dipl. Ing. Martin Sperber, clearly shows this in regard to the eight named gliders. Martin Sperber has carried out an experimental study on preventing "submarining" of the pilot in an accident, by using a steeply raked seatpan in conjunction with a correctly positioned four point seat harness. These factors make a possible medical complication of this steep angle worthy of study. This complication is deep vein thrombosis.

Deep vein thrombosis is a condition in which blood clots form in the veins situated deeply in the calf or the thigh. If these clots break off, they travel in the blood vessels, via the heart, to the lungs - here they cause a condition called pulmonary embolism. This can be a very serious condition.

There are many pre-disposing factors favouring the development of a deep vein thrombosis. In this report, I will only discuss those relating to aircrew and passengers. Virchow, in 1856, proposed a triad of conditions favouring the formation of thrombi:

- changes in the coagulation mechanism of the blood
- damage to the lining of the blood vessel
- reduction in the blood flow (venous stasis)

(A fourth component is now added, the fibrinolytic state of the patient.)

Prolonged sitting may cause thrombosis. Venous blood flow may be reduced by two thirds when sitting. This situation is made worse by pressure of the edge of the seat on the calf. Thrombosis has developed on a flight as short as 4 hours. More commonly, it occurs in passengers on very long haul flights of 15-16 hours, with restricted seating space.

The steeply raked glider seat and the semi-recumbent seating position will have several effects. The return of venous blood from the legs will be improved. Against this, there will be local compression of the calf veins, and pooling of blood in the veins in the pelvis. This should, therefore, lead to an increased risk. The magnitude of this risk is difficult to assess. It would not be ethical to carry out an experimental study, owing to the serious risk to the person involved.

During the prolonged circling and associated banking involved in gaining height in thermals, there is an increase in G loading. This will adversely affect the movement of venous blood from the legs.

During the course of a gliding flight, the legs are fairly immobile, only slight rudder pedal movements being made. This favours stasis of the venous blood in the legs.

Many glider pilots are of an older age group. The risk of thrombosis increases above the age of 40 years.

Local injury to the vein or a previous episode of thrombosis makes a further attack more likely.

Immediately after a surgical operation, the risk of incurring a deep vein thrombosis may be as high as 30 per cent. Three weeks of full mobility is the minimum before flying as a pilot.

In pregnancy, there is a five-fold increase in risk of thrombosis as compared with non-pregnant females. This is only significant after the first three months. Modern low-estrogen contraceptive pills carry a negligible risk.

It is generally accepted that dehydration should be avoided, as it increases the viscosity of the blood and hence the risk ofclotting. (One interesting study showed that excessive fluids given by the intra-venous route also increased the risk of clotting. However, I consider this is a special case, and does not apply to fluids taken in normal quantity by mouth.)

Many general illnesses are associated with an increased risk of thrombosis, but aircrew would not be flying if they were affected.

Incidence of deep vein thrombosis.

It is difficult to assess the incidence of deep vein thrombosis in the general population, especially as the diagnosis may be difficult. The death rate from pulmonary embolism in England and Wales gives a guide - 1/10000 men and 1.5/10000 women a year.

At London Airport, Heathrow, over a three year period, 18 per cent of the 61 sudden deaths in long distance passengers were due to pulmonary embolism.

In the UK, the incidence of deep vein thrombosis in military and civilian aircrew is negligible. A very few airline pilots have been affected, but no more than would be expected in the general population. This is difficult to explain, in view of the long flights on autopilot with limited leg movements, and the age spectrum of commercial pilots. (Flight deck crew do get up and walk around, which must help.)

A research paper from the USAF reports deep vein thrombosis in three military transport pilots - all three returned to flying duty.

There is little information available on the incidence of this condition in gliding. The British Gliding Association have no record of a case.

Prof. Dr. R. Henn, an aviation pathologist, had no record of a case in Germany.

Conclusion

Glider pilots have many of the risk factors associated with deep vein thrombosis. However, the actual incidence appears to be very low indeed. It is possible that cases have occurred and not been recorded. I consider it advisable to avoid excessive rake of the glider seatpan, to avoid adding to the known risk factors. Short pilots, and this will include many women pilots, will be at especial risk due to the venous stasis induced by the steeply raked seatpan.

References on page 16

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"Gesamtruckhaltesysteme in Segelflugzeugen"
report - TüV Rheinland, Cologne, Germany.
1991

Types of Glider: (LS4, LS6, LS7, DG600, ASW20, ASW24, Discus, Ventus)
Super-Imposed Outline of Seatpan Shapes

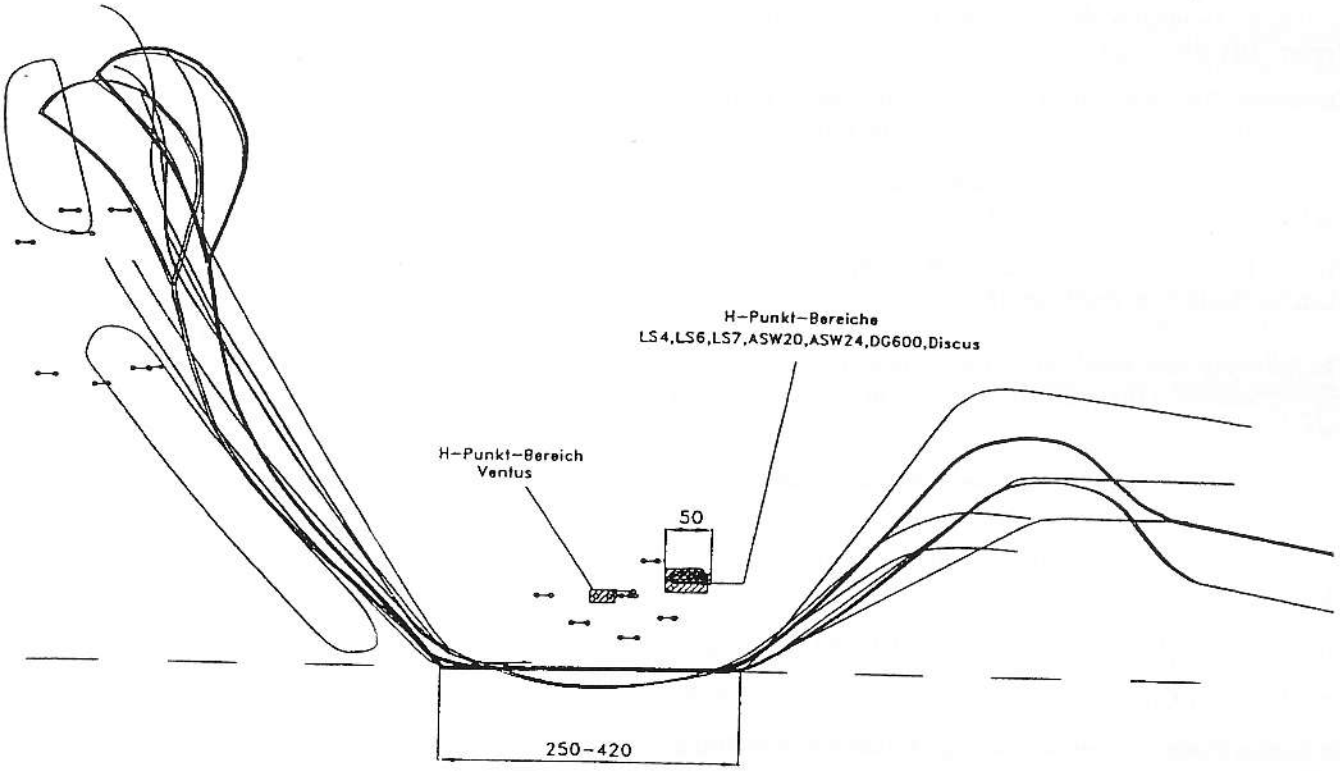

Bild 10: Uberlagerung aller vermessenen Sitzschalen

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The following have kindly given advice in private correspondence. (The opinions expressed in the report are my own.)

Air Cdr. A J C Balfour (ret). RAF Institute of Pathology and Tropical Medicine, Halton

Dr. H C Drysdale. RAF Institute of Pathology and Tropical Medicine, Halton

Prof. Dr. Rainer Henn. Aviation pathologist. Icking, Germany

Dr. S B Janvrin. Civil Aviation Authority, UK

Dr. Sandra Mooney. Head Occupational Health Services, British Airways

Prof. 0. Zaffiri. University of Turin, Italy; consultant anaesthetist.

Dr. Antony M. Segal 21/8/92

Note 3: Resonance Frequency of the Glider Undercarriage and the Pilot's Body

A report on the Critical Consideration of Today's Landing Gear Design and Construction was presented by Mr. Ullrich Kopp (Luftfahrt-Bundesamt Braunschweig, Germany) at the 22nd OSTIV Congress, Uvalde, USA. Statistics provided by the German LBA showed that spinal injuries to glider pilots involved in heavy landings were increasing. This was despite steady improvement to landing gear. Mr. Kopp considered one factor involved was the low load tolerance of the seated pilot in the z-axis at 5 Hz. (See Fig. 1, ref. 1)

This Note discusses the significance of the resonance frequencies of the pilot's trunk, spine, and abdominal and thoracic organs. I am grateful to Dr. J R R Stott (Medical Officer Research, RAF Institute of Aviation Medicine, Farnborough) for his help and advice. I am, of course, responsible for the opinions expressed in the Note.
Mechanical impedance is a measure of the potential to absorb vibrational energy. Mechanical impedance (Z) is defined as the ratio of the peak oscillatory force (F) exerted on an object by a source of vibration, to the resulting peak velocity (v) measured at the point of contact with the vibration source.

$$Z = \frac{F}{v} \quad (\mathrm{N.s.m^{-1}})$$

The mechanical impedance of a seated subject is shown in Figure 2 (ref. 2). This shows two peaks, at the frequencies of the first and second whole-body resonances. The first peak, at 4-5 Hz, is due to resonance of the shoulder girdle, and the liver/diaphragm/mediastinum (the mediastinum contains the heart) within the body cavity.

A trough then follows, due to compression of the soft tissues of the buttocks, and flexion of the lumbar spine, isolating the upper trunk from the source of the vibration.

The second peak is at 12-15 Hz. This is due to axial compression of the pilot's trunk, damped by the elastic properties of the spinal column and its supporting muscles (this is a theoretical explanation without direct supporting experimental evidence).

The shape of the impedance curve is modified by the posture, type of seating and restraint system, and by G loading (at 3 G the first peak is moved upwards to 8 Hz). Impedance curves are used for the calculation of theoretical models of vibration-protection systems, such as seats. They can not be used to calculate the properties of single parts of the human body, such as the spine. Also, the system being tested (the human body) must remain in constant contact with the vibration transmitting surface (the seat). Finally, parts of the body that are close to the site of entrance of the vibration influence the impedance curve to a greater extent than body parts that are further away.

Mechanical vibration models for the seated subject are shown in Figure 3 (ref.2). The single mass/spring/damper system demonstrates the effect of frequencies up to 10 Hz, so including the first whole-body resonance.

The double mass/spring/damper system demonstrates the effect of frequencies up to 13 Hz, so including part of the second whole-body resonance.

The seven mass/spring/damper system would come close to reality but would be very complicated.

These models cannot be used to determine the effect of vibration on single parts of the human body, such as the spine.

The following information on the effect of vibration on single parts of the human body in the seated position is based on Chapter 5, "The Effects of Mechanical Vibration" from the book *The Effects of Whole Body Vibration* by Dupuis and Zerlett (ref. 2). This gives a detailed and critical account of the relevant experiments. The effect on the lumbar spine, the head and neck (cervical spine), and the internal organs will be discussed.

Vibration behaviour of the Lumbar Spine-seated position.

The distance between the vertebral spinal processes of L3-L4 and L4-L5 were measured at a constant acceleration of 5.0 m/s/s. At 12 Hz, there were changes of the relative positions of adjacent vertebrae of 0.05mm. At 4-5 Hz (the resonance frequency), there were changes of the relative positions of adjacent vertebrae of 0.6mm

A Dr. W. Christ used himself as an experimental animal, and had wire marker pins temporarily implanted in the spinal processes of thoracic vertebra T 12, and lumbar vertebra Ll-L4. The ends of the pins were marked, and filmed during the course of the experiment. (This technique meant that the test subject was not exposed to prolonged X-ray radiation.) The input vibration displacement was 5mm. The frequency range was 0.5 - 8.0 Hz. The lumbar spine had a resonance between 2 - 6 Hz, with a maximum at 4 Hz. There was another interesting finding, the lumbar vertebrae also moving in the x axis. L4 showed the greatest displacement in the x axis. The vertebrae also rotated in the vertical z axis. T 12 vertebra was the most mobile in rotation. The maximum rotational change occurred at 3-5 Hz. (Fig. 4, ref. 2)

Vibration behaviour of the Head and Neck - seated position.

Vibration transmission from the seat to the head was studied. The transmissibility factor V increased steeply to 4-5 Hz, then decreased steeply, as shown in Figure 5 (ref. 2). At the resonance frequency, more of the vibration was transmitted to the head. Outside the resonance frequency, the vertebral column acted to absorb the vibration being transmitted to the head.

If a seat-back and headrest was used, more of the vibration energy was transferred directly to the head, bypassing the vertebral column.

In a further experiment using a seat-back, the seat-back angle with respect to the horizontal seat surface was varied from 90° to 140°. With an angle of 90° - 105°, and the head leaning against a headrest, there was almost no change in the transmission of vertical vibration to the head. When the angle was increased to 140°, there was a considerable decrease in the transmission of vertical vibration to the head. (This is a cosine change.)

Dr. W. Christ's experiment (see above) also showed the effect of vibration on the cervical spine. Resonance occurred in the frequency range 2.5 Hz - 5.5 Hz. (See Fig. 4, ref 2.)

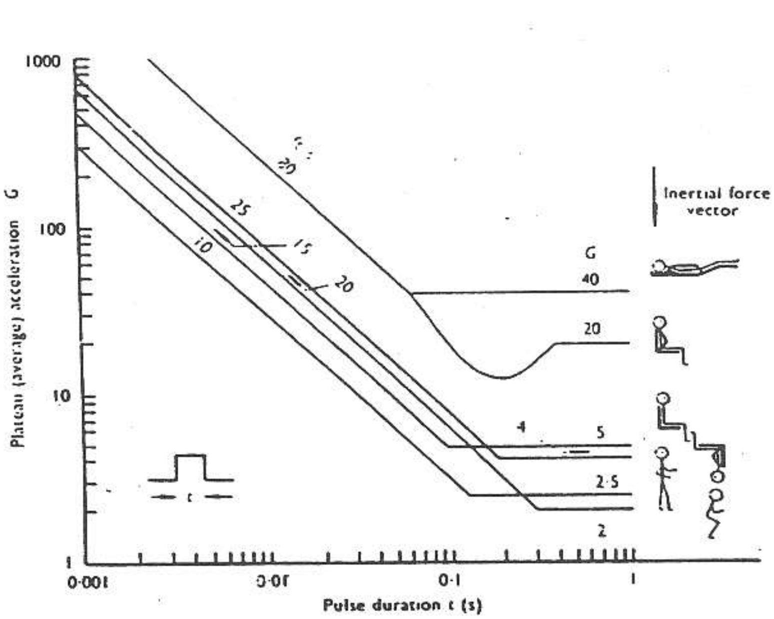


***Fig.1*. Tolerance to whole body impact in the attitudes and restraints illustrated in the inset diagrams. The inertial force vectors shown are generally perpendicular to the Earth's surface.**

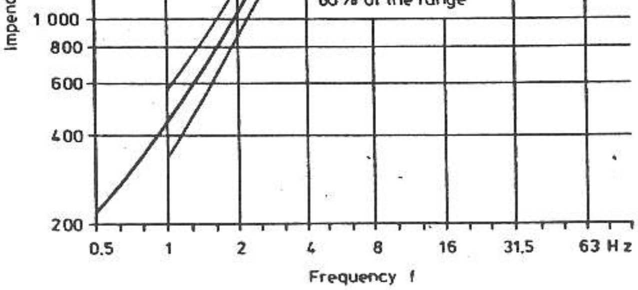


Fig. 2 . Impedance of the human body in the sitting posture (ISO 5982) Sinusoidal vibration with acceleration amplitudes of 1.0 - 2.0 m/s^2 .

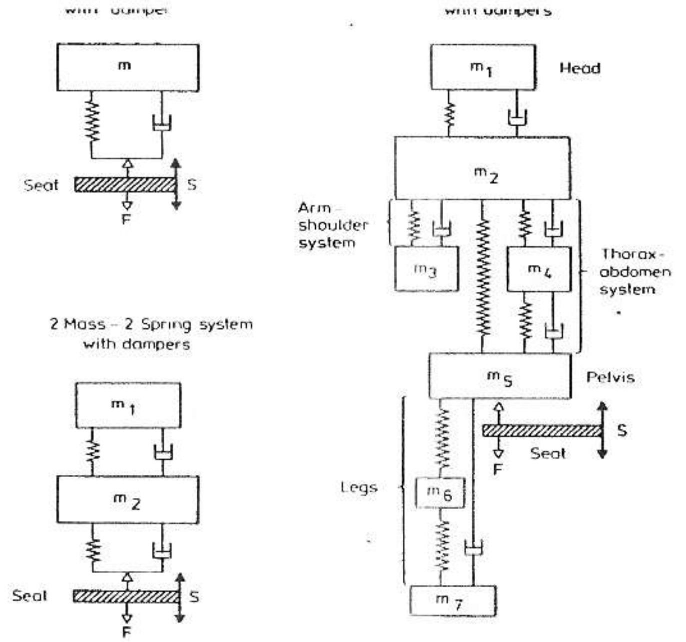
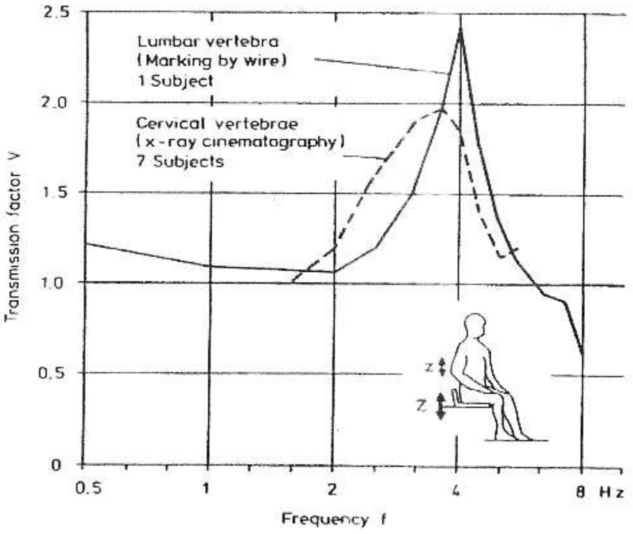


Fig. 3 . Mechanical vibration models for the human body in the seated posture [adapted from Dieckmann (1957, 1958) and Coermann (1963, 1965)]

Fig. 4. Frequency-dependent vibration transmission from the seat to the lumbar spin (*LS*) and cervical spine (*CS*) in the vertical direction z (Dupuis 1969)



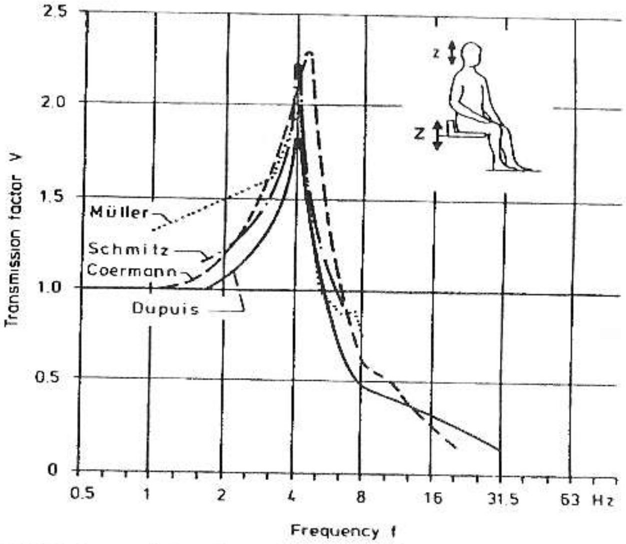


Fig. 5 . Frequency-dependent vibration transmission from the seat to the head in the vertical direction z (Müller 1939; Schmitz 1959; Coermann 1963; Dupuis 1969)

Vibration behaviour of the Internal Organs - seated position.

In humans subjected to vibration in the z axis, the liver, diaphragm and mediastinum (the mediastinum contains the heart) vibrated as one unit. The resonance frequency was 3Hz - 5Hz, with a damping factor of 0.2 - 0.25. Occasionally, another peak was seen at 7Hz - 10Hz. Variation in tension in. the abdominal wall resulted in variation in the peak frequency.

The vibration of the stomach was maximal at 4hz - 5Hz. This coincided with the whole-body vibration. It was not possible to determine the independent vibration resonance frequency of the stomach.

Vibration of the internal organs

Experiments on dogs showed a resonance of 4Hz - 5Hz in the z axis. The resonance frequency in the x and y axes was higher, at 9Hz. This was due to the low mobility of the viscera in the x and y axes caused by the presence of the ribs, vertebral column, and the pelvis.

Conclusion

The resonance frequencies of the seated human submitted to vibration in the z axis are as follows.

First whole-body vibration	4-5Hz
Second whole-body vibration	12-15Hz
Lumbar spine	4-5Hz 2-6Hz (maximum at 4Hz) (Different experiments)
Head and neck	4-5Hz 2.5-5.5Hz (Different experiments)
Internal organs	3-5Hz sometimes, a second peak at 7-10Hz

Resonance in the x and y axes will be at 9Hz, or somewhat lower. The mobility of the viscera is lower in the x and y axes, than in the z axis.

References.

1. Glaister D H. Human Tolerance to Impact Acceleration. *Injury. The British Journal of Accident Surgery*. Vol. 9/ No.3. 1977.

2. Dupuis H., Zerlett G. *The Effect of Whole Body Vibration* Springer Verlag, 1986.

3. Ernsting J., King P. *Aviation Medicine*. Butterworths. 1988.

4. Griffin M J., et al. "The Biodynamic Response of the Human Body and its Application to Standards". University of Southampton. *AGARD Conference Proceedings* No. 253. 1978.

Cautionary note.

The report by M J Griffin (ref. 4) points out the extreme variability of the human response to vibration in the z axis, in regard to its transmission to the head. There is a difference in transmission between men, women, and children. Body weight was significant. Transmission also varied in the same subject. Posture, muscular tension, thigh position, and head position all had an effect. One experiment used a Sea King helicopter seat and harness. Transmissibility was increased at 16, 32, and 50Hz, but decreased at 2Hz. The shape of the vibration pulse also affected transmission.

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