Symposium Paper

AEROMEDICAL PROBLEMS OF HIGH SPEED LOW ALTITUDE FLYING

Escape during High Speed Low Level Flying

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Introduction

THE escape from a disabled aircraft has been one of the most critical problems in military aviation. The ever changing operational and tactical requirements have always guided the improvement of assisted escape system to meet the challenge of providing optimum, if not ideal, survival potential for the aircrew.

Modern fighters have capabilities of transonic to supersonic speed at almost tree top heights and such performance of aircraft encroaches upon the human tolerance limits. The term—low level, high speed in military combat/operational flying is used when the flying is conducted at altitudes below 300' and speeds exceeding 0.9 mach (650 knots). However, the majority of these aircraft have escape systems with minimum safe ejection altitude (MSEA) between 300'—500' and speeds not exceeding 600 knots. The escape systems range from open ejection to close canopy ejections for subsonic, transonic and supersonic speeds. Zero-zero ejection capabilities have been provided in modern aircraft but low altitude high speed escape is more critical, especially with diving a flight path or a high sink rate. Some salient features of escape system for specific problems of flying below 300' altitude at speeds exceeding 0.9 Mach are discussed.

Escape system available in modern fighter aircraft

Various assisted escape devices available in modern aircraft to meet the challenge of operational requirements are as follows :—

(a) Open ejection seat :—
 (i) Semi automatic
 (ii) Automatic—through canopy ejection with detonation cord (upward/downward)—canopy integration system.

(b) Closed ejection :—
 (i) Jettisoning nose escape
 (ii) canopy shield ejection
 (iii) encapsulated seat

(c) Capsule ejection :—
 (i) fuselage capsule
 (ii) cockpit capsule

These systems may have the following altitude—speed capabilities:

Altitude	Speed
0'	0
0'	Low
Low	High
High	Low
High	High

(d) Underwater ejection

(e) Special developments like "Discretionary descent system" and "Rocket extraction system"[3].

Limitations of aircraft ejection capabilities

At different altitudes and different speeds of the aircraft, the requirement of escape system varies. By changing the aircraft pitch angle from level flight an alteration of seat trajectory in relation to ground will occur. This will reduce upward vector and time available for operation of system. A change in aircraft bank will also produce similar results. But nevertheless, upto 45° high pitch/bank angles will not appreciably degrade upward seat vector. As the performance (speed) of aircraft increases to supersonic, escape by means of open ejection becomes unsafe and capsule closed ejection system is the only answer.

Ejection forces and human tolerance limits

The propulsion system of the ejection seat, either

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ballistics, rocket or combination of both, pushes the seat/man combination in a particular sequence. This moves upward from zero velocity to its maximum velocity of 60'–80'/sec depending upon the boost of the gun. This change in velocity over a duration of 0.2–0.5 sec and a distance of approx 72 inches induces accelerations of 18–20g in vertical axis of human spine. Human tolerance to the ejection forces depends upon (i) total magnitude (peak g), (ii) duration of acceleration, (iii) jolt factor, (iv) direction of force, and (v) surface area exposed.

Problems of escape at low altitude

The problems of escape with increasing air speeds (above 600 knots IAS) at low altitude could be discussed under following headings :—

(i) Pre-ejection consideration
(ii) Ejection phase
(iii) Post ejection phase
(iv) Landing phase and subsequent survival

Pre-ejection consideration : Average time taken for pilot's decision alone in an emergency situation is 2 secs and activities required for initiating firing mechanism after the pre-ejection drill may take another 1-2 sec.

Ejection phase : An average time taken in sequence of seat operation is as follows :

Pilot initiates ejection (pulls the firing handle)	0 sec
Canopy is jettisoned	1.0 sec (through canopy with MDC will reduce this time by 0.5 sec
Ejection seat carried out of cockpit	.18 sec
BTRU activated (seat/man separation delay)	1.5 sec
Parachute deployment starts	2 – 3 secs
	4.68 – 5.68 secs

Reduction in the delay time from 1 to 0.5 sec in integrated canopy jettisoning system and provision of through canopy ejection with miniature detonation cord(MDC) system will further reduce the time of canopy jettisoning. The mechanism must ensure canopy separation without hovering or flailing. Through canopy ejection is preferred with MDC (MB Mk 10 has this facility).

Egress phase : Total time taken for seat/man egress from cockpit after initiation is around 0.18 to 0.2 secs. During this phase the seat/man combination is moving out of the cockpit, hence the incidence of spinal injuries and contact injuries to limbs are known even in modern seats [1, 2, 4]. To avoid any contact injuries during seat egress, all body members should be adequately restrained automatically so that they don't graze against cockpit environment.

Post ejection phase :

(a) Seat/man exposed to RAM air pressure : At this stage the seat/man combination is exposed to RAM air pressure which is higher at low altitudes because of air density. The effect is commonly known as Q force (wind blast effect) which is a function of aircraft speed (IAS), density of air and surface area (frontal area).. Head and neck are exposed first, followed by upper limbs, chest and lower part of the body. The combined effects of low altitude and high speed can cause serious injuries. Such effects have been studied using rocket sled/water immersion experiments.

These effects can be minimised by following methods :

(i) At supersonic speeds the choice rests between a closed canopy capsule ejection or use of helmets with +G loaded visors covering head and neck completely. However, advantages gained in one phase of a system will be detrimental in other phase i.e. closed canopy/capsule will restrict differential drags and separation of seat/man may be delayed.
(ii) Speed of ejection should be restricted to transonic (as in MB Mk 10).

(b) Wind sheer effects : High speed may cause loss of protective clothing due to increased air pressure and may even cause secondary injuries. This could also be circumvented by closed canopy.

(c) Thermal injuries : Aerodynamic frictional heating can raise the temperature to 300–320°F at 1.7 Mach (IAS) and cause second degree burns unless special protection is provided [2]. To overcome these effects, speed restrictions have also been imposed during ejection. Alternatively, canopy ejection system (Type 77) or capsule ejection modes can be provided but they have inherent problems of increased weight and terminal velocity, wind drag effect, poor stability and requirement of higher velocity gun.

(d) Wind drag deceleration : Due to Q forces, the seat/man combination starts abrupt linear deceleration in the air stream. The frontal area of seat/man combination (5.8 sq ft) gets exposed to this and causes malposture of unrestrained body parts with consequent injuries. Sufficient vertical height is essential for clearance and this depends on drag/weight ratio (D/W). The drag depends on IAS. At aircraft speed of 200 to 400 mph, the D/W ratios are 2 and 8 respectively. An increase in D/W ratios brings the trajectory closer to the tail fin of the aircraft, and thus reduces the clearance. Another important feature is lift/drag ratio (L/D). After leaving the cockpit, the seat is accelerated upward by positive lift which progressively decreases at a rate corresponding to the deceleration. Finally the highest point of trajectory is reached and the seat starts dropping. Increasing speeds encroach upon the vertical height though there is a definite gain in time which is a beneficial factor, though only upto a speed of 610 knots. However, with different attitudes, the upward vector reduces tremendously and minimum safe ejection altitudes for the same seat is further reduced. Today's limitation in ejection is due to wind drag deceleration and not the wind blast effect. The wind drag deceleration is related to surface area, true air speed (TAS) and weight of seat/man. If the TAS increases, the deceleration increases and so also the increased surface area makes the man more susceptible to decelerative injuries. In actual practice (open ejection) 650 knots speed is the final limit. By increasing speed from 1 Mach to 1.1 Mach, the decelerative force increases from 35 to 40g. To ward off the effects of wind drag deceleration, following factors are important :—

(i) Increased weight of seat/man combination. If weight is more, duration of exposure will be more (peak g will be less). In this case, higher ejection boost is required which is possible only by rocket. At the same time, the limit of 700 knots is maximum. Thus, a gain in one phase becomes a disadvantage in the other.

(ii) Providing fins/stress lining the ejection seat. This increases lift and minimises drag.

(iii) Rocket assistance to propel the seat in direction of thrust/flight. This reduces the effects by about 15g. The rocket thrust has minimum eccentric loading and seat/man stability is assured.

Tumbling/spinning : High speed ejections have also limitations of tumbling and spinning which increase the complication of wind drag deceleration leading to effects of compression and hydraulic shock wave in the cardio-vascular system.

Seat/man and parachute deployment : In the limited time available the basic requirement is early deployment of parachute with minimum opening shock and effective seat/man separation. At higher speeds with closed canopy and rocket assistance the deceleration forces exceed the limit of human tolerance. To achieve this, automatic full inflation of aero conical parachute and seat/man separation are required.

Landing problems : If minimum safe ejection altitude is not adhered to, all the subsequent phases are delayed with consequent increase in landing velocity and concommitant injury potential.

Conclusion

Requirements of escape system in a multi-role aircraft are conflicting. High speed low altitude escape has definite problems particularly with open ejection system. The open ejection system will cater for speeds upto 600 knots only and that too with adequate body restraint and protection against the ejection trajectory. For speeds above 600 knots, canopy/capsule ejection systems are the only answer to cope up with the wind drag deceleration.

Training and indoctrination of aircrew in escape system, its limitations and MSEA must be adhered to for achieving maximum survival potential. The engineering design of escape system with single firing action, high impulse rocket, stabilised seat, positive seat/man separation, automatic gun/slug operation parachute deployment, automatic activated distress signal unit and survival kit will only meet the challenge of modern tactical operational requirements.

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