HUMAN PROBLEMS OF ESCAPE FROM JET AIRCRAFT

WG. Cdr. Ajit Nath

P.M.O., H.Q. Training Command.

The pilot and navigator of our Canberra aircraft shot down by the Pakistan Air Force had a miraculous escape from an altitude of approximately 47,000 ft. So far this is the highest ejection in the Indian Air Foce. About the same time last year, in April 1958, a R.A.F. Canberra B.6 with a Scorpion motor exploded at a height of approximately 56,000 ft. The crew ejected safely and lived to fly again. Similar hair-raising escapes from jet aircraft have been reported in other countries.

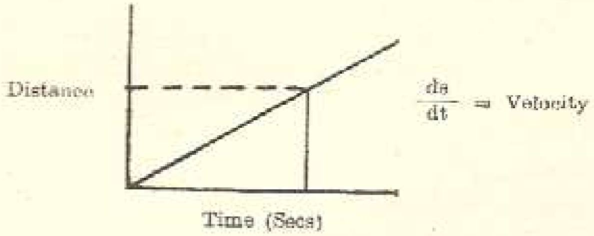
Escape from high speed aircraft was a dangerous hazard a few years ago. To-day, it has become such a safe and simple procedure that every jet pilot is given training and practical experience of ejection on the ground. The ejection seat has become not only an insurance against sudden disaster in the air, but also an important factor in raising the morale of pilots. There is some evidence to show that, since the introduction of run-way ejection mechanism, an increasing number of jet aircraft after flame-out (which would normally be abandoned in the air) are now landed safely. Pilots consider it a safe risk to bring a jet fighter into land with a dead engine, because they know that they can always escape even at the last moment. You can imagine the effect of such confidence on flying efficiency and morale of a pilot.

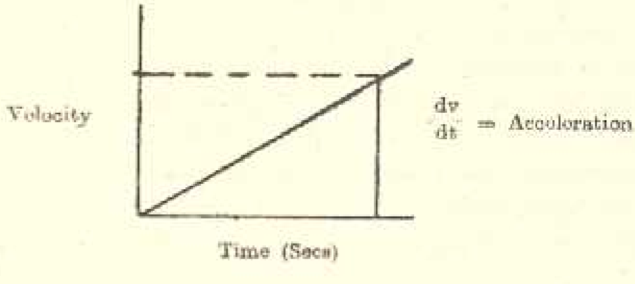
Like many other safety devices in the aircraft, the ejection seat is a piece of hard-ware which has been designed and perfected through years of combined research by aero-medical specialists and aeronautical engineers. The need for assisted escape or ejection from aircraft arose during the last World War when speed of aircraft increased rapidly. At speeds above 200 M.P.H. it was found increasingly difficult to bale-out. The wind blast and air turbulence near the exist push the pilot back into the aircraft, and acceleration forces cause severe limitation of body movement. In addition, there is grave danger of hitting the tail or some other part of the aircraft. These human problems of escape established the need for ejecting the pilot out of the aircraft.

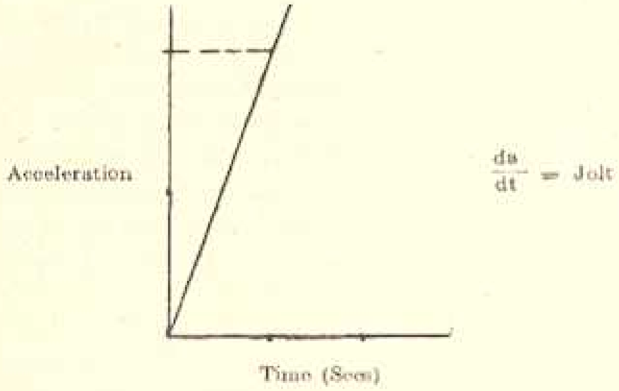
The German Air Force were the first to develop the ejection seat. By 1939, Ruff and other aero-medical specialists in Germany had carried out considerable research on ballistics of seat guns using dummies and human volunteers. Several ground test rigs up to a height of 30 ft. with metal seats running along guide rails were built in Germany for this purpose. Junkers the well known German Aircraft firm, had perfected an ejection seat under their own patent in 1941. Other firms like Focke Wulfe, Dornier and Heinkel also developed ejection seats which were fired by compressed air or a gun. The ejection velocity of the German seats was a little more than half the velocity attained by the latest British seat. Even at these comparitively low ejection velocities the percentage of spinal fractures and injuries was high. This was apparently due to lack of proper appreciation, by the Luftwaffe, of the physiological effects of high jolt factor, body alignment, and use of a proper restraining harness.

The problem of escape from jet aircraft has two distinct aspects. Ejection and survival from effects of airblast, free fall, altitude and speed. Safe ejection depends on integration of ballistics and engineering design with physiological tolerance of the human body to short duration acceleration. From the ballistic and engineering point of view, the problem of ejection is a simple one. All that is required is to produce an upward or a downward force which attains its peak over a distance of 3 ft., the distance over which the seat must travel on guide rails before it can leave the cock-pit. In upward ejection, as in I.A.F. aircraft (which has also been universally accepted) ejection velocity of the seat depends on the speed of the aircraft and design of its tail.

In order to produce a given velocity, 'v' within a vertical distance 's' the acceleration required for the seat to be shot out can be worked out by the simple equation $a = v^2/2s$. For instance, to attain a velocity of 60 ft/s over a distance of 3 ft. would require an acceleration of 18.7 g. A more important consideration in the physics of seat ejection is that a stationary seat has to be suddenly accelerated from zero acceleration to the required peak. This sudden increase or the rate of change of acceleration is described as the "jolt factor" Spinal injuries during ejection depend more on the degree of jolt factor than the peak acceleration. If acceleration is built up slowly, the jolt factor is reduced, but a higher peak or final acceleration must be endured to attain the same terminal velocity.







Physiological tolerance to ejection may be defined as the maximum acceleration and its rate of onset which can be sustained by the seated human body without injury. Some of these factors were not properly defined by the Germans. Preliminary work in this field was done by Stewart at Farnborough in 1944, and latter continued by Latham. These studies have helped to define clearly the limits of human tolerance to short duration accelerations acting along the long axis of the spine.

Research and testing of new seats is done on a 155 ft. high vertical test rig and the rocket trolley at Farnborough. In the last decade various types of propellants have been investigated. Force--time curves of different guns have been worked out. Acceptable limits of jolt factor and peak thrust have been evaluated. The R.A.F. have laid down that the upper limit of jolt factor or the rate of change of acceleration should not exceed 300 g/s and peak thrust should be approx. 25 g, with a stiff seat cushion.

Ejection and Gun Cartridge Design.

The Indian Air Force Hunter, Canberra and Vampire trainer aircraft are fitted with Martin Baker ejection seats, with 60 ft/sec., double cartridge guns. This ejection seat has a peak thrust of 15 to 18 g and jolt factor of approx. 240 g/s, with a pilot of average weight, and at ambient temperature. This performance allows a sufficient margin of safety for variations in cartridges, pilot's weight and temperature.

The subject of guns and cartridges for ejection seats is fundamentally a problem of ballistics, but it is useful to know how variations in body weight and temperature can alter performance of an ejection gun and cartridges. To ensure uniformity in performance of cartridges, manufacture and blending of explosives such as cordite has to be strictly controlled. Inspite of this, a normal scatter in performance is likely. For example, at 18°C, a pilot of average weight has 1 in 50 chance of exceeding a rate of rise of 300 g/sec. To this scatter we must add the effect of variation in body weight of pilots. A low environmental temperature and a heavy pilot would result in reduced ejection velocity.

Design specifications of ejection seat cartridges in the R.A.F. lay down that their performance should be normal between temperature range of minus 25°C and plus 40°C. In the I.A.F. we may have to alter these specifications to suit our requirements.

All kinds of propellants have been considered including compressed air, but none has prove so satisfactory as cordite. The R.A.F. attach great importance to proper storage of cordite, and filling of cartridges, because on these simple details may depend the life of a pilot. Whenever a new ejection gun or a new ejection system is introduced in the R.A.F., scatter of cartridges and performance of the gun is measured at Farnborough. Performance of cartridges is determined by firing the seat on the ejection rig and measuring the gas pressure in the gun chamber. Before a new seat is accepted, it is fired on the rocket track with a life-size dummy to test its breaking strength. Similar test schedules are used for accepttance trials of seat harnesses.

Seat Packs.

Seat packs and cushions play a significant part in safety during ejection. Practical experience has shown that the ejection seat pack on which the pilot sits should be as hard as is compatible with comfort. A soft springy cushion or pack is not suitable, because it adds to the elasticity of the ejected mass and plays a significant part in producing over-shoot of peak acceleration. Springiness of the cushion increases relative lag in movement of the man. During the initial period of ejection surplus kinetic energy is stored in the seat which later produces oscillations between the man and the seat. The human body has natural compressibility and some initial lag in man's movement during ejection is, therefore, understandable. On account of this natural compressibility it is essential that not more than 5 g is applied to the seat in the first 0.01 seconds. The concept that a soft springy pack compresses rapidly in the initial stage of ejection, and thereby introduces a delay in response of the man is supported by evidence. It has been observed that ejection during inverted flight when the pilot is hanging by his harness, and is separated by a few inches from the seat, has always resulted in spinal injury.

An ideal seat pack has been defined by Latham as one which has a soft upper surface to spread the load over a wide area of the body, yet at the same time full compression is achieved with the normal weight of the pilot. A slow responding foam plastic 2-2½ inches thick is very suitable as a seat cushion. Compressibility of the remainder of the pack should be reduced to a minimum by pre-stressing or even by enclosing the dinghy and survival equipment inside a rigid container with the upper surface hollowed and moulded as a bed for the cushion.

When assessing any material for use as a cushion, or a seat pack as a whole, it is necessary to consider its damping characteristics. The higher the damping qualities the better it is for use with the ejection seat. If any increase in sitting height is required in an aircraft fitted with an ejection seat, the cushion should preferably be made as an extension of the foam plastic layer of the pack itself. Two inch thick Dunloprene is considered ideal for use as a cushion.

Every time a new survival pack is introduced or an existing one is modified, static and dynamic tests are carried out at Farnborough before the pack is accepted for use in Service. Static testing is a simple procedure. The pack is put on a solid base e.g. cement floor. On the top of the pack is placed a pre-load (a weight of wood or lead) weighing 10 to 15 kg. This pre-load is instrumented. Four small accelerometers, 'Lancles' type are fixed to the four corners of the pre-load. Accelerometers are then connected to the recording system, which consists of a galvano-recorder and amplifiers. A standard weight of 10 kg (a piece of lead) is dropped on the pack with the help of a quick release mechanism and paper recordings are taken. In the experience of the R.A.F., if the compressibility value 'k' is less than 0.5 then the pack is considered safe for live testing. Any figure higher than 0.6 makes the pack unsuitable.

Acceptance of the pack for service use, however, depends on the subjective feeling of an experienced doctor who rides every new pack on the ejection rig. Each of these runs is instrumented. One accelerometer is fixed on the seat and another is strapped on the iliac crest of the tester, through a leather belt. From the output of these accelerometers peak acceleration and jolt values are derived. A 60 ft/s gun with a primary charge is used for testing. With a primary charge there is no change in the jolt factor, but peak acceleration is lowered. Peak acceleration of less than 10 g. has been found to be insufficient for detecting defects in the cushion or seat pack. On subjective feelings of an experienced doctor, who decides whether the ejection ride was smooth and safe, or rough and painful, depends the final acceptance or rejection of a seat pack.

Body Alignment.

In addition to the acceleration characteristics of seat guns and nature of seat packs, body alignment, plays an important role in safety during ejection. The human body can escape injury during ejection if the body is adequately supported and flexion of the spine is prevented. During early experiments it was noted that forcible flexion of the neck was a limiting factor for higher ejection velocities.

The development of the blind-firing technique, which is now a standard method of operation of Martin Baker seats was an important advance. It proved an effective method of restraining the head from moving forward. To use the blind firing handle, both arms have to be flexed over the chest and raised to the fore-head to pull down a canvas screen over the face. The blind-firing technique not only prevents forward movement of the head, but it also helps to transfer some weight of the shoulder girdle to the face-blind through the hands, and thereby reduces compression load on the lower thoracic vertebrae. Raising the arms upwards and backwards also helps to extend the spine and increase the tone of the erector spinae muscles.

Even with heavy head gear e.g. bone domes, now in use by pilots, the face blind does restrain the head from moving forward. With heavier head gear like a pressure helmet, injury to the atlanto-occipital joint is likely to be a serious problem particularly when manual over-ride hand-firing control is used. This is one of the reasons why the I.A.M. Farnborough do not favour manual firing device on British seats, which is an Air Staff requirement as a safety over-ride, in case the blind-firing mechanism fails.

The importance of spinal extensors as a safety factor in ejection was realised by the German research worker, Wiesehofer. He mentioned that if the rate of increase of acceleration is too rapid, reflex muscular contraction of erector spinae does not occur with sufficient speed and intensity. It is well known that a flexed spine is particularly prone to severe injury when a force is applied along its axis. During seat ejection, fractures occur usually in the region of 11th thoracic to 2nd lumbar vertebrae, on account of jack-knifing injury, a sudden, forceful forward flexion movement of the upper torso. Spinal injury in this region is understandable when we consider that the centre of gravity of upper torso is in the region of 12th thoracic vertebra.

Another important consideration in proper body alignment is the mounting of the seat in the cock-pit. To avoid fouling of pilot's knees, with the metal arch of the instrument panel or the wind screen, the ejection seat is so mounted on guide rails that it follows an upward and backward path. There is an included angle between the thrust axis of the seat and the pilot's spine. Such an included angle leads to an increased forward thrust on the upper part of the torso during ejection. The magnitude of this forward flexing component varies directly as the sine of this angle. Limitations of the included angle are governed by the magnitude of the forward load imparted to the upper trunk, and the degree of flexion of the spine which can take place within the harness. With a large included angle the flexing component becomes greater and the safety harness less effective in preventing forward flexion of the spine.

In a small cockpit, the guide rails of the seat may have to be tilted further backwards so that pilot's knees do not foul during ejection. Tilting of seat backwards means that the included angle between pilot's back and the ejection path is increased. Theoretically, to measure the included angle it is assumed that a pilot is sitting straight up against a flat board which determines the line of his back. For practical purposes this line is assumed to pass through the seat datum and the front edge of the parachute back pan. No British aircraft these days has an ejection seat with an included angle of more than 8–10 degrees.

The pilot must separate from the seat after ejection and come down with the help of a parachute. In earlier ejection seats some of the vital actions e.g. disconnection of oxygen etc., canopy jettison, harness release, opening of parachute had to be performed by the subject. Now the ejection seat has been made fully automatic. Once it is fired all vital actions follow a set sequence.

In a fully automatic British seat all essential services like oxygen, mic/tel, g-suit etc. by which the pilot is connected to the cock-pit are disconnected automatically. The canopy is jettisoned and after a set time period, when the pilot is clear of the aircraft, the seat stabilizer drogue fires stablishing the descent of the seat. This is followed by firing of the barostatic parachute release mechanism which is pre-set to an altitude of 10,000 ft. or lower after a time delay of 1½ secs. Earlier British seats have a 3 second time delay.

Ejections in the I.A.F.

Ejected Total Nos.	Killed Nos.	Seriously Injured Nos.	Nature of Injury
6	Nil	3	Fracture spine 3 Fracture Leg 1

Both the pilot and navigator of the Canberra had fracture spines. The pilot also had a fracture of Rt. Leg. The third case of fracture spine was the pilot of a Hunter aircraft.

Analysis of ejection seat escapes in the R.A.F. show that fully automatic seats have proved invaluable in saving lives of pilots of high speed aircraft. All R.A.F. aircraft are fitted with Martin Baker Seats.

The following figures collected by the R.A.F. show comparative advantages of fully automatic seats.

Ejections in the R.A.F.

	Ejected Total Nos.	Killed Nos.	Percentage	Seriously injured Nos.	Percentage
1951	5	2	40	1	20
1952	12	4	33	3	25
1953	17	6	35	3	17.5
Introduction of fully automatic 3 secs delay.					
1954	23	2	9	1	4
1955	26	9	35	2	8
Introduction of 1½ secs. delay					
1956	20	2	10	2	10

1957/58 —The above figures are likely to be lower after introduction of the automatic speed selector device in the existing seats in the R.A.F.

Injuries can be sustained on ejection, soon after ejection, during descent, and on landing. Human problems of escape, therefore, do not end with ejection. Physiological limitations of wind blast, free fall, and seat separation have to be overcome before reaching the ground.

Wind blast.

After ejection at high speed, wind blast can give rise to serious injuries. Dummy and human experiments have shown that a speed of 350 knots is about the safe limit of exposure to air blast. Above this speed, air blast forcibly separates the knees resulting in severe damage to the hip joints. At 450 knots the abduction air load on each leg has been calculated as 700 ft. lbs., and full abduction of hip joints takes approximately 0.1 second. With such a force pulling the knees apart muscular action alone is not sufficient to keep the knees together. Suitable leg restraint is essential to stop the knees from flailing during escape at high speeds. Abduction injuries of hip and knees joints have been considerably reduced in the R.A.F., since the introduction of leg restraint on ejection seats.

Arms and shoulders are equally vulnerable to wind blast. Injury to arms and shoulder joints is more common in downward ejection seats. Seat-firing mechanism on these seats is located on the arm rest. During ejection, grip on the arm rest is lost, arms flail, resulting in serious injuries to shoulder joints. The blind firing mechanism used in British seats is considered safer in this respect. Only a few cases of arm and shoulder injuries have been reported in the R.A.F., when the pilot has been unable to reach the blind with both hands, and it has been fired with only one hand.

Other parts of the body such as the abdomen and chest do not appear to suffer any ill effects from short duration air blast upto sonic speeds at sea level. Facial distortion does occur when the face is exposed. Blind firing mechanism in British seats provides adequate protection to the face upto a speed of 350 knots. Above this speed, gloves, shoes, helmets and masks are frequently lost. Flying clothing is torn. From the physiological point of view damage to oxygen assembly and pressure clothing is more important, specially in case of high altitude escape. In the R.A.F., before any oxygen assembly is introduced in the Service, wind blast tests are carried out by placing dummies wearing the new equipment behind a controlled air stream produced by a jet engine.

Free Fall.

After ejection at high altitudes free fall is absolutely essential for the following reasons:—

(a) Parachute opening shock at high altitudes can injure the individual and damage the parachute.

(b) Temperatures as low as minus 40°C–50°C at high altitude make it imperative that the individual falls rapidly to a lower altitude and higher temperatures, thereby reducing the chances of frost-bite and exposure to severe cold.

(c) Slow descent means larger supply of oxygen.

(d) Exposure to low atmospheric pressure and likelihood of decompression sickness is increased by slow descent.

Human experiments and study of behaviour of manlike dummies during long free falls has shown that free falling bodies of man-like configuration assume a prone position parallel to earth's surface and spin about a vertical axis. The body seems to rotate around 1 revolution per second. For a human body the limits of tolerance for such spinning vary from about 1.5 r.p.s. lasting one minute to about 1.75 r.p.s. lasting 15 seconds. This is highly significant in relation to the problem of high altitude escape, since during free fall, descent from 50,000 ft. to 20,000 ft. takes about 100 seconds.

The actual load on any part of the rotating body depends upon the square of the angular velocity, and upon the distance between that part of the body and the axis of rotation. When the axis of rotation is in the region of the thorax, body fluids are flung outwards towards the extremities. Venous return and cardiac output are thus impaired and everywhere venous and arterial pressures approach one another. The heart rate increases probably due to diminished venous return. Spinning of the human body during free fall is known to cause severe headaches, vomiting, superficial haemorrhages in the conjunctivae, face, neck and ends of both extremities and severe pain in the legs. Parachutists making relatively long free falls have complained of severe confusion and impending loss of consciousness, with obvious danger of failure to pull the D-ring of the parachute at a safe altitude.

Disorientation is a common symptom reported by pilots who have ejected at high altitudes. Disorientation and vomiting were reported by the crew of the R.A.F. Canberra who ejected last year at 56,000 ft. The seat stabilizer drogue did not function in the case of the R.A.F. pilot during descent. He, therefore, spun violently during descent in a spread-eagle manner, as if his arms and legs being stretched. He also vomited and saw his vomit swirling round before him. He also lost consciousness.

There was marked swelling of his neck and face upto the hair-line; he had severe conjunctival haemorrhage and ecchymosis of eyelids, his nose was swollen; there was bloody discharge from his left ear with a haematoma in the meatus; he had numerous petechial haemorrhages on the soft palate, pharynx, and fauces; the retinae were clear; both fore-arms and back of the hands had marked petechial haemorrhages; right hand more than the left; the palms were clear; both feet showed small haemorrhages on the anterior half of the dorsum of each foot. The navigator whose seat was stabilized during descent and who "therefore" did not spin had none of these injuries. Both the pilot and navigator, however, were deaf for a few days.

Seat Separation.

These effects of free fall confirm the need for stabilization of the man after ejection at high altitudes. The aim of stabilization is to keep the man fully conscious throughout descent, because he may do something foolish or undesirable while losing or regaining consciousness. Speed of descent should also be as high as possible. This can be most efficiently accomplished by retaining the man in the seat under barometric control. This fact can be appreciated when we consider that to stabilize a man requires a parachute with a drag area of not less than 35 sq. ft. Parachute of such a size can be stowed more easily on the seat than on the man. Moreover, emergency oxygen and pressurisation services can be carried better on the seat than on the body.

Pulling the man out of the seat with a drogue is considered better than aero-dynamic separation, because it can be controlled to a set time period. Aero-dynamic separation on the other hand may vary from 1½ to as long as 10 seconds. Gripping the arm rest or some other part of the seat structure involuntarily by the subject further delays separation.

Limitations of Ejection Seats.

Limitations on ejection seats are placed not so much due to failure of equipment to operate correctly, but due to injuries resulting directly or indirectly from air blast. Injuries can be caused directly by exposure of the man's body to very high dynamic pressure, and indirectly by aero-dynamic drag forces causing rapid deceleration of the seat and man's body, his limbs and head. With increasing altitude of flight, man's personal equipment such as head gear will increase the drag and inertia forces on the head. The pilot's head gear is already creating a restriction on operation of the blind firing mechanism which acts as a restraint to the head.

Limiting speed for ejection seats becomes a function of decleration. It can be assessed from drag and weight of the seat. Maximum decleration for an ejection seat has been taken at 50 g which is probably about the limit of human tolerance. Maximum limit of tolerance of existing harnesses is about 20 g. With an ejected wt. of about 300 lbs. a decleration of 50 g is obtained at a speed of about 650 knots E.A.S. Limiting speed for latest ejection seats in service is probably about 550 to 600 knots. For future aircraft ejection seats would require very considerable improvements if escape at maximum speed is an essential requirement.

Decleration at a given speed can be reduced by increasing the weight of the ejected mass and by reducing aero-dynamic drag. There is little possibility of reducing the drag, but considerable weight can be added. Comprehensive limb and head restraint, stabilization to keep tumbling within level of tolerance with fins etc., and putting oxygen bottles on the seat can increase the weight. The seat can be shaped to provide necessary support to the limbs and body. Assuming an ejected weight of 470 lbs, the 50 g limit is raised to 800 knots, E.A.S. This would mean a weight penalty of 100 to 150 lbs per seat and also a larger cockpit. An E.A.S. of 800 knots is considered to be the limit to which the ejection seat could be developed. At speeds higher than this, Mach 2 and more, some form of capsule is necessary to escape safely from aircraft.

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