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Life Saving Aspects of Pilot for Escape Aid Explosive (EAX) System Applications: Some Considerations

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ABSTRACT

This manuscript deals with life saving aspects of the pilot for escape aid explosive (EAX) system applications under emergency situation. During the ejection from the aircraft, the pilot is subjected to the various forces such as linear, angular and transverse accelerations, decelerations, wind drag accelerations, wind blast, dynamic forces, aerodynamic forces, spinning and tumbling. Linear accelerations (decelerations) of major interest in aviation are those of a high magnitude and a short duration that occur in emergency ejection from the aircraft or occasionally in a high altitude at high-speed parachute opening, as they tend to exceed the strength limitations of the skeletal structure of the pilot body. The human body is a heterogeneous mass that is made up of solid, liquid and visco elastic components. The effects of these forces on the pilot's body are crucial in nature and significant pertains to an injury. This article is described with some considerations of ballistics, kinematics with different forces and their effects on the pilot body for aircraft applications during an entire flight trajectory. In conclusion, this kind of study is very essential considering the pilots safety and its performance at low and high altitudes during an emergency.

Keywords: Aerodynamic forces; Biodynamic consideration; Escape aid explosive; Wind blast and spinal injury

NOMENCLATURE

A - Area of piston on which pressure acts, mm^2
C - Charge weight of propellant, g
C_L - Equivalent chamber length, mm
D - Web size, mm
E_{LF} - Frictional loss factor
F - Force constant, J/g
f - Web fraction
ng - Constant (peak) acceleration, ms^{-2}
P - Pressure developed in the gun, MPa
t - Time, millisecond
v - Velocity of ejection, m/s
W - Ejection weight, kg
x - Distance travelled by the piston in the gun tube, mm
Z - Mass fraction
θ - Angle of ejection with respect to horizontal
β - Burning rate coefficient
α - Pressure index
γ - Specific heat ratio

1. INTRODUCTION

This article is described for determining the effects of various forces experienced by the pilot while ejecting from the endangered aircraft. During the ejection from the aircraft, the pilot is subjected to linear accelerations. The upward motion of the ejection seat-pilot combination affects the build up of pressures, the burning rate, acceleration and loads during the seat ejection. This dynamics affects the performance of the ejection seat[1]. The human body *i.e.* the pilot is subjected to linear decelerations during landing, re-entry from space or during arrested aircraft carrier landings. The effect of a high acceleration (g) can damage to the circulatory system even after sufficient time has elapsed[2]. This high level of g leads the displacement of blood in the human that is sustained for few minutes. On the contrary, low level of g for less than a second can cause the structural damage to the pilot[3]. Linear accelerations of major interest in aviation are those of a high magnitude and a short duration, such as in crashes, ejection from aircraft or occasionally at high altitudes in high-speed parachute opening as they tend to exceed the strength limitations of the skeletal structure of the human body. In case of linear acceleration or a constant velocity motion, a change in direction produces centripetal or radial accelerations. And if in the course of such change in the direction of aircraft, angular accelerations are produced about the long axis of the aircraft. Radial accelerations are generally of lower magnitude and longer duration and important because of their effects on the cardio vascular pulmonary systems.

The application of biodynamic is very important in the emergency situation for safe escape of the pilot from the military aircraft for which ejection system developed[4]. The biodynamic is directly related to response of the pilot human body due to high accelerations and airstream velocity. The biodynamic limitations are those values that the pilot can tolerate with commonly accepted values of rate of rise of acceleration (RR_g) is 350 gs^{-1} and peak acceleration is 25 g. The working values

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of RR_g of 300 gs^{-1} and peak acceleration of 21 g under real conditions are chosen less than the limits deliberately have provisions for overshoots. The field of biodynamic has made significant contributions to meet the requirements of the pilot during emergency exit[5]. The study of modelling and simulation of biodynamic pertaining to pilot-seat combination was studied by Daren[6-7], *et al*.

In high-pressure ejection gun system the friction can be accounted. Usually in the high pressure (Artillery) guns most of the energy losses are taken and affected by increasing the total weight of the shot. Leaving alone the pressure, the major difference between high-pressure in normal gun and low-pressure ejection gun is that the time to exhaust may be 30 to 40 times higher for ejection gun. This is discussed in dynamics considerations. The importance of this work is explained in this paper considering the safety aspects on human body of the pilot. Hence, specific literature or information pertaining to this issue is not readily available in the open access sources. All these considerations are discussed in the following sections.

2. BIODYNAMIC CONSIDERATIONS

Biodynamic deals with the effects of mechanical forces on living tissues. It is concerned with physiological, anatomical changes in a living body that occurs during or following an exposure to mechanical stresses. The resistance of a mass being moved is termed as inertia, and the resistance of a moving mass to stop is momentum. Inertia and momentum are defining properties of mass. Work is done by a change of speed or by a change of direction of motion of a mass. Either case is a change of velocity. Change in velocity with respect to time is acceleration. Change in acceleration is jolt or rate of motion per second. Hence, a maximum tolerance to a specific 'g' load is determined by the system that is most severely affected.

The various factors that affect the maximum loads will be imparted on human body are:

- Magnitude of acceleration
- Rate of change of acceleration
- Duration of acceleration
- Direction of acceleration

The physiological and anatomical changes in the body that occur due to the above types of forces are broadly divided into:

- Non-injuries: These give acute, immediately reversible anatomical and physiological reactions
- Injurious: Acute, persistent, anatomical and physiological reactions with signs of injury like neuro circulatory shock, concussion (brain injury), pain and anxiety with associated changes in the vital signs and physiological reactions; abrasion, tear and rupture of the skin and sprains; strain, dislocations of the joints or even fracture of bones and cartilages (elastic substance covering the joints)
- Chronic: Irreversible anatomical and physiological reactions with disabling injuries. These include (a) Survived permanent impairment of function in an organ or structure of the body (b) Irreversible damage in an organ or structure of the body
- Fatal injury: This includes immediate and delayed effects on vital structures and functions due to:
  (a) Hypoxia, obstruction, direct trauma to respiratory or cardiac control centers (b) combined effects of multiple injuries and shock and (c) Decapitation

These effects result from abrupt velocity changes of a moving body. Deceleration experienced by the pilot is due to the following factors:

Table 1. Effects of accelerations on the various parts of the pilot body[8]

Type of g	Direction of body movement	Aircraft manoeuvring	Accelerations	Physiological human limits
Positive	Head to foot	1. Pull out or tight turn	1. 8 g for 15 s 4.5 g for 5 min	1. Black out due to unconsciousness, pain in leg etc.
		2. Controlled escape deceleration	1. 15 g for 1.75 s	2. Unconsciousness
		3. Ejection escape (upward)	1. 20 g for 0.1 s with face curtain	3. Skeletal damage
Negative	Foot to head	1. Push over	1. 4.5 g for 5 s 3 g for 32 s	1. Subjective pain fullness of neck head
		2. Ejection escape (downward)	2. 10 g for 0.1 s with leg support	2. Pain
Transverse supine	Chest to back	1. Catapult launches escape	1. 5 g for 2 s	1. No damage
		2. Escape deceleration	2. 15 g for 91/2 min lying flat	2. Surface hemorage and chest pain
		3. Crash (facing aft)	3. 55 g for 0.01 s 35 g for 0.12 s	3. Skeletal damage
Transverse prone	Back to chest	1. Arrested landing	1. 5 g for 2 s	1. No damage
		2. Escape deceleration	2. 5 g for 0.1 s	2. Surface hemorage and chest pain
		3. Crash (facing upward)	3. 60 g for 0.01 s	3. Skeletal damage

- Escape from the aircraft or spacecraft by catapult or rocket ejection of seats or capsules
- Parachute opening and landing shock
- Survival of aircraft crashing and ditching forces
- Rocket accelerations of space flight
- Re-entry decelerations of space flight
- Exposure to supersonic wind blast

Critical body areas are those vulnerable to impact forces such as the head, neck, face, chest, abdomen and the spinal column. It calls for dynamic stress analysis to determine the protective design criteria for helmets, face visors, head restraints, seat cushions and backs and the performance characteristics of ejection catapults and rockets. The highest recorded human exposure to abrupt upward acceleration without spinal injury occurred on an ejection seat tower on which they are inadvertently catapulted upward at 35 *g* and 500 *g*/*s* rates of onset.

The effects of accelerations on the various parts of the pilot body during the aircraft manoeuvring are given below at Table 1.

The data on effects of accelerations divided into three categories fatal, injurious and tolerable concerning to acceleration, rate of change of acceleration and time is reflected at Table 2.

Table 2. Data on acceleration effects, type of injuries and tolerable limits[8]

Direction of acceleration	Fatal	Injurious	Tolerable
$+g_z$	100 *g* at 3000 *g*/*s* 0.1 - 0.2 *s*	10 *g* at 2000 *g*/*s* 35 *g* at 400 *g*/*s*	33 *g* at 500 *g*/*s*
$-g_z$	100 *g* at 2000 *g*/*s* 0.05 - 0.2 *s*	25 *g* at 500 *g*/*s* 0.02-0.1 *s*	16 *g* at 200 *g*/*s*
$+g_x$	200 *g* at 5000 *g*/*s* 0.1 - 0.5 *s*	60 *g* at 500 *g*/*s* 0.01 – 0.5 *s*	38 *g* at 1400 *g*/*s* 0.15 *s*
$-g_x$	200 *g* at 500 *g*/*s* 0.1 - 0.5 *s*	25 *g* at 500 *g*/*s* 0.1-0.5 *s*	50 *g* at 100 *g*/*s* 0.25 *s*
			9 *g* at 500 *g*/*s*
			9 *g* at 500 *g*/*s*

From the Tables 1 and 2, it is seen that a high rate of accelerations acting for a short time, especially in the direction of $+g_z$ and $-g_z$ produce the skeletal damage. In an emergency escape systems or ejection seats the direction of accelerations is one of these. With the rise in aircraft velocity, it is necessary to have a high ejection velocity in order to have the following objectives.

- Escape the aircraft's tail fin
- Gain the sufficient height to avoid the entangling of the pilot with the tail fin of parent aircraft.

However, the present day requirements of emergency escape systems range from escape at a low altitude or to very high altitudes. Thus systems of escape have to be designed to impart high escape velocities in a few milliseconds. To avoid very high jolts combination of the ejection gun and rocket pack becomes the integral part of the modern aircraft seat ejection systems.

The requirement of throwing the ejection seat safe out of the cockpit and ensuring that the seat does not hit the aircraft tail fin demanded the use of an explosive assisted gun to attain the required minimum velocity. The maximum velocity that can be attained with the stroke length of three telescopic tubes is also limited to 24.384 ms^{-1} considering the biodynamic aspects of the ejection. This velocity of 24.384 ms^{-1} is not enough to take the seat to a safe altitude for the parachute deployment especially at zero height ejection and also for low heights. So the minimum height that should be achieved by the ejection power system should be 91.44 m to 121.92 m. Hence, the need to supplement the ejection gun with a rocket motor which starts burning of the propellant just before the gun leaves the outer tube. The power system design must now take into consideration the extended time of high *g* application and accordingly reduce *g* level from a biodynamic point of view. The acceleration - time curve as a combination of rocket and gun is depicted at Fig. 1[9]. After the completion of stroke at 0.24 *s*, rocket packs help to enhance the additional velocity. Rocket pack burning is completed at 0.5 *s*.

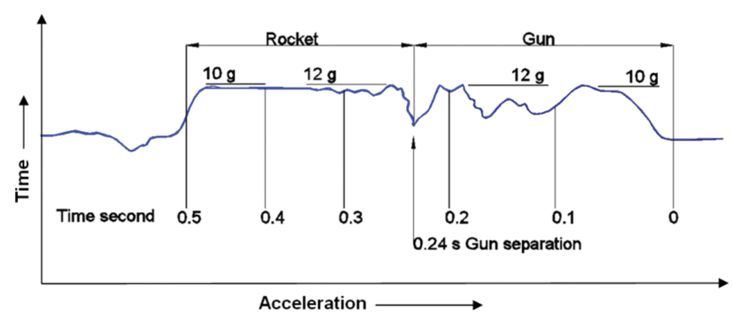

Figure 1. Acceleration - time curve.

The spinal injury patterns due to ejections have been another subject which resulted in the modification of the aircrew ejection system as a whole. Two important aspects that need to be mentioned are the ideal posture of the pilot before the ejection and the nature of the survival pack in respect of its compressibility and damping characteristics. The breaking strength of various vertebras as worked out by Ruff and Stacch, shows that the weakest area with a high load is vertebra. It shows that the load at 50 % of body weight and static *g* loading required to cause the compressive fracture is the least. The breaking strength under dynamic load changes a lot, but the weakest area of the vertebra column is the hinge point. The spine is least able to withstand comprehensive loads, when flexed as the load that is concentrated on the anterior lips of the vertebra. The center of gravity of the upper trunk lies in the front of the spine, at the manubrium sterni and such a bending moment factor that leads to loads being applied at the angle to the long axis of the spine. This will thus tend to increase the risk of fracture. A loose shoulder harness allows the greater forward flexion of the trunk to take place during the ejection. Inadvertent and unprepared ejections are more likely to be initiated with a loose shoulder harness and have more often led to compression fractures. An additional factor is the

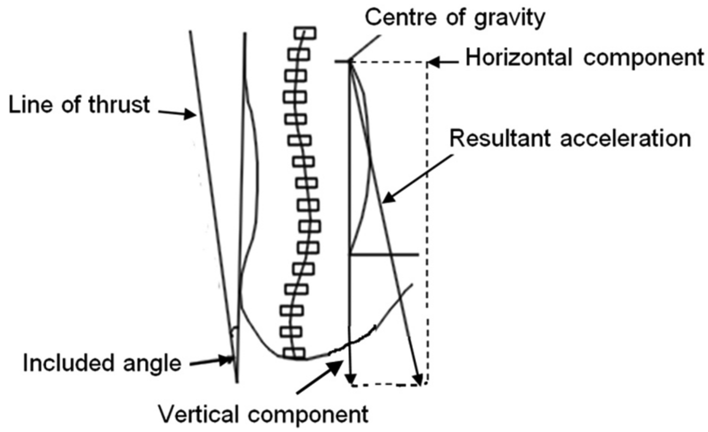

Figure 2. Forces acting on the spine of the pilot.

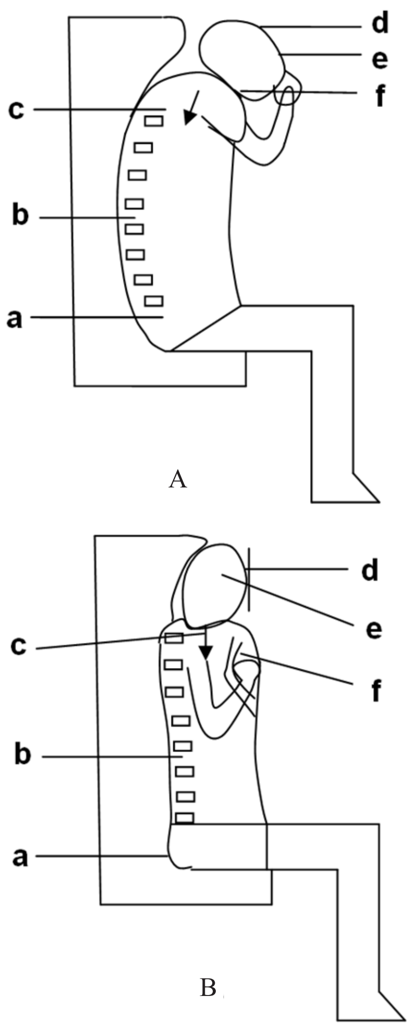

Figure 3. (A) Unsatisfactory seat, and (B) Improved seat.

presence of the included angle between the line of thrust and the long axis of the spine. Forces acting on the spine of the pilot are illustrated in Fig. 2. The included angle between the line of thrust and the back of the pilot is illustrating the forces acting about the center of gravity of the upper part of the body. As the included angle increases, the magnitude of the force tending to flex also increases. Unlike the case of other species, the human spine is a chain of bones with four arches like a spring. It consists of three vertebrae (cervical supporting neck thoracic supporting chest and lumber, the lower one which carry most of the human body weight). It is essential that these are square to each other so that the least injury is caused to the spine; because the discs cannot sustain a high compression if the above condition is not met. Correct posture is maintained with the help of face blind, leg and arm restraining devices and harnesses.

Such an included angle imposes an increased forward thrust on the upper part of the torso during the ejection. With adequate head restraint and good harness, an angle up to 18^0 is permitted. Correct alignment of the spine can be achieved by accurate contouring of the backrest in order to support the normal spinal curvatures and also by shaping the upper surface of the seat pack so that the lower end of the spine is kept well back. Such a position is most comfortable. Figures 3(A&B) shows unsatisfactory and improved version of the ejection seat. These two figures show how the early seats were re-arranged so that spinal vertebrae are square to each other. The revised position allowed the intervertebral disc to sustain high compression loads imposed by the ejection.

In Fig. 3(A) Unsatisfactory seat: (a) 'submarining' permitted by poor harness restraint system (b) poor seat back contour (c) harness restraint induced force (d) face curtain induced flexion (e) face curtain induced force (f) poor harness restraint system resulting in induced flexion.

In Fig. 3(B) Improved seat: (a) adequate lower torso restraint (b) improved back contour (c) reduced shoulder harness force (d) proper face curtain (e) no vertical face curtain induced force (f) reduced shoulder harness flexion.

Survival pack situated below the seat pan plays an important role. An important characteristic of the survival pack is the vibration. If the cushioning effect of the survival pack is such that it has some compression strength and a high damping that will be an ideal solution. To avoid accelerations overshoots it has been found that the surface of the survival pack should be hard and hence the use of the rigid fiber glass survival pack has been finding favor. The ejection seat has a rigid fiber glass survival pack. The characteristics of the survival pack will be defined by spring constant *k* and a damping coefficient *c* (or the damping force per unit velocity). It is assumed that damping force is proportional to the velocity of vibration. Damping

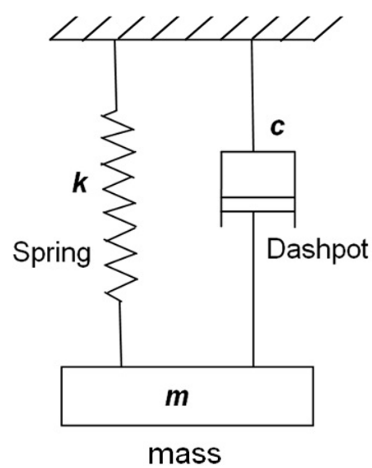

Figure 4. Model for seat-man combination.

force is the resistance to the motion of the body. The first approximate vibration model for the seat- man combination is illustrated in Fig. 4, in which a spiral spring, whose one end is fixed and the other end is free. A body of mass *m* is suspended from the free end of the spring. A dashpot is provided between mass and rigid support. Hence mass is attached to the dashpot as shown in Fig. 4.

2.1 Effects of Radial, Angular and Transverse Acceleration

During the ejection, the pilot is exposed to the forces of acceleration in one form or another almost constantly throughout flight. The principle kinds of acceleration commonly referred are:

- Linear
- Radial (centripetal)
- Angular

Radial accelerations are strictly related to the square of angular acceleration but by common usage both terms are used largely due to the difference in magnitude and effects on the pilot or aircrew man. Angular acceleration is the time rate of change of angular velocity and involves the rotation about an axis which may be through to the pilot's body. If the axis of rotation is through to the pilot's body, it is expressed as angular acceleration, whereas the acceleration of the body at right angles to the pilot's flight direction and with the axis external to the pilot's body (in an aircraft making a turn) is more commonly expressed as radial acceleration.

The pilot is exposed to linear acceleration on take-off during an increase in speed and during a catapult launching from an aircraft carrier or rocket launch in space. He is exposed to linear deceleration on landing, re-entry from space, during other clearances in speed, or during arrested aircraft carrier landings. Linear acceleration is also involved during the ejection from an aircraft and during deceleration in the wind stream to the terminal velocity. Varying combinations of complex curvilinear, radial and angular accelerations can also occur in the ejection seats. Thus, if during any of these linear accelerations or decelerations or at any constant linear velocity a change in the direction of the vehicle, it banks or roll, angular accelerations are produced about the long axis of aircraft. Linear accelerations (decelerations) of major interest in aviation are those of high magnitude and short duration that occur in crash ejection from the aircraft or occasionally in high altitudes at high-speed parachute opening, as they tend to exceed the strength limitations of the skeletal structure of the body. Radial accelerations on the other hand are generally of a lower magnitude and longer duration and are of importance principally because of their effects on cardiovascular pulmonary system. Escape at high speeds with relatively long deceleration times can also produce cardiovascular reactions and fluid shifts that are more commonly identified with radial acceleration. With this brief introduction, it would be seen that it is very difficult to separate the effect of acceleration into the categories of linear, radial or angular acceleration.

Post-ejection forces can be sub-divided into four headings (1) wind drag deceleration (2) wind blast (3) thermal effects and (4) Spinning and tumbling. These are discussed below.

2.2 Wind Drag Deceleration

Of all factors in a high-speed escape perhaps the most formidable is wind drag deceleration. The abrupt/linear variations caused by the air loads on the ejected pilot. The seat, as it enters the airstream in every sense it is a crash force. In fact, the lethal potentialities of wind-drag deceleration of a given magnitude are magnified beyond those of ordinary crash deceleration in the duration of high *g* forces may be in the order of 10 to 20 times as long. Further, the elements of instability during deceleration, resulting in tumbling and spinning produce a very complex pattern of mechanical forces acting upon the body. If the stable system is assumed the rate of onset, magnitude and duration of deceleration forces are primarily dependent upon the body.

- The speed at the time of the ejection
- Air density
- The exposed frontal area of the occupied seat and
- Its drag coefficient

It would be noted that the maximum linear deceleration *g* values indicated are practically constant for the given indicated air speed (IAS) regardless of the altitude. The maximum liner deceleration expressed at Mach one (1) at sea level is approximately the same as that experienced at Mach two (2) at 39,000 ft. The values of *g* were calculated using the ejection seat drag coefficient. These values vary considerably for different ejection seats and occupants. Such variations affect the speed at which it is safe to eject. Among the other variables which affect the severity of deceleration injury is altitude of the body at the time of ejection, the effectiveness of the body restraint, time of separation from the seat, spinning and tumbling and ejection altitude. Altitude is important from the start point of deceleration duration which is itself imposes the human tolerance limits. As the ejection altitude is increased, the deceleration time is prolonged. The increased altitude for any given IAS results in higher kinetic energy for the ejected occupied seat as the kinetic energy is the function of square of the true air-speed (actual velocity). At 40,000 ft this kinetic energy is increased the threshold that at sea level for given IAS. This increase in kinetic energy must be dissipated as a function of time in the less dense atmosphere at altitude.

Human tolerance limits for acceleration forces, as determined by strap are:

- 50 g at the rate of 500 gs^{-1} for 0.2 s
- 40 g at the rate of 1500 gs^{-1} for 0.16 s
- 20 g at the rate of 500 gs^{-1} for 1 s

However, for the safety zone, 35 *g* value has been considered allowing for uncertainties that may result due to bending of the torso and tumbling. A large number of fatalities and injuries are attributed to wind deceleration drags. An apparent discrepancy between the force magnitude tolerance limit and 35 *g* limit exists. The most important reason for this is that 35 *g* value has been proposed as an escape system design criterion limit which considers many important variables such as body attitude, the effectiveness of restraints and seat stability. The values as determined by the strap were obtained under rigidly controlled conditions and therefore, not compatible with most survival situations following an emergency. An additional fact is that above 35 *g* level small increment of force, as well as a change in the direction of the acting force vary rapidly becomes more critical. It is assumed that the force direction does not change, indicating that the system must be stabilized with the man in a forward facing seated position. It may be feasible with appropriate support and restraint to use these *g* criteria for other body positions. The wind drag deceleration makes high speed, high altitude ejection difficult if not impossible because of the decay being slower. Open ejection seems to have no answer when ejected at speed of more than 600-650 knots.

2.3 Wind Blast

Loss of canopy jettison or ejection at supersonic speed exposes the aircrew man to wind blast and wind drag (function of air density and speed), the combined action of which is measured as ram pressure. Normal man tolerates the ram pressure up to 0.031 MPa at speed of 375 knots. At 450 knots (IAS) 0.037 MPa ram pressure force exerted on the body by wind blast which is harmful to the human body with the following effects.

- Tearing of body cloth
- Difficult to control the movement of the body
- Bleeding on the face, eyes
- The helmet may be ripped off unless it is properly harnessed
- Injury to abdomen and lungs

  In the abdomen, rupture of air filled viscera and sub-capsular hemorrhages of solid viscera are usual findings during the escape from aircraft in flight about Mach 1(one).

Open ejection from an aircraft flying more than 500 knots is not advisable and ejection beyond 650 knots is very dangerous.

It is evident that the higher speed and lower the altitude the greater the ram pressure that will be encountered during the escape from the high-performance aircraft. The wind blast effect is predominant at high speed and low altitudes. Loss of vital protective equipment and flailing injuries is at speed in excess of 400 knots. IAS, called wind blast erosion, aggravates the problem. One factor over which the pilot can exercise a degree of control is of the altitude at which an attempt to escape is initiated. Ram pressure will be four times as great at 5,000 ft altitude as at 40,000 ft for the same velocity. As both the deceleration and wind blast is a direct function of ram pressure, a margin of several hundred percent (safety) can be gained by prompt ejection to take advantage of all possible altitudes. Another hazard of canopy jettisoning at supersonic speed is the turbulent flow over the cockpit. The pilot experiences the wind blast force as he streams with outside air. Wind blast dependent on its magnitude, speed and air density. The utilization of the specific type of ejection seat depends on this dynamic pressure. Hence a proper study of parameters with Mach number, altitudes and speeds are required before a final selection regarding an open ejection. The sudden exposure to the airstream of high velocity has various effects on the human body. These effects of wind blasts are usually quite loosely defined. These are discussed below.

- The first effect is the development of great aerodynamic forces primarily drag which decelerates the body relative to the air
- The second one is constituted by the fact that the various parts of the body having different drags. The difference between these drag forces can cause injuries
- A wind blast effects the excessive deformation or even Laceration of tissue of the face or possibly lungs and in the respiratory tract.

The upper limit of tolerable deceleration is 45 *g*. The possibility of an injury due to different drag forces on the various parts of the body is more difficult to evaluate. At first, one is led to believe that the forces between the parts are equal to the difference between the two forces acting on the parts considered. It should not forget however that the entire body is in an acceleration state and the inertia forces must be taken into account. The acceleration of the body expressed in terms of acceleration due to gravity is equal to the drag-weight ratio.

After the ejection, the pilot is suddenly exposed to the full dynamic pressure of the fast moving air stream. The effect of this sudden increase in pressure due to the effect caused by the blast from explosions seems to be very close. The characteristics of explosions are due to sudden rise of air pressure at the explosion point. This pressure disturbance travels away from the point at a certain speed. During the propagation, the pressure rise tends to become more pronounced finally forming a shock front with an extremely abrupt onset of pressure. The development of such a steep point of compressive wave in air is intercut with the physical properties of air. The rise in pressure is then confined to a very small space in the order of a fraction of mm. Since such compressive shock travels with speed that is several times the speed of sound. The shock wave usually does no excessive harm except when it crosses from a medium of high density to low density so that the chest and lungs are filled with air. In such cases, the interference between the two media can be ruptured because the heavier medium must extend too far before it can transfer its energy to the lighter one. It is in this way that lungs injuries are supposed to occur. A blast effect in ejection becomes more comparable to effects from explosions if cases are considered far away from the point of explosion. This shock wave has a sharp rise in time that is much more significant and comparable to the time involved in ejection.

2.4 Thermal Stresses of Ejection

Thermal effects are encountered with very high supersonic speed. As the speed is increasing the thermal stresses become significant. Third degree burns can result if the time of exposure of a human reaches to 10 s even at a moderate temperature 60° C. Aerodynamic thermal effects would limit the use of an open ejection seat.

2.5 Spinning and Tumbling

Spinning and tumbling are usually problems for the ejection seat otherwise stable at low altitudes. It is experienced from a high-speed aircraft where ejection seat stabilization is not achieved. As a first step, consider flat spin and head-over heel tumbling and their combination *i.e.* high alternating positive and negative accelerations can be produced. As the man tumbles, the decelerative force is directed alternatively to the opposite end of his body. Human tolerance limits for spinning with centre of rotation indicate that unconsciousness is produced when spinning at 160 rpm in 3 to 10 s. The situation becomes worse if the centre of rotation is moved downwards. The human can withstand 45 rpm for 10 minutes whereas 125 rpm can be tolerated for upto 4 s only. Drogue parachute for seat stabilization therefore plays vital role in controlling spinning and tumbling. It is a common to experience that ejection seat begins to tumble as soon as it left the cockpit. The behavior is different for the different seats as its shape and size varies. Practically all the seat starts a tumbling motion in the forward direction. This initial movement is caused by the fact that the line of thrust of the catapult does not pass through the seat-man combination and therefore exerts a moment. This moment is taken up by upper and lower rollers as they are in their rails. After the upper rollers have lost contact, the thrust will turn the seat forward. In addition to that, it has been found that the upper part of telescoping start swings violently forward after the separation and imparts its energy to the seat. Thus increases the forward motion of the seat. After the separation, the seat is subjected to the aerodynamic forces of drag, lift and the moment in which the air-stream strikes the seat. Static stability alone however is not sufficient to prevent a tumbling motion. The seat must have sufficient damping to slow down any rotation. A stabilizing chute or drag chute is the means of providing the sufficient damping to stop the entire rotation.

3. KINEMATIC RELATIONS

In order to achieve an ideal pressure-time profile, one has to match the increase in volume due to piston movement in the gun with the amount of the propellant burnt during any time interval. This can be obtained in two ways[10-12].

- The total estimated charge is split to provide a number of smaller cartridges that are allowed to burn in stages to approximate the pressure-time profile. The cartridge which is initiated at the beginning of the ejection is called the primary cartridge which yields the maximum permissible pressure during the first phase. The cartridge which burns subsequently in stages due to heat and pressure developed by the primary cartridge is called the secondary cartridges and they are positioned in the gun to sustain the peak pressure developed by the primary cartridge during the second phase.
- Instead of using the secondary cartridges for the purpose of sustaining the pressure, a constant thrust rocket booster can be used for the second phase. In modern aircraft, rocket packs are used to facilitate the ground level ejection by imparting additional velocities.

The values chosen can be considered average values acquired from experience. Consider the acceleration-time curve for an ejection gun as shown in Fig 5 (Ideal curve is shown with a firm line and a physically permitted curve with a dotted line). The physically permitted curve is indicated in red colour, while the acceptable design curve is indicated in green colour. The dotted line gives the actual acceleration vs. time and approximate values of t_m.

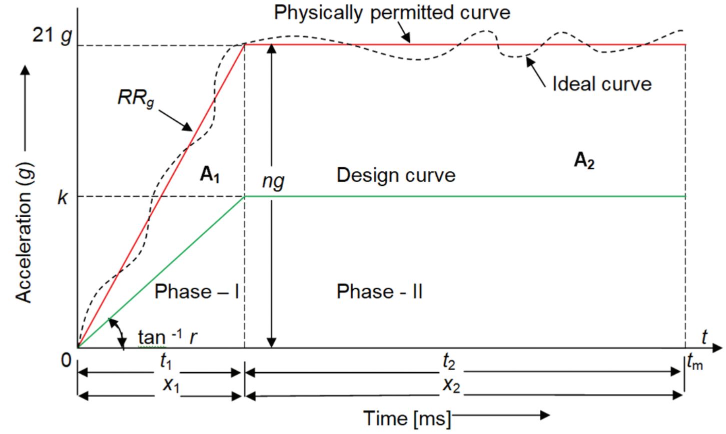

Figure 5. Acceleration *vs.* time curve.

v_m = Maximum velocity at the exit
x_L = Maximum stroke length
t_m = Total time taken= (t_1+t_2)
RR_g = Rate of rise of 'g' (gs^{-1})
ng = Constant (peak) acceleration

The area under the acceleration ('g') - time curve represents the velocity and the area under the velocity curve gives the distance travelled. The velocity v imparted to the ejection will be the area under 'g' curve.

4. DYNAMICS RELATIONS

A mathematical model for aircrew seat ejection, its dynamic simulation study and trajectory of ejection seat is carried out by Sarsar[13], *et al*. The authors used reference frames for analyzing the motion of seat relative to aircraft for safe separation, inertial frame, aircraft frame and ejection seat frame. The acceleration is imparted to the seat by gas pressure generated inside the gun after firing the cartridges[11]. During this operation, a large portion of the heat content by the propellant gases may be lost to the gun body. It is required that the heat losses and frictional losses are separated out for ejection guns. In high-pressure ejection gun system, the friction can be accounted for. The ejection frictional losses are accounted by increasing the effective ejection weight W by a suitable frictional loss factor (E_{LF}).

$$W_1 = W \times E_{LF} \tag{1}$$

The frictional loss factor for aircraft seats as observed by pressure-time and acceleration-time curves is indicated as high as 1.2.

5. BALLISTICS RELATIONS

The internal ballistics relation for the pressure developed P for ejection gun at any time t having equivalent chamber length (C_L) can be computed using Rasal's energy equation[6]. It is expressed as

$$P = \frac{100\ F\ C\ Z - W_1(\gamma-1)\ (ng\ \sin\theta + 50\ v^2)}{g\ A\ (x + C_L)} \tag{2}$$

Using Eqn. 2, pressure at any interval can be found. The numerical interpolation can give the pressure values within an interval also. The charge weight (C) can be obtained from the burning law of the propellant, such as:

$$D_w \left|\frac{df}{dt}\right| = \beta\, P^{\alpha}$$

This equation is expressed as:

$$\Delta f = \frac{\beta\, P^{\alpha}}{D_w} \Delta t$$

Here, Δt is a small time interval. We know Δf from this relation. So $f = f_1 - \Delta t$. The web fraction (f) will have values from 1 to 0. Once web fraction is known, mass fraction (Z) can be obtained

The mass fraction (Z) can be expressed as a function of web fraction (f) from the geometry of the propellant web.

$$Z = Q_o + Q_1\, f + Q_2\, f^2 + Q_3\, f^3$$

where, Q_o, Q_1, Q_2, Q_3 are constants directly derived from grain shapes such as tubular, hepta tubular etc. As the total charge is distributed in one primary and two secondaries

$$CZT = C_1 Z_1\, u(t\text{-}t_1) + C_2 Z_2\, u(t\text{-}t_2) + C_3 Z_3\, u(t\text{-}t_3)$$

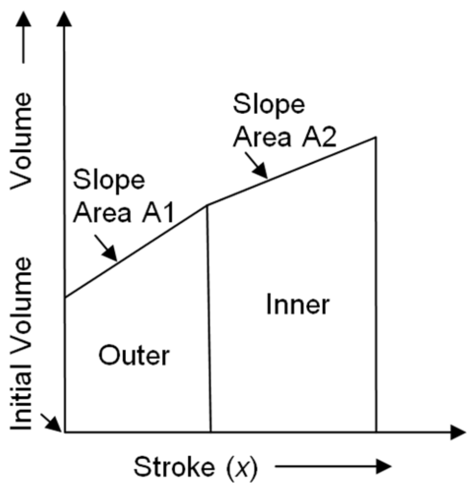

Figure 6. Volume *vs*. stroke.

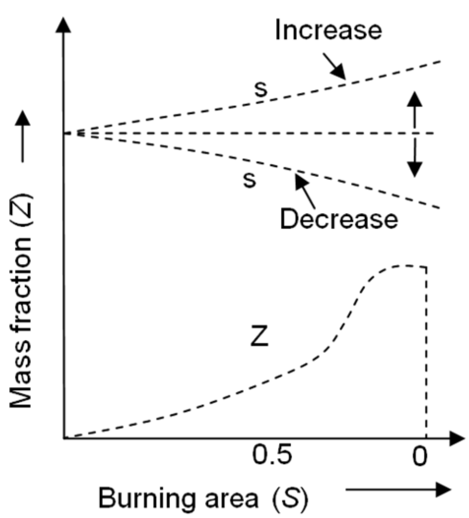

Figure 7. Mass fraction *vs*. burning area.

where, C_1, C_2, C_3 and Z_1, Z_2, Z_3 are the charge weight and mass fractions at any instant respectively for one primary and two secondaries. t_1, t_2 and t_3 are the instants of limitation and $u(t)$ symbolises unit function.

In the above equation, *FCZ* represents the energy released by the propellant burning. Therefore, any heat energy lost from hot gases to the gun body by conduction, radiation etc. may be accounted for by reducing the *FCZ* by a suitable factor known as heat loss factor (HLF). The heat loss due to gas leakage and heat transfer is found to be considerably high. 100 *FCZ* being the total energy content, the heat loss can be accounted upto a certain extent by introducing HLF. The effective value of heat energy released by burning of the propellant upto any instant of time is given by HLF. *FCZ* for any ejection gun, this HLF is established by examining the actual firing records of that gun. It is convenient to associate this factor with the force constant F alone so that the effective value is expressed as

$$F_1 = \text{HLF} \times F \tag{3}$$

After examining the firing records, it shows that this factor i.e. HLF is considered as 0.70.

Figure 6 shows, the inner and the outer volumes of the guns *vs*. stroke distance. The volume inside the gun when pistons have not started will be the initial volume. The slope of each part of the curves will be the respective cross sectional area of the pistons on which pressure acts. Fig. 7 depicts the relationship between mass fraction and the burning area. As the burning progresses, the burning area may increase depending on the grain geometry. Similarly the burning area may also decreases. Mass fraction curve (Z) can be expressed in the grain shape parameters such as web fraction.

6. CONCLUSIONS

The research work covered in this paper, brought out the effects of ballistics, kinematics, dynamics and the forces due to accelerations, decelerations, wind drag, blast and spinning that are contributing injury to the spinal cord and other organ of the pilot during the emergency from the disabled aircraft. The studies of these forces are critical in nature considering the acceptable physiological limits as laid down by Institute of Aerospace Medicines (IAM), Bengaluru. The biodynamic, dynamics, kinematics and ballistics studies are very useful to study and analyse various conditions of aircraft motion, sequence of seat ejection as well as environmental factors for a particular aircraft. This systematic study will help the designer to define the safe criterion for ejection to the pilot. All the scientists, engineers and researchers are working in these areas for safe escape of the pilot with minimum injury and fatalities within acceptable limits. The author has explained the various essential findings of life saving aspects of the pilot for EAX system application in this research paper.

7. FUTURE WORK

A detailed study and analysis is required in the life saving areas to minimise the effects of all these forces that the pilot has experienced for sophisticated design, development and to establish the emergency escape aid system for the fighter aircraft application considering the performance related to smart ejection seat.

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