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EJECTION SYSTEMS and THE HUMAN FACTOR: A GUIDE FOR FLIGHT SURGEONS AND AEROMEDICAL TRAINERS

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ABSTRACT

This report outlines the Canadian Forces (CF) experience with ejection escape systems and the human factors involvement in their use during the period 1952 through 1987. It is intended as an introductory guide to Flight Surgeons and other aeromedical personnel of the Canadian Forces investigating accidents or incidents involving ejection systems, or for personnel responsible for training aircrew in the use of ejection systems.

The report analyses human factors involvement in ejection decision formulation and the medical/physiological considerations of the ejection, descent, landing and survival phases of the escape sequence. Case histories are used to illustrate the hazards involved in ejection escape, and emphasis is placed on ejection statistics for the period 1972 through 1987.

INTRODUCTION

During the Second World War, allied aircraft were typified by the Hawker Hurricane, Supermarine Spitfire, Mosquito, Mustang, P40 Kittyhawk, and Hawker Typhoon. These aircraft were characterised by piston engines that could rarely exceed 400 mph, and by relatively "high" wing surface areas that provided controllability at fairly low flying speeds of 70 to 80 mps (Figure 1). As a result of these minimum control parameters, emergency egress procedures were limited to "bail-out", i.e., the pilot undid his lap belt and shoulder harness assembly, opened the canopy and jumped out, manually opening his seat pack parachute.

During the War, prompted by Allied successes at shooting down Axis aircraft and pilots, the Germans experimented with the development of the ejection seat. Busch carried out the first successful ejection at 300 mph from a Heinkel aircraft in 1939, and in 1944 the Heinkel Ejection Seat was fitted to the Heinkel Jet Fighter and twin-engine Messerschmitt. By the end of the War, German pilots had made 60 successful ejections.

Other countries were quick to follow this technological advance. In 1943 Sweden prototyped their first seat into the SAAB 17B Bomber and SAAB J21A Fighter, and their first ejection was recorded 29 July 1946. The United States recorded their first ejection in November 1946, followed by France in February 1948. The RAF tested their first "dummy" ejection in 1945 from a Defiant aircraft, and on 26 June 1946, Lynch became the first UK ejectee from a Gloster Meteor at 515 kph in a Martin-Baker seat.

The introduction of jet aircraft with high minimum controllability air speeds, high air speeds that precluded conventional "bail-out" techniques, and high "sink rates" that arose with engine failure, necessitated the use of the ejection seat.

Milestones in RCAF/CF Ejection Systems

The first Canadian Forces (RCAF) operational ejection seat equipped aircraft was the F86 Sabre jet, taken on strength in August 1950 (Mark I), followed by the Mark II in February 1951. Improvements in design continued through the Mark VI before the Sabres were replaced in 1967. The Sabre ejection seat was a ballistic system, and initially it was manually operated. That is, the pilot and seat were "explosively" blown from the cockpit after the canopy had been manually jettisoned. Free of the aircraft, the pilot had to undo his lap belt, push away from the seat, then manually deploy the parachute before ground impact. Needless to say, many deaths resulted from the length of time required to manually perform all the steps in the ejection sequence. Not all pilots trusted the system - many elected to force land the aircraft rather than eject, that resulted in numerous fatalities. Canopy jettison failure also accounted for fatalities, along with several failures of the ejection gun. During the latter half of the 1950s the Sabre ejection system was converted to one of semi-automatic operation. After jettisoning the canopy, the pilot ejected from the aircraft. He was still required to manually undo the lap belt and kick away from the seat, however, as he did so, a parachute arming cable attached to the seat lap belt activated a spring-loaded timer which fired two .22 calibre blanks. When they fired, gas pressure pushed against a piston that withdrew the parachute pins allowing the parachute to open. A number of fatalities continued to occur because aircrew occasionally forgot to attach the arming cable to the lap belt during seat strap-in. Fuel exhaustion, stalls on landing approach and mid-air collisions accounted for many deaths during the Sabre era. During this time-frame, the Sabre ejection system exhibited an approximately 80% success rate.

In 1953 the CF100 Canuck was acquired by the RCAF. It was the first two-seat ejection aircraft to be manned by a pilot and an Air Intercept navigator. This system was the first Canadian fully automatic ejection seat, although it remained a totally ballistic impulse system (Figure 2). The CF100 remained on inventory until 1981. The seat, built by Martin-Baker (UK), also incorporated the first leg retraction/garter anti-flail restraint system used by the RCAF (Figure 3A, B). It was also the first system to use the drogue gun/drogue parachute extraction method, virtually the same system later incorporated into the CF188 aircraft ejection system. Ejection was initiated by reaching upwards and pulling a face blind over the head which activated two firing cartridges - one to jettison the canopy and one to fire the seat. The seat was designed to operate at a minimum altitude of ground level with 90 knots forward air speed. Use of the face blind by the back seat navigator was not without hazard as the following incident illustrates;

A CF100 at Cold Lake 'got into a tuck' on exceeding Mach 0.84. The aircraft became uncontrollable and dived. The navigator was ordered to eject, but when the pilot 'blew the canopy', the navigator while reaching for the face blind above his head, had his arms sucked out into the slipstream, and he was pinned there. The pilot managed to regain control and returned to base, unaware that the navigator was still onboard. The intercom had become unserviceable following canopy ejection. The navigator received badly frostbitten fingers (that subsequently required amputation) of both hands, a fractured left humerus and dislocated left shoulder.

In 1955 a rear windshield was installed to assist in the deflection of the slipstream to allow the navigator to reach the face blind ejection curtain, and an alternate seat ejection ring was placed on the front of the seat pan structure. Loss of aircraft control, engine flame-outs, and mid-air collisions took a constant toll of CF100s and their crews until its retirement in December 1981. The CF100 exhibited an ejection success rate of approximately 70%.

In 1959 the CF101 Voodoo came on line, the first supersonic aircraft in the RCAF inventory, complete with after-burners (AB) and drag-chutes. The ejection system was still ballistic, but fully automatic, incorporating a shoulder harness inertia reel, ballistically-opened lap belt, and positive man-seat separation system (Figure 4). When the pilot operated the ejection handles, the canopy was jettisoned, the rear ejection seat was fired and 0.5

seconds later, the front seat was ejected. The system was designed to work at ~' feet above ground and 120 knots. Pitch-up and loss of aircraft control contributed significantly to losses until the aircraft was retired in 1982. The ejection success rate was approximately 91%.

The next milestone in RCAF ejection system development occurred with the acquisition of the CF104 Starfighter in 1961. This was the first aircraft to incorporate a rocket catapult (ROCAT) ejection system with both arm and leg retention devices. The aircraft was also the first to have a MASTER CAUTION light, an enunciator panel, stall warning (shaker) and automatic pitch control (APC) system. The design of the system gave a ground level, 90 knot capability. Ejection was initiated by pulling the "D" ring on the front of the seat pan (Figure 5). On ejection, the legs were retracted by metal cables attached to spurs" worn on the pilot's boots and two bars swung forward to encase the pilot's arms in webbing to protect against flail. The CF104 ended its career in 1982 with an ejection success rate of 92%. Its low-level, high speed role resulted in considerable losses due to bird ingestion, engine failure, and controlled flight into terrain.

The most recent milestone in CF ejection systems occurred with the acquisition of the CF188 Hornet. This aircraft has a "zero-zero" ejection capability. It also incorporates a head-box mounted steerable parachute, remote rocket motor (under seat pan), and a Simplified Combined Harness (SCH) system (Figure 6). Upper and lower leg retention garters are used for flail protection. Like the CF100, man-seat separation is by parachute extraction. To date, the CF188 has a 100% ejection success rate. The only other aircraft with the same success rate is the CF116 (CF5) Freedom Fighter.

BASIC EJECTION SYSTEM COMPONENTS

An ejection seat must perform two functions. It must provide basic seating and restraint, and it must provide for the mechanics of emergency egress. The basic components of an ejection seat are (Figure 7A-C):

a. head-rest and canopy breaker;

b. seat structure;

c. harness systems;

d. ejection system; and

e. seat pack/survival kit.

Head Rest and Canopy Breaker. This provides minimal head buffet/flail protection when the pilot is ejected into the slipstream. A canopy "spike" (CF5), wedge (CF188) or bar (CT114, CT133) is incorporated on the head-box to provide positive canopy penetration should the canopy fail to jettison on ejection. The head-box on the CF188 seat also houses the 17 foot aeroconical parachute and the 22 inch and 5 foot drogue chutes.

Seat Structure. The seat structure provides the physical support and protection required on ejection, and serves as the platform to house the various components of the ejection system (ballistic devices, high pressure lines, restraint lines). The seat structure contains the seat kit that houses the personal survival items (Figure 7C).

Harness Systems. There are two distinct harness systems incorporated into the ejection seat for all aircraft except the CF188. They consist of a torso restraint system and a seat separation system. The restraint system consists of a set of shoulder straps, a lap belt, and a negative-G strap, all of which are connected to the Rocket Power Incorporated (RPI) buckle (Figure 8A, 8B). Also connected to the RPI buckle is the parachute arming key that is attached by a cable to the MK10 barostat in the personal parachute. As the seat/occupant separate following ejection, the RPI lap belt is separated by gas pressure, and the pilot is positively ejected from the seat by retraction of the rotary actuator (butt snapper). As separation occurs, the parachute arming cable is pulled from the MK10 barostat thus activating it, and the shoulder straps, lap belt, and negative "G" strap are freed, allowing the pilot to physically separate from the seat. The rotary actuator consists of webbing routed under the seat pack, connected to the forward edge of the seat pan at one end, and to a ballistic reel at the other end. At the instant of seat separation, the opening of the RPI lap belt and the retraction of the rotary actuator occur simultaneously. Separation occurs due to the differential drag between pilot and seat.

The CF188 seat presents a different concept in the harness system because the parachute is located in the head-box rather than on the pilot's back. In this system, the pilot straps into the parachute harness, that in turn is anchored to the seat at four positions: the ballistic inertia reel (BIR), lower harness locks, sticker clips, and negative-G strap. This system is the SCH, (Figure 9A-C). Following ejection from the cockpit (assuming all seat parameters are met), seat separation occurs when the scissor shackle opens allowing the aeroconical parachute to deploy from the head-box through the action of the drogue chutes. The lower leg restraint pins, "T" handle seat attachment (negative G strap), and BIR shoulder harness are released. The aerodynamic drag of the parachute provides the positive separation of the pilot from the seat.

The CF188 seat also incorporates a leg restraint system. This consists of a set of upper and lower leg garters attached by arrow fittings to leg restraint lines. These restraint lines (Figure 10) incorporate a "break link" to allow separation from the aircraft on ejection. The lines are attached to a floor bracket by a quick release pin, pass through a snubbing box and the upper and lower leg garter arrow attachments, and connect to taper plugs fixed to the left and right lower seat pan sides. On ejection of the seat, the restraint lines retract the legs against the seat pan, and the break link separates as the seat leaves he cockpit. The legs are maintained firmly against the seat by the frict.on lock of the snubbing unit. On seat separation, the taper plug is freed allowing the leg garters to slip free of the restraint lines.

Ejection Systems. (Figures 11-15) The seat ejection system is composed of two sub-systems: the ballistic catapult and the rocket motor. Such an ejection seat is usually termed a ROCAT (rocket-catapult) seat system (Fig. 11). All CF ejection seat aircraft possess essentially the same mechanism for ejection. When the ejection handles are raised, a sear pin is withdrawn from the ROCAT initiators allowing them to be fired by percussion. Gas pressure is directed through hoses to the BIR to retract the pilot into the seat, and to the canopy jettison system. After a pre-set delay of 0.3 to 1.0 seconds depending on aircraft type, (Tables 1 to 4) initiators fire the rocket catapult. The ROCAT is a set of telescopic tubes (three in the CF188 catapult) attached vertically to the rear of the ejection seat, the inner tube attached at the top to the seat guiderails of the aircraft. The initial ejection force is provided by the ballistic charges in the catapult, followed by ignition of the rocket motor that provides thrust through a controlled burn over 0.25 to 0.46 seconds depending on aircraft type. In all except the CF188, the rocket thrust is directed rearwards from the ROCAT. The CF188 system differs in that the catapult and rocket systems are physically separated (Figure 16). The telescopic catapult is located at the rear of the ejection seat, but the rocket motor is located beneath the seat pan. As the seat travels ballistically up the guiderails, a static line cable attached to the floor fires the rocket initiator. Whereas the rocket motor nozzles of other ejection seats are directed from the rear of the seat, the CF188 rocket nozzles are directed from the sides of the seat. The 9A seat nozzles are larger on the right side than on the left side and provide a seat trajectory to the left. The 10A seat exhibits the opposite characteristics. Thus, on a dual ejection, the front seat trajectory is to the right, and the rear seat is to the left.

Seat Pack/Survival Kit. (Figure 17) The emergency seat pack fulfils three basic functions: provides a seat cushion during normal operation, provides a relatively firm and stable base in the event of ejection, and provides containment for the storage of emergency survival items. The seat pack is of contoured fibreglass and is held to the parachute harness by left and right "airlock" fasteners. The pack has an actuating handle on the right side which when pulled, deploys the pack contents. The pack contents are physically secured to the pilot via a nylon lanyard connected to either the parachute harness or the life preserver when worn. The basic contents of all ejection seat kits are standardised, although there is variation between aircraft and squadrons as to additional items carried. The quantity and type of items carried is dependent on the volume of the seat kit. Basically, all kits contain a survival items packet, a food packet, life raft, first aid kit and sleeping bag. Table 5 lists the various items found in the CF116 (CF5) seat kit as an example. Following ejection, the seat pack is normally deployed by pulling the actuating handle at an altitude of about 500 to 1000 feet above ground, unless descent is made into a wooded area, then it is recommended that it not be deployed.

For all aircraft except the CF188, deployment of the seat kit occurs by the retraction of two retainer pins on the seat kit bottom (Figure 17). The withdrawal of the pins allows the canvas cover to open, spilling out the seat kit contents that are all connected to a 26 foot nylon lanyard that is in turn attached to the pilot. Withdrawal of the retainer pins also allows the fibreglass seat kit container to fall away from the pilot's body. As the kit contents fall the length of the lanyard, the one-person life raft is automatically inflated as the CO2 cartridge is activated by the weight of the dangling sleeping bag and contents bag.

Activation of the CF188 seat kit deployment handle produces similar results. However, since the emergency oxygen cylinder is attached to the underside of the seat kit lid, only the bottom half of the fibreglass kit falls away from the pilot, thus deploying the contents. The seat kit lid remains attached to the simplified combined harness (SCH) throughout the landing sequence. The 26 foot lanyard suspending the seat kit contents is attached either to the life preserver when worn, or to a bandolier slung over the shoulder.

Parachute. There are three types of parachute currently in use in CF aircraft. The CF116 has a 28 foot diameter canopy, the CT133 and CT114 a 24 foot diameter canopy and the CF188 a 17 foot diameter GQ aeroconical parachute. In the CF188, parachute opening is by two drogue "chutes" (60 inch and 22 inch diameter controller and retardation drogues). These drogues extract the parachute from the head-box when the barostat opens the scissor shackle at 13000 ± 1500 feet and when seat deceleration drops below 2.5G. Below 7000 feet MSL, the parachute is extracted 1.8 seconds after initiating ejection (the 'G' limiter is inoperative below 7000 feet). In all other aircraft, the parachute opening is controlled by the Mark 10 barostat set to open at 16000 ± 500 feet MSL, or when below this altitude, one second after seat separation. Timings for the ejection sequences are listed in Tables 1 to 4. Only the CF188 parachute incorporates steering lines to control forward descent speed. Descent velocities (with a 200 pound weight) are 19 fps for the 17 and 28 foot canopies, and 22 fps for the 24 foot canopy.

EJECTION STATISTICS

There are four distinct phases to any aircraft ejection sequence;

a. the decision phase that comprises the time span from emergency onset to formulation of the decision to eject;

b. the ejection phase, that consists of the time required to activate the ejection handles and be ejected from the cockpit;

c. the descent phase, that occurs from rocket motor burn-out to ground/water landing; and

d. the survival phase, consisting of the period of time from landing to rescue.

Each of these four phases has inherent limitations and hazards that can jeopardize a successful outcome. Each of these phases will be covered separately in the following pages, analyzing their impact on CF ejection statistics since the first ejection on 9 April 1952 from an F86 Sabre.

Table 6 lists the elementary breakdown of data gathered for this study from a wide variety of sources. Initial data were obtained from Brent (3,4,5,6) and Smiley (23,24,25,26,27), and supplemented by NDHQ'S Directorate of Flight Safety (DFS) Documents (8,9). Maximum use was made of the Medical Boards and Boards of Inquiry held at the Medical Life Support Division at DCIEM Toronto. Information on early accidents is sketchy; techniques of investigation were not as well developed as they are today, and knowledge of human factors was very limited. In many cases, cause factors assigned could, by today's standards, probably be debated. The author of this report disagreed with a number of findings in some Boards, however, in most cases, deference to the official Board was maintained. In several cases, this author would not accept some conclusions, and as a result, the data contained within this report may not strictly conform to official statistics. For example, there were several cases in which a completely successful ejection was carried out but the individual died from the effects of drowning or exposure (hypothermia) before being rescued. Smiley documents such cases as "fatal ejections". Clearly they are not fatal ejections in the context of this report. They resulted from a failure in either the rescue system or in the ability to survive until rescue. As a cautionary note, the accent of this paper is not on accident cause factor analysis, but is rather an analysis of the dividing line between a fatal and non-fatal accident. The cause of an accident is rarely the cause of the fatality. In this important respect, the accident analyses in this report differ from cause factor analyses conducted officially by DFS. A total of 720 personnel involved in ejection seat aircraft mishaps were identified (Table 7).

It is also necessary to define terms used in this report. Within the context of this study, an "attempted ejection" occurs when an individual makes the initial attempt to carry out the ejection sequence. It is indicative that a decision was made to abandon the aircraft, of recognition of an emergency as life-threatening. In older manual ejection systems, separate jettisoning of the canopy indicates the initial attempt to eject. In current systems, the first action to eject is to raise the ejection handles. This distinction can be important in the investigative process. In a fatal accident, if it can be established that there was intent to eject, some cause factors may be eliminated such as "incapacitation". Sometimes, it is not readily apparent that the pilot had such intentions. For example, it was originally concluded in the crash of a CT133 at Peggy's Cove in 1982 that there was no attempt to eject - the aircraft had abruptly bunted nose down at a low altitude and crashed almost vertically with total disintegration. Theories of incapacitation of the pilot were formulated to fit this conclusion. Yet the evidence had been there, and a year later the Aerospace Engineering Test Establishment found that the pilot had pulled the ejection handles before impact. Evidence was obtained from examining the canopy remover, drop-away tube and canopy frame and conducting an inch by inch sectional analysis of the ejection gas lines.

"Attempted ejection", as depicted in Table 6, is further sub-divided into "completed" and "not completed" . A "completed" ejection is one in which the individual exits the cockpit. Included within this group are "manual bail-outs" and "inadvertent ejections". There were five manual bail-outs and three inadvertent ejections recorded. Of the manual bail-outs, four were from CT133 aircraft and one from an F-86. Only one bail-out (CT133) was unsuccessful. An "attempted ejection" that was "not completed" includes those identifiable situations where the individual commenced the ejection sequence (jettisoned the canopy in the manual systems or pulled the ejection handle in the automatic system), but was not ejected from the cockpit. Failure to eject was attributable to some failure of the ejection system - the canopy would not jettison (manual system), the ejection seat would not fire, or the individual could not work the system due to interference from other factors (negative G forces, equipment hang-up). There may have been cases where the ejection system was activated prior to impact, but aircraft disintegration occurred before the seat catapult was fired. In fatal accidents, intent to initiate ejection is difficult to establish in situations where it is obvious that the seat was not ejected from the cockpit. Even in those cases where the seat has been ejected, it is necessary to ensure that ejection was not the result of crash forces at impact.

Another term requiring definition is "no apparent ejection attempt". This includes all accidents where there was no conclusive evidence that the individual attempted to eject from the aircraft prior to impact. Over 30% of the individuals involved in "A" category accidents, as far as can be determined, made no attempt to eject. Eighty per cent of these individuals were killed. The causes for not making an attempt to eject will be analysed later to determine why, and what can be done to decrease these losses. It is important that the Flight Surgeon, as far as is possible, establish intent to eject. Failure to do so may result in the establishment of incorrect hypothesis for the accident causation, and worst of all, may result in a conclusion of "Cause Undetermined".

DECISION PHASE

Making the decision to eject is the single over-riding factor influencing survival. For example, from January 1972 to December 1987, of 147 personnel involved in "A" category mishaps (Annex A), 45 or 30% did not eject. Thirty-seven (82%) of them were killed. It is probable that most of them did not even make the decision to eject. This figure may be as high as 27 of the 37. Not only is making the decision to eject necessary to survival, but the decision MUST be timely. Failure to execute the decision due to delay has claimed many a pilot.

Arriving at a decision to eject from an aircraft in flight, in many cases, is not easy. It is currently accepted that the role of the pilot in any man/machine interface is that of an information processor inserted in the control loop. The pilot receives input from the environment through the sensory systems (kinaesthetic, visual, vestibular) in analog fashion. The sensory organs act as transducers, relaying the information to the brain.

Due to physiological limitations placed on the sensory systems, the brain never receives a 100% accurate "picture" of its environment. Sensory input is usually lacking in either quality or quantity. There are five basic steps required in the formulation of any decision and therefore, five possible error points. To begin, the pilot must acquire the information from the environment through the sensory systems (subject to their limitations). The information must be integrated in the brain, and the quality and quantity of the information must be perceived as reliable and adequate. It is then processed centrally until a limited number of decision alternatives are formulated (eject, force land). The pilot then uses judgement to assess the probability of success of his limited number of decisions and selects one course of action. The selection of the decision is highly individual, based on training, experience, personality, and physical and physiological state. For the decade 1977 to 1986, 24% of the "personnel-pilot" cause factors involved faulty judgement. Lastly, the pilot must implement the selected decision using learned skills. In the same decade, 30% of the "personnel-pilot" cause factors were due to "technique" errors. CFP 135 Chapter 16 Annex D lists standardized formats for cause factor analysis. Table 8 lists the analysis of Air Accident Personnel-Pilot Cause Factors for 1977-1986.

Of particular importance to the Flight Surgeon is the concept of information processing/judgement as these two actions are so highly individualized and subject to existing physiological/medical influence. Judgement is the result of information processing; implementation, the result of judgement. It is necessary to assess the cockpit environment, both physical and ergonomic, and the physiological state of the pilot when analyzing a pilot's decision or lack of decision in the handling of an in-flight emergency. The probability that the pilot's judgement in selecting a decision response will be correct depends on:

a. The quantity of sensory input used to select decision alternatives. Too much and too little input are detrimental to decision formulation, especially in rapidly changing situations. The rate that information must be processed is a limiting factor in decision selection. It is also generally accepted that a human is a single channel sequential information processor, and can only devote 100% attention to one novel event at a time. Competing stimuli must be prioritized by perceived importance, a totally cognitive and subjective function (Table 9). Recent accidents involving heads up displays (HUD) on the CF188 give current meaning to this axiom. On a recent accident (CF188), Air Command Headquarters was prompted to explain:

> "Information presented on the HUD or DDI (Digital Display Indicator) during a spin ... (is) displayed in brief flash sequences ... not long enough to be useful for any constructive action. The rapidly changing aircraft attitudes far exceed the ability of the human processing system to keep up and apply correct control inputs as required ... it takes approximately 500 hours to become comfortable with all aspects of the HUD displays. This is at least our second episode where the loss of a CF188 may have been facilitated by problems related to difficulties in

interpreting the information on the HUD."

b. The quality of the input and its reliability. It is a well known fact that a pilot learns to disregard most sensory input during flight, and to seriously question the rest. Instrumentation packages are provided for conflict resolution, yet disorientation conflicts still persist (CF188717). Humans are "pattern recognizers" and current advanced digital/analog display cockpits do not present aircraft attitude changes in patterned formats that can quickly be assimilated by the pilot;

c. The manner in which the information is presented. This includes ergonomics and instrument design and layout, and the use of visual presentation (HUD, DDI, HDD, flashing lights) or auditory presentation (buzzers, beepers). Transitioning from heads-up displays for precision weapons delivery to heads-down displays for aircraft orientation can create fatal delays in information processing;

d. Individual processing capability. This varies diurnally with circadian rhythms, and is affected by numerous operants such as personality, training and experience, physical and physiological state at the time of the emergency, and medical condition. Most of these factors influence autonomic arousal and there is an inverted 'U' relationship between performance efficiency and arousal (Figure 18). Generally, as arousal level increases, performance efficiency also increases until at some point performance is maximum. As arousal continues, performance begins to fall. Note also, that when an individual is working at maximum performance, a removal of stress, or a reduction in arousal, may also result in a decrease in performance. The double curve also illustrates that performance on complex tasks deteriorates before that of simple tasks as arousal increases. This is known as the Yerkes-Dodson Law (19).

In cases where an individual does not have sufficient information quality or quantity, the information may be interpolated or extrapolated to produce a more subjectively complete picture. The degree of interpolation or extrapolation depends highly on training and experience and the rapidity with which information is changing. A pilot who makes a decision error based on erroneously interpreted input commits a false hypothesis. Accepting the false hypothesis may result in an error due to cognitive failure: commission, or doing the wrong thing; or omission, doing nothing. A false hypothesis is most likely to occur under conditions where arousal levels are distorted:

a. when the individual has been pre-conditioned to expect an event to occur or not occur;

b. when arousal levels are distorted;

c. following periods of high arousal;

d. when attention is diverted; and/or

e. when incorrect hypothesis or beliefs have been held for a long period of time.

One most common form of false hypothesis is "expectancy", an officially recognized personnel-pilot cause factor. Expectancy arises whenever an individual is pre-conditioned to an event occurring or not occurring, and reacts inappropriately when cue stimuli are presented. With extreme expectancy, an individual may perceive cues that are not really there (interpolate, extrapolate), or conversely, may not perceive cues that are presented. The following histories illustrate cases of expectancy.

A CF116 test pilot departed on a Pulse Code Modulation check flight in an aircraft configured with three full 125 gallon fuel tanks and empty rocket launchers with nose cones. Shortly after take-off, following landing gear and flap retraction at 230K, the pilot noticed that "at least one" of the Fire Warning lights were illuminated. He then retarded throttles from MAX AB to IDLE with a brief pause at MIL. Fire warning lights remained on. He then advanced power to MIL, receiving normal thrust response, then back to IDLE and to MIL again. Both times, when advancing from IDLE to MIL, the aircraft yawed left. The aircraft at this time was at an altitude between 200 and 400 feet AGL. The pilot, believing that the fire warning and yaw control problems were related, ejected from the aircraft. The Board of Inquiry (BOI) determined that all aircraft systems were operating normally at aircraft impact. Bulb filament analysis indicated at least one of the two fire warning bulbs was not on at impact, and the yaw control problem was a normal aircraft r.sp 2onse when configured in the heavy gross weight/high drag configuration. The pilot did not follow the AOI's during the perceived emergency, and as a result, ejected from an apparently serviceable aircraft after assuming engine problems! (He did not eject external stores);

A CF188 pilot attempted to take off from Cold Lake on a deployment and ferry mission with a 707 tanker support to CFS Goose Bay, and ultimately Baden-Soellingen. As the aircraft accelerated to full military power followed by AB selection, the pilot attempted to rotate the aircraft at the lift-off speed. The aircraft failed to rotate, and abort procedures were initiated at the 7200 foot mark. The arrester hook was lowered but failed to engage the cable and the aircraft continued to roll off the departure end of the runway into the approach lights area and exploded. The pilot ejected about one second before the fire-ball and suffered a sprained ankle and some bruises and muscle strains. The briefed take-off procedure had called for a stabilator setting of eight degrees NU (nose up). During a thirty minute delay, the pilot completed his pre-take-off check and inadvertently set the stabilator setting to eight degrees ND (nose down) on the DDI. Prior to take-off each pilot called their stabilator setting as eight degrees NU. This was the second time the pilot visually mis-read eight degrees ND as NU. Additionally he elected to do a heavy weight take-off from the 2000 foot mark, and delayed his ejection for eleven seconds after crossing the arrester cable. The hook failed to engage due to nose down trim and excessive braking.

As previously mentioned, successful escape also depends on making the timely action of initiating the ejection sequence following the decision. Delay may occur while alternate actions are being addressed, by the need to steer the aircraft away from an inhabited area, or even by a perceived need to salvage the aircraft beyond reasonable limits. Among the factors the Flight Surgeon must analyse if undue delay in initiating an ejection sequence is suspected are:

a. physical and physiological reaction times (receptor-effector, cognitive, perceptual);

b. personality (fear of implementing the decision, ego, attempting to salvage the situation beyond rational limits);

c. temporal distortion (failure to appreciate "real time");

d. complacency, or lack of anxiety (a pilot accustomed to high speed, low level flight may lose or suppress the "low altitude anxiety response", and fail to appreciate the rapidity at which the aircraft is travelling);

e. lack of appropriate training (unfamiliarity with egress procedures, habit-transference, ambiguous AOI's);

f. self-sacrifice (turning the aircraft away from inhabited areas, delaying ejection while a passenger ejects);

g. technique error (too many salvage attempts, trying to enhance ejection parameters, "groping" or "fumbling);

h. control surface, control loop response delays;

j. miscellaneous delay-inducing effects of negative "G", fatigue, stress, circadian desynchrony and transient situational disturbances.

The following accident illustrates a case of excessive delay:

The pilot of a CF116 took off on a test flight following a double engine change, to be followed by an air display practise. The aircraft was configured with a refuelling probe and three pylons without tanks. Following satisfactory run-up and take-off, the pilot flew a practice air display over a lake north-east of the airfield while waiting for his block time. His last manoeuvre was to be a battle break followed by a full stop landing. The aircraft ran in for the break at 430 KIAS and 80-90% rpm. Pulling up for the break, the pilot throttled back to IDLE and selected SPEED BRAKES OUT. During the break the MASTER CAUTION and RIGHT GENERATOR lights came on. Assuming generator failure he rolled out at 1800 feet and lowered the landing gear and flaps. Getting no throttle response and noticing both engines had decayed to 12% rpm, the pilot identified a double-engine flame-out. Two "TIGER STARTS" were attempted, the throttles shoved into max AB and back. The engines failed to relight and the aircraft was sinking rapidly. Deciding to eject, the pilot reached for the handles and missed. Straightening the aircraft, the pilot then looked down, grabbed the handles, and ejected at 400 feet. The investigation revealed that the pilot had been reluctant to eject initially because of a perception that the Base Commander and Squadron CO would not appreciate losing one of their aircraft. As a result he had wasted valuable time at extremely low altitude attempting two relights which, even if they had been successful, would not have saved the aircraft from its descent trajectory. The ejection and crash occurred in a valley below normal ground level. If it were not for this, the delayed ejection would have in all probability been fatal.

A Flight Surgeon investigating a fatal accident where ejection was not initiated faces a difficult challenge in trying to determine why ejection did not take place, especially in situations where all aircraft components are determined to have been functioning normally at impact. In such cases, in-flight incapacitation or distraction are always highly speculative, especially if witness statements indicate there was no observable attempt to avoid ground collision. Physiological collapse, disorientation, inattention, and self destruction would also account for such an accident. In all such cases, deductions must be made from evidence gleaned from personal medical documents, autopsy (coronary artery disease, cardiovascular accident), toxicological screening, psychosocial/psychiatric investigation (psychological autopsy), and in-flight factors that may have been operating prior to the accident (hypoxia, "G" forces, etc.). In addition to physiological or psychological impairment, ejection failure may also occur from physical factors that make ejection impossible such as severe negative Gz or ejection system malfunction.

As stated earlier, there were at least 37 fatalities arising from failure to eject during the period January 1972 to December 1987. These fatalities may be loosely categorized into three groupings that account for failure to eject (Table 10): unable to eject, unperceived aircraft to ground closure (controlled flight into terrain) and rapidity of events (one case of unknown cause).

Unable to eject. Eight cases (21.6%) may have arisen through some physical or physiological factor(s) preventing ejection. This group may include such diverse factors as severe negative G forces (which inhibit reaching the ejection handle), violent aircraft manoeuvres, in-flight break-up, mid-air collision, ejection system failure, loss of consciousness, and psychological impairment (hypoxia, drugs). The following three case histories illustrate accidents in this category:

The first case involved a CF104 aircraft in an air-to-air gun attack on a towed target (DART). During the third successive attack, the aircraft entered into a 15 second 4.5 - 5.0 Gz after-burner turn, then abruptly went 30 to 40 degrees nose low, continuing on to impact. After examination of all the facts, the BOI concluded that the most likely causes of the accident were either acute severe barotrauma "G" induced loss of consciousness (LOC). The pilot had a resolving upper respiratory tract infection and mild chronic sinusitis with post nasal drip. Additionally, he had been on a self-imposed diet for an undetermined time pre-accident, was a long distance runner, and had only 5.5 hours of sleep the previous evening. All are known G-tolerance reducers. Finally, rapid, successive +Gz loadings have a cumulative effect on lowering arterial oxygen saturation.

The second case involved a CF104 dual on a basic fighter manoeuvre training mission in defensive counter-measures. During the second air-to-air gun attack against another CF104, the aircraft performed a defensive roll-under followed by a nose-down extension manoeuvre. The aircraft entered cloud at 2000 feet in a 20 to 30 degree nose down attitude and impacted the frozen surface of a lake at high velocity. It was felt by the BOI that during the -Gz defensive manoeuvre, both pilots' seat packs had dislodged from their seat pans, jammed the control column forward and prevented the use of the ejection "D" rings on the front of the seat pan.

The third illustrative case involved a T-33 with two pilots that took off on a full card air test. One minute after take-off the aircraft captain radioed that he was experiencing control difficulties. The aircraft was laterally unstable and remained in left bank as a result of what was later diagnosed as mis-rigged ailerons. After several circuits about the airfield the decision was made to eject. The rear seat pilot ejected first. The front seat pilot then flamed the aircraft engine out and attempted to eject. The seat would not fire as a result of the ejection handle jamming in the partially raised position due to excessive play in the linkage and a design fault. The pilot was unable to re-light the engine due to low rpm. Twenty-five seconds after the rear seat pilot had ejected, the front seat pilot transmitted with great finality that he was unable to eject. Twenty-six seconds later, the aircraft stalled, rolled inverted and crashed into a stand of trees killing the pilot.

<u>Unperceived Ground Closure</u>. This is also called "controlled flight into terrain (CFIT)" and "situational unawareness". Nineteen of the thirty-seven fatal cases (51.4%) fit into this category. In all cases the pilot, apparently in complete control of the aircraft, flew into the ground or water, or entered into some aerobatic manoeuvre such as a dive, loop or roll without sufficient air space to complete the action. CFIT may result from visual illusion, inattention or distraction, willful self-destruction (deliberate sabotage) or physical factors such as insufficient "G" for bank. In all accidents in this category, there did not appear to be any physiological or psychological impairment accounting for a lack of ground avoidance procedures. Four aircraft and six aircrew flew flight paths into water, and 11 aircraft and 13 aircrew flew into the ground. There are many instances of CF104 aircraft flying into the ground as a result of the pilot attempting to maintain visual meteorological conditions (VMC) in deteriorating weather while flying over rising ground. The following case history illustrates a "controlled flight into terrain" accident.

Kiwi 17, a CT133 with two pilots onboard took off from Baden-Soellingen on a planned low level navigation mission. Twenty minutes into flight, their track converged with that of a Belgian F-16 also on a planned navigation route. The F-16 pulled up and turned left in a mock attach on the

CT133. The CT133 pilot apparently responded with a defensive steep left 4G 180 degree turn. Rolling out of the turn, the aircraft struck a stand of trees on a ridge. The abrupt decelerative force probably rendered both pilots unconscious, and the aircraft continued descent to ground impact where it exploded. The most probably cause was channelized attention in that both pilots were probably concentrating their attention on the attacking aircraft to the exclusion of clearing their flight path.

Of interest is a 1983 USAF study on distraction and vigilance (Table 11). Using experienced A10 instructors, the study found that a simple TACAN channel change required as much as 15 seconds with a corresponding aircraft altitude loss due to distraction of up to 100 feet (average 38 feet). More complicated secondary distractions such as fuel computations resulted in altitude losses as great as 900 feet. Transitions between the exterior of the cockpit to the interior and back consumes valuable time and creates momentary "loss of situational awareness".

Another CFIT accident involved a CF104 dual on a cross-country visual navigational trip in Germany. The final leg of the trip was discovered to be marginal or below visual meteorological conditions (VMC), and the pilot apparently deviated right of his track in an attempt to acquire better VMC. Turning right, he apparently passed through a patch of low lying cloud. Diving from the cloud, the aircraft levelled off and continued to fly a shallow descent until it impacted the crest of a ridge at five to ten degrees right-hand bank and ten to twenty degrees nose up pitch. After initial impact, the aircraft "skipped" into the air and the fuel tank exploded accelerating debris and the pilots' bodies over 1,000 feet. Both pilots were probably killed by the initial decelerative force at impact. Lack of characteristic fractures of the front seat pilot's right hand indicate that he may have had his hands on the ejection "D" ring at the moment of impact.

A similar situation occurred during another CF104 visual navigation sortie in marginal weather conditions. For undetermined reasons the pilot attempted to maintain VMC and deviated 3.8 nm left off his track over gently rising ground. While attempting to accurately pin-point his geographical position, he may have momentarily diverted his forward vision to his map. The aircraft, flying at 450 knots, crashed into the top of a dense stand of snow-covered trees at the crest of a hill in a descending flight path. The aircraft and pilot disintegrated through the trees.

Disorientation may also be involved in a number of accidents in this category. As a contributing factor, disorientation must be deduced by a process of elimination. Reconstruction of the aircraft flight path and flight manoeuvres may provide evidence to the possibility of disorienting conditions. Witness statements may provide valuable information on any last minute aircraft attitude changes which may be explained by disorientation. The following case history outlines one accident wherein disorientation was a probable cause factor.

A CF188 pilot proceeded from Bagotville to Summerside to participate in an air show. As the weather was unsuitable for flying, he spent the day with his aircraft on static display. Later that afternoon, he taxied to the runway for the return trip. On take-off he did a steep AB climb into cloud based at 300 feet and 4000 feet thick. Twenty-five seconds later the aircraft descended from the clouds and impacted the water of Malpeque Bay off the end of the runway. Information from the data recording system supported the theory that the pilot experienced a somatogravic illusion during climb, pushed forward on the control column and induced the classic inversion illusion.

Rapidity of Events. Low-altitude high speed tactics leave little margin for error. In many cases, the time margin may be less than human reaction time. In critical situations where time and air space are marginal, the time required for reaction may be the precipitating factor in a mishap. Total minimum reaction time has been calculated to be as long as nine seconds in a complex man/machine system where a decision must be formulated from alternates. This time would significantly increase whenever arousal levels are distorted (stress), or when multiple simultaneous emergencies occur (workload). To minimize decision times, aircrew must predetermine their reactions to any given set of conditions. However, if the situation is misinterpreted, the wrong procedures may be initiated! Nine fatalities (21.6%) probably resulted from a lack of time to react.

Accidents in this category resulted from the occurrence of two primary situations; loss of power on take-off, or a lack of sufficient air space to complete an initiated aircraft manoeuvre such as a dive, turn, or roll. To illustrate: A CF116 dual with a student and instructor crashed on the runway following a touch-and-go approach. The aircraft had initially touched down, then after a short roll the student lifted it off with excessive nose up attitude. At 50 feet above ground the aircraft began oscillating, then abruptly rolled right and crashed with 135 degrees right bank and slightly nose down attitude. The Board concluded that the student had allowed the aircraft to become prematurely airborne with excessive nose up attitude, thereby creating an aerodynamic stall. Ejection was not initiated due to a lack of response time as a result of extremely low altitude and high sink rate.

In some instances, the personality of a pilot may contribute to a mishap. Strong desires to succeed stemming from egotistical, compulsive, or borderline personality disorders may over-ride rational decision-making process in an emergency situation, and indeed may even be responsible for the emergency situation arising, e.g. "press-on-itis". Underlying personality may have directly contributed to four fatalities and the loss of three aircraft.

The first illustrative case involved a CT114 student pilot on a clear hood solo flight. He was authorized to practice stall procedures and slow flying in the area, and then some touch-and-go landings in the circuit. After take-off, he deliberately deviated from his flight plan, proceeding to his aunt's farm where he made two low passes. Following this, he flew east to his cousin's farm and made a low pass. On the second pass, he flew over in a left bank, then lined up for another pass. As he went by, he entered a left roll that continued to aircraft inversion. The nose pitched down 45 degrees and the aircraft struck the ground and exploded. During his flying training, his instructors had consistently used the word "over confident" when describing him. His last flight was a pre-planned "pretentious display" of "showing off", that allowed him to get into a situation from that his lack of experience would not allow him to recover.

The second incident is similar in most respects. This rather inexperienced CT133 pilot filed a visual flight rule (VFR) flight plan knowing that enroute weather was below VFR minimums. He deliberately deviated northeast of his track to a small civilian aerodrome where he had previously done some sky diving, and made two high-speed low level passes down the runway, executing a crisp right roll on the second pass. Banking right, he appeared to be preparing to rejoin his original flight track, but suddenly made a tight 90 degree left bank to return to the spectators that had gathered. During this fly past, he executed a "sloppy" right roll and began a left roll. At 45 degrees into the roll, the aircraft nose pitched down 20 degrees, and the aircraft flew into the ground, exploded, and disintegrated. During the investigation, the pilot was described as "self-critical", and "underconfident" during his flying training. The BOI concluded that his personality contributed to his desire to "show off", attempting flight procedures for that he was grossly inexperienced.

The last case involved fatalities because of a conscious delay in the decision to eject. This aircraft accident involved a CT114 with a student and instructor pilot on an extra dual training mission. On the final leg of the return trip to home base, the pilot transmitted an unspecified emergency. For 20 seconds, the instructor managed to stabilize the aircraft in a wings-level, shallow descent. At 8.5 NM from base and 50 feet AGL, a slow speed stall occurred. The aircraft abruptly banked 33 degrees right, pitched 21 degrees nose down and crashed. Why had both pilots not ejected from the aircraft during the final 20 seconds? It is interesting to note that the instructor had previously been commended for recovering a CT114 after an engine failure in flight.

<u>Non-Fatal "A" Category Mishaps</u>. Four aircraft were involved in mishaps where the occupants did not eject, but survived. In three cases, the accident occurred after the aircraft had landed, breaking the vertical descent rate, and in one case the accident occurred on the take-off roll. The following two case histories illustrate accidents in this category.

The first accident involved a CF101 on a radar square pattern approach to a full-stop landing. Due to pilot fatigue, post-alcohol syndrome, and a visual illusion, the pilot allowed the aircraft to touch down 90 feet short of the runway threshold. It continued onto the threshold where the right main landing gear collapsed and separated from the aircraft. Continuing to slide, the aircraft departed the right side of the runway with the right wingtip and aileron dragging, and the navigator ejected. After departing the runway, the nosewheel sheared off, the aircraft slewed right collapsing the left main wheel inboard, and the left wing dug into the ground flipping the aircraft over. The pilot, who had remained with the aircraft, was later rescued from the inverted cockpit suffering only a fractured left clavicle and some contusions. The navigator received two superficial bruises to the head.

The second accident involved a CF116 during a TACAN straight-in approach. The runway had not been cleared of snow, leaving a windrow ploughed down the centreline. On touch-down, a large hole was torn through the floor of the front cockpit allowing snow to enter forcing the centre console to the left trapping the pilot's left leg and fracturing both legs. Snow pressure actuated the mechanical tripper, firing the RPI lap belt and butt snapper, forcing the pilot up and forward, enhancing his leg injuries. The back-seat pilot received no injuries, and egressed the aircraft after it came to a stop. The front seat pilot was unable to extricate himself until assisted by rescue personnel.

In all fatal no-ejection accidents, the Flight Surgeon must conduct the investigation by listing all possible cause factors that could account for the failure to eject; then through exclusion, arrive at the most probable cause(s). Close liaison with other BOI members to compare facts and theories is mandatory. The following should not be overlooked as potential sources of information:

a. Flight Path Reconstruction. Instrumentation analysis, flight data recorders, flight briefing data, witness statements, strip maps, and weather reports provide clues to the flight path and flight environment and may provide evidence for the existence of disorienting or illusory conditions or support hypotheses of physiological collapse. Fly the exact route under the same conditions, if appropriate.

b. CF2034. Look for any evidence of a medical nature that may corroborate hypotheses of physiological collapse or psychological dysfunction such as: medications, recent illnesses, psychological or psychosomatic complaints such as fatigue or depression.

c. Witness Interviews. In some cases, this may be the only evidence on that to formulate accident cause theories. Spouses, friends, relatives, or other squadron personnel may provide clues to personality, intentions, psychosocial stress, fatigue, workload, or substance abuse that may support or confirm other evidence.

d. Training Records. Course reports and performance assessments can show deficiencies in training or technique and even provide insight into character or personality traits such as "immature", "over confident", "aggressive", or "lacks confidence". This is a good place to gain insight into currency and proficiency of the individual or individuals involved.

e. <u>Aircraft Operating Instructions</u>. Determine if the individual adhered to the AOIs. Are the AOIs current and complete?

f. <u>Human Engineering</u>. Does the position of switches, warning lights and instruments lead to possible disorientation or distraction during certain phases of flight? Can instruments be misinterpreted? Could there have been any habit transferrence during an emergency (in this regard was the individual qualified on two different aircraft types, or had the pilot recently flown different aircraft)? Is the flight data presented in a way that allows for significant and rapid assessment by the pilot (for example, the CF18 HUD presents rapidly changing information that is difficult for the pilot to integrate quickly)?

g. <u>Laboratory Analysis</u> Instrumentation settings, power settings, switch positions, warning light bulb filament analysis and engine inspection provide evidence of flight conditions at impact, and may provide clues to events occurring within the cockpit prior to impact.

h. <u>Wreckage Distribution Plot</u> This gives a picture of the aircraft attitude and approximate speed at impact.

j. <u>Toxicological Drug Screen</u> Analysis of body fluids may show the presence of a foreign substance.

k. <u>Autopsy</u> Look for evidence to support incapacitation - coronary artery disease, aneurysm. For multiple fatalities, x-rays of hands and feet may provide clues as to who was flying the aircraft at the time of impact.

m. <u>Aircraft Maintenance Records</u> These log books may show recent problem areas or recurring mechanical failure patterns that may fit the accident profile.

n. <u>Pilot's Flying Log Book</u>. This diary shows the individual's experience, currency and proficiency. It may indicate possible flying fatigue, and in rare cases, even personality. For example, one pilot involved in a mid-air collision had been using his log book as a personal diary, entering off-handed demeaning and sarcastic remarks about his superior officers and other squadron personnel. This helped the BOI to evaluate his personality profile.

o. Flight Recordings Analyse gun camera film or data recording system information whenever available.

p. Psychological Autopsy Hobbies, music collection, marital and sexual history, type of car (bumper stickers, custom plates), clothing, pets, lifestyle and locker contents all provide clues to personality and mental state.

EJECTION PHASE

Between January 1952 and December 1987, at least 481 individuals attempted to eject from RCAF/CF aircraft. Of these, 450 completed the ejection sequence or bailed out; 74 were killed following egress. This gives an approximate 35 year ejection success rate of 80.5% (Table 7).

Normally, the ejection phase immediately follows the decision phase, though not necessarily. When it does, it is usually preceeded by a time delay. The delay is equal to the individual's reaction time plus the system reaction time. Tables 1 to 4 show that the system reaction time is mechanically fixed from 0.3 seconds for CF188 seat ejection to 1.5 seconds for CT133 seat ejection. Human physiological time is variable. By far, the greatest number of fatalities arising following ejection initiation were because of ejecting outside the design limits of the system, or "out of the envelope". Modern ejection systems are one-step, irreversible and fully automatic. Only a system failure will prevent ejection once the handle is pulled. Figures 12 through 15 illustrate the automatic sequence for current CF aircraft. A generalized ejection sequence is shown in Table 12.

Once the ejection handle or "D-ring" is pulled, the ejection sequence has begun. The ejection phase ends with rocket motor burn-out. Although the ejection phase is extremely short, it accounts for many of the injuries that occur. Included within the ejection phase are the effects of explosive decompression, positive Gz acceleration and windblast. Since the Flight Surgeon is responsible for analysing injuries occurring on ejection, it is important that there is an understanding of the events that may produce injury during this sequence.

Activating the ejection sequence results in immediate jettison of the aircraft canopy with cockpit depressurization to ambient. This exposes the ejectee to all the attendant risks of altitude including: hypoxia, decompression sickness, barotrauma and cold. Several cases of conjunctivitis have been reported because of dust and dirt from the cockpit floor entering the eyes during depressurization. Since 1972, all ejections have occurred below 16000 feet MSL (Figure 22) however, before this ejections tended to be higher (Table 13). There are numerous cases of F86 and CF100 ejections above

20000 feet MSL, and several of these were above 25000 feet. At least four ejections were over 30000 feet, the most recent being from CF100789 in May 1971. Annex B presents some ejection parameters for CF ejections since 1972. A few cases of hypoxia following ejection have been recorded. These appear to be confined to high altitude F86 ejections where the oxygen bottle and mask were lost on ejection, resulting in varying degrees of hypoxia during descent and in one case, loss of consciousness (F86 23278 May 1955). No recorded cases of decompression sickness were found. Aerodynamic suction also occurs on canopy jettison because of Bernoulli's principle. This suction has been known to pull an individual off his seat cushion because of slackness in the harness restraint system, thereby increasing the accelerative "jolt" on the spine at the time of seat ejection.

Injury analysis of 67 successful ejections from January 1975 to December 1987 (Table 15) show that there is over an 86% chance that some form of injury will occur during ejection. During the ejection sequence, all of the following injury mechanisms have been known to occur:

a. knee contact with the instrument panel to produce fracture and/or laceration;

b. knee contact with the canopy bow to produce punctures, lacerations and fracture;

c. knee and thigh contact with arm rests or ejection handles to produce contusion;

d. elbow contact with the canopy sill;

e. collision with loose objects in the cockpit;

f. shoulder contusion because of ballistic inertia reel harness retraction forces; and

g. posterior thigh contusion from seat pack contact.

As the ejection seat ascends the guide rails, positive Gz force is created. Table 14 provides some physical data on current CF ejection seats. Accelerative forces vary between 14 and 20 Gz, with onset rates from 180 to 300 Gz/sec/sec. The actual loading on the body depends on the occupant's weight and the slackness in the restraint system. The CF116 is the worst case scenario. For a 5% body weight male, peak "G" will be in the vicinity of 20 Gz. For a 5% female, peak "G" may reach 28 Gz. All ejection seats except the CF188 are designed for the 5 to 95 percentile individual; the CF188 seat is designed to accommodate the 3 to 98 percentile (130 to 225 pounds) individual. Lighter individuals tend to experience higher "G" loading, a faster ride up the ejection rails and greater seat tumbling.

Conversely, heavier individuals would experience lower "G" loading, a slower ride up the rails and a decreased seat height trajectory.

Figure 19 illustrates a "typical" acceleration versus time pulse of a ROCAT seat. A ballistic charge or charges explodes creating pressure that, contained within telescoping tubes, propels the pilot/seat system up the guide rails. As it does so, a mechanical tripper or wire fires the rocket motor that provides a fairly constant acceleration over the next 0.25 seconds or so. The initial impulse thrust is approximately in the Gz plane, varying from 10 to 22 degrees rearwards of the vertical, depending on seat type, to allow instrument panel knee clearance. Since the centre of gravity of the head and torso lies anterior to the vertebral column, the head is rotated forward and down creating flexion and strain of the cervical spine and musculature. In addition, the inertia of the viscera connected to the rib cage and spine increases the load on the vertebral column. The vertebral column is a compound "S" curve that can be divided into four regions of alternating curvature:

a. cervical spine, anteriorly convex;

b. dorsal (thoracic) spine, posteriorly convex;

c. lumbar spine, anteriorly convex; and

d. sacrococcygeal spine, posteriorly convex.

Effectively, however, the spine may be divided into two at T12 to form the cervicodorsal column and lumbosacral column.

During the ballistic phase of seat ejection, the spine and body act in semi-rigid fashion (intervertebral disc compression), but the fleshy buttocks and seat pad compress, allowing the ejection seat to build up a relative velocity before striking the occupant. The travelling seat strikes the stationary occupant with a "jolt" that may exceed vertebral tolerance (18 to 20 Gz). This is known as "dynamic overshoot". If the occupant has adopted poor posture such as flexing or slumping, a shear force through the area of greatest curvature (thoraco-lumbar) may result in fracture. Loose restraint harnesses also magnify accelerative jolt. When the upward travelling seat strikes the stationary buttocks, the occupant is accelerated to a greater velocity than the seat and is momentarily extended into the shoulder harness. The looser the harness, the greater the extension. As the harness decelerates the upward travel of the occupant, the accelerating seat impacts the buttocks again, creating an extremely high impact pulse that may be in the order of 500 G/second. There are two primary vertebral injuries that may occur during the ejection phase as a result of excessive forward flexion of the spinal column because of poor posture or loose restraint systems:

Anterior Cuneiform Fractures These are caused by forward flexion and vertical compression forces. Most frequently, these are characterised by anterior wedge fracture of the upper and/or lower vertebral lips and a decreased height of the vertebral body with or without protrusion into the spinal canal; and

<u>Comminuted Fractures</u> These are caused by obliquely acting forces that drive the anterior inferior edge of the superior vertebra into the upper surface of the inferior vertebral body. The intervertebral disc is usually torn and ligaments ruptured. The vertebral body is shattered and the fragments expelled. As the angle of the ejection seat back increases, anterior cuneiform fractures tend to become comminuted. In addition, increasing the seat back angle creates greater flexion of the thoracic spine necessary for optimum head attitude, that increases the risk of spinal fractures in the mid-thoracic region. The USAF reports 15 to 20% of all ejection vertebral fractures are not accompanied by clinical manifestations. Thus, the most searching examination cannot provide sufficient evidence to eliminate with certainty a fracture of the spinal column, and a radiological examination is always prudent.

Spinal injury is rather common during ejection. From 1975 through 1987, DCIEM aircraft accident files indicate six cases of vertebral fracture occuring during ejection out of a total of 67 ejections. This gives an incident rate of 9%. In addition, there were eight more instances of vertebral fracture attributed to improper landing. Distribution of these 14 cases shows all fractures were incurred in the T6 to L5 region (some patients presented with multiple fractures):

a.	T6 - 1		e.	L1 - 10	
b.	T10 - 2		f.	L2 - 2	
c.	T11 - 2		g.	L3 - 1	
d.	T12 - 5		h.	L5 - 1	

Most of the compression fractures were mild, characterised primarily by tenderness in the area on palpation. Compared to other aircraft types, the CT114 (Tutor) appeared to have the highest incidence of associated vertebral compression fracture while the CF104 predominated with cervical sprain/strain. Spinal sprains/strains are also somewhat common. During the same time period, 15 cervical sprains were recorded. Table 15 documents ejection injuries occurring during 1975 to 1987.

Another factor to consider during the ejection phase is windblast. The seat and occupant are subjected to dynamic air pressure, or windblast often called "Q" force, that is proportional to the square of aircraft velocity and inversely proportional to altitude. Thus, the worst "Q" forces occur during high speed low level ejections. The stagnation frontal area of the occupant/seat combination creates a ram pressure that acts to decelerate the seat to "zero" horizontal velocity. During this deceleration, air flow over, under and around the seat system creates an erosive effect that may lead to loss of protective equipment (helmet, mask), tearing of exposed skin (eye lids), and limb flail. There have been seven cases of windblast helmet loss since 1975, all from CF104 and CF101 crew ejecting into more than 300 KIAS. This represents a 10.5% loss rate.

Windblast contributes to the greater number of injuries encountered during ejection, and are largely limited to superficial facial abrasions and lacerations caused by mask and helmet interactions. A study of injuries by Noble and Olsen (Table 16) records several cases of internal organ damage by the ram pressure of windblast. Of 67 non-fatal ejections 1975 through December 1987, only nine received no injuries. This figure has not significantly changed since 1952 when Smiley reported a 75% to 80% injury rate during the decade 1952 to 1961. Since 1972, all CF ejections have been below 500 KIAS, with 50% of these being below 250 KIAS. There have been two possible ejections from the CF104 in the 450 to 500 knot range at 90 feet and 200 feet above ground. The pilot of CF104859 ejected at 90 feet inverted following a mid-air collision with a light aircraft. He lost his helmet, mask and spectacles from windblast and sustained a concusion and amnesia from severe head buffeting. In the second case, the pilot of CF104769 ejected at 200 feet after colliding with trees following a bomb delivery. He lost his helmet and lost consciousness following ejection. He awoke on the ground with only minor injuries.

A bizarre case relating to windblast occurred to the pilot of CT13321551 on 30 May 1961. This pilot lost control of the aircraft at high speed through speed-brake failure. Ejecting at 1000 feet in a spiral dive at high airspeed, ram air pressure is suspected to have caused enough flexion of the parachute pack that the retainer pins were pulled allowing the parachute to deploy prematurely before seat separation. This resulted in severe maceration injuries to the pilot's pelvis and lower legs resulting in death five hours later.

A 1973 USAF Aeromedical Research Laboratory study (Brinkley) concluded that the incidence of limb flail following ejection increases exponentially with airspeed, being "significant" in the 300 to 400 KIAS range averaging 32% in the 400 to 500 KIAS range) and reach 100% in the 600 KIAS range (Figure 21).

In general, the effects of windblast may be responsible for:

a. flailing of limbs causing dislocation and fracture;

b. head buffeting producing concussion and/or amnesia (there are at least four recorded cases since 1972, and all occurred at ejection airspeeds above 400 KIAS);

c. failure of equipment (tearing of protective clothing; loss of protective equipment such as helmet, mask, gloves and boots);

d. contusion and rupture of internal organs;

e. petecchial haemorrhage;

f. ocular haemorrhage, edema, conjunctivitis;

g. laceration of eyelids, nostrils and lips (if mask lost); and

h. sinus, bronchial and gastrointestinal inflation (if mask lost).

EJECTION ENVELOPE

The "ejection envelope" is a set of defined physical parameters within that an ejection may be successfully executed. It is primarily an interaction of two independent sets of parameters: the physically designed characteristics of the particular ejection system, and the dynamics of the aircraft flight profile at the moment of ejection. Although not a part of the ejection phase per se, it is an operating pre-condition to ejection success, and will be covered with "ejection". Each ejection system has a minimum fixed operating time from ejection to parachute deployment varying from 3.5 seconds plus canopy inflation time for the CT133, to 1.8 seconds plus canopy inflation time for the CF188. Full canopy inflation may take an additional two to three seconds. The minimum time available for a successful ejection must be at least equal to pilot reaction time plus system operation time. The dynamics of the aircraft flight profile that will affect ejection success are: altitude, bank angle, pitch angle, airspeed, and sink rate. In most situations, all these flight parameters are operating simultaneously, and their net effect determines ejection success. The interaction of these factors is normally presented graphically in the aircraft technical manual. An example is given at Figure 20.

Taken in isolation, each of the above factors affect ejection success by either increasing or decreasing ejection time available (ETA) as follows:

a. Altitude. The greater the altitude above ground level, the longer the descent time. Most CF ejections since 1972 have been under 2000 feet (Figure 22);

b. Bank Angle. Increasing the bank angle reduces the vertical component (i.e. height) of the ejection seat thrust. At a 30 degree bank, the vertical component is reduced 14%; at a 60 degree bank there is a 50% reduction; and at 90 degrees, a 100% reduction. To illustrate using CF188A data (60 degree dive, 130 kts), to be successful a zero degree bank requires a minimum ejection altitude of 420 feet AGL; a 60 degree bank, 480 feet AGL; and a 90 degree bank, 550 feet AGL;

c. Climb/Dive. In a climb, the vertical component of the aircraft velocity vector will add to that of the ejection seat. As a result, a higher ejection trajectory is attained and ETA is increased. In a dive the opposite occurs and the downward velocity vector is subtracted from that of the ejection seat; ETA is decreased. To maintain ETA, a greater altitude is required. To illustrate using CF188A data (0 degree bank, 130 kts), a 30 degree dive requires 120 feet AGL for successful ejection; a 60 degree dive, 420 feet; and a 90 degree dive, 620 feet;

d. Airspeed. Airspeed has no effect on the vertical ejection component in straight and level flight, but it does affect the horizontal travel of the seat. In a climb, increasing the airspeed will increase the upward velocity, hence altitude attained, of the ejection seat. In a dive the opposite occurs. In a bank, airspeed may become an important factor. As bank angle increases, greater forward airspeed is required to maintain level flight: 60 degrees bank requires +2Gz; 75 degrees bank requires +4 Gz; and a 90 degree bank needs about +11Gz. Thus, when an aircraft loses power, it is extremely hazardous for it to enter a bank condition, since without enough power to maintain the required Gz loading, the nose will drop and a sink rate will develop. The time to ground impact will be proportional to its height, h, above ground

$$\sqrt{\frac{2h}{9.8}}$$

and the horizontal distance travelled will be proportional to forward velocity (airspeed), v,

$$v\sqrt{\frac{2h}{9.8}}$$

e. Sink Rate. This refers to the vertical descent velocity. In freefall, following a power loss during level flight, sink rate would be proportional to the acceleration because of gravity, "G", (9.8 meters/sec/sec). If the aircraft is in a climb, the vertical acceleration constant would be subtracted from "G"; if the aircraft is in a dive, the vertical acceleration constant would be added to "G". Thus, high sink rates may overcome the vertical acceleration of an ejection seat, producing a net downward acceleration of the man and seat.

Table 17 lists the ejection fatalities that occurred between January 1972 and December 1987. Eleven fatalities occurred on impact as a result of lack of time available for the system to operate fully (technically, one individual was fatally injured because of cervical fractures incurred when he struck a high tension wire after ejection). One fatality, a CT133 passenger, was killed on water impact when his system did not function properly because of improper strap-in and posture at the time of ejection.

Three fatalities arose because of deliberate delays in starting the ejection sequence. When the ejections were finally begun, the flight parameters had drastically changed, and they were then unfortunately "out of envelope". A CT114 pilot and student who experienced engine flame-out due to bird ingestion lost valuable time while attempting to steer the aircraft away from a residential area at a civilian airport. Both ejections were made at low altitude with left bank nose down attitude and high sink rate. The pilot of a CT114 pilot that experienced engine failure on take-off because of fuel pump malfunction delayed ejection for two seconds after the left hand pilot had successfully egressed. By then, however, the aircraft was out of the envelope with severe right bank and nose down pitch at low altitude. One CT133 pilot commenced ejection during a severe nose-over bunt at low altitude, but the aircraft impacted the ground just after canopy separation.

The following case histories illustrate two "typical" out-of-envelope ejections;

a. The first accident involved a CT114 with two pilots executing an ILS touch and go at a civilian airport at night. Following touchdown, full power was applied and a normal overshoot procedure commenced. Shortly after lift-off, at about 150 feet AGL, the engine flamed out because of main fuel pump failure. As RPM was rapidly decaying the decision was made to bail out. Two seconds after transmitting "bailing out", the left-hand seat pilot started the ejection sequence. As the canopy and left seat departed, the aircraft began to pitch down and roll right. Two seconds later, with the aircraft under 100 feet AGL, rolling through 120 degrees of right bank and pitching through 30 degrees nose down, the right-hand seat pilot ejected. One second later the aircraft impacted the runway. One and one-half seconds after ejecting, as the lap belt opened and the "butt snapper" began operation, the pilot impacted the runway head first, killing him instantly. The surviving pilot suffered a 25% compression fracture of the T12 vertebra on ejection and a mild sprain to the right knee on landing. It is unknown why the second pilot delayed his ejection for two seconds after the first pilot bailed out. Unfortunately, by then, the aircraft had dropped out of the ejection envelope.

b. The second accident involved a CF101. This aircraft, with a pilot and navigator, was scrambled on a flush alert during a base EDP exercise. Immediately after becoming airborne, the aircraft experienced a hung main landing gear. The pilot began "fumbling" for the circuit breaker, and while "head down" allowed the aircraft to enter a left turn with decaying airspeed and a high roll rate. It suddenly pitched up 45 degrees and entered a steeply descending right-hand turn with after-burners on. At approximately 355 feet AGL with high right bank, the pilot ejected. About 0.5 seconds later with more than 90 degrees right bank and at approximately 224 feet AGL, the navigator ejected. At four to six feet above ground, the pilot separated from his seat, and his parachute began streaming. He was killed on ground impact; the navigator was just separating from his seat at impact. The pilot's aggressive personality may have been secondarily involved in this accident; he had several recent admonishments regarding his impulsive and overconfident flying behaviour.

At this point it is historically interesting to note that there have been five manual bail-outs to date:

a. CT13321078 - 7 July 1954 - successful (19000 feet);

b. CT13321390 - 14 December 1954 - fatal (altitude unknown);

c. CT13321460 - 13 January 1957 - successful (20000 feet);

d. F8623673 - 28 August 1957 - successful (24000 feet); and

e. CT13321611 - 31 March 1966 - successful (20000 feet).

To illustrate, the pilot of CT133611 experienced a mid-air collision with an F-4 (Phantom) at 20000 feet. The aircraft immediately entered into a severe tumble, pulling alternating positive and negative G. The rear seat pilot ejected first. The front seat pilot experienced difficulty grasping the ejection handles. He was finally able to do so, and pulled. Being an ex-CF104 pilot who had recently ejected from a CF104, he forgot that in addition to pulling upwards on the ejection handles to eject the canopy, the triggers on the handle had to be squeezed to fire the seat. (Note: triggers have since been removed from ejection seats.) Sensing that perhaps there was a seat failure, the pilot then undid his seat belt and was thrown clear of the cockpit where he manually deployed his parachute and made an uneventful landing.

In addition to the five manual bail-outs, there were three cases of inadvertent ejection:

a. F8623243 - 28 February 1957 - successful (12000 feet);

b. CF100321 - 25 September 1958 " (11000 "); and

c. CF100747 - 7 November 1962 - " (15000 ").

To illustrate, CF100747 with pilot and navigator on board, was undergoing an air test at 15000 feet. While pulling negative G, the navigator and his seat went crashing through the canopy into space because service technicians had failed to anchor the seat to the floor after re-installing it following maintenance. The pilot's seat was also not anchored to the floor, and it too rose up the rails, but the pilot managed to prevent himself from penetrating the canopy by holding tight to the control stick. The navigator, finding himself falling through space, managed to separate from his seat and deploy his parachute, landing without injury. The pilot managed to land successfully back at base.

DESCENT PHASE

Even though an ejection occurs within the ejection envelope, fatalities have continued to arise because of problems encountered during the descent and survival phases. The ejectee is totally dependant on the system to function automatically. The typically low altitudes that ejections generally occur would preclude manual separation from the seat and activation of the parachute should the automatic function fail. The descent phase begins with rocket motor burn-out and ends with ground or water landing.

During the descent phase, the individual must separate from the ejection seat through the positive action of the rotary actuator or by parachute extraction (CF18), followed by parachute deployment and landing. The successful function of these events depends on sufficient time remaining for the automatic features to operate, and the absence of adverse precluding factors such as improper strap-in. A review of CF ejections since 1952 has shown that injuries or fatalities may occur through any of the following mechanisms:

a. seat/occupant interaction during separation;

b. seat/parachute collision/entanglement;

c. failure to separate from the seat;

d. failure of parachute to function;

e. parachute/pilot entanglement;

f. parachute canopy/parachute riser entanglement; and

g. parachute/seat pack interaction.

Seat/Occupant Interaction. During separation from the seat, the differences in aerodynamic drag between the occupant and the seat usually provides for good physical separation; the ejection seat, decelerating faster, trails behind the ejectee. There have, however, been ample instances of the pilot contacting or being suspected of contacting, the seat - usually as a result of seat/occupant tumbling at the time of separation, from a so-called "death grip" (holding on to the ejection handle during operation of the rotary actuator), or from equipment snags (CF104778 June 1964- incomplete cable cut resulted in leg contact injury). Injuries range from abrasions to concussions to fractures.

Seat/Parachute Collision. Except for the CF188, ejection is followed within one second by seat separation, and if ejection is below parachute opening altitude (16000 plus or minus 500 feet), parachute deployment is virtually simultaneous with seat separation (one second). There is, therefore, always a probability of the ejection seat colliding with the deploying parachute at these lower ejection altitudes. Instances exist of pilot chute - seat entanglement (CT133524 May 1964), parachute shroud line - seat entanglement (CT114086 December 1971) and parachute canopy - seat entanglement (CT133076 June 1962). There have been at least five fatalities resulting from seat/parachute interaction since 1952.

Seat Separation Failure. Historically this was a common occurrence on the

F-86 and CT133 manual systems in the 1950s. Even with the conversion of these systems to semi-automatic (canopy jettison was still a separate manual step), there was the occasional failure to separate from the seat, for example, through failure of the lap belt opening (CF104794 September 1963, CT13321169 June 1958). Since the acquisition of totally automated ejection systems such instances are virtually non-existent. There have, however, been a few instances of partial failure of the rotary actuator since 1957, but none contributing to fatality. For example, the pilot of CF104635 who ejected in May 1968, experienced severe parachute opening shock as the opening parachute snatched him from the seat following failure of the rotary actuator to provide good separation.

Parachute Deployment Failure. Such instances are rare. Those that have occurred were the result of faulty maintenance or accidental damage. The pilot of CT133527 ejected at 1000 feet on 25 May 1962 and was killed when his parachute failed to deploy due to improper maintenance. The pilot of CT133286 ejected at 11000 feet on 9 April 1963 and had to manually deploy his parachute after it failed to open because of improper maintenance. A tragic incident occurred 30 July 1969 when the pilot of CT114157 successfully ejected and separated from the seat, but fell from his harness on parachute opening because the quick release box (QRB) was in the UNLOCK position. Laboratory evidence showed that the pilot was suffering from acute carbon monoxide poisoning (14% COHb). More recently, a pilot and navigator of CF101019 ejected on 12 August 1973 at 9000 feet following an in-flight breakup. Both aircrew passed through the aircraft fireball that burned both parachutes. The navigator's parachute deployed normally, but the pilot's parachute was fused by heat and only opened slowly after a free fall of 7000 feet.

From 1952 through 1987, there are at least 14 fatalities resulting from parachute failure:

a. mechanical failure to deploy (disconnected automatic cable, defective barometric release, damaged ripcord) resulted in eight deaths;

b. destruction by burning - one fatality;

c. canopy shredded on deployment at high speed - one fatality;

d. failure to open because of flat spin freefall - one fatality; and

e. fell out of parachute - three fatalities.

Parachute/Pilot Entanglement. These cases are rare, and the few instances reported involved unusual circumstances such as tumbling during parachute deployment. For example, the pilot of CF101452 on 10 November 1962 collided with a Viscount aircraft that had taxied onto the runway while the CF101 was taking off. Lifting off, the main gear of the Voodoo sliced through the Viscount. Control was lost and the pilot and navigator ejected successfully at 700 feet, 200 knots and 90 degrees bank. During seat separation and parachute deployment, the pilot's right arm and foot entangled in the shroud lines and the ejection seat snagged in the parachute. He managed to free himself before landing, and suffered only lumbar strain, thigh and shoulder bruises.

Parachute/Seat Pack Entanglement Premature deployment of the seat pack contributed to one fatality. On 13 May 1964, the pilot of CT133524 became lost and flew to fuel exhaustion. Unfortunately, he had neglected to connect the seat pack airlock fasteners to his parachute harness and during ejection the free-hanging seatpack, attached to the pilot by the lanyard, fouled in the parachute shroud lines. The pilot parachute fouled in the ejection seat, and the main parachute was unable to inflate.

Parachute Canopy/Riser Entanglement. These cases have involved risers splaying over the parachute canopy to produce a "brassiered" effect. These fouled risers may be manually worked off the canopy during descent, or if severely snared, may be cut. Fortunately such instances are rare.

During descent to landing, an ejectee may be forced to survive a number of potentially fatal physiological stresses:

a. altitude;

b. deceleration;

c. freefall;

d. tumbling and spinning;

e. parachute opening shock; and

f. landing impact.

Altitude. The effects of altitude per se on the individual following ejection have been rarely encountered. Most ejections have been reasonably low enough that hypoxia and decompression sickness were not a significant hazard. There are at least 22 high altitude ejections recorded that necessitated significant freefall to parachute opening (Table 18).

The longest exposure to altitude following ejection was sustained by the crew of CF100 89 who ejected following acute loss of control in a CB cloud. The pilot and navigator ejected at 31000 feet in a steep dive at an unknown airspeed. During ejection, windblast tore off both helmets and while freefalling, both were affected by hailstones, snow, freezing rain and rain. On parachute deployment, both were subjected to up and down drafts, prolonging the descent, and the navigator was struck by lightning that fused and melted his parachute in several areas. The time from parachute deployment to landing was recorded as 20 minutes for the pilot and 25 minutes for the navigator. The pilot landed on a hardened surface and sustained a large hematoma on his left elbow, numerous punctate bruises on the face, haemorrhage of the left eye, and a compression fracture of T-11. The navigator sustained mild compression fractures of T-11, T-12 and L-1; multiple abrasions to the face and extremities from hail; and frozen hands, with a loss of sensitivity present one week after ejection.

Hypoxia was recorded on two of these high altitude ejection cases (F8623278, CT13321600). The pilot of 278 lost consciousness while descending in his parachute since he had lost his emergency oxygen bottle with his seatpack during ejection. Hypoxia may have contributed to the death of the pilot of F862333 who ejected 13 August 1956 following a mid-air collision with another Sabre (23543, fatal). While apparently hypoxic, this individual pulled his parachute ripcord while still strapped in his seat following ejection. Hypoxia may also have contributed to at least six other fatalities by incapacitating the aircrew before ejection (CF10018146 10 November 1953, CF10018122 17 August 1954, F8623654 20 August 1956, and CT13321235 30 December 1957). Mild hypoxia has also been mentioned on several lower altitude ejections.

Deceleration. Following ejection, the seat and occupant are decelerated from the airspeed at the time of ejection to zero horizontal velocity. This decelerative force is dependent on altitude and airspeed and may be measured as a "G" loading. The increase in "G" load as a function of airspeed varies as the 2.47 power of the velocity (12). For example, a 15% increase in indicated air speed (IAS) results in a 50% increase in "G" load. At 600 KIAS under 10000 feet, "G" load is approximately 30G (1200 pounds per square foot). These decelerative forces may result in equipment loss (erosion) or failure, or some degree of physical injury. Injuries that may occur are essentially those of negative G and comprise:

a. head and face congestion;

b. periocular edema;

c. subconjunctival haemorrhage;

d. retinal haemorrhage;

e. leg abduction;

f. sinus haemorrhage and congestion;

g. pulmonary compression with decreased arterial oxygen saturation;

h. cyanosis;

j. petecchial haemorrhage; and

k. mental confusion.

As ejection altitude is increased, deceleration time is prolonged.

Deceleration time at altitude is inversely proportional to the square root of the ratio of the altitude air density over sea level density. For example, it takes approximately twice as long to decelerate from 35G to 10G at 40,000 feet as it does at sea level.

The following case histories illustrate four CF high speed, low level ejections. In all cases, helmets and masks were lost, and personal injury occurred. Amnesia and disorientation were prevalent.

a. CF101: (Ejection at 350 KIAS, 5000 feet AGL); severe right knee flail injury. "Just after the smoke cleared he (pilot) yelled "eject, eject, eject!". So I pulled the handle and went. I hesitated for a second, disbelief and shock. I could not believe this was happening to us ... it took the canopy ages to go. The canopy was really slow it seemed ... I felt the windblast for a second then I blacked out. When I came to I was under the chute, I was out of my seat already, the chute was open. Initially I could see KP (the pilot). I was having trouble focusing my eyes beyond a certain distance ... On the way down I went to check my oxygen mask and realised that it was gone, and I did not have a helmet on ... My leg had hurt from when I regained consciousness, as soon as I realised where I was, there was a lot of pain in the leg ..."

b. CF104: (Ejection at 400 KIAS, 3,500 feet AGL); 20% anterior compressior fracture to T7 vertebra. "I looked down to make sure of getting the handle, grasped it firmly with both hands, and gave a sharp pull. Just before pulling, I attempted to get a good position but know that I was not in fact in an ideal ejection position. What appeared to be about one second after pulling the handle there was a great roar (probably the canopy going) and almost immediately a tremendous blast effect. This was followed shortly by a jolt that I assume was seat separation, and what seemed like two to three seconds later my chute opening (the force of that was quite severe). Taking stock of the situation, I found that my helmet, mask, and gloves, were gone (chin strap had been fastened but visor was not down). I have no actual recollection of losing these items and was in fact completely disoriented until chute opening ... about this time I checked my chute and saw that ... it did have several ripped gores".

c. CF104: (Ejection at 430 KIAS, 1000 feet AGL); concussion and amnesia because of head flail. "My recollection is of reaching for the handle and realising that the aircraft attitude was critical, but I don't remember what it was and the remainder was hazy, so much so that if anyone had told me that I had not ejected I would have believed them. It's not firm at all, I just don't have it. But I wasn't surprised when I was in the hospital, when I found out that there was a mid-air ... I remember nothing of the impact itself or of what occurred before it, other than the fact that I had a vague recollection of rolling to the right and reaching for the handle and not being happy with the attitude of the aircraft (Note: ejection was at 270 degrees bank.)

d. CF104: (Ejection at 500 KIAS, 90 feet AGL); concussion and amnesia, cervical and lumbar strain, dislocated right shoulder from flail. "As it (the aircraft) came through the inverted position to level flight I consciously slowed down the roll rate ... I pulled the handle. I recall the tremendous rush of wind as the canopy separated and noted that I was still sitting in the aircraft. The next thing that I distinctly remember was sitting aboard the helicopter ... I don't recall anything specific except for the fact that it was suggested by one of the crew members that I lie down, and it was about that time that I realised that I had done something to my right arm and I was having some difficulty in lying down."

Freefall. When an ejection occurs above parachute opening altitude, freefall must take place. Parachute opening altitude is controlled by the MK10A Barostat that is pre-set to 16000 $\pm$ 500 feet ASL for all aircraft except the CF188 (that is set at 14500 to 11500 feet ASL). After ejection from the cockpit, the pilot is separated from the seat by the action of the "butt snapper", and must stabilize his freefall to parachute opening. For the CF188 aircraft, 0.5 seconds after ejection, a 22 inch controller drogue chute and 60 inch stabilizing and retardation drogue chute are deployed from the headbox. One point five seconds after the pilot/seat system has descended through 14,500 feet, the scissor shackle opens and the harness release system is operated. This frees the drogue chutes, the parachute mechanical lock, the BIR shoulder straps, and the lower restraint harness. The drogue chutes withdraw the parachute from the headbox that, in turn, extracts the pilot from the seat.

For all successful ejections between January 1972 and December 1987, none were over 15000 feet AGL, therefore no freefalls were recorded. Many ejections occurred at and below 2000 feet.

For situations where freefall occurs, the physiological problems of concern are:

a. Freefall (Terminal Velocity). Figure 23 illustrates the relationship between altitude and true air speed (TAS). Freefall velocity varies directly with altitude, being balanced by acceleration because of gravity and the "drag" force of air resistance. Wind drag may cause buffeting, flailing, and injury to exposed skin surfaces from thermal and friction effects.

b. Spinning and Tumbling. During freefall, tumbling and/or spinning may occur that, if uncontrolled, may reach extremely high rotational rates upwards of 400 rpm. Centrifugal forces compel arms and legs to move outwards cartwheel fashion, and generate stagnant hypoxia through blood pooling in the periphery. Vertigo, nausea, and vomiting may also ensue. Spinning during automatic parachute deployment could result in twisting of the risers with increased canopy deployment time.

Freefall has been implicated in causing one known fatality. On 28 August 1957 following a mid-air collision at 24000 feet, the pilot of F8623669 ejected. Seat separation was apparently unremarkable, except that following separation, the pilot adopted a "back to the earth" freefall posture. It is felt that the dynamic air pressure against the parachute pack prevented the parachute from deploying, resulting in a fatal ground impact.

Parachute Opening Shock. All CF parachutes except for the CF188 (that deploys at 13000 plus or minus 1500 feet) are designed to automatically deploy at or below 16000 feet ASL. They may, however, be manually deployed at higher altitudes by pulling the "D" ring located on the left-hand side of the parachute. (The exception is the CF188 parachute that is located in the headbox and cannot be manually deployed.) The opening characteristics of a parachute canopy depend on TAS, that in turn varies inversely as the square root of air density, i.e., TAS increases with altitude. Generally, a parachute must travel six to eight times its diameter before being fully inflated, therefore, since TAS is greater at altitude, a parachute opens faster at higher altitudes. Coupled with a faster terminal velocity, this may result in high decelerative "G" loads (Figure 24). High opening shocks may damage the escape system (tear the parachute canopy and risers), cause loss of life support equipment and clothing (boots, gloves), and result in personal injury. For example, parachute deployment at 30000 feet exerts about 18 G on the body, while automatic opening at 16000 feet is equivalent to an 8G load.

Premature deployment of the parachute may result in parachute failure (tearing, shredding), loss of personal equipment (gloves, boots), and personal injury (groin abrasion, contusion, hematoma). At least two fatalities have resulted from premature parachute deployment. The first case occurred 30 June 1959 when the pilot of CF100762 became severely disoriented at 42000 feet and lost control of the aircraft. The navigator ejected at an estimated altitude of 35000 feet and manually deployed his parachute where it shredded to pieces and he was killed on impact. The pilot crashed with the aircraft. The second case occurred to the pilot of F8623333 who ejected at an unknown altitude following a mid-air collision 13 August 1956. Apparently, while hypoxic, he deployed his parachute will still strapped into the ejection seat.

In addition to injuries and fatalities, there are at least four recorded cases of boot loss during parachute deployment and numerous instances of spectacles, gloves and watch loss. On 10 March 1960, the pilot of F8623646 ejected at 8000 feet following engine seizure at 17000 feet. The ejection occurred at 300 KIAS, and on parachute opening, the pilot lost his boots, a pair of Wellingtons. He also lost his helmet, seatpack and dinghy (not connected to parachute), and landed in the Rhone River where he had to swim to shore. He was rescued eight hours later and was treated for lacerated feet incurred while walking through stubble fields.

LANDING

Although part of the descent phase, landing may be appropriately addressed as a separate topic. In preparation for landing, an individual may be faced with a number of circumstances: tree landings, hard ground, high winds, water, and obstacles such as power lines. During ground landing, the individual must convert linear momentum to angular momentum and decelerate his velocity to zero over the greatest distance to yield low frequency acceleration pulses, if injury is to be avoided. This is normally done by executing a parachute landing fall (PLF) to distribute deceleration forces over the foot, shin, thigh, hip and chest. Since aircrew do not normally receive instruction and practice in executing proper PLFs, it should be expected that each ejection carries a high risk factor of injury on landing due to incorrect technique, but this does not appear to be the case. Injuries that occur strictly due to landing show a rare incidence. Instead, those that have occurred appear to be directly related to seat pack retention. A previous study by Smiley (1964) indicates that there is also a tendency for injuries to be associated with unfavourable drift. He reported that 74% of those drifting backwards or sideways, and 57% of those drifting forward were injured. Although purely subjective, 50% of 195 ejectees (April 1952 to January 1964) reported their landing as "severe".

Severe winds present a hazard; the pilot may be injured while being dragged in the parachute, or drown following water landing. for example the pilot oF CF116760 who ejected 2 May 1976 was dragged for 1200 feet by high winds. The adoption of the "T" handle harness release on the CF188 parachute allows for quick one-step release and should prevent dragging problems in the future.

Landing in trees presents a particular hazard. Injuries can occur during tree landing and during attempts to descend after landing. For example the pilot of CF104804 landed in a tree following ejection on 23 July 1971. While trying to descend from the tree, he fell to the ground sustaining crush fractures to T12 and L2. To minimize injury while landing into trees, it is therefore standard procedure not to deploy the seat pack.

Landing vertebral fractures are almost always anterior cuneiform or comminuted due to relatively vertical impact force and hyperflexion of the dorsolumbar column, especially in the area of the T12 to L1, with sharp predominance at L1. There have been at least eight cases of vertebral landing injury since 1975. Strong hyperflexion may also result in chin contact with the quick release box (QRB) and myocardial contusion (CT114123 11 May 1976). Intervertebral disc/rupture has also been reported (CT13321020, 29 May 1957). Instances of fractured legs (F-86 19619), ankles (F-86 23152), sprained ankles (F-86 23086), fractured ribs (F-86 23193), and miscellaneous contusions and abrasions have been encountered. The following cases illustrate landing injuries. The first occurred to the pilot of CT114123 on 11 May 1976, and the second to the pilot of CT133442 on 14 February 1981.

CT114. (Bird strike engine failure, ejection at 2,900 feet AGL, 130 KIAS; failure to deploy seat pack.) Medical report on pilot: "The injuries sustained are typical of those seen in previous Tutor ejections being sustained on impact with the ground ... (the pilot) sustained ... compression fractures of T12, L1, L2 and L3 with approximately 25% loss of anterior margins. He developed a regional ileus after 12 hours and this cleared slowly over the following four days ... hematuria was present for 24 hours and cleared spontaneously ... a small pleural effusion was demonstrated on the third day and this cleared slowly without surgical intervention ... It is proposed to eventually use a Taylor Brace or plaster jacket cast for three months ... It is concluded ... these injuries were sustained at the time of landing in as much that (he) failed to deploy his seat pack and in so doing fell heavily on the pack. (The pilot) recalls his head snapping forward when he landed ... (which) would cause the chin to contact the Quick Release Box hard enough to split his chin open."

CT133. (Fuselage pump failure, engine flame-out on final approach for landing; ejection at 450 feet AGL with high sink rate; failure to deploy seat pack). Injuries occurred when pilot landed on seat pack. The pilot sustained "... a compression fracture of L1 with at least 50% loss of the volume of the body of L1. The fracture extends into the posterior elements and there is some widening of the pedicles noted on the A.P. view. As well, there is slight posterior displacement of the fracture fragments into the spinal canal (Note: the body of L1 restored to its previous height over 48 hours) ... the compressed lumbar vertebra protruded about 1/4 inch into the spinal canal. He can be expected to be treated with bed rest, with his back in hyperextension for the next two months, at which point it is expected that he will be placed in a body cast for a further period ... even though there is no neurological involvement, there is a 50% chance of recurring back problems as a consequence of this injury ..."

Water landings present a particular hazard, especially with the possibility of entanglement in risers, ingestion of water while being dragged, and difficulties in releasing the parachute. Injuries are particularly hazardous to survival following water landing. There have been at least five drownings following successful ejection since 1952. Historically, difficulties were often encountered with finding and activating the life-preserver inflation toggle following water landing. These problems were corrected by installing an automatic inflation device (AID) on the life-preservers. Exposure following cold water landing is also an ever present hazard.

SURVIVAL PHASE

The survival phase commences with ground or water landing and lasts until rescue. The possibility of having to face long survival times in the wilderness following ejection was very real. Canada was less developed in the 1950's. "Stations" were more isolated, search and rescue facilities were rudimentary, locator devices were crude. Modern locator devices (locator beacons, crash positions indicators, SARSAT) and highly efficient search and rescue facilities have virtually precluded long survival periods following ejection. Consequently, it can be expected that data will show a continuing reduction in rescue times since the 1950's - and this is indeed the case.

Since 1952, there have been eight instances of overnight survival, and two of survival over 48 hours. The record for length of survival following ejection occurred on 10 December 1956 when the pilot and navigator of CF10018411 ejected following double engine flame-out and electrical failure. Both ejections were made through the canopy into a cold winter wilderness. They were rescued by a search team after 43 hours (two nights). The last overnight survival occurred following ejection from CT13321614 on 18 November 1965 in the Vosges mountains of France. During a TACAN let-down in zero visibility, the aircraft struck trees. The pilot zoomed the aircraft and twice ordered the second pilot to eject. Both ejected, but the aircraft captain, who delayed his ejection, was killed on ground impact. The second pilot survived for 14.5 hours (overnight) until rescue.

For historical interest, the longest survival period since the war is apparently credited to Flight Lieutenant McKenzie who ditched his Gloster Meteor EE311 in Helen Barr Lake in Northern Ontario on 29 June 1946 while on a trip from the Winter Experimental Establishment (WEE) Flight in Namao. Flight Lieutenant McKenzie survived 27 days in the bush before being picked up by fishermen. The Gloster Meteor, like the Vampire, was not equipped with ejection seats.

The greatest hazard to survival is injury, especially burns and fractures. Two Sabre pilots who ejected over water drowned before rescue. One had received a basilar skull fracture with bruised larynx during the ejection phase. A CT133 pilot who ejected following an in-flight fire, and endured a night in the bush, was unable to open his ration pack because of severely burned hands that subsequently required skin grafting.

Lastly, there have been a few cases where the rescue attempt has been too late. On 18 April 1952, the pilot of F8619181 ejected over the North Sea following a mid-air collision with F8619177 (which crashed in the sea killing the pilot). He did not have a dinghy as part of the survival kit and as a result, succumbed to exposure before rescue. Similarly, on 14 April 1960, the pilot of F8623229 ejected for unknown reasons over the water of Mirimichi Bay. His ejection was successful, but he died of exposure. His body was discovered three months later, floating in the life-preserver.

SUMMARY

This report has outlined RCAF/CF ejection experience from 1 April 1952 to 31 December 1987, with emphasis on ejection statistics covering the period January 1972 to December 1987 (Annex A). One hundred and three ejections from 107 aircraft were analysed. Ninety-two of these ejections were successful which represents a success rate of 89.3%. Forty-five individuals did not eject for various reasons, of which 37 perished in the crash. The greatest cause for these fatalities appears to be due to unperceived ground closure, or controlled flight into terrain (Table 10). Included in this category is the phenomenon of "late awareness", essentially a form of CFIT, but a realization at the last moment that ground contact is inevitable. In this context, late awareness has some of the elements of "rapidity of events", but differs in that a serviceable aircraft was "flown into the ground" while under complete control as a result of an error in pilot judgement.

Of the 67 successful ejections since 1975, nine were completed without injury. The most common form of ejection injury was due to windblast pressure on the mask and helmet, resulting in facial lacerations, abrasions or contusions. The second most frequent injury pattern observed was thigh contusions from seat pack or ejection handle contact during the ejection of the seat from the cockpit, and vertebral fractures from improper positioning either on ejection or on landing.

The majority of ejections occurred at very low altitude, all under 15,000 feet. Airspeed varied from 0 to 500 knots with the majority of ejections occurring between 200 to 250 knots. There appeared to be no correlation between severity of injuries and airspeed; however, windblast effects appeared to increase as airspeed surpassed 350 to 400 knots. In this range injuries became more numerous through the action of aerodynamic forces on the helmet and mask, and were limited to facial abrasions, contusions and lacerations. Helmet losses appeared within this airspeed range, and as airspeed increased above 400 knots, the incidence of dislocations increased (elbow, shoulder and knee).

Table 6 summarises RCAF/CF ejection experience over the period January 1952 through November 1987. These data were extracted from four separate sources, and the data trends were consistent. The overall success rate for attempted ejections has steadily increased while the total number of ejections has decreased. A noticeable turning point in low altitude ejection success occurred throughout the 1960s, and may be correlated with the introduction of the rocket assisted ejection seat of the CF104 aircraft and the incorporation of an automatic opening parachute. A "new awareness" among aircrew as to the importance of timely ejection may have also manifested itself with the supersonic era ushered in by the CF101 and CF104, perhaps coupled with the phase-out of wartime fighter pilots and the "ditch or bail-out" mentality of the Hurricane era. Unfortunately, the success rate for low altitude ejections does not appear to have continued to increase through the decade of the 1970s despite fully automated ejection systems. The reasons for this are not clear, but may be due to the employment of supersonic aircraft as low level tactical fighters. This would effectively lower the margin for ejection success as flight parameters approached the mechanical limits of the ejection system, and success became more dependent on the human factor. DCIEM studies (22, 29) have implicated workload, critical time sequencing, rapidity of events, pilot inexperience, and lack of information presentation when "heads up" during high speed low level flight or tactical weapons delivery, as overriding factors in low altitude no-ejection fatalities. If this is true, then improvements in ejection systems alone will not increase survival rate. What will be required is a closer matching of the aircraft design to its operational role requirements.

CONCLUSIONS

Aircrew flying ejection seat aircraft must be regularly briefed and reminded of the necessity to make rapid and correct responses to emergencies at low altitude, and to recognize the limitation to human information processing during high speed low level flying. In 21st century aircraft such as the CF188, this should also include the effects of "information saturation", as opposed to "information lack" characterised by century series airplanes, and the limitations to cognitive processes engendered by digital/analog cockpit displays.

Aeromedical briefings on ejection physiology should continue to emphasize the importance of posture during ejection, and the mechanics of back injury. Airspeed and windblast effects should also be covered in detail, as well as the importance of releasing the seat pack before ground landing. Lastly, aircrew must thoroughly understand the minimum operating parameters of their escape system under all conditions. Approximately 10% of all fatalities (11 out of 103) arose due to ejection outside the "envelope".

As older and slower ejection systems are replaced by the "zero zero" seat, the CF ejection success rate should increase to well over 90%. The limiting factor will always be the human information processing system.

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Table 1. CT133 Ejection Time Sequence

ELAPSED TIME (sec)	ACTION
0	(R) Right pulled, Canopy Jettison and BIR activation
1	Rear seat ejected
1.5	Front seat ejected
2.0	Rear rotary actuator lap belt separation
2.5	Front rotary actuator lap belt separation
3.0	Rear parachute begins deployment
3.5	Front parachute begins deployment
6.2	Rear parachute stable
6.7	Front parachute stable

Table 2. CT114 Timing Sequence

ELAPSED TIME (sec)	EVENT
0	Handles pulled
0	Canopy initiator
0	BIR activation
0.5	Seat catapult, bail-out tone, UHF and transponder
0.65	Seat at top of rails, rocket fires
0.90	Rocket burns out
1.50	Lap belt released, rotary actuator
2.5	Parachute deployment (below 1600 + 500 ft)
5.0	Stable Parachute

Table 3. CF116 Ejection Time Sequence

ELAPSED TIME (sec)	ACTION
0	Handles pulled, canopy jettisoned and BIR actuated
0.3	Seat ejection
1.3	Rotary actuator, RPI lap belt
2.3	Parachute deployment (below 16000 + 500 ft)
5.05	Stable parachute

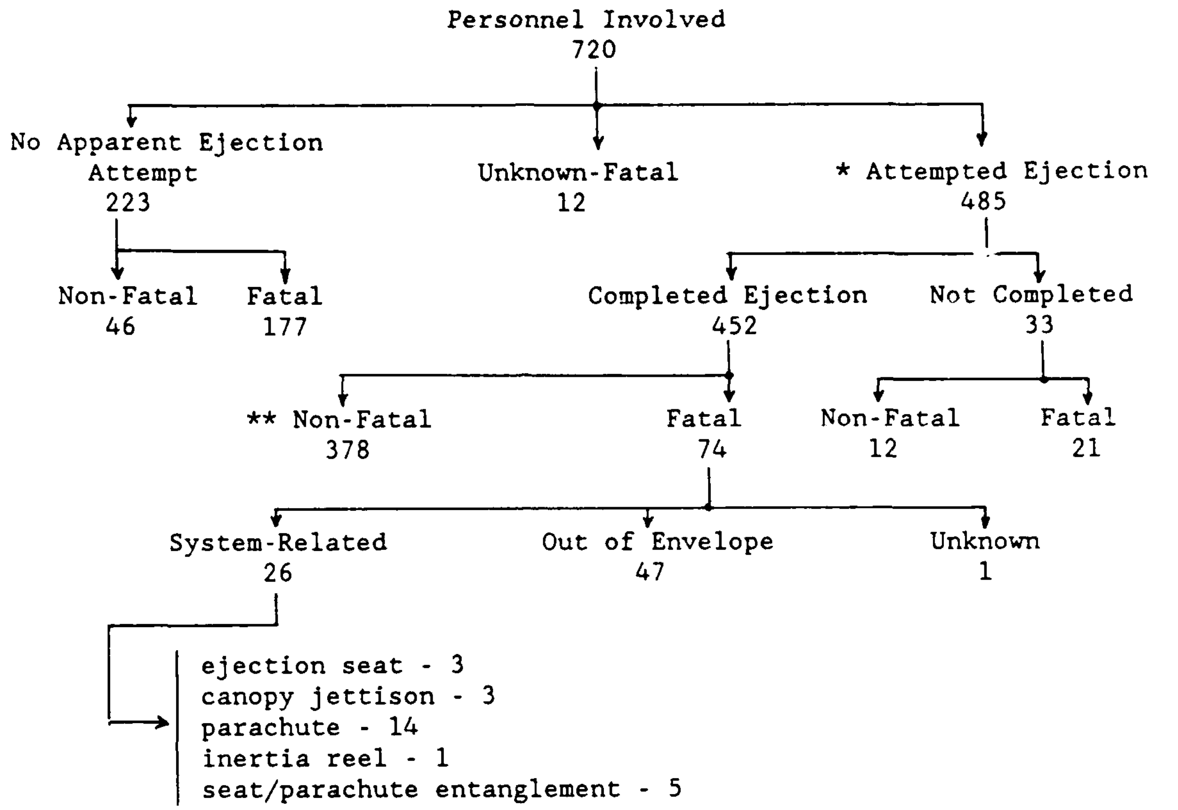
Table 4. CF188 Ejection Time Sequence (SJU-9/A)

ELAPSED TIME (sec)	ACTION
0	"D" ring pulled, canopy jettisoned, BIR activated
0.3	Seat ejection
0.8	Drogue chutes deployed
1.8	Parachute deployment (14500 - 11500 ft)

Table 5. Equipment Check List - CF5

1. Booklets: a. How to use the Silva Prospector Compass Magnetic Model
   b. CFP 222 Land and Sea Emergencies
2. Vinyl Single blade boat paddle (2)
3. Yellow rubberized boat bailer (1)
4. Leak stopper set (1)
5. Emergency fishing kit (1)
6. One-man inflatable life raft - 1800 psi compressed gas cylinder (1)
7. Tinted protective eyeshield (1)
8. Seawater de-salter kit (1)
9. Flat bastard file (1)
10. 1.5 lb. single bit axe (1)
11. Flint (1)
12. AN/PRQ 501 radio beacon (1)
13. 11.2v dry cell battery (1)
14. Magnetic compass (1)
15. Dimenhydrinate anti-seasickness tablets
16. Insect repellant stick
17. Water purification tablets
18. Survival hunting knife (1)
19. Sponge (1)
20. Survival first aid kit
21. Polyethylene plastic bag (2)
22. Aluminum foil 18" x 24" (1)
23. Insect head net (1)
24. Unlined work type mittens (1 pr)
25. Unlined leather work type mittens (1 pr)
26. Wool/nylon socks (1 pr)
27. Whistle (1)
28. Sunburn ointment tube (1)
29. Facial tissue (1 pk)
30. Sleeping bag (1)
31. 800 calory Food packet (1)
32. 400 cal Food packet (1)
33. Fuel tablets (1 pk)
34. 25 feet 0.028 dia. brass wire
35. Watertight matches (1 pk)
36. Signal kit - a. hand-held projector (1)
   b. signal pyrotechnics (7)
   c. signal mirror (1)
   d. red cotton signal panel

Table 6. RCAF/CF Ejection Seat Mishaps - April 52 to Dec 87



* includes 5 bail-outs and 3 inadvertent ejections

** includes 2 cases of fatal hypothermia and 3 drownings

Table 7. Ejections by Aircraft Type to December 1987

Aircraft Type	Attempted	Not Completed (Fatal Only)	Completed	SUCCESSFUL Number	SUCCESSFUL * Per Cent	FATAL Equipment Related Number	FATAL Equipment Related Per Cent	FATAL Out of Envelope Number	FATAL Out of Envelope Per Cent	FATAL Unknown
F-86	112	4	104	84	77.8	8	9.5	11	13.1	1
CF100	90	8	80	60	68.2	7	8.8	13	16.3	-
CT133	88	7	86	70	75.3	8	11.4	8	11.4	-
CF101	32	-	32	29	90.6	-	-	3	10.3	-
CF104	88	2	86	79	89.8	2	2.5	5	6.3	-
CF116	15	-	15	15	100.0	-	-	-	-	-
CT114	44	-	44	36	81.8	1	2.8	7	19.4	-
CF188	5	-	5	5	100.0	-	-	-	-	-
Total	485	21	452	378	79.9	26	5.8	47	10.4	1

* As compared to column (2) plus (1) to compensate for the early manual and semi-automatic systems.

Table 8. Air Accident/Cause Factor:Personnel-Pilot 1977-1986

A Breakdown of Personnel-Pilot cause factors. 1986 cause factors are subject to revision since some cases are still under investigation.

Factors	1977	'78	'79	'80	'81	'82	'83	'84	'85	'86	Total
Information/communication			1				1				2
Human Engineering							1				1
Acceleration effects					1		1				2
Disorientation	1					1			1	1	4
Fatigue								1			1
Noise, Vibration/Buffet	1										1
Visual Illusions/Limitations		1		1		1				1	4
Physical/Physiological - other							1				1
Carelessness	1	1			1	1	1		1	1	7
Channelized Attention					1		1	1	1		4
Complacency										1	1
Distraction						1	1				2
Expectancy									1		1
Human Information Processing			1	1					1		3
Inattention (*)	8	4	8	2	3	5	6	3	1	2	42
Judgement (*)	12	3	8	5	4	7	5	1			45
Motivation			1							1	2
Non-compliance with orders			2	2		1			1		6
Technique (*)	7	5	13	3	2	7	7	6	2	3	55
Training				1							1
Psychological - other		1									1
TOTAL	30	15	34	14	12	24	25	12	9	10	186

Table 9. Effects of Stress on Information Processing

From: *Aviation Medicine; G. Dhenin et al; William Clowes & Sons Limited London; 1979; p. 715.*

PSYCHOLOGICAL MECHANISM	Notes and Examples
Omission	The subject simply does not respond to a situation. The undercarriage of an aircraft may not be lowered during the final approach because the pilot is either fatigued or overloaded.
Error	A subject may respond incorrectly to a given stimulus. He may select the wrong lever and raise the undercarriage instead of the flaps.
Queuing	This is a process of sequential delaying. The operator realizes that he has several things to do, but because of the pressure of work he delays certain actions until the workload falls to a more acceptable level. A pilot may delay fuel-state checks whilst negotiating uncomfortable turbulence.
Filtering	Instead of queuing, the subject may resort to the rejection of certain tasks in order to compensate for the workload. The rejection is a conscious process and might be accompanied by verbal phrases like "I've got enough on my plate without worrying about . . . . ."
Approximation	In order to produce rapid results, aircrew may approximate, either consciously or subconsciously, in calculations or in flying technique.
Coning of attention	As the stress increases the environmental field to which man pays attention decreases. It is as if man were travelling down a cone towards the vertex. The further down the cone he goes, the less he 'sees'.
Inability to integrate information from various sources	This is related to the coning of attention. Whereas the normal pilot adequately scans several instruments and integrates the information from each of them to obtain a mental picture of the aircraft as a whole, the severely stressed pilot may concentrate on fewer and fewer instruments and even then have difficulty in integrating the information that they give.
Regression	Human beings under stress will often regress to a pattern of behaviour that was learned at an earlier time. A stressed pilot may confuse the location of a switch or trim control in one aircraft with the location of the control in an aircraft he flew at a much earlier date. The groping for something which is not there may last for a vital second or two, before the pilot realizes what is wrong.
Muscle tension, tremor, or freezing	These are some of the physiological accompaniments of stress which can occur even to experienced pilots. Freezing might explain some of the so-called 'suicide' flights, dubiously labelled as such because no other rational explanation seemed possible at the time.
Escape	The ultimate response is to seek refuge from the task by the rejection of stimuli or suppression of response in favour of avoidance. The operator may simply 'give up', panic, or as sometimes occurs in aircraft accidents, be unable to do anything whatsoever, that is, freeze.
Post-stress behaviour: reliving the experience, rationalization, imaginary conversations, etc.	The detrimental effects of stress do not suddenly disappear once the stress has been removed. It is common for people to have disturbed sleep because they relive the stress in some way. Often this process involves thinking what one should have done or having imaginary conversations with the other people involved in the stressful situation, or simply excusing one's own behaviour. The disturbed sleep caused by these mental processes could give rise to human error.

Table 10. 37 Fatalities/Failure to Initiate Ejection - 1972-1987

Reason for Failure to Initiate Ejection*	Aircraft Type	No. of Aircraft	No. of Fatalities	Predisposing Factors
A. Unable tc eject	CF104	4	5	control jam-2? mid-air - 2 GLOC - 1 ?
21.6%	CF116	1	1	GLOC ?
	CT114	1	1	mid-air
	CT133	1	1	system failure
B. Unperceived Aircraft/Ground Closure Rate	CF100	1	2	illusion?
	CF101	1	2	distraction
	CF104	7	8	
51.4%	CF116	2	2	disorientation?
	CT133	1	2	inattention
	CF188	2	2	disorientation
	CT114	1	1	distraction?
C. Rapidity of Events	CF101	1	2	stall
24.3%	CT114	2	3	
	CF116	2	3	
	CT133	1	1	personality
D. Unknown	CF116	1	1	
2.7%				

* Not official cause factor

Table 11. Time Intervals and Altitude Deviations During Routine In-Flight "Distractions" (Goebel)

Task	Time Used (Seconds)			Altitude Changes (Feet)	
	Min.	Max.	Average	Max.	Average
TACAN Change	2	15	6.3	100	38
Weapons Switching	4	20	9.7	300	38
UHF Change	5	16	9.6	100	37
IFF Change	4	22	9.8	300	80
Checklist Reference	10	54	28.8	600	197
Letdown Book Access	7	46	26.3	500	169
Letdown Book Reference	12	80	26.6	200	84
Bingo Calculation	5	69	27.4	900	214
Fuel/Distance Calculation	17	120	44.4	300	144

Table 12 General Ejection Sequence

1. Handle pulled
2. Zero delay initiator(s) fired
3. Canopy jettison, BIR activation
4. Seat ejection

CF116, CT114, CT133

5. Rotary actuator activation and seat separation
6. Freefall to 1600 ± feet
7. Barostat activation
8. Parachute deployment
9. Parachute descent
10. Seat pack deployment
11. Landing
12. Release parachute

CF188

5. Drogue chutes deployed
6. Freefall to 13000 ± 1500 feet
7. Barostat activation
8. Scissor shackle opened
   Parachute deployment
   Harness release
   Seat separation
9. Parachute descent
10. Seat pack deployment
11. Landing
12. Release parachute

Table 13. RCAF/CF Ejection Experience - January 52 to April 1986

Altitude (Feet AGL)	1952 - 1961* Attempted	1952 - 1961* Success	1962 - 1971** Attempted	1962 - 1971** Success	1972 - 1986*** Attempted	1972 - 1986*** Success
0 - 140	7	0	14	7	10	4
150 - 240	2	0	4	4	5	3
250 - 340	4	0	1	0	3	3
350 - 440	6	4	6	6	3	3
450 - 950	26	13	16	13	10	9
1000 - 9500	88	81	58	58	54	53
10000 19500	47	42	15	14	12	12
20000	32	25	6	6	0	0
% Success Rate	77.9		90.7		89.7	
Unknown	6		9		1	

Data Sources:

* S/L Smiley JR; RCAF Ejection Experience 1952 - 1961; RCAF IAM Tech Memo 64-TM-1; January 1964

** CF Ejection Experience 1962 - 1971; CFHQ DFS Publication
CF Ejection Experience 1972 - 1979; NDHQ DFS Publication

*** DCIEM/MLSD Accident Files

Table 14. Ejection Seat Characteristics

Aircraft Type	CF188	CF116	CT114	CT133
Catapult Forces				
"G" Onset (G/sec)	180-210	300	178	178
Max "G"	14- 16	20	14	14
Velocity (fps)	65	81	50	60
Rocket Time (sec)				
Burn Time (sec)	.25	.35	.46	.25
Thrust (lb)	4500	4600	6631	U/K
Max Ejection Airspeed (kts)	600	500	420	450
Min. Ejection Parameters (alt, airspeed)	0, 0	0, 70	0, 60	0, 70
Miminum Operating Time (sec)	1.5	2.3	2.5	3.5
Seat Angle (deg)	22	10	17	14

Table 15. Injury Analysis - 67 Successful Ejections - 1975-1987

Note: Figures not mutually exclusive, one ejectee may present with several injuries.

Aircraft Type	CF101	CF104	CT114	CF116	CT133	CF188	Total
No. of Types	7	15	13	8	3	5	51
No. of Ejectees	13	17	19	8	5	5	67
No. Injured	11	15	16	7	5	4	58
Superficial Injuries							
Head/Neck	9	7	7	4	4	1	32
Torso	-	-	1	-	-	-	1
Arms	-	1	3	4	-	-	8
Hands	-	-	-	1	-	-	1
Shoulders	1	2	2	2	-	2	9
Legs	-	-	3	-	2	-	5
Thighs	6	5	4	1	1	-	17
Groin	4	4	6	1	-	-	15
Knees	-	3	1	-	2	1	7
Feet	-	1	1	1	-	-	3
Sprain/Strain:							
Cervical	2	7	3	2	-	1	15
Shoulders	3	-	-	-	-	-	3
Ribs	-	1	-	-	-	-	1
Ankles	-	-	-	-	-	1	1
Knees	1	-	1	-	-	1	3
Thoracolumbar	-	-	1	-	-	-	1
Fracture:							
Ulnar	-	-	1	-	-	-	1
Vertebral	-	1	8	-	2	1	12
Clavicle	1	-	-	-	-	-	1
Knees	-	1	-	-	-	-	1
Nose	1	-	-	-	-	-	1
Other:							
Concussion/Amnesia/LOC	3	2	1	-	-	3	9
Dislocated shoulder	-	1	-	-	-	-	1
Lung contusion	-	-	1	-	-	-	1
Myocardial contusion	-	-	1	-	-	-	1
Barotrauma	-	1	-	-	-	-	1

Table 16. Non-Fatal Canadian Forces Ejection Injuries - 1966-1974

Average Q Force (psi)	No. of Ejections	Type of Injury
MINOR INJURIES (N = 63)		
.56	15	Facial
1.3	17	Facial
2.4	12	Facial
4.5	4	Facial/Muscular Aches
7.5	2	Facial/Muscular Aches
Unknown	13	Facial
SERIOUS INJURY (N = 19)		
.56	5	Contusion to kidney
		Compression Fracture to T-10,T-12
		Compression Fracture to T-4,T-6
		Fractured ribs/torn bladder
		Burns
1.3	6	Fractured skull
		Compression Fracture T-11,T-12
		Compression Fracture T-12,L-1
		Compression Fracture T-10,T-11
		Compression Fracture T-8
		Compression Fracture D-9,10,11,12
2.4	2	Compression Fracture T-8
		Burns
4.5	2	Compression Fracture T-12,L-2
		Fracture upper arm, broken ribs
		Compression Fracture L-1
7.5	2	Burns
Unknown	2	Compression Fracture T-11
		Compression Fracture T-10,T-11

Table 17. Post-Ejection Fatalities - 1972-1987 *

Type	Personnel	Fatalities	Cause	Ejection Attitude
CF101017	2	2	Pitch-up, stall after take-off	229 - 355 ft AGL $\geq$ 90 deg RH bank
CT114010	2	1	Fuel Pump Failure on take-off; delayed ejection	< 100 ft AGL 35 deg ND 120-135 deg RH bank
CT114028	2	2	Birdstrike after take-off; delayed ejection	< 50 ft AGL 20-36 deg LH bank 15-42 deg ND
CT114118	1	1	In-flight break-up during airshow	40-50 ft GL 60 deg ND, 90 deg LH bank high sink rate
CT133363	2	1	Vertical fin stall	500 ft AGL, 30-45 deg ND, 30 deg LH bank
CT133639**	1	1	Undetermined (fire?)	ground level; 70-80 deg ND
CF104864	1	1	Pitch-up	150 ft AGL
CT114127	1	1	Landing, lost control	40 ft AGL
CT114136	2	1	Loss of control	low
Total= 9	14	11		

* Total ejections for this period is 103. Thus, ejection success rate is 89.3%.

** Technically the pilot of 639 had pulled the ejection handles, the canopy had jettisoned, but ground impact occurred just prior to the ejection gun firing. It can therefore be classified as an out-of-envelope attempted ejection.

Table 18. Ejections Requiring Freefall to Parachute Opening - 1952-1987
(including manual bailouts)

Aircraft Type	Date	Ejection Altitude (ft)	Disposition
CT13321078	7 Jul 54	19000	bailout-successful
21252	21 Oct 54	20000	successful
21460	13 Jan 57	20000 - pilot 20000 - 2nd pilot	bailout-successful successful
21600	7 Jul 60	20000 - pilot 20000 - 2nd pilot	successful successful
21646	5 Dec 61	31000 - pilot 31000 - 2nd pilot	successful successful
21611	31 Mar 66	15000 - pilot 20000 - 2nd pilot	bailout-successful successful
F86 23278	27 May 55	27000	successful
23384	9 Jan 57	28000	successful
23413	9 Jan 57	28000	successful
23514	12 Jun 57	27000	successful
23669	28 Aug 57	24000	fatal
23556	10 Feb 58	35000	successful
23546	1 Aug 60	28000	successful
CF10018762	30 Jun 59	35000 - nav only	fatal
18789	8 May 71	31000 - pilot 31000 - nav	successful successful
CF10412884	24 Feb 65	19000	successful
12738	13 Aug 65	20000	successful

Figure 1. Aircraft Airspeed - 1940-1985

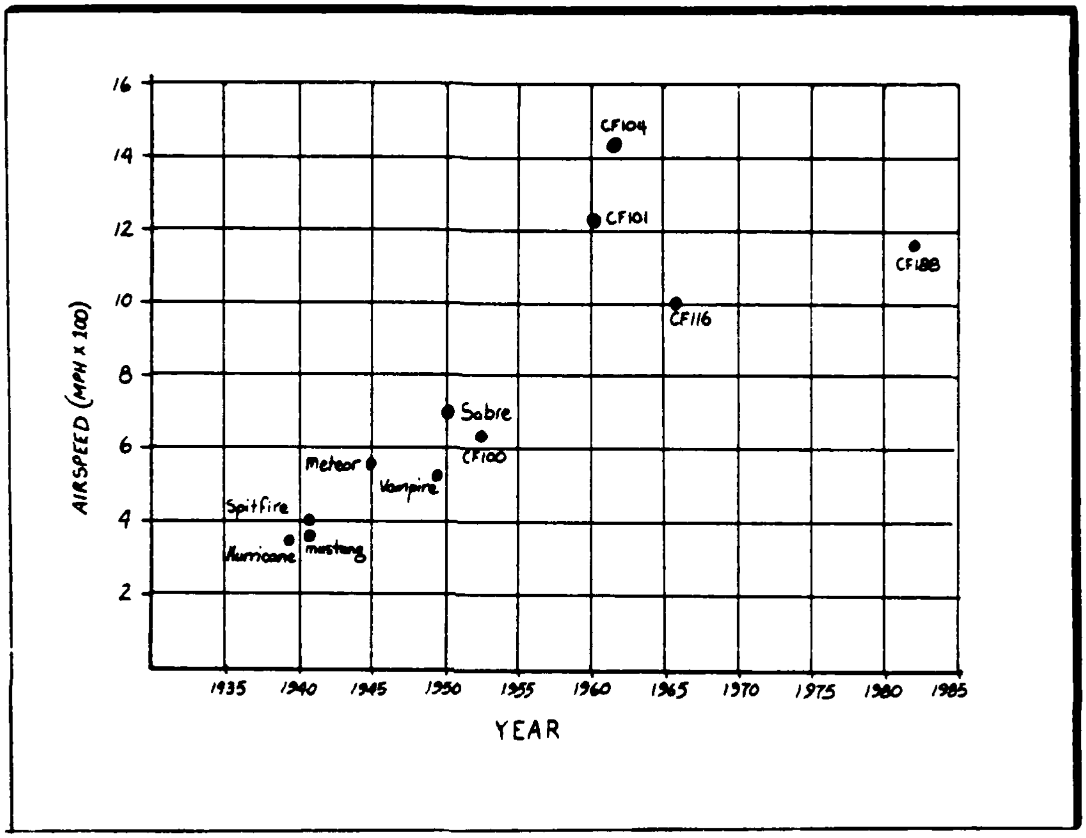


Figure 2. The CF100 Ejection Seat (1967)
(EO-55-50-2C)

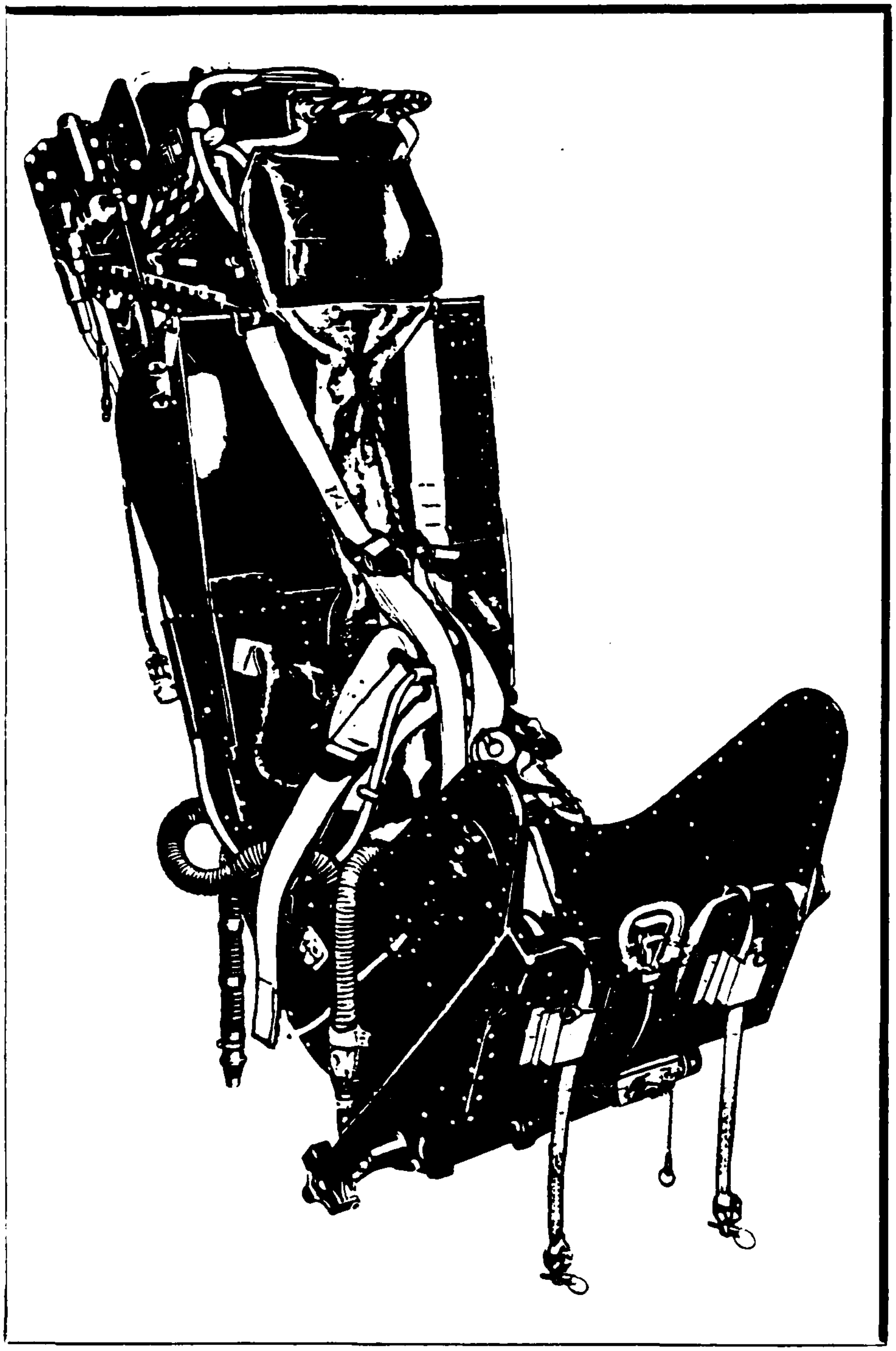


Figure 3.a. Leg Restraint System

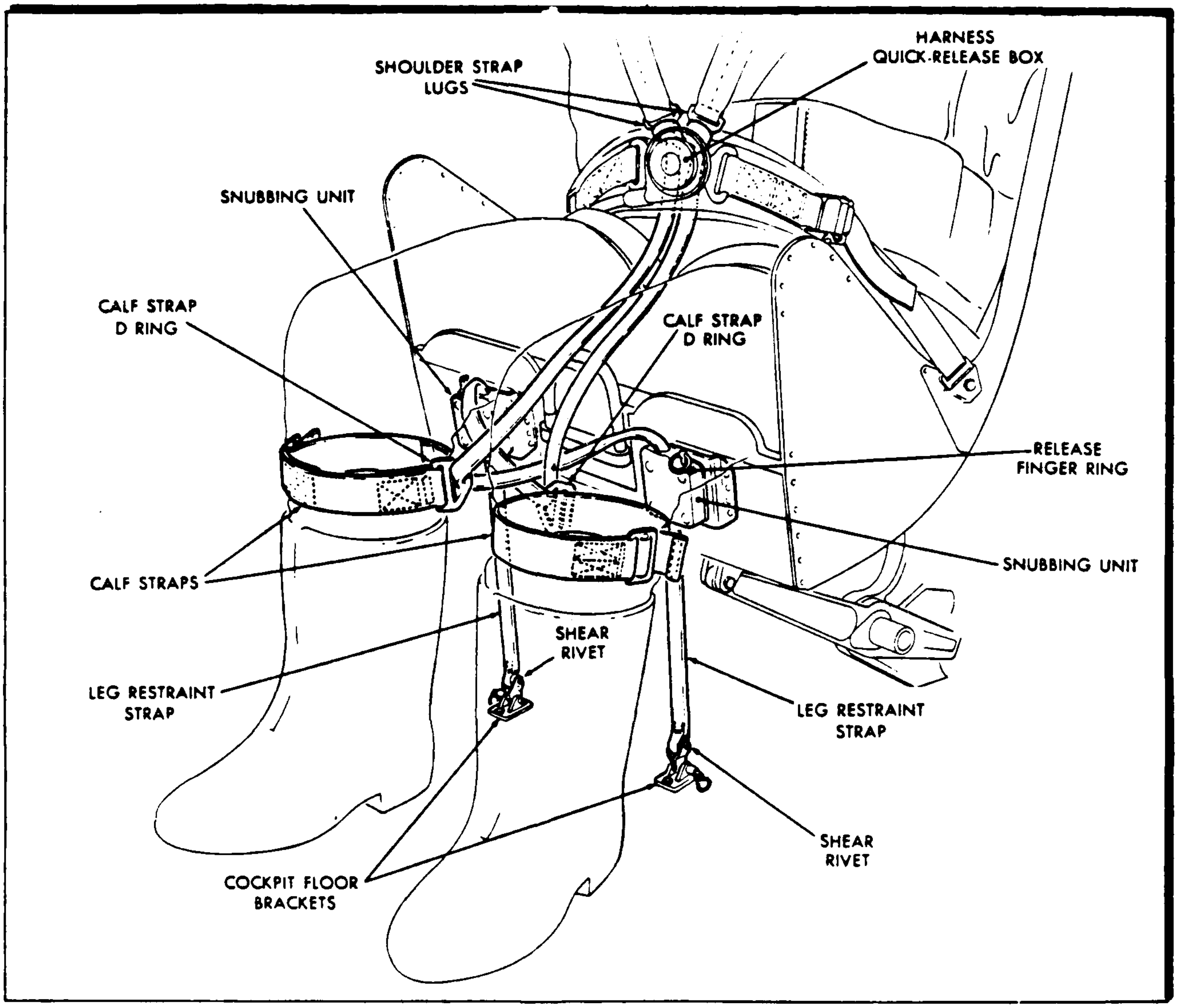


Figure 3.b. Operation of the Leg Restraint System

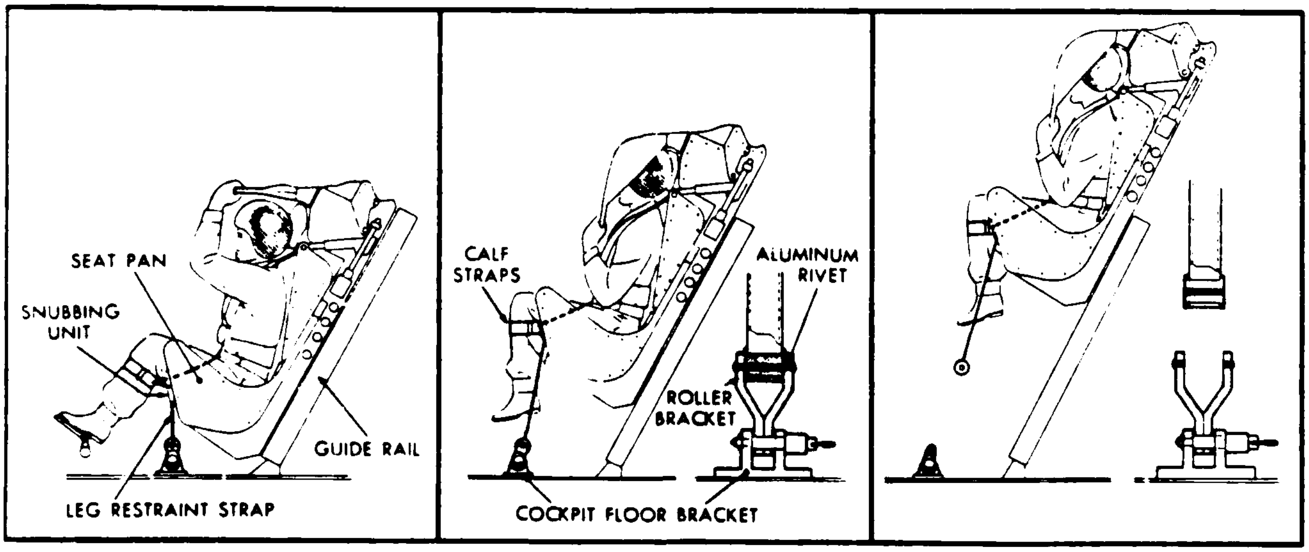


Figure 4. CF101 Ejection Seat (T.O. 13A5-18-3)

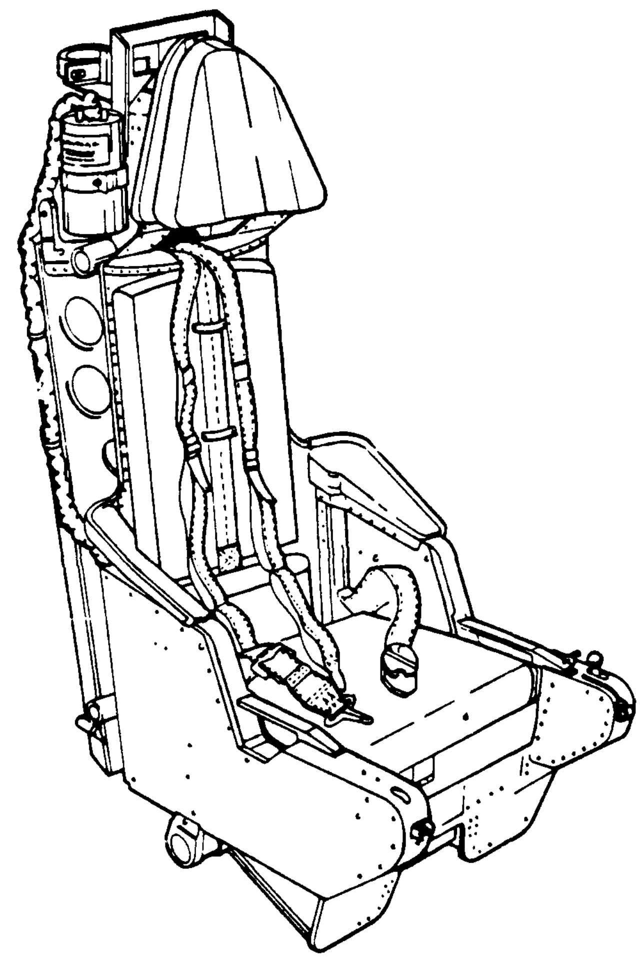


Figure 5. CF104 Ejection Seat (EO 55-50A-3)

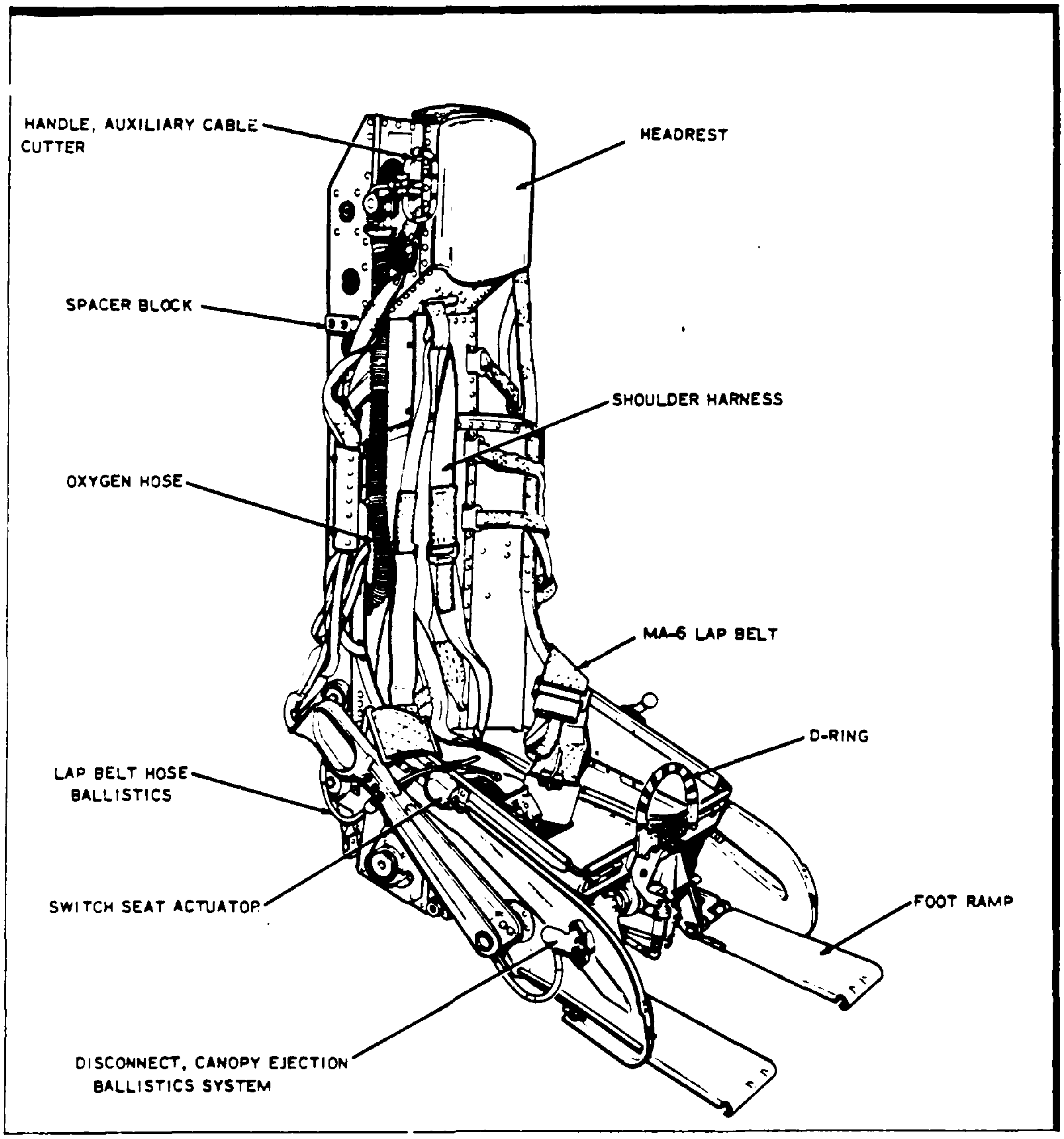


Figure 6. SJU-9/A CF188 Ejection Seat (left-hand view)

1. Parachute container
2. Drogue gun
3. Oxygen hoses and mic/tel lead
4. Sticker strap
5. Lap strap
6. Seat Bucket
7. Go-forward lever
8. Locating block
9. Rocket motor
10. Seat height actuator switch
11. Leg restraint line (2)
12. Lower garter buckle (2)
13. Upper garter buckle (2)
14. Survival kit
15. Seat firing handle
16. Back rest
17. Parachute risers
18. Head pad
19. BIR
20. Oxygen gauge
21. Canopy breaker
22. Trip rod to drogue gun
23. T handle
24. Initiators
25. Cross strap
26. rocket nozzle

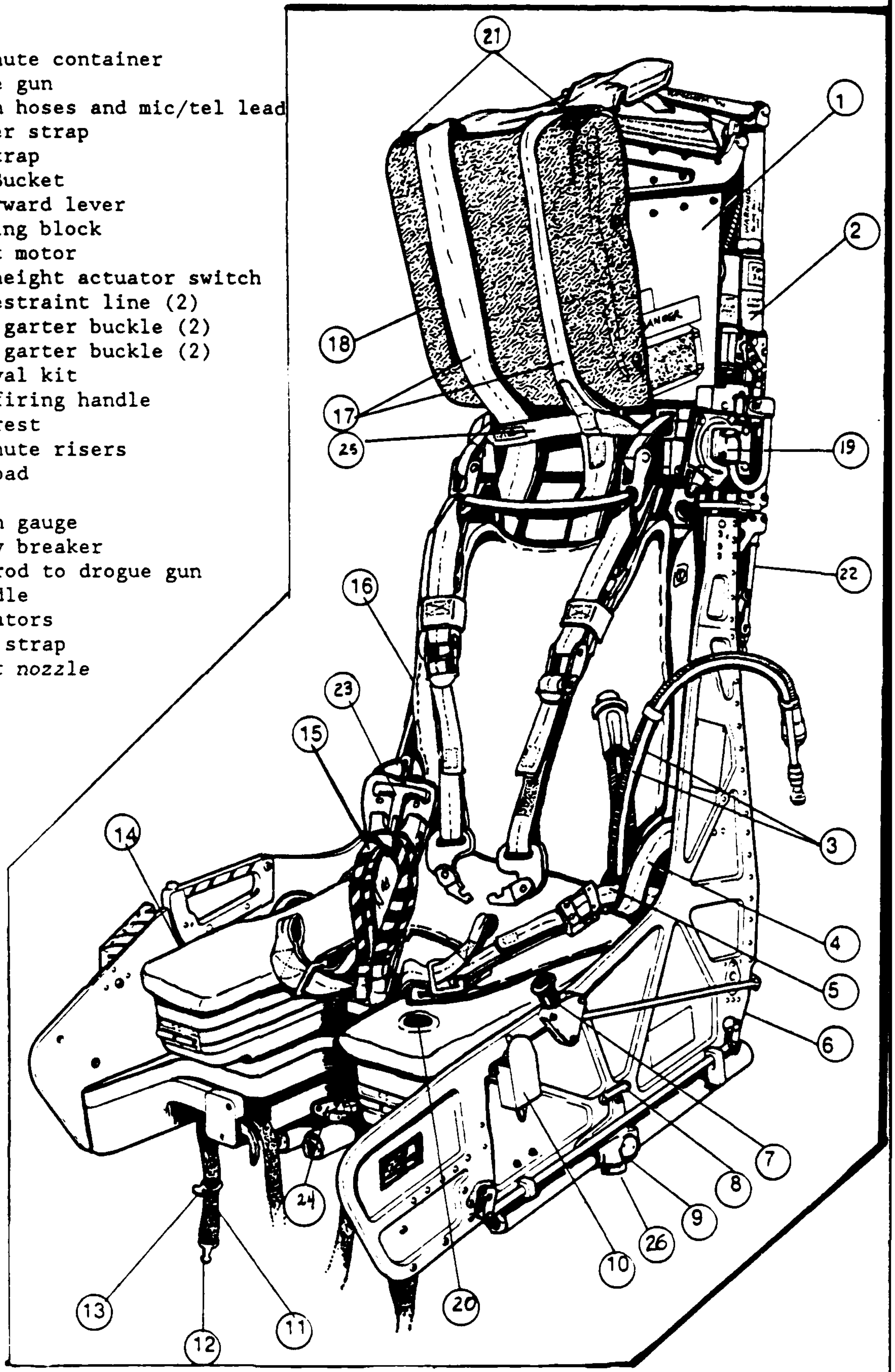


Figure 7.a. BASIC COMPONENTS OF CONVENTIONAL EJECTION SEAT Showing: canopy breaker (1), headrest (2), seat frame(3), ROCAT attachment (4), seat bucket (5), rotary actuator (6), shoulder harness (7), RPI lap belt (8), seat kit (9), negative-G strap (10), ejection handles (11) and ballistic hose (12).

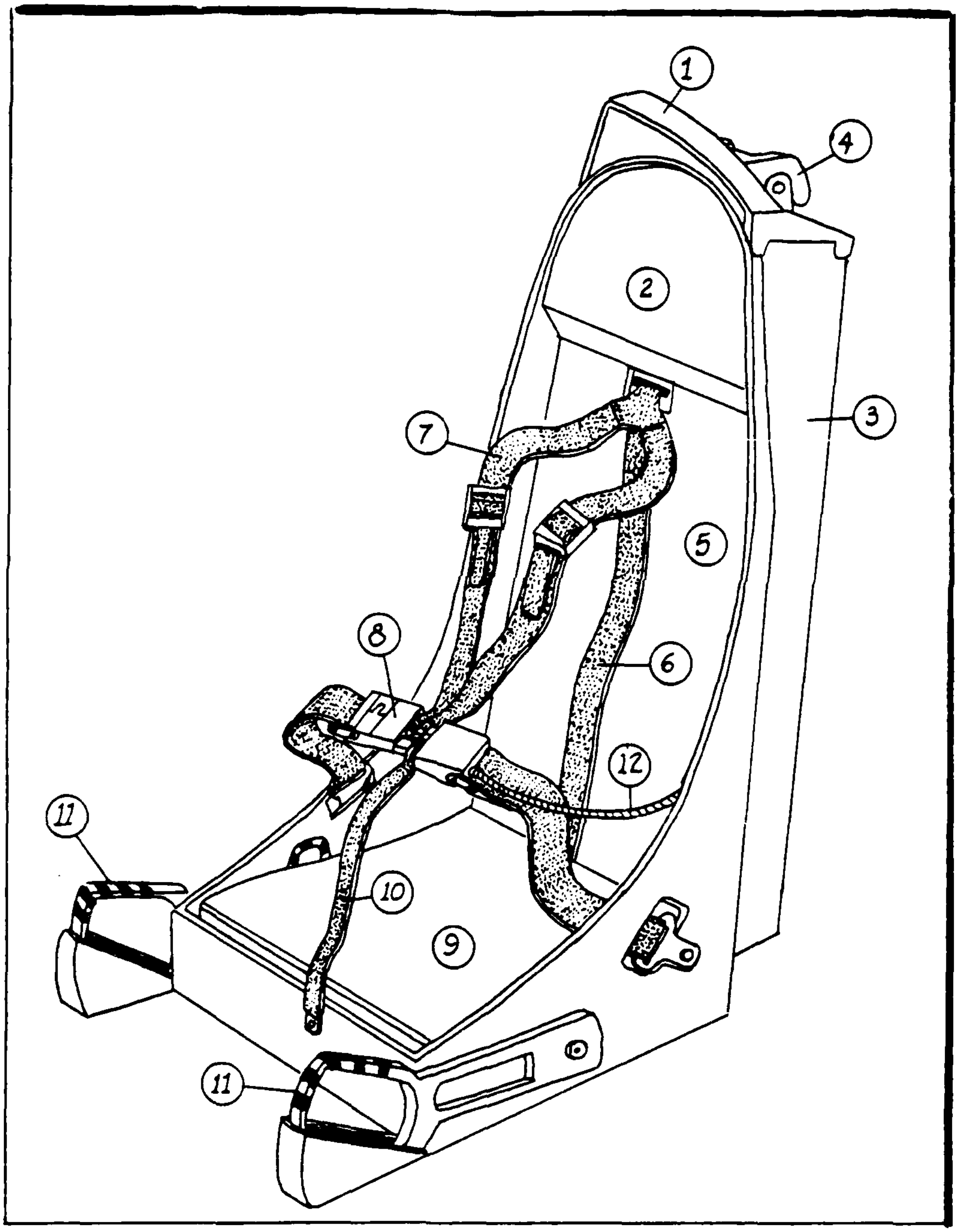


Figure 7.b. CT114 Ejection Seat Schematic showing Rotary Actuator Webbing

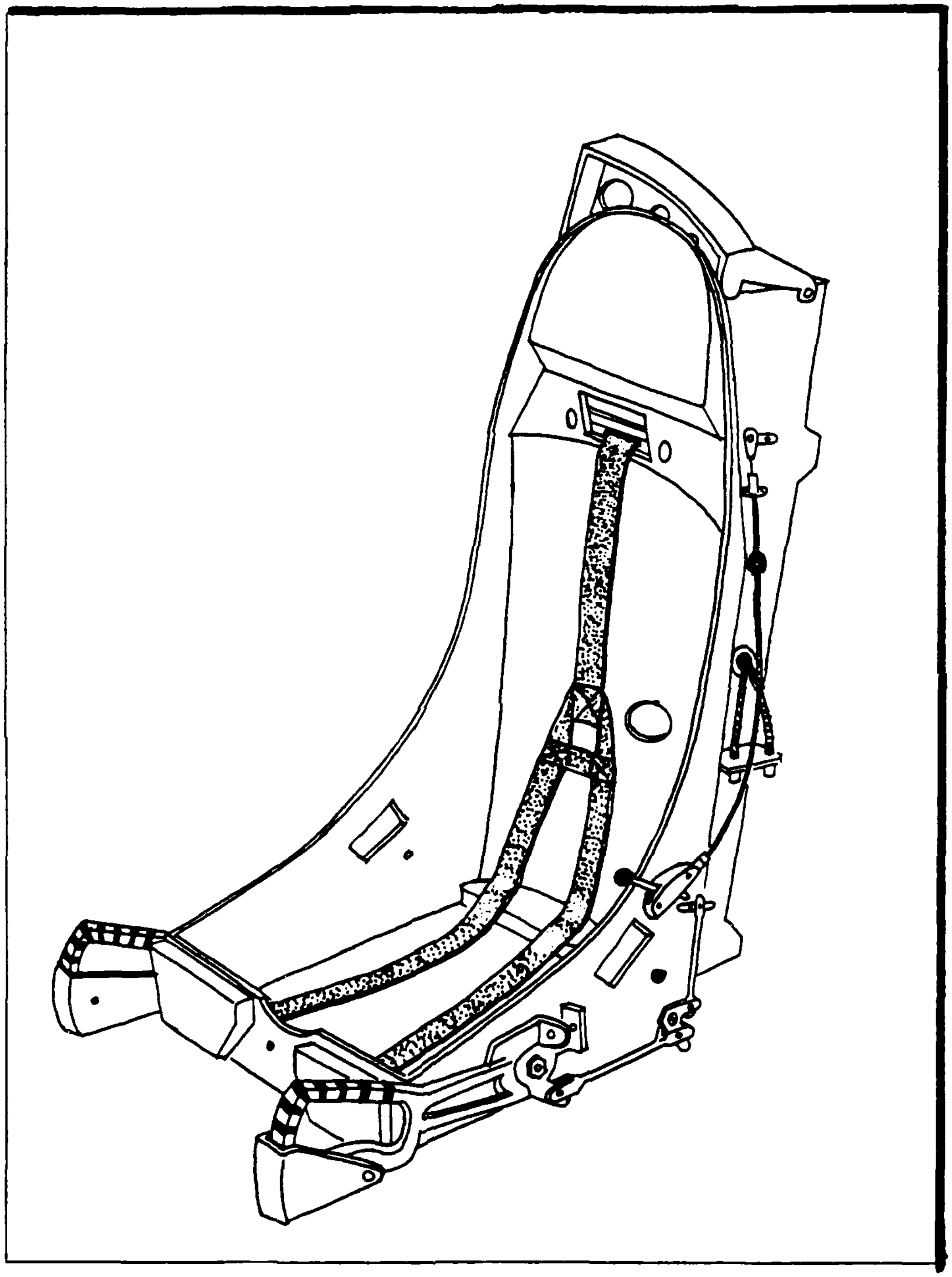


Figure 7.c. CF188 Ejection Seat Components

1. Seat bucket
2. Seat kit
3. Head box/parachute
4. Ballistic Inertia Reel
5. Main Beams
6. Catapult/guide rails
7. Rocket motor initiator
8. Drogue gun
9. Barostatic time delay/G limiter/ shackle release
10. Rocket Motor

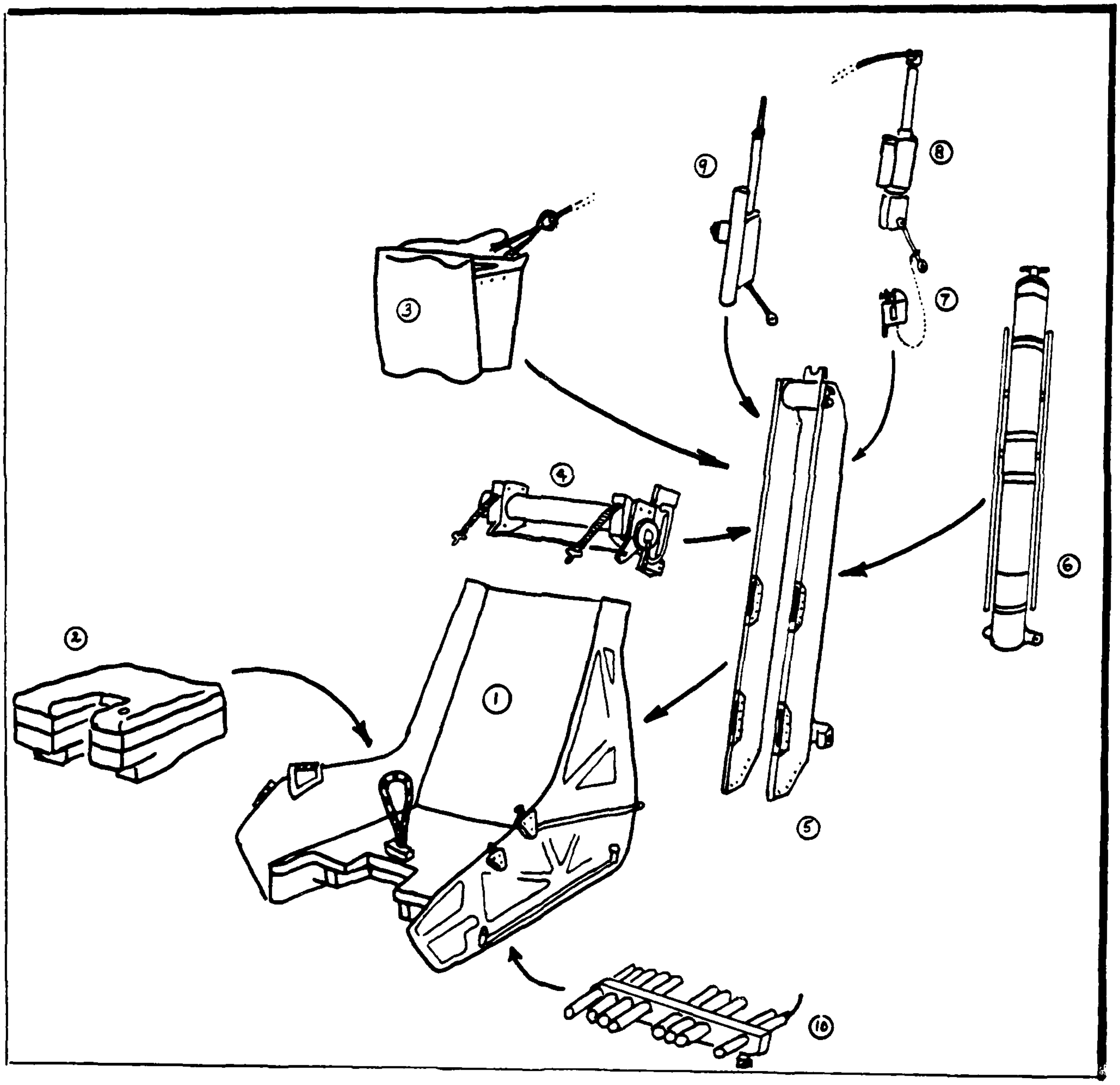


Figure 8.a. RPI Lap Belt Buckle showing: parachute arming key (1) right shoulder harness (2), left shoulder harness (3) and negative-G strap (4).

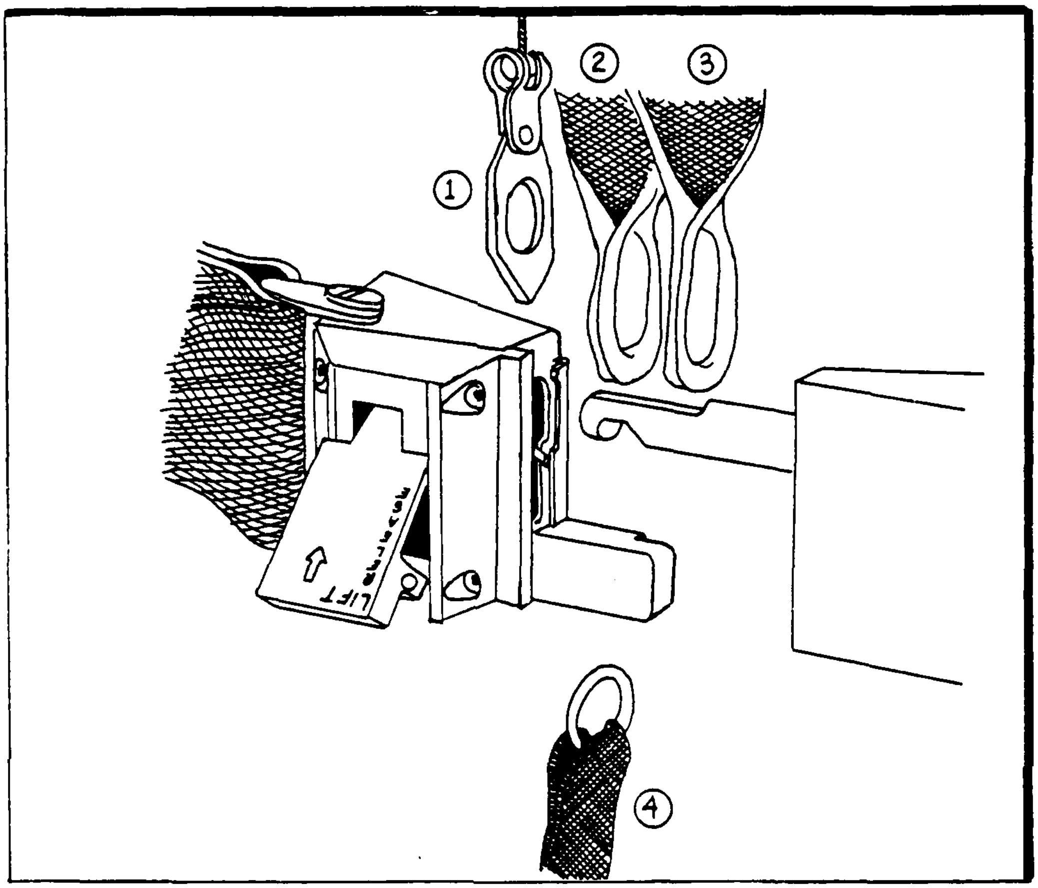


Figure 8.b. RPI Lap Belt in Lock Position showing: ballistic cable (1)

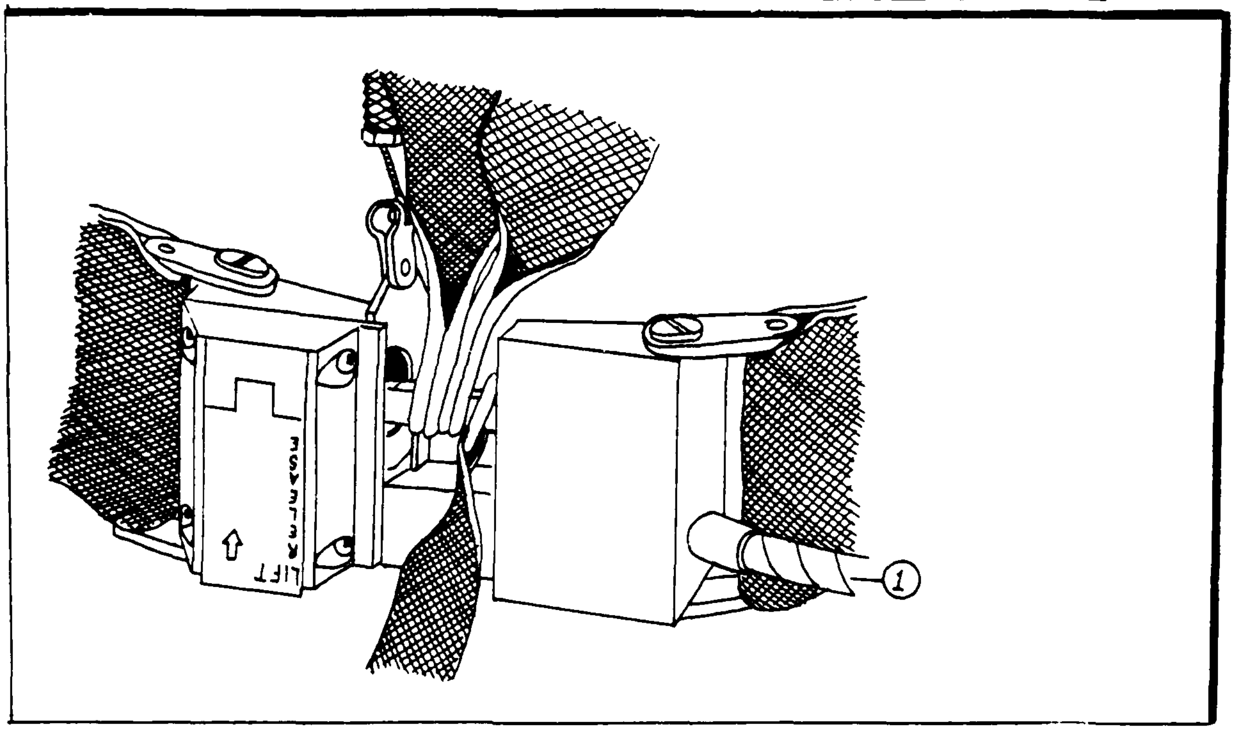


Figure 9.a. Quick-Release Fitting - Don Position

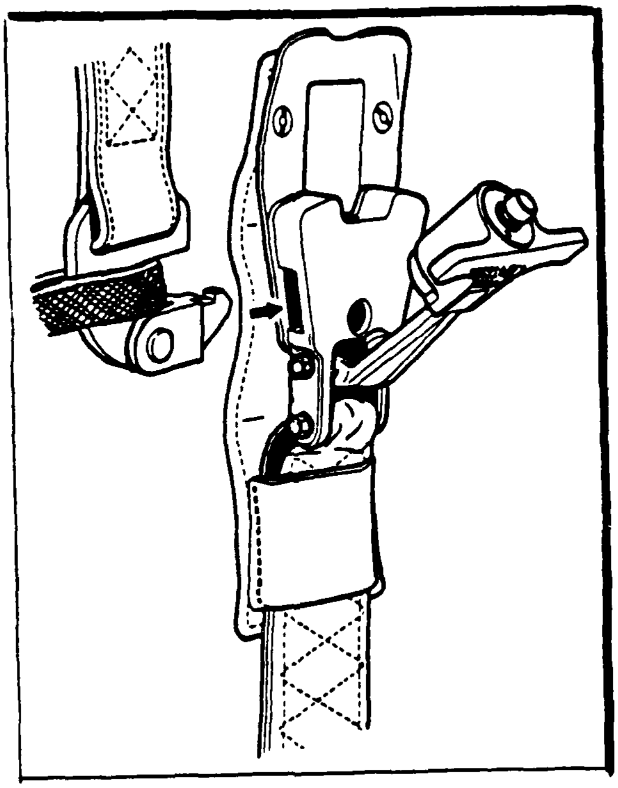


Figure 9.b. Quick-Release Fitting - Unlocked Position

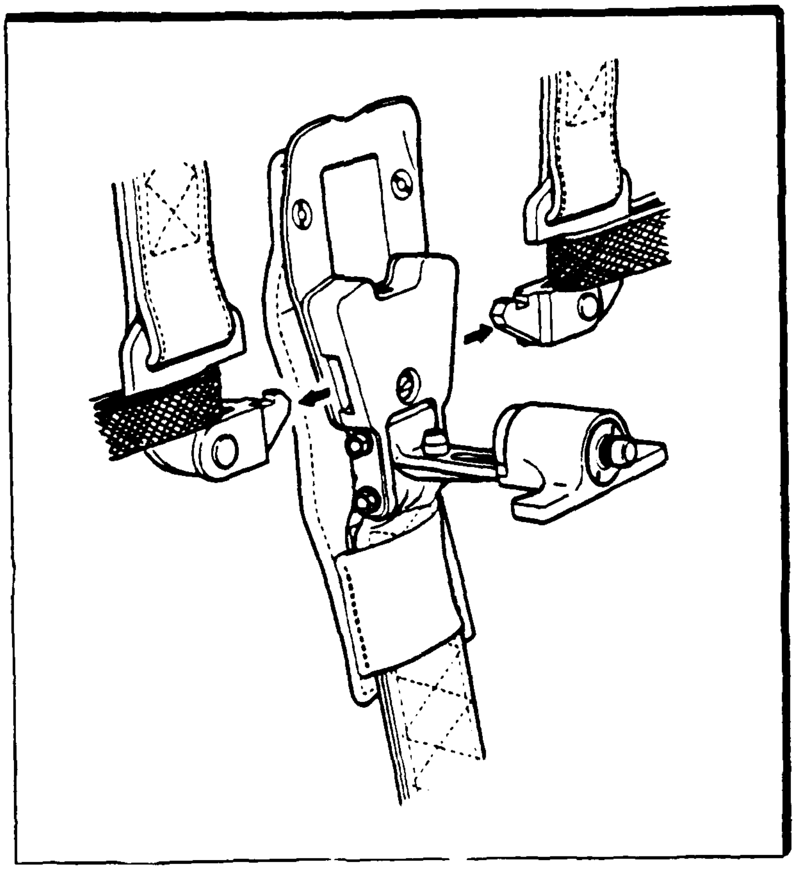


Figure 9.c. CF188 Simplified Combined Harness (SCH) showing: seat attachment points (◄); risers (1), BIR attachment (2), shoulder strap adjust (3), T-handle (4), leg strap adjust (5), sticker clip (6), lower harness lock lug (7), seat pack connect (8), V-strap (9), negative-G strap (10), and velcro patch for oxygen regulator (11)

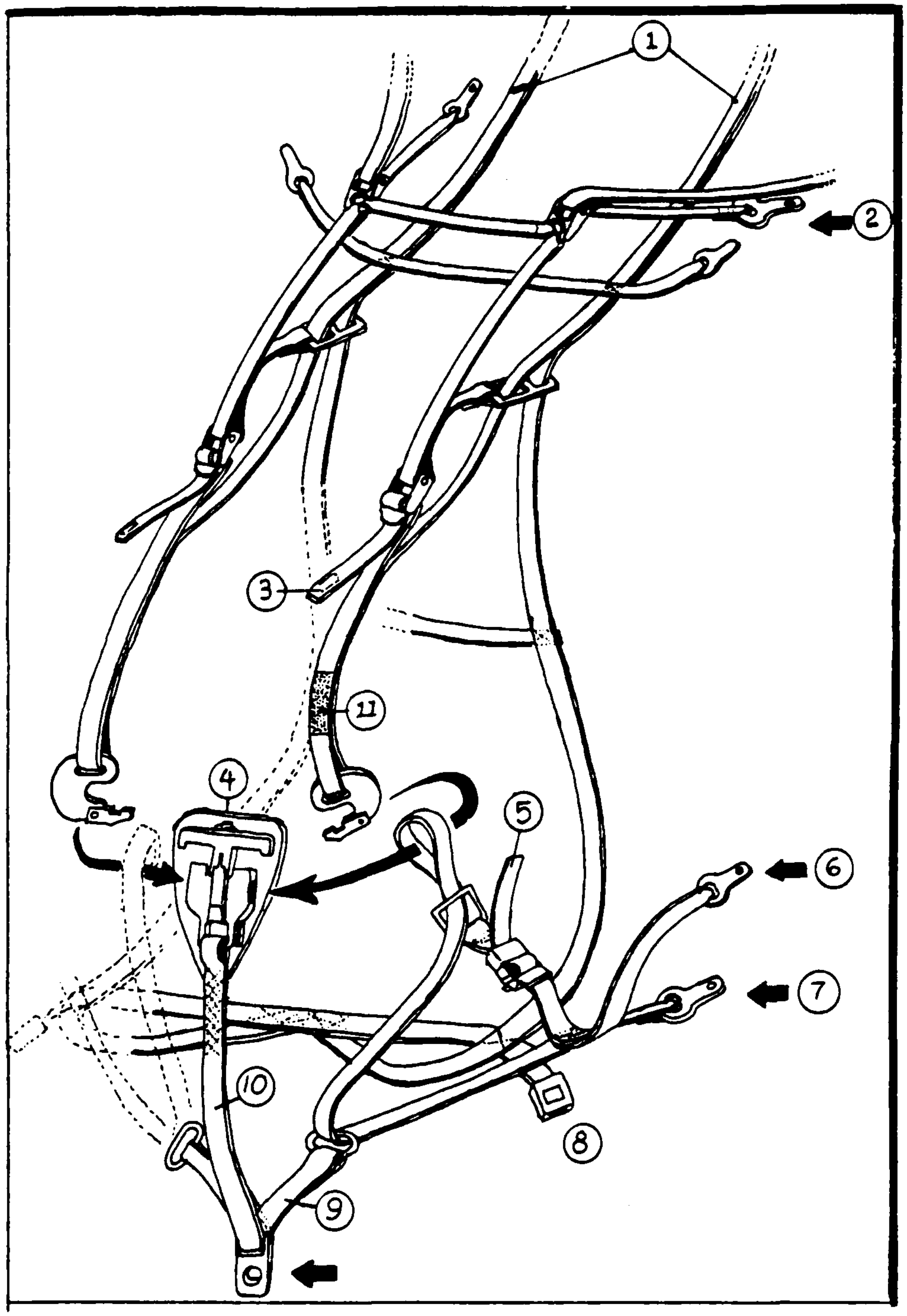


Figure 10. CF188 Leg Restraint system showing: Taper plug (1), upper garter attachment (2), lower garter attachment (3), snubbing box (4), release tab (5), break link (6), and floor attachment (7) (right-hand side)

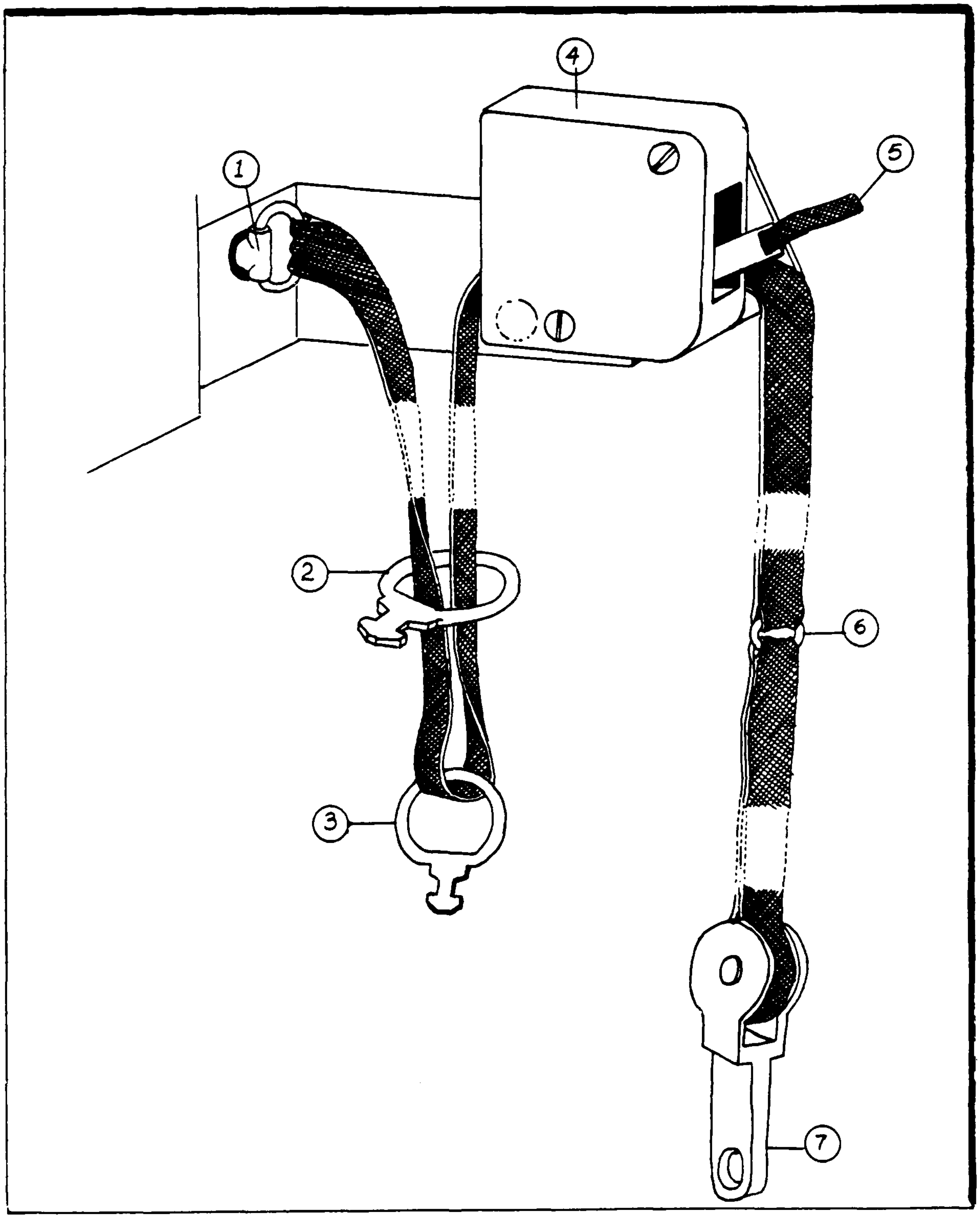


Figure 11. Conventional Rocat System
showing: ejection seat guiderail (1), catapult (2), rocket (3), main beams (4) and venturi (5).

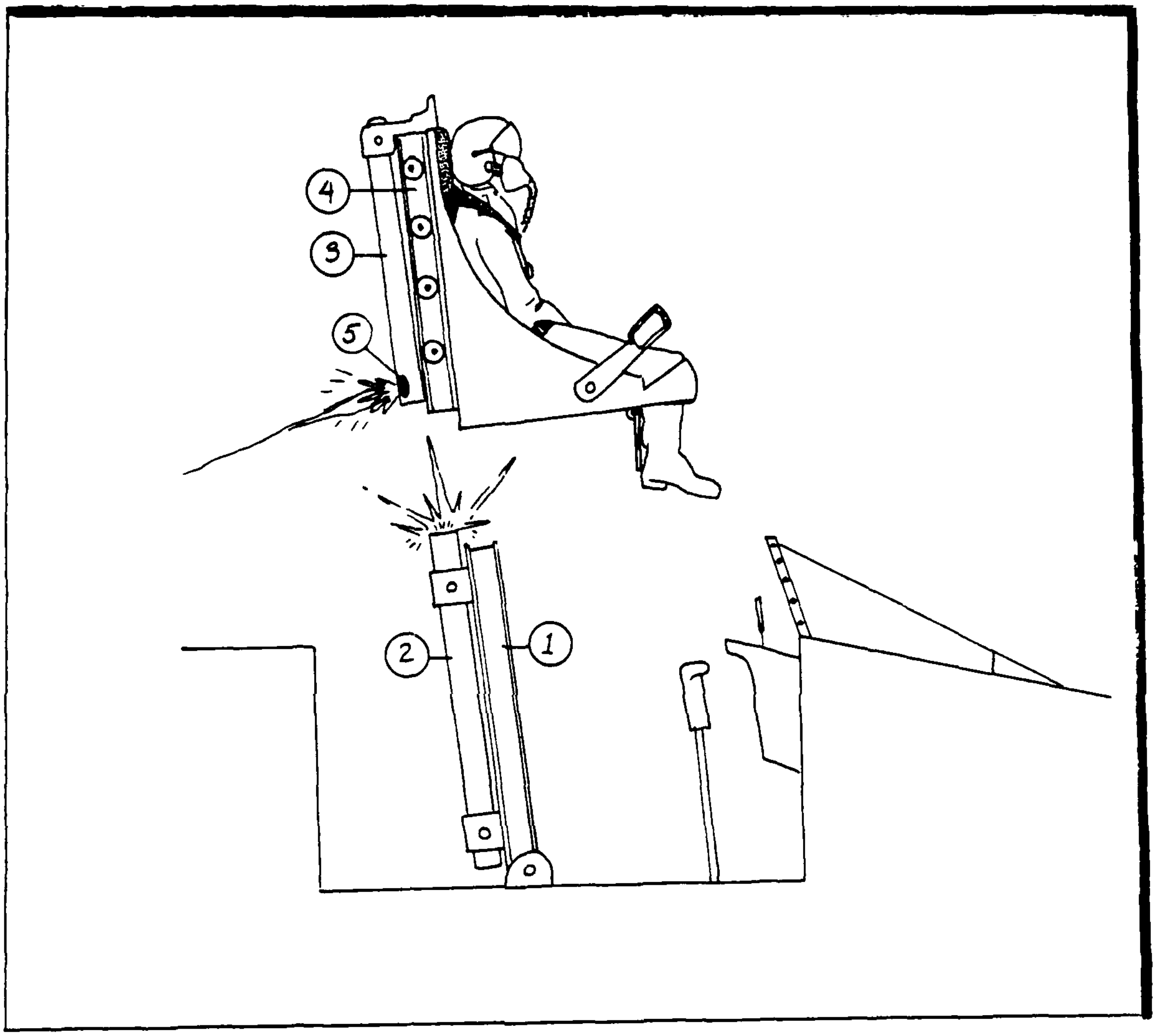


Figure 12. CT133 Ejection System Schematic

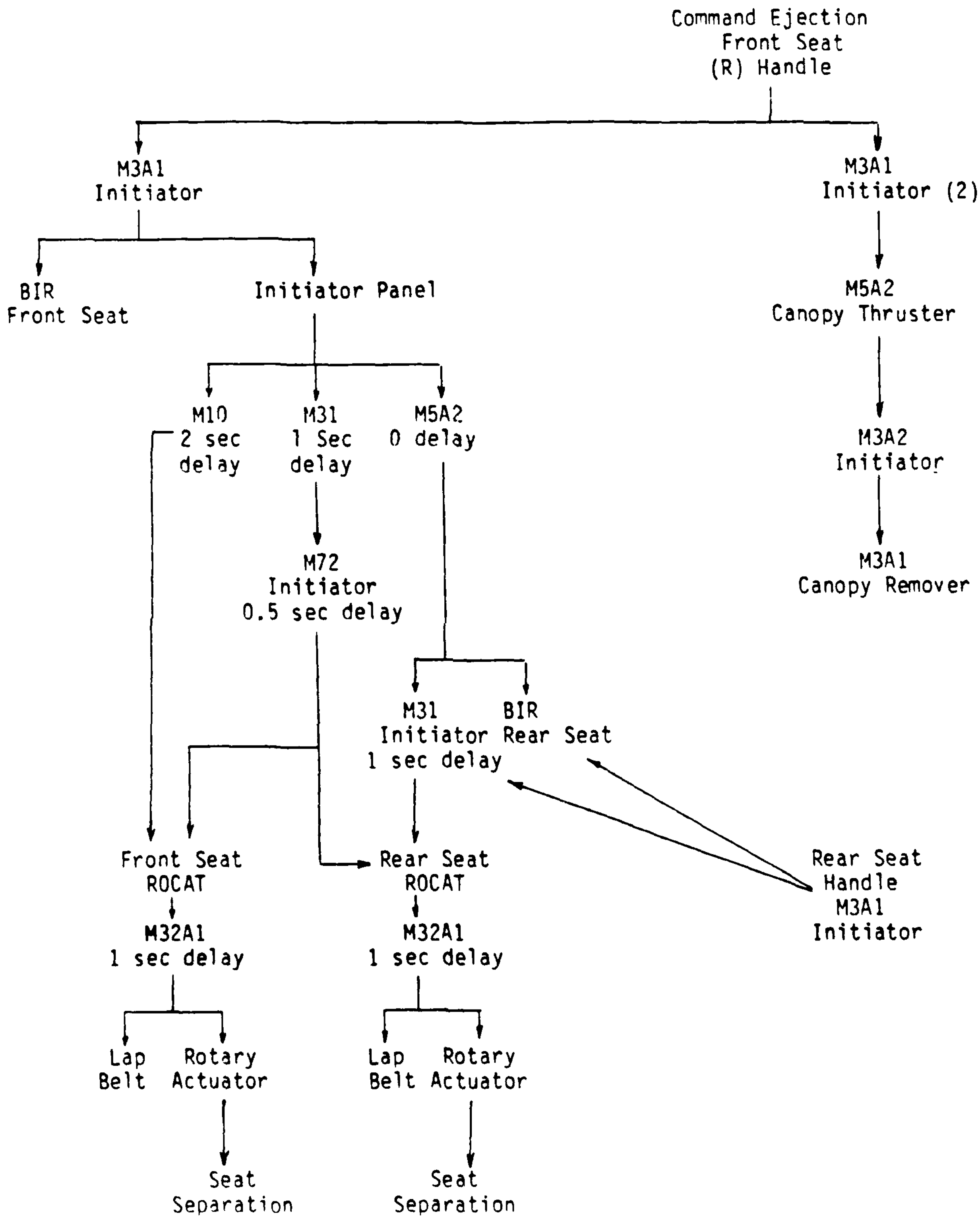


Figure 13. CT114 Ejection System Schematic

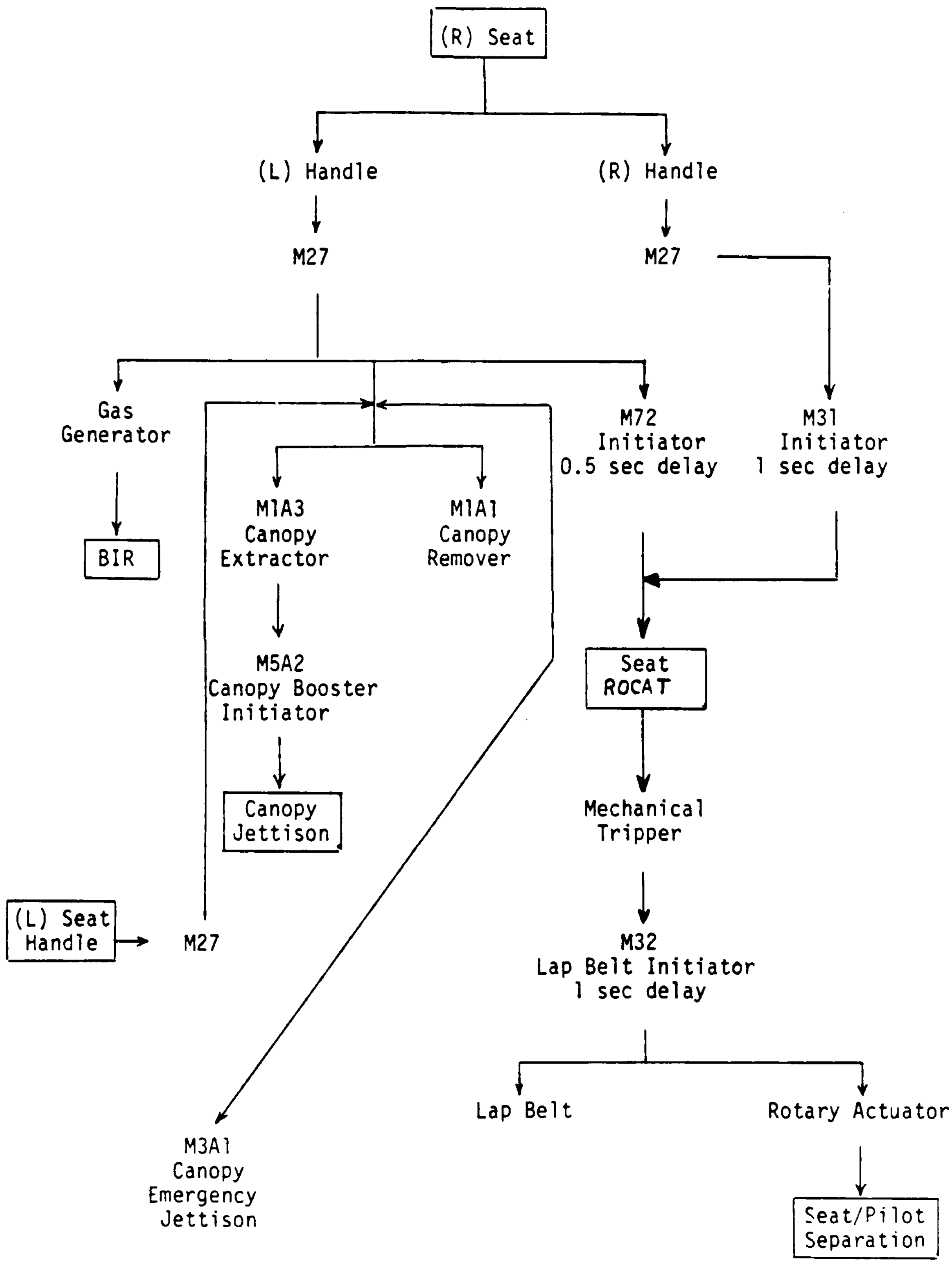


Figure 14. CF 116 Ejection System Schematic

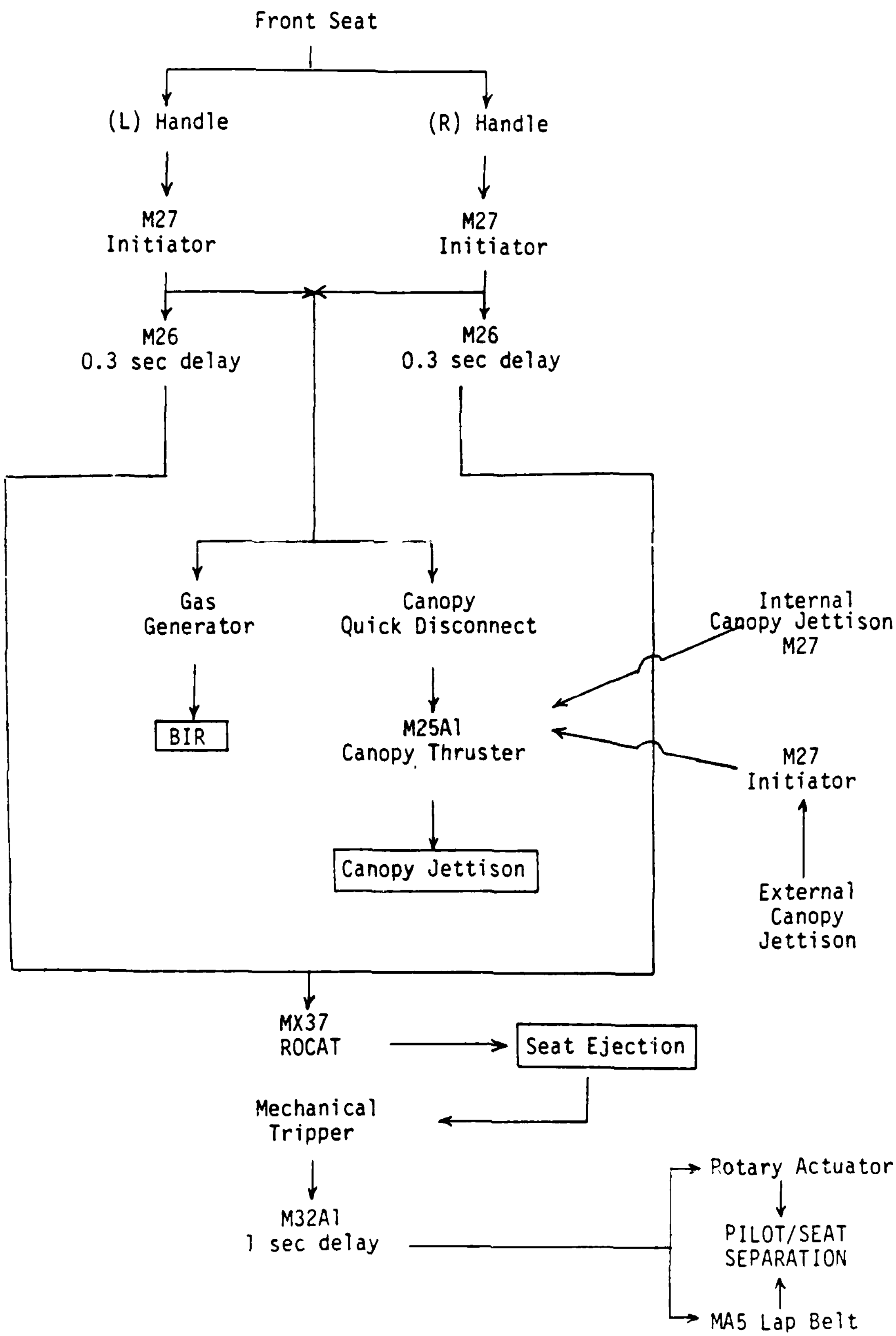


Figure 15. CF188 Ejection System Schematic

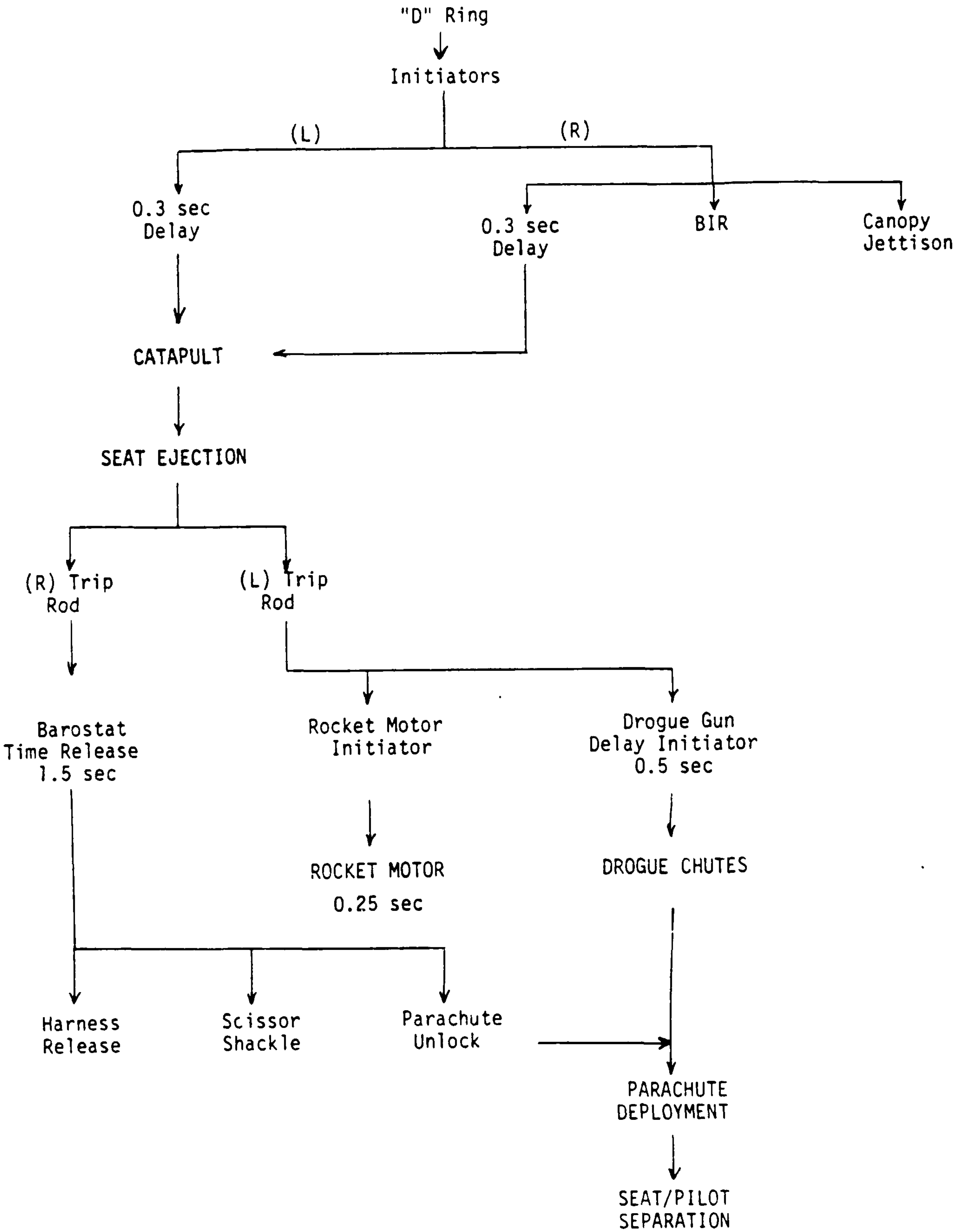
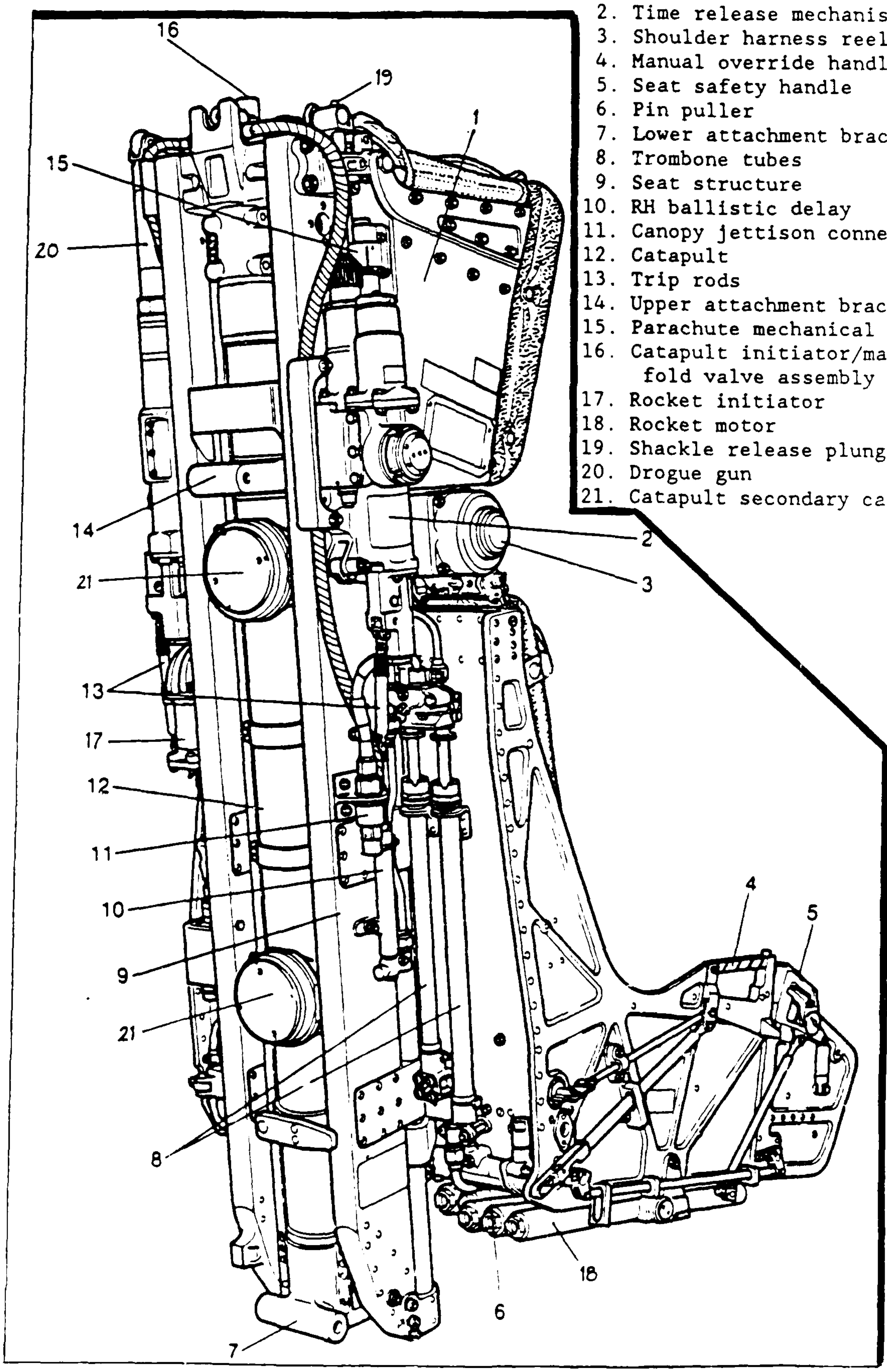


Figure 16. SJU-9/A Ejection Seat



1. Headbox
2. Time release mechanism
3. Shoulder harness reel
4. Manual override handle
5. Seat safety handle
6. Pin puller
7. Lower attachment bracket
8. Trombone tubes
9. Seat structure
10. RH ballistic delay
11. Canopy jettison connector
12. Catapult
13. Trip rods
14. Upper attachment bracket
15. Parachute mechanical lock
16. Catapult initiator/manifold valve assembly
17. Rocket initiator
18. Rocket motor
19. Shackle release plunger
20. Drogue gun
21. Catapult secondary cartridges

Figure 17. CT114 Seat Kit (A), and Details of Bottom Lock Mechanism (B) showing: lanyard (1), airlock connector (2), fibreglass kit (3), deployment handle (4), canvas closure (5), pins (6) and pin cover (7).

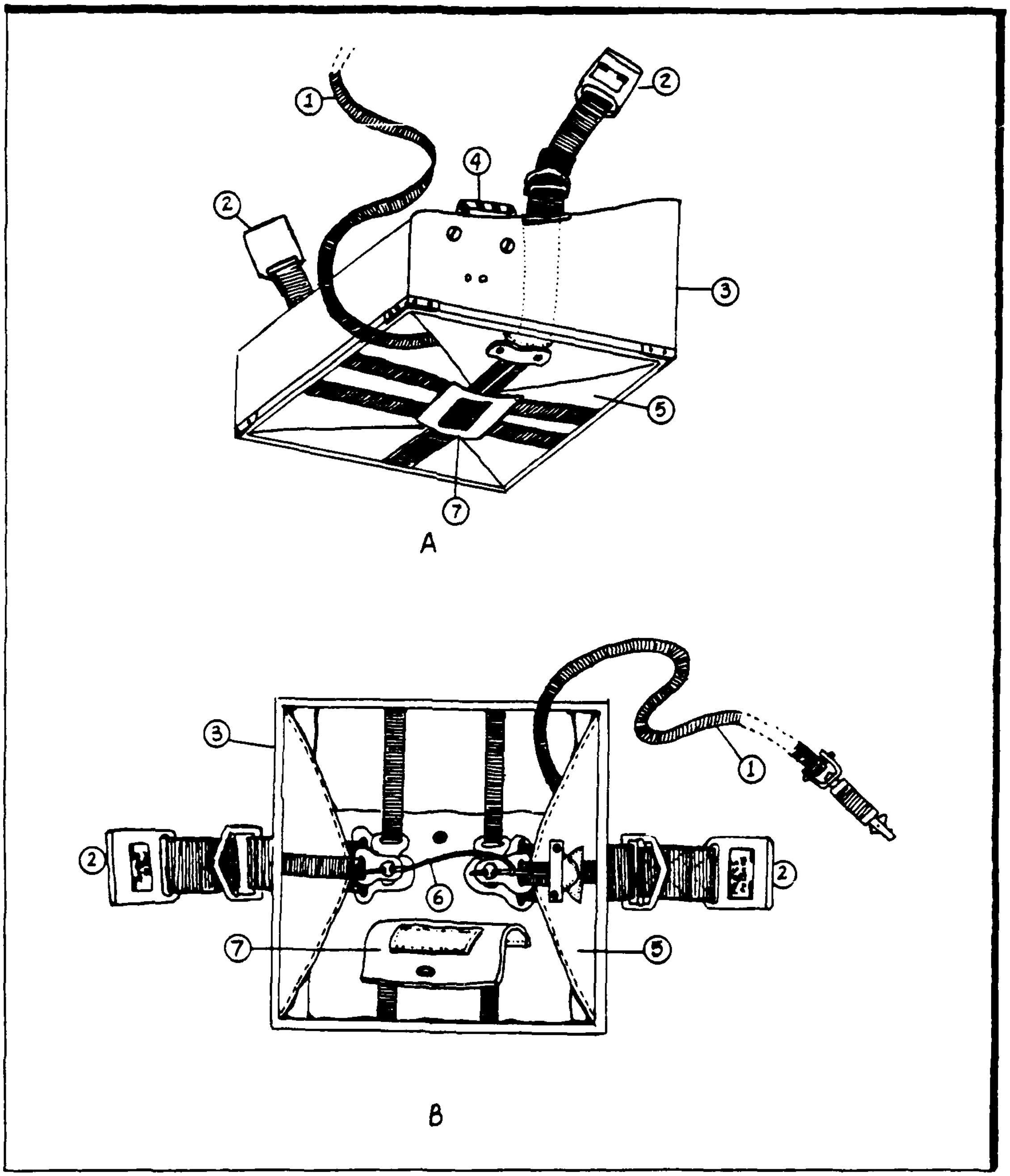


Figure 18. The Relationship Between Performance and Arousal

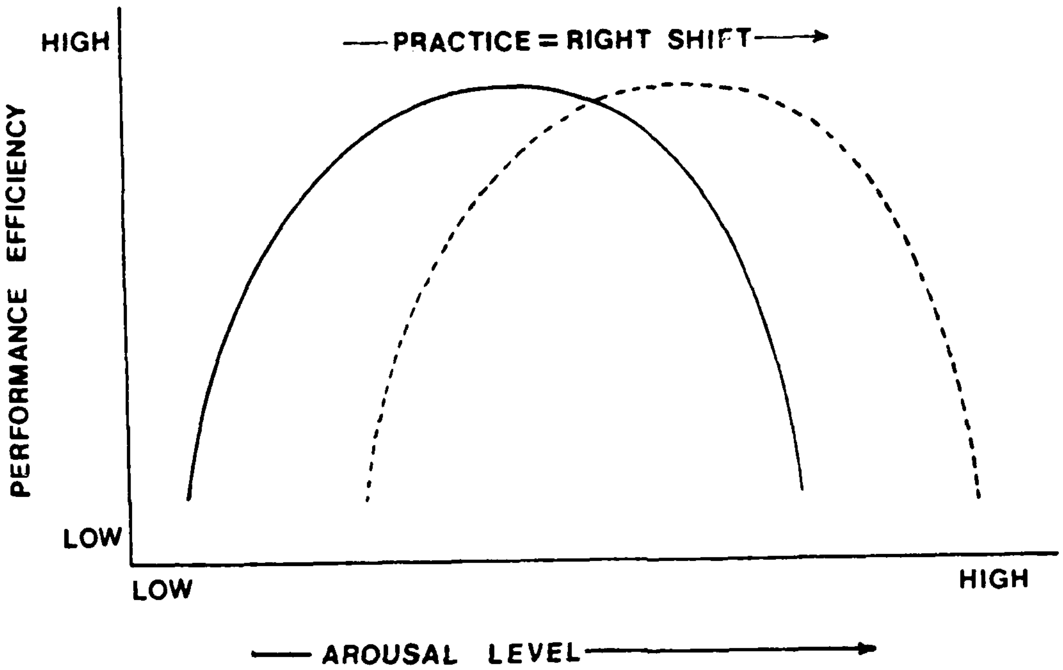


Figure 19. Ejection Loading as a Function of Time for a Typical Rocat Seat Line AB, catapult acceleration phase; BC rocket phase; dotted line - occupant acceleration (modified after White 1985).

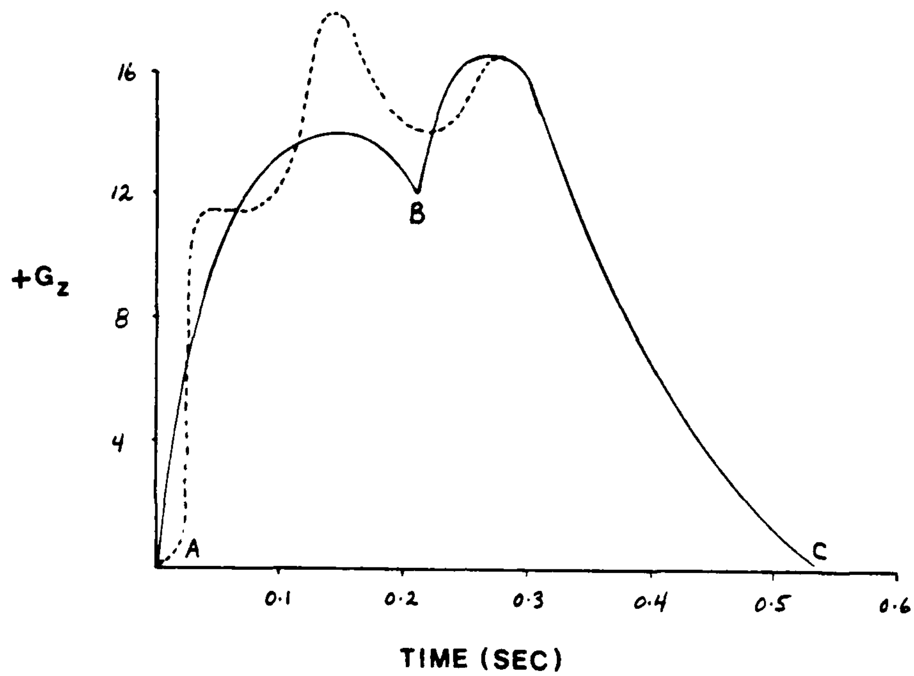


Figure 20. Minimum Ejection Altitude (CF188A)

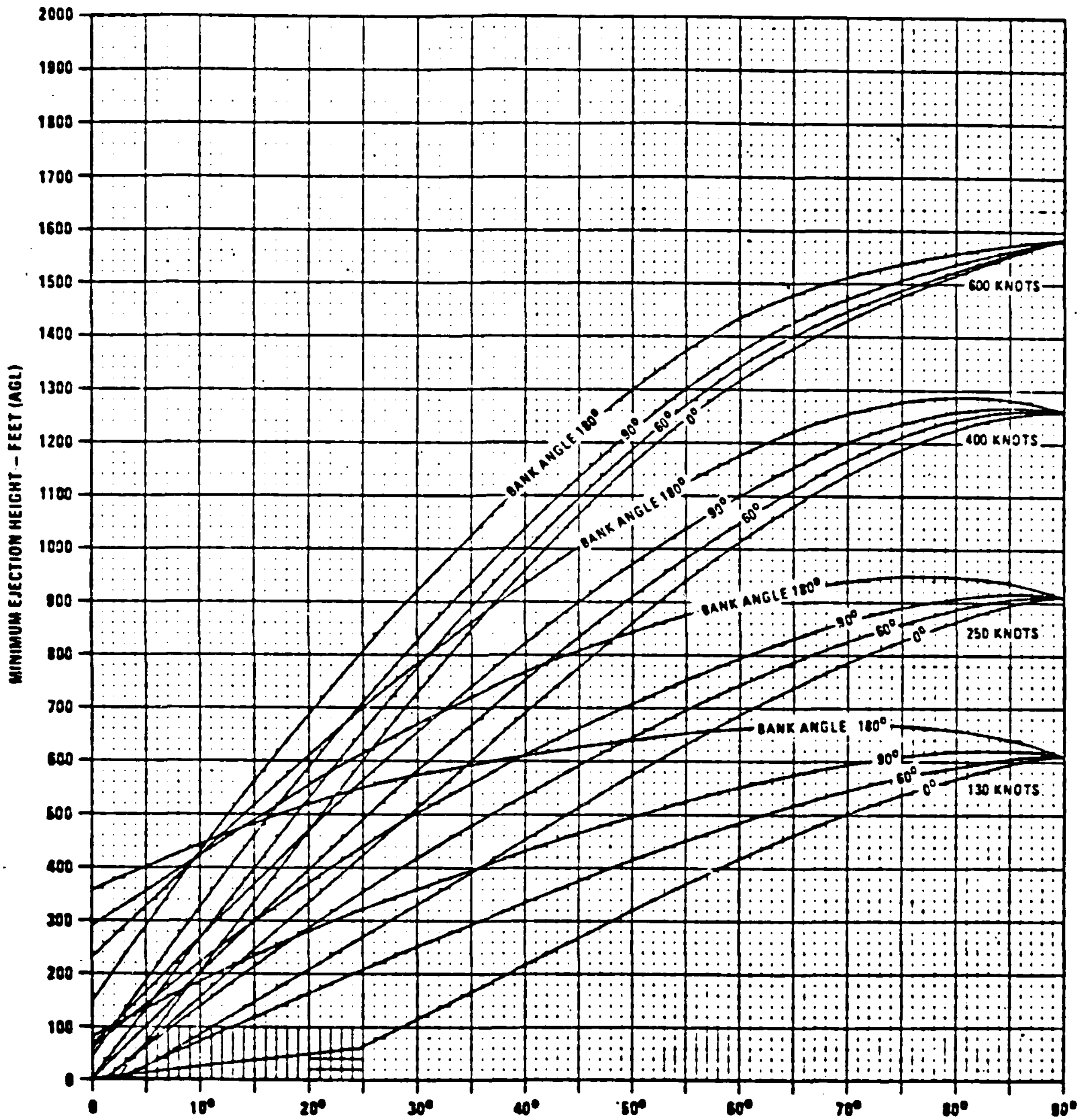


Figure 21. USAF Ejection Flail Injury Versus Airspeed/1964-1972
(Brinkley 1973)

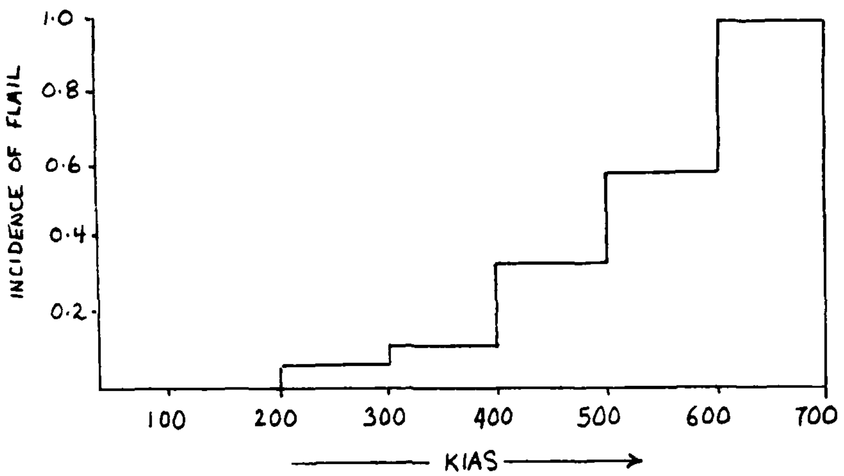


Figure 22. Altitude Distribution of 87 Successful Ejections - 1972-1986
(Data extracted from Annex B)

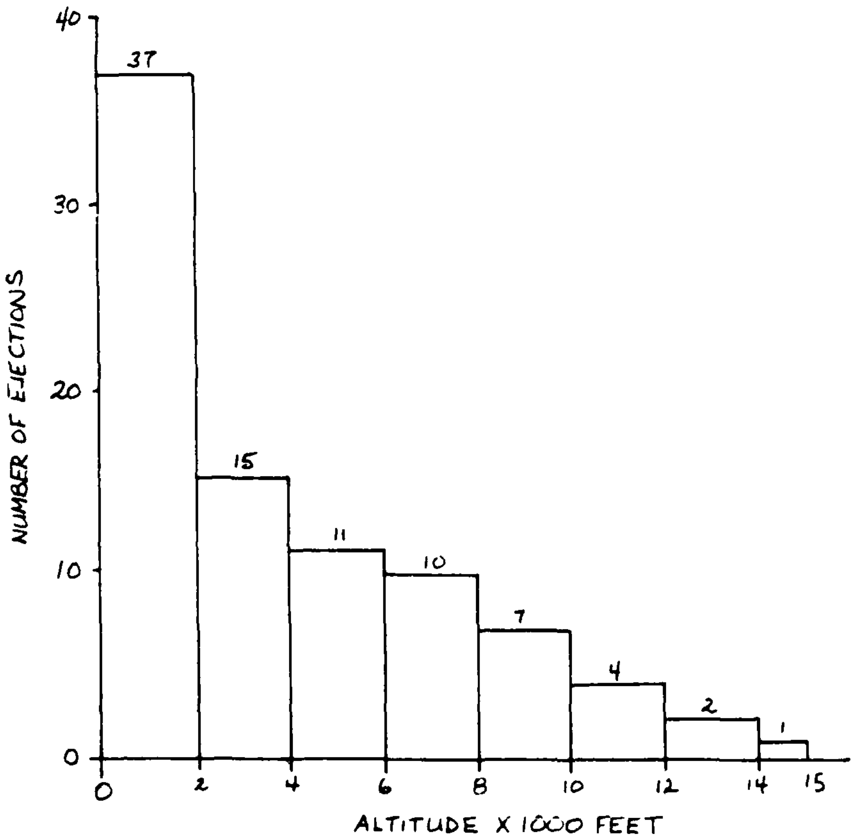


Figure 23. The Relationship Between Altitude and True Air Speed At Terminal Velolcity in a Free-Falling Man (Ernsting 1978)

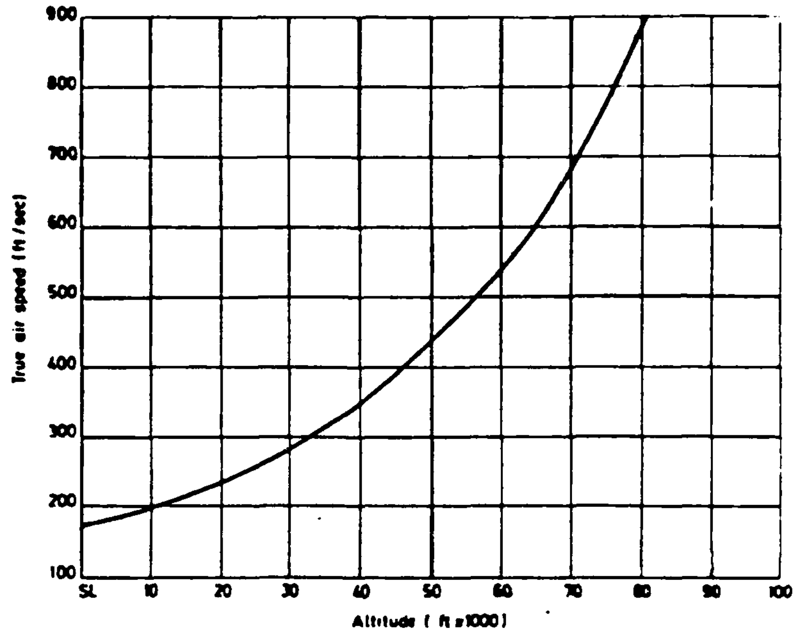
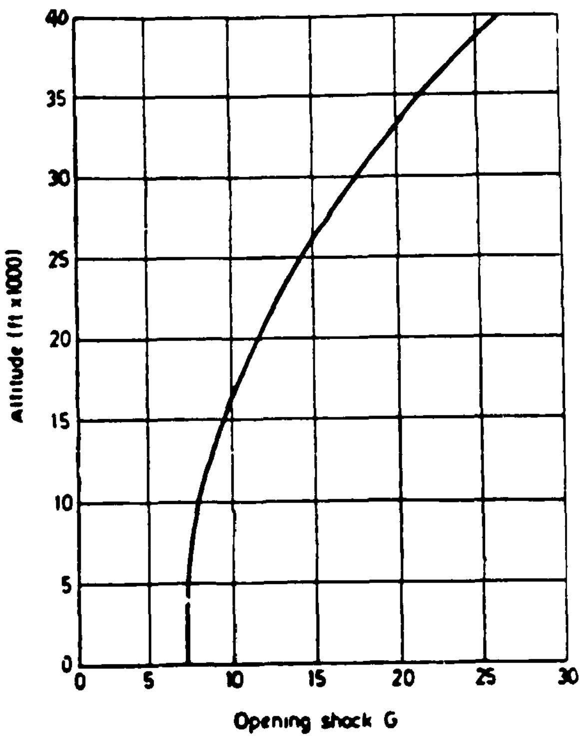


Figure 24. Parachute Opening Shock at Various Altitudes of Deployment. (Values shown are typical of those obtained at the terminal velocity of man using a 28 foot canopy.)



"A" CATEGORY AIRCRAFT ACCIDENTS
1972 - 1987

Code: NENF - No Ejection, Non-Fatal; NEF - No Ejection, Fatal
CFIT - Controlled Flight Into Terrain; ROE - Rapidity of Events
UE - Unable to Eject; UK - Unknown Cause

Crew	Aircraft No.	Date	Deaths	Eject.	Fatal Eject.	NENF	NEF	Cause *
2	CF100788	17 Oct 73	2	0	0	0	2	CFIT
2	792	3 Mar 72	0	2	0	0	0	
2	CF101007	22 Jun 84	0	2			-	
2	016	14 May 75	0	2			-	
2	017	1 Dec 77	2	2	2		-	
2	018	29 Nov 79	0	2			-	
2	019	12 Aug 73	0	2			-	
2	023	14 Jan 78	0	1		1	-	
2	026	19 Apr 82	0	2			-	
2	029	15 Sep 83	0	2			-	
2	033	25 Sep 80	0	0		2	-	
2	039	4 Jul 75	0	2			-	
2	049	7 Jul 73	0	2			-	
2	055	19 Feb 80	2	0			2	ROE
2	061	5 Jul 76	2	0			2	CFIT
2	062	14 Feb 73	0	2			-	
2	CF104631	7 Nov 74	0	2			-	
1	640	3 Dec 82	1	0			1	UE
1	647	3 Dec 82	1	0			1	UE
2	649	17 Nov 77	2	0			2	UE
2	651	24 Jun 80	0	2			-	
2	656	4 Mar 77	2	0			2	CFIT
2	665	16 Mar 81	0	2			-	
2	666	5 Mar 75	0	0		2	-	
1	705	11 Dec 81	0	1			-	
1	714	12 Feb 76	1	0			1	CFIT
1	715	11 Dec 74	0	1			-	
1	720	17 Aug 73	0	1			-	
1	732	30 Apr 82	0	1			-	
1	744	18 May 83	1	0			1	UE
1	754	21 Feb 79	1	0			1	CFIT
1	762	9 Jun 81	0	1			-	
1	769	4 May 73	0	1			-	
1	772	18 Apr 73	1	0			1	CFIT
1	775	15 Nov 77	1	0			1	CFIT
1	779	9 Sep 75	0	1			-	
1	789	27 May 74	0	1			-	
1	807	27 Nov 80	0	1			-	
1	813	22 May 83	0	1			-	
1	821	10 Jan 83	0	1			-	
1	827	29 Jul 82	0	1			-	
1	829	19 Aug 78	0	1			-	

Crew	Aircraft No.	Date	Deaths	Eject.	Fatal Eject.	NENF	NEF	Cause*
1	CF104830	16 Jun 83	0	1			-	
1	838	7 Mar 78	0	1			-	
1	840	25 Jul 78	1	0			1	CFIT
1	857	22 Oct 73	1	0			1	CFIT
1	859	27 Aug 80	0	1			-	
1	864	10 May 73	1	1	1		-	
1	872	11 Mar 74	0	1			-	
1	892	4 Jun 82	0	1			-	
1	895	14 Mar 74	0	1			-	
1	CF116706	13 Dec 79	0	1			-	
1	711	3 Jan 74	0	1			-	
1	720	12 Nov 87	0	1			-	
1	728	11 Jul 79	0	1			-	
1	731	20 May 77	0	1			-	
1	735	26 Feb 81	1	0			1	UE
1	741	2 Mar 76	0	1			-	
1	755	7 Jun 77	1	0			1	UK
1	756	12 May 74	0	1			-	
1	760	2 May 76	0	1			-	
1	761	12 Feb 79	0	1			-	
1	770	10 Aug 77	1	0			1	UK
1	771	20 Jan 83	1	0			1	CFIT
1	816	7 Mar 73	1	0			1	CFIT
2	817	22 Dec 83	0	0		2	-	
2	820	11 May 76	0	1		1	-	
2	844	30 Apr 82	2	0			2	ROE
2	CT114007	3 Apr 78	2	0			2	ROE
2	010	26 Jun 85	1	2	1		-	
1	016	19 Dec 73	0	1			-	
2	028	31 May 76	2	2	2		-	
2	029	12 Aug 75	0	2			-	
2	057	24 Nov 78	0	2			-	
2	074	21 May 75	0	2			-	
1	082	16 Jul 77	0	1			-	
1	088	16 Jul 77	0	1			-	
1	117	16 Apr 80	1	0			1	CFIT
1	118	4 May 78	1	1	1		-	
1	122	30 Oct 79	1	0			1	ROE
2	123	11 May 76	0	2			-	
1	125	13 Jul 78	0	1			-	
1	127	20 Mar 72	1	1	1		-	
1	129	17 Jun 86	0	1			-	
1	132	24 Jan 77	0	1			-	
2	136	22 Aug 73	1	2	1		-	
2	137	26 Feb 74	0	2			-	
2	138	14 Sep 76	0	2			-	

Crew	Aircraft No.	Date	Deaths	Eject.	Fatal Eject.	NENF	NEF	Cause*
1	CT114158	15 Nov 79	0	1			-	
2	165	23 Sep 79	0	2			-	
1	179	14 Jul 73	0	1			-	
1	183	10 Jun 72	1	0			1	UE
2	CT133069	21 Sep 82	1	1			1	UE
2	315	7 Apr 87	2	0			2	CFIT
1	349	1 Feb 76	1	0			1	ROE
2	363	14 Sep 84	1	2	1		-	
2	405	20 Aug 80	0	2			-	
1	442	14 Feb 81	0	1			-	
1	520	19 Sep 73	0	1			-	
1	603	19 Sep 73	0	1	0			
1	639	26 May 82	1	1	1			
1	CF188715	12 Apr 84	1	0	0		1	CFIT
1	717	24 May 86	1	0	0		1	CFIT
1	721	21 Sep 87	0	1	0			
1	737	4 Jun 85	0	1	0			
1	761	20 Oct 87	0	1	0			
2	919	4 May 87	0	2	0			
148	107		48	103	11	8	37	

* Not to be confused as official cause factor. These are the most probable causes for failure to eject from the aircraft as subjectively evaluated by the author from reading the Board of Inquiry.

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4. AUTHORS (Last name, first name, middle initial. If military, show rank, e.g. Doe, Maj. John E.)

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EJECTION SYSTEM
EJECTION ENVELOPE
PARACHUTES
SEAT PACKS
SURVIVAL
ACCIDENT INVESTIGATION
DECISION MAKING
EJECTION INJURY