ESCAPE AND SURVIVAL

CLINICAL AND BIOLOGICAL PROBLEMS IN AERO SPACE MEDICINE

Editor
P. BERGERET

ESCAPE AND SURVIVAL:

Clinical and Biological Problems in Aero Space Medicine

Edited by
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BIOLOGICAL PROBLEMS OF ESCAPE AT HIGH ALTITUDES

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RÉSUMÉ

Les travaux expérimentaux sur l'évacuation du bord aux grandes altitudes sont difficiles à réaliser parcequ'elle met en jeu des contraintes qui ne peuvent être toutes réunies lorsqu'elles sont simulées au sol—par ailleurs les essais en vol sont coûteux.

Séparément cependant, ces contraintes ont été étudiées, mais bien que l'on dispose de nombreuses données physiologiques concernant la réaction de l'organisme, notre connaissance en ce domaine comporte encore des lacunes. Ces contraintes sont brièvement passées en revue et l'une des "expériences" les plus complexes qui aient été réalisées à ce jour, à savoir, une évacuation réelle au-dessus de 50.000 *ft* (15.000 *m*), *est décrite.*

Les problémes d'évacuation dans l'avenir, sont évoqués.

EXPERIMENTAL work of a biological nature on escape at high altitudes is difficult to undertake, for stresses are involved which cannot be simulated in combination on the ground. Flight experiments are extremely costly and are limited in that they can seldom be done up to the limits to which contemporary aircraft are operating. An important series of live experiments in recent years are those of MAZZA[1] and later of SPERRY NIELSEN and BARASH.[2] Other experiments have been undertaken by firms and organizations concerned with the development of ejection seats. Here, however, biological data has been of secondary importance, and the aim has been rather to ensure the satisfactory working of the machine.

At the present time, by far the most important means of escape from aircraft is the ejection seat, and some of us believe that it should be available to all aircrew in military aircraft. Moreover, it is likely to remain an essential device for very many years. It is therefore this means of escape that is principally under consideration in this paper.

Despite experiments such as those just mentioned, and despite the test work undertaken by the development organizations, escapes often occur in practice under conditions which in some measure exceed the range of biological experiment, and even sometimes of mechanical experiment. Much of our knowledge, and therefore much of the needs of development, come from the user of the escape device, who, by taking a major risk in circumstances which would otherwise be fatal to him, undertakes an experiment which could not be justified in a research and development programme. The first point therefore is that the biological test programme regarding improved ejection seats is undertaken mainly by the squadron pilots of the air forces, and that scientific experiments elsewhere complement the knowledge so gained. The corollary is that a careful analysis of successful or unsuccessful ejections is of much importance.

Escape by ejection seat at high altitude exposes the man to a series of physical insults about which our knowledge is incomplete. Of particular interest, the following may be briefly considered.

Rapid decompression. There are various ways of leaving pressurized aircraft. Ideally, if time allows, the aircraft will be slowed down, the pressure let out, the cockpit cover jettisoned and the seat fired. This ideal sequence may, for various reasons, be impractical, and the whole action may be telescoped into a very few seconds, so that a rapid change in pressure will be associated with exposure progressively to wind blast with resulting pressure gradients, and a series of linear and angular accelerations. These circumstances lead to a complex picture which cannot be readily broken down into sections which are subject to experimental investigation on the ground. Even so, a knowledge of the individual stresses is of value.

Experiments on rapid and explosive decompression have been undertaken by many workers and it is not intended here to give a review of this subject. It may be said however that no precise limit can be stated as a dividing line between safe and dangerous degrees of pressure change, and that insufficient knowledge is available with regard to the degree of protection, or the converse, brought about by personal equipment. It has for a long time seemed that means of assessment of the protection afforded by personal equipment against rapid pressure change is a fruitful field for research.

The risks of hitting a fast moving air stream will not be considered here; for though this is indeed a problem, the difficulties at any given speed are much greater at low altitudes than at high altitudes. It should however be noted that the loss of equipment at high altitude may have a much greater penalty than lower down, due to the need to supply oxygen and pressure.

After escape at high altitude there are many reasons for coming down as quickly as possible; the effects of cold, and anoxia, to name two of them. Moreover opening a parachute of the standard type at high altitude is not without major risk. Therefore, after abandoning the aircraft, descent should be as fast as possible. The disadvantages here are two-fold, namely, the chance of barotrauma which can be accepted, and the risk of spinning which cannot be neglected.

A body shaped like one half of a cylinder split longitudinally, falling through the air, is acted on by aerodynamic forces which will develop a spin around an axis at an angle to the long axis of the cylinder; and, within limits, the further the body falls the greater may be the rate of rotation, with the overriding consideration that it will be greater with higher speeds of fall. It has been shown that the human body acts similarly, and that in a fall from 40,000 ft high rates of rotation can be achieved.[2] It has further been demonstrated that the rates produced can have definite pathological effects.[3] It is necessary, therefore, to stabilize the man during descent while at the same time allowing him to fall as quickly as possible. These are compatible requirements, for a man unstabilized falls quite slowly due to the large area he presents.

Cold is another stress of particular significance in high altitude escape, and while, at present altitudes, there appears to be little risk of death due to exposure, frostbite is a real hazard. This is a fruitful field for research, for the thermal balance of a man at very low temperatures is not well worked out and, where the air is rarefied, thermal exchange is largely by radiation. While such work is for the future, even at present day altitude we have little experimental evidence of the risks from frostbite in an air stream of high velocity, or indeed the potential effect of anoxia on this condition, though WEBSTER and SMEDAL[4] have laid down clear rules. It should be remembered too that this exposure to cold may, if the aircraft has been flying really fast, follow a brief exposure to severe heating.

Anoxia is, of course, a major hazard of very high altitude escape but little will be said here with regard to it, for the principles of protection are clearly understood, and the practical problems are those of stowage of supplies and maintaining the integrity of the equipment.

Decompression sickness may also be dismissed briefly—but with the statement that there is practically no published work on the incidence or effects of this condition during brief exposures to extreme altitudes using partial pressure equipment of greater or less coverage. There is a potential field of research here.

A recent escape from high altitude serves as an example of some of these problems:

A Canberra aircraft exploded at a height of 54,000 ft and both aircrew escaped by use of the ejection seats.

These seats were of an early pattern, embodying a modification which makes them fully automatic. However the modification is not ideal in that the seat separates from the man immediately after ejection—the man then falls unstabilized until the parachute opens automatically below 13,000 ft. The bailout oxygen supply is not pressurized. In this particular event the aircrew concerned have memory for only part of the incident. The pilot, though disorientated by gyration of the aircraft, remembers firing his ejection seat and a generalized misting of the cockpit while doing so. He remembers no more till he regained consciousness, spinning violently, his arms and legs being stretched outwards by forces which he could not overcome. Eventually his parachute opened and he saw the lines twist and untwist as the direction of rotation reversed. He lost his left glove during the fall and the right sleeve of his clothing had to be cut to allow his swollen hand and wrist through the sleeve.

The navigator also remembers the aircraft gyration and the misting, and difficulty in reaching the handle which jettisons the canopy. He does not remember jettisoning the canopy or firing the seat, but must have done so effectively. He came to, falling in a gentle spiral—spread-eagled face downwards. He saw that his hands were frozen and tried to protect them by folding his arms. He had not been wearing gloves.

The results of this adventure are shown on the slides, for which I am indebted to Air Commodore G. H. Morley [here follows a brief description of the slides].

This talk has been principally concerned with escape by means of ejection seats of present-day type. In the future, developments will progress in proportion to aviation development, and it is not too difficult to predict special forms of escape device being built into satellite and space craft. There will be a trend to enclose the ejection seat or use it in conjunction with full pressure suits. Escape devices such as jettison cabins have a place in future aviation and appear attractive at high altitude—and the higher one flies the more attractive they become, until in space there appears to be practically no alternative. Jettison cabins have been developed more slowly than might be expected. This is due to 3 factors—their specialized nature, the difficulties of a test programme and the inherent difficulty of escape from low altitudes. If they are to be used, it is likely that they will be fitted with ejection seats for escape at low altitudes, where the necessary "split second" timing must inevitably lead to a large weight penalty if a complete capsule is to be controlled.

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ESCAPE FROM AIRCRAFT AT HIGH SPEEDS AND LOW ALTITUDES

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RÉSUMÉ

Exposé des recherches expérimentales récentes sur l'évacuation du bord aux basses altitudes et état actuel de la question.

Le problème de l'ouverture du parachute aux grandes vitesses constitue une difficulté fondamentale aux vitesses inférieures à 600 milles/heure. Les questions relatives à la protection physique contre la "gifle" et les forces de décélération élevées sont ensuite étudiées pour des vitesses allant jusqu'à 800 milles/heure.

INTRODUCTION

THE results of ejections from aircraft near ground level have in the past been very unsatisfactory, and while high speed ejections have safely taken place, they have mainly taken place at relatively high altitudes where the Mach number was high but the indicated airspeed was relatively low.

In considering escape from an aircraft by means of an ejection seat, the height, speed, aircraft behaviour and attitude are the significant factors, and when dealing with escape at high speed, and low level, the latter is of fundamental importance.

SOME CONSIDERATIONS ON EJECTION

To study the effects of the aircraft flight path at the time of ejection, upon the lowest height at which a safe escape could be made, a series of tests was carried out in the United Kingdom.

Fully representative dummies were ejected from a Meteor aircraft flying at 50 ft above ground level and at speeds up to 600 m.p.h., the aircraft flying straight and level at the time of ejection. A series of lights were placed along the track of the Meteor, 100 yd apart, and using a wide angle lens camera it was possible to get a complete record of the dummy's behaviour throughout its flight with a simple distance-measuring system already superimposed upon the films.

From these tests it was found that the dummy travels approximately 1100 ft before it actually hits the ground when ejected at 600 m.p.h. This is represented in Fig. 1.

There is virtually no difference in the decelerations involved, time taken and distance covered, should this test have been carried out in

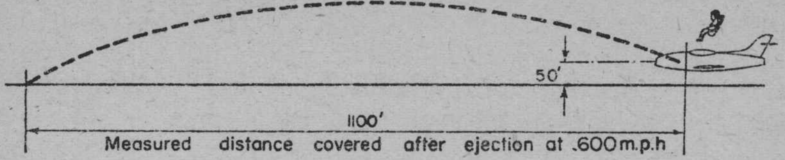

Fig. 1. Measured distance covered after ejection at 600 m.p.h.

the vertical plane—the main difference being that of 1G, which at these loads is of little real practical implication.

So that if one plots a curve of 1100 ft radius from the point of impact of the dummy, then, as shown in Fig. 2, the effect of the flight path of the aircraft at the time of ejection can be correlated with the minimum safe height at which ejection could take place. Thus a seat which in one set of circumstances gives a facility for ground level escape may require a fairly large height allowance in different circumstances.

One of the reasons for the failure to escape near the ground is therefore obvious, and with higher speeds both the horizontal line in Fig. 2 and the vertical line will move farther away from the impact point, for with higher speeds more time must be allowed for deceleration prior

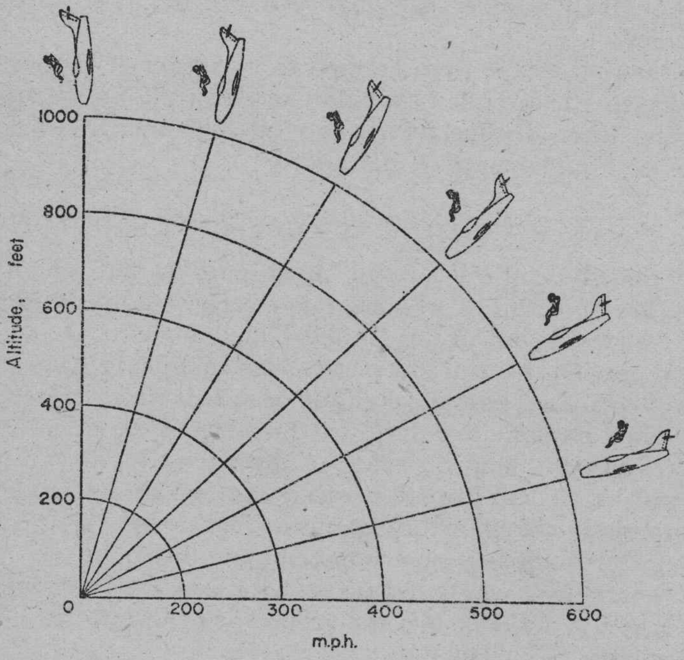

Fig. 2

to canopy development. Yet, while the human body can withstand much higher linear decelerations for short periods than it experiences with the present ejection principles, the parachute canopies will not, and so it is desirable that an improvement be looked for in this field.

Before dealing with canopy deployment, perhaps it would be logical to consider two other factors which precede this in ejection sequence.

Firstly, the need for cutting down time to an absolute minimum, in getting away from an aircraft once ejection has been decided upon, and secondly, the protection against blast at high indicated air speeds consequent on ejection and while deceleration is taking place.

EJECTION CONTROLS

When a pilot abandons an aircraft quick action is vital and the escape facilities of aircraft must not prejudice the chances of emergency escape. We are all too fully aware of pilots using up vital time operating hood jettison gear and other devices, then being left with insufficient time to escape.

When escape becomes necessary, quick action is of paramount importance. There must be only one control which a pilot is required to operate to achieve this escape. Stick snatching and power operated hood jettisoning must be linked to the ejection seat operation in a manner which will ensure safe and speedy ejection by the operation of the seat firing mechanism only.

PROTECTION AGAINST BLAST AT HIGH INDICATED SPEEDS

Having left the aircraft, then, the body must be protected from the damaging effects of air blast and the seat slowed down with acceptable deceleration to a speed at which it is safe to deploy the parachute.

Some time ago an R.A.F. pilot ejected at 25,000 ft. at an indicated Mach. No. of 1.1. The seat was an early model and did not have leg restraint, nor was the canopy jettison system and ejection seat mechanism interlinked. Due to this and the fact that he did not have full blind protection, he sustained a broken arm, two black eyes and a pelvic injury.

Had he had the facilities of the latest type of seat, i.e. interlinked canopy jettison and automatic leg restraint, then his injuries would have been prevented.

The automatic leg restraint, firing handle grip and face screen provided in the latest Martin Baker seats seem to give satisfactory protection up to speeds in the order of 600 m.p.h., and the need has not yet arisen for any further body protection.

When considering probable ejection speeds it is well to study the reports of ejections to date. From this it is seen that ejections at the higher speeds of aircraft capability are rare and somewhat exceptional. Pilots wishing to escape will, if possible, reduce speed; a reduction in speed will also result from the rapid rise of drag in an aircraft breaking up following air collision or structural failure. Although it is right and proper to cater for the highest speed it will invariably be found that most emergency ejections will lie in the more modest speed ranges, between 40 per cent and 80 per cent of the aircraft top speed.

However, as probable ejection speeds increase, there is a need to provide additional body protection, particularly in the chest region, and this could be provided for in the seat structure.

THE DEPLOYMENT OF THE PARACHUTE

Having got the man safely from the aircraft and protected from blast, the problem is two-fold.

Firstly to reduce rapidly, with acceptable deceleration, the speeds of the ejection to a speed at which it is safe to deploy the parachute and, secondly, at the same time prevent explosive opening of the canopy which is so damaging and which in itself can be fatal.

In the latest mark of ejection seats in service in the UK, these two aims are met by the use of the Martin Baker Duplex Drogue system.

The Duplex Drogue scheme employs two stabilizing drogues in tandem, a small drogue, known as the controller drogue and a larger main drogue. The controlled drogue is automatically extracted by a drogue gun after ejection, and, when deployed, brings the seat back into a horizontal attitude and then tows the main drogue out of its container. The main drogue then streams the main parachute, which, when developed, lifts the occupant out, the seat falling cleanly away.

The action of the controller drogue secures two indispensable aims, firstly to get the seat into a horizontal attitude so that the subsequent deceleration on the seat and occupant is linear and consequently more tolerable; secondly, and most important, it prevents explosive opening of the main drogue.

In tests when a 5 ft diameter drogue was deployed at 600 m.p.h. at a height of 150 ft without a controller drogue, it was torn to shreds. Also, the large drogue produced such violent loads that the face screen was torn and the seat harness shoulder straps were broken.

Tests done with a controller drogue were all satisfactory, none of the components showing any signs of distress.

In the latest seats, the time release mechanisms are fitted with a sensing device which automatically selects the time required for safe deployment of the parachute to meet the conditions of height and speed prevailing at the time of ejection.

Finally, I would like to mention the possibility of using a capsule or pod for ejection.

The capsule would have to accommodate the crew and all flight facilities and provide instant separation cleanly in emergency.

After separation, the aerodynamic performance is vital. Stabilization and retardation must be arranged. The capsule must be landed or the crew ejected from it and brought down safely by parachute. Time would be required for this deployment, and although obvious advantages would accrue from the use of a capsule at extreme altitude, it would seem to be quite impossible to do a low escape, near ground level, with a capsule.

PARACHUTIST'S SPIN PROBLEM

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RÉSUMÉ

Les divers paramétres qui déterminent un degré de liberté d'auto-rotation sont analysés pour différentes configurations. On démontre la vrille libre à plat effectuée par une maquette cylindrique placée dans un écoulement d'air vertical. L'estimation de la vitesse de descente en vrille d'un parachutiste, tombant en chute libre à partir d'une grande altitude, est faite en utilisant les coefficients de moment de vrille obtenus avec une figurine de parachutiste effectuant une auto-rotation. L'auteur présente une rapide analyse des méthodes permettant de surmonter les causes fatales de vrille.

PROBLEM AND APPROACH

THE Aeronautical Research Laboratory of the Air Force Research Division was recently informed of the hazardous flat spin conditions that a parachutist is likely to encounter during a free fall from high altitude. Some small scale laboratory tests were conducted for the purpose of gaining an understanding of the flat spin phenomena of man and, if possible, to find means of eliminating this hazard to high altitude escape.

The problem was approached through a study of the autorotation characteristics inherent in different configurations, including man.

A motion picture was made of these experiments. In one test a spin axis is inserted into the model under investigation and this shaft is supported by ball bearings which are mounted in a slender tube. Thus, the model is allowed to rotate with one degree of freedom. A blower furnishes a uniform wind which is directed parallel to the spin axis. The conditions can be demonstrated which make a model autorotate under the influence of the wind, and which conditions would prevent auto rotation. The wind blows in a horizontal direction in this test set-up for convenience only. The wind speed resembles the velocity of a free falling body.

Aerodynamically, the configuration of a man is pretty complicated. Therefore, simple shapes will be studied first.

LANCHESTER TYPE

A chart was made showing schematically the aerodynamic spinning moments versus spin rate coefficient for a group of configurations which, for historical reasons, will be called "Lanchester Type".

The classical "Lanchester Aerial Tourbillion", known to aerodynamicists for approximately 50 years, is a half cylinder with the flat side directed toward the wind. This configuration will not start to autorotate due to its stable equilibrium at zero spin rate and will come to a complete stop if a moderate spin rate less than the unstable equilibrium spin rate is forced upon the model. However, if a spin rate exceeding the unstable equilibrium spin rate is forced upon the model, then the spin rate increases under the influence of accelerating moments until the second stable equilibrium is reached at spin rate *B*. This latter spin rate is called the autorotation rate. Also, approximately half a century ago, Riabouschinsky found that a simple plane plate has qualitatively the same autorotation characteristics. A plate having the edges beveled reaches a very high autorotation rate. Also, an elliptical cylinder exhibits the Lanchester type spinning moment characteristics at least at the low Reynolds numbers of this test.

The last Lanchester type model is a rectangular solid.

All these models display qualitatively the moment characteristics which was shown on the chart. Certainly, the magnitude of the accelerating or decelerating moments is different for various configurations. Also, the value of the autorotation rate depends on the aerodynamic properties of the cross-section. The higher the lift-to-drag ratio, the higher the autorotation rate. For example, the autorotation rate coefficient 2·5 was observed for the plate with beveled edges. The last shown rectangular solid which had an aerodynamically poor cross-section—a rectangle 1 × 2—only reached an autorotation rate coefficient of 0·5.

DAMPING TYPE

The next model type had only one equilibrium, i.e. a stable equilibrium at zero spin rate. For any spin rate which may be forced upon this "damping type" of model there will always be a decelerating moment which will bring the model to a complete stop.

Some representative models of the damping type are as follows: A wedge with the edge directed toward the wind; a reversed Lanchester tourbillion with the rounded surface toward the wind; a cylinder and a combination of cylinder and wedge.

WINDMILL TYPE

Both Lanchester types and damping types exhibit characteristics which are desirable for a falling man; i.e., a stable equilibrium at zero spin rate. Unfortunately all these models can easily be converted into a "windmill type".

The spinning moment curve of the windmill type shows accelerating moments at zero spin rate and a stable equilibrium at a finite spin rate coefficient.

The elliptical cylinder, basically a Lanchester type model at low Reynolds numbers, will be converted into a windmill type by adding a little plate close to the spin axis. Comparison of this modified model with the parachutist model reveals that the plate is not larger than the model's hands.

The test showed immediate acceleration as soon as the model was exposed to the wind. It must be concluded that an unfortunate position and attitude of a hand could bring a falling parachutist into a flat spin.

Bodies with varying cross-section, man included, but still having a plane of symmetry, are likely to autorotate as soon as the spin axis is somewhat tilted out of the plane of symmetry. The combination wedge-cylinder model which was previously given as a damping type demonstrates this fact.

Also, a circular cylinder, known before as a damping type, can be converted into a windmill type. To do this, the spin axis must be displaced out of the plane of symmetry and be slightly tilted.

FREE SPIN

The autorotation of all of these models only indicates that the aerodynamic moments about the fixed spin axis are zero at a certain spin rate and that this condition represents a stable equilibrium.

The question now arises whether or not the observed autorotation is possible for more than one degree of freedom, as for instance, in the case of free fall where all degrees of freedom are released.

The free spin certainly is the subject of dynamic and aerodynamic considerations. With reference to the autorotating cylinder, this means that an aerodynamic force must be furnished by the flow to balance the centrifugal force which results from the fact that the center of gravity circles around the spin axis; or an aerodynamic moment must be available to balance the inertial couple which tends to align the body axis perpendicular to the spin axis.

The next test showed that this balance of forces and moments was possible. A circular cylinder, two diameters long, with the C.G. located at $\frac{4}{10}$ of its length from the leading edge was placed in a vertical wind stream. At first, the body axis is parallel to the wind vector. The wind velocity is adjusted so that the cylinder's weight is balanced by the aerodynamic drag.

Continuous limit cycle oscillations of the free floating model were observed. They are explained by non-linearities in damping. In fact, the model is dynamically unstable within a limited amplitude range.

However, it does not overturn because of its static stability. A flat spin cannot be expected under these conditions.

The model reveals its flat spin capability as soon as it is released into the windstream under a large angle of attack.

Dynamics and aerodynamics obviously make, under free floating conditions, a stable autorotation possible which is very similar to that shown previously with only one degree of freedom.

ONE DEGREE OF FREEDOM ROTATION OF MAN

A parachutist model was investigated. At first equipment and limbs are symmetrically arranged and the spin axis is in the plane of symmetry. With the experience gained from the tests with simple configurations, it must be expected that autorotation is impossible under these conditions. The test proved that the model does not start to rotate under the influence of the wind and also comes to rest again after a rotation is forced upon it.

Any asymmetry in the configuration makes the model autorotate. Autorotation in both directions results from clockwise or counterclockwise displacement of the feet.

Autorotation even with equipment and limbs symmetrically aligned occurred when the spin axis was tilted out of the plane of symmetry.

So far, we have dealt mainly with one-degree-of-freedom autorotation except for the case where a free spin of a cylindrical model was demonstrated.

It is also known that the configuration of man can spin in a free fall and the spin rates, which must be expected during a fall from high altitudes, will be discussed next.

SPIN RATE OF FREE FALLING MAN

The spinning moments acting on the $\frac{1}{10}$ scale parachutist model were measured for different spin rates. The results are shown in Fig. 1, in dimensionless form for four different combinations of body configurations and orientation of the spin axis. The spinning moment is expressed by the coefficient

$$C_m = \frac{M}{\rho/2\, v^2\, l^3}$$

and the spin rate by the ratio

$$\frac{l\omega}{v}$$

M = spinning moment in ft/lb.

ρ = air density in slug/ft³.