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Biomedical review of aircrew weight as a risk factor in CT 133 and CT 114 ejections:

1970 - 1998

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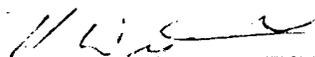
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Abstract

This review was undertaken in Jan 1999 in response to growing concern over Canadian Forces CT133 and CT114 aircraft ejection safety. Occupant weight was a suspected risk factor for serious injury or death during an ejection. A review of literature and examination of all CT133 and CT144 accident reports from 1970-98 was done to investigate occupant weight as a risk factor during all phases of ejection (firing of the seat, windblast and tumbling, seat-person separation, opening shock, landing forces, and post-landing factors). Heavy weight does not appear to be a significant risk factor for major injury or death from a biomedical perspective, although further study is recommended to clearly establish the influence of mass and body size on tumbling and seat-person separation. Heavy weight does lead to higher descent rates and possibly associated landing injury, although our data cannot establish this, nor can it rule out influence of inadequate training in landing technique. Light weight may be a risk factor with respect to injury associated with acceleration, tumbling and opening shock. It should be noted that there may be engineering concerns regarding these specific ejection systems that are outside the scope of this review.

Résumé

La présente étude a débutée en janvier 1999 à la suite d'une inquiétude croissante quant à la sécurité des dispositifs d'éjection des appareils CT133 et CT114 des Forces canadiennes. On suspectait alors le poids de l'occupant de constituer un facteur de risque dans les cas de blessures graves ou de décès durant l'éjection. Un examen de la documentation disponible et de tous les rapports d'accidents des CT133 et CT114 pour la période 1970-1998 a été entrepris afin de déterminer si le poids de l'occupant constituait un facteur de risque dans l'une quelconque des phases de l'éjection (mise à feu du siège, souffle aérodynamique et culbutage, séparation du passager et du siège, choc à l'ouverture, choc à l'atterrissage et facteurs intervenant après l'atterrissage.) Un poids élevé ne semble pas, d'un point de vue biomédical, apparaître comme un facteur de risque significatif en matière de blessures graves ou de décès mais une étude plus approfondie semble souhaitable afin de déterminer l'influence de la masse et de la taille du corps sur le culbutage et la séparation du passager et du siège. Un poids élevé entraîne de fait une vitesse de descente plus élevée et joue peut-être un rôle dans certaines blessures à l'atterrissage bien qu'il n'ait pas été possible d'établir ce dernier fait à partir de données disponibles et ou d'écarter l'hypothèse d'une formation aux techniques d'atterrissage inadéquate. Un poids faible peut également constituer un facteur de risque au regard des blessures associées à l'accélération, au culbutage et au choc à l'ouverture. Il convient de noter qu'il est possible que les dispositifs d'éjection en question présentent des problèmes de conception se trouvant hors du champ de la présente étude.

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Executive summary

Ongoing concern regarding ejection safety of Canadian Forces CT133 and CT114 aircraft has been expressed in service papers, briefing notes and a recent TV program. Occupant weight has been suggested as a risk factor.

There are many influences on the probability of injury in an ejection. Flight parameters such as airspeed, altitude, and manoeuvring at time of ejection play a large role in injury potential, as do windspeed and landing terrain. The complex interactions of a number of factors make it difficult to accurately predict the outcome of a given ejection based on occupant weight.

This biomedical and aircraft occurrence data analysis suggests heavy weight is not a significant risk factor for major injury or death. This analysis does not support a pilot weight restriction of 90 kg (190 lb). Two successful ejections above this weight indicate that the ejection system can function safely with such a mass (one ejectee weighing 97 kg (214 lb) sustained only minor injuries). This analysis indicates that a better strategy would be to focus on preventing injuries through improved equipment, procedures, and training. It should be stressed that engineering concerns may apply that are outside the scope of this review.

There are four phases in the ejection sequence where ejectee weight has some influence:

- a. Acceleration injury: lightweight individuals are more at risk of acceleration injury. Training to ensure proper strap-in and optimal posture on ejection could result in reduced risk for all;
- b. Seat-separation: heavy weight may play a role in reducing the distance produced by the "butt-snapper". It is not yet clear what role weight plays in tumbling and how tumbling can influence seat-separation, but light weight may be more of a concern than heavy. Work to modify seat stability and reduce seat interference from an engineering perspective is the most logical approach;
- c. Opening shock: lightweight individuals are more at risk of opening shock injury. It appears that parachute systems that spread the force out over a greater time will reduce this risk; and,
- d. Landing injury: heavyweight individuals are theoretically more at risk owing to higher descent rates, although our data cannot establish this, nor can it rule out influence of inadequate training in landing technique. Landing technique can make a large difference in dissipating impact energy. Larger parachute canopies can reduce the rate of descent.

Review of accident data indicates a potentially troublesome pattern of seat-interference, but there is no evident correlation to ejectee weight.

The review was sent to Directorate Flight Safety and 1 Canadian Air Division Surg, and forwarded to Comd 1 CAD in Feb 1999.

Wright HL, Salisbury DA, Bateman WA. 2000. Biomedical review of aircrew weight as a risk factor in CT133 and CT114 ejections: 1970-1998. DCIEM TM 2000-100. Defence and Civil Institute of Environmental Medicine.

Sommaire

Des documents militaires, des notes de breffage et, plus récemment un programme télévisé ont exprimé une inquiétude persistante quant à la sécurité des dispositifs d'éjection des CT133 et CT114 des Forces canadiennes. Il a été suggéré que le poids de l'occupant pourrait être un facteur de risque.

Nombreux sont les facteurs qui peuvent influencer sur la probabilité de blessures à l'éjection. Des paramètres de vol, tels que la vitesse aérodynamique, l'altitude et la manœuvre effectuée au moment de l'éjection, tout comme d'autres facteurs tels que la vitesse du vent et le relief du point d'atterrissage, ont une grande influence sur de tels risques de blessures. L'interaction complexe qui existe entre ces différents facteurs rend difficile de prédire avec exactitude ce que sera le résultat d'une éjection donnée en fonction du poids de l'occupant.

L'analyse biomédicale et aéronautique des données relatives aux événements semble suggérer qu'un poids élevé ne constitue pas un facteur significatif de risque de blessures graves ou de décès. Les résultats de cette analyse indiquent que la limitation du poids du pilote à 90 kg (190 lb) semble injustifiée. Deux éjections réussies avec des poids supérieurs à cette limite ont démontré que le dispositif d'éjection pouvait fonctionner en toute sécurité avec des occupants d'un tel poids (un des occupants éjectés, pesant 97 kg (214 lb), a subi des blessures sans gravité). Les résultats de cette analyse indiquent également qu'une meilleure stratégie consisterait à se concentrer sur la prévention de telles blessures au moyen d'un équipement, de procédures et d'une formation améliorés. Il est important de souligner qu'il peut exister des problèmes de conception se trouvant hors du champ de la présente étude.

Les phases d'une éjection où le poids de la personne éjectée joue un certain rôle sont au nombre de quatre :

- a. blessures lors de l'accélération : les personnes de faible poids sont plus exposées à des risques de blessures lors de l'accélération. Une formation sur la façon correcte de se sangler ainsi que sur la posture à adopter durant l'éjection pourrait réduire ce type de risques indépendamment du poids;
- b. séparation du siège et du passager : un poids élevé peut avoir tendance à réduire la distance résultant du \leftrightarrow tape-cul \approx . Le rôle que joue le poids dans le culbutage et la façon dont ce dernier influe sur la séparation du siège et du passager n'ont pas été clairement établis, mais il semble qu'il faille plus s'inquiéter d'un poids faible que d'un poids élevé. Travailler à modifier la conception du siège afin d'améliorer sa stabilité et de réduire les risques d'interférence avec le siège semble l'approche la plus logique;
- c. choc à l'ouverture : les personnes de faible poids sont plus exposées à des risques de blessures résultant du choc à l'ouverture. Il semble qu'un système d'ouverture du parachute qui répartirait la force exercée sur un plus grand intervalle de temps permettrait de réduire de tels risques; et

- d. blessures à l'atterrissage : les personnes de poids élevé sont théoriquement exposées à des risques plus importants en raison de leur vitesse de descente plus élevée, bien que ce fait n'ait pas pu être établi et qu'il ne soit pas possible d'écarter l'hypothèse que la formation aux techniques d'atterrissage soit inadéquate. Ces techniques jouent un grand rôle dans la dissipation de l'énergie d'impact. Des coupoles de parachute plus grandes pourraient permettre de réduire la vitesse de descente.

L'examen des données relatives aux accidents indique une fréquence des interférences avec le siège qui pourrait être inquiétante, mais aucune corrélation n'a pu être établie entre ce fait et le poids de la personne éjectée.

La présente étude a été remise à la Direction de la sécurité des vols et au Chirurgien de la 1^{re} Division aérienne du Canada, une copie en ayant été transmise au Commandant de 1 DAC, en février 1999.

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Background

Ongoing concern regarding the Canadian Forces CT133 and CT114 aircraft and ejection safety has been expressed in service papers and briefing notes (G11500CK-1 (Comd FG), dated 10 July 1996; C11500CK-1 (CO) dated 14 Jan 1997; 11500-84 (DAPM(C) 5-2, dated 12 June 1997). Occupant weight has been identified as a risk factor and a weight restriction of 90 kg has been imposed on CT133 and CT114 aircrew (1 CAD HQ 300130Z JAN 99). This review was undertaken at the request of Directorate of Flight Safety to evaluate from a biomedical perspective the effect of weight on injury in CT133 or CT114 ejection¹.

The CT133 and CT114 ejection systems are similar. They both use the same type of thruster and ballistic chain, a rotary actuator or "butt-snapper" (which facilitates person-seat separation), and a 24' aircrew-carried parachute.

Forces on the body cause injury in an ejection. The body's tolerance of an applied force is influenced by: magnitude; duration; direction; site; and, rate of onset. Many factors influence the sequence of events in an ejection. Most of these are variable, including: aircraft orientation; descent rate; altitude; roll rate; pitch rate; and, speed. The complex interaction and number of variables make it difficult to accurately predict ejection outcome based on only one parameter such as occupant weight.

¹ Telcon Maj McCarthy (DFS)/Capt Wright (DCIEM), Jan 99

Method

There were two phases to this investigation of the influence of occupant weight during an ejection:

- a. A literature search was performed to find historical ejection accident statistics and information on influence of weight on ejection success. CF documents dealing with the subject were also reviewed; and,
- b. A review of material collected during the accident investigations into all CF CT133 and CT114 accidents from 1970-1998. This included details on injury and problems experienced during the ejection, as recorded by the investigation teams.

Ejection in this paper generally refers to the entire event from decision, pulling the handles, posture on seat firing, windblast exposure, seat-person separation, opening shock from the parachute, descent, and landing forces.

The purpose of this review was to examine the effect of weight on injury when using the CT133/CT114 ejection system. No attempt has been made to examine other factors in ejection survival such as: relative range of ejection envelope; flying role; timing of ejection initiation; or annual flying hours per aircraft type². Comparison of CF "successful ejection" figures to the experience of other militaries does not include out-of-envelope ejections³. It should be stressed that many factors influence probability of ejection survival and overall comparison of fatality or serious injury rates should be made with caution.

² These factors have a major influence on overall ejection success rates, but do not influence the capability of a given ejection system (15).

³ Statistical analysis of Canadian Forces CT133 and CT114 since 1970 may be misleading for a number of reasons. The small number of ejections and variety in: altitude; speed at ejection; descent rate; and, manoeuvring at time of ejection, make the events difficult to compare. There is also reason to suspect that the injury cause assignments made by investigators may not always be accurate (4, 5).

Accident review

Details from the review of CF CT133/CT114 accidents are in Annex A. Table 1 summarises survived ejection figures from several military groups. Most USAF aircrew who did not survive suffered fatal injuries in the landing or post-landing phase, some because of parachute or equipment problems⁴. The Australian⁵ and Swedish⁶ experience included problems with parachutes being damaged. Figures for all CF aircraft types from 1952-1961 did not identify the CT133 at any additional risk (12). The CT133/CT114 ejection figures since 1970 included three aircrew who did not survive an in-envelope attempt: one CT114 pilot received fatal injuries when struck by the aircraft⁷; one CT133 pilot experienced seat-parachute interference which likely lead to a rapid descent rate and fatal injuries upon landing⁸; the third fatality was a photographer in a CT133 who had an improperly adjusted restraint system⁹. Overall, the fatality rate of CF CT133/CT114 within-envelope ejection appears similar to that of other aircraft types and militaries.

Table 1. Summary of rate of survived ejections

MILITARY (ALL AIRCRAFT TYPES UNLESS NOTED)	YEARS ENCOMPASSED	IN-ENVELOPE EJECTION ATTEMPTS	SURVIVED EJECTIONS
USAF (5)	1962-66	756	700 (92.5%)
RAAF(8)	1951-92	79	77 (97%)
Swedish Air Force (11)	1976-87	86	83 (96.5)
CF (14)	1975-87	68	67 (98.5)
CF CT133/CT114	1970-98	53	50 (94%) ¹⁰

Aircrew who weighed 90 kg or more have made only three within-envelope CT114/CT133 ejection attempts¹¹. This number is insufficient to calculate with any statistical validity a relative risk of serious injury or fatality based on weight. One of these three ejectees weighed

⁴ 30 % of these were due to landing without a functioning parachute or from drowning or exposure (5).

⁵ In these two cases, ejection was initiated but structural damage to the seat by obstacles in the ejection path caused seat malfunction (8).

⁶ Two of the three fatalities were due to failure of the parachute to deploy, one due to high altitude deployment of the parachute with subsequent seat-parachute interference (11).

⁷ CT114169 August 1990

⁸ CT133266 August 1994

⁹ CT133363 September 1984

¹⁰ Does not include CT114156 in December 1998. The FSI is pending at the time of this report.

¹¹ CT133266 August 1994; CT114010 June 1985; CT114179 July 1973

97 kg and sustained only minor injuries indicating that the ejection system can function safely with such a mass¹².

22 of 53 CT133/CT114 in-envelope ejections since 1970 reported some type of person-seat or parachute-seat interference, which in most cases was benign. In the period 1952 to 1988 it is reported that there were at least five fatalities resulting from seat-parachute interaction (15)¹³. Other militaries have also reported problems with seat-parachute or seat-person interference (5). Incidence of seat interference may be reduced with more capable ejection systems (13). A primary area of concern with the CT133/CT114 system is the potential for seat-parachute interaction, which has caused at least one fatality, and two serious injures since 1970¹⁴. The reason for the seat-parachute interaction in these cases is unclear. The accident record suggests that seat-person interaction is unrelated to weight as interaction occurred across the weight range from 60 to 96 kg. No relationship to weight is evident.

Firm, statistically valid conclusions about trends in CF ejection data are often not possible owing to the very small accident numbers. A recent effort to apply statistics to our CT133 data (6) suggested that the probability of an individual sustaining any injury does increase with weight of the occupant. An example given stated that a 100 kg (220 lb) pilot is 50% more likely to sustain any injury (including minor ones) than a 84 kg (185 lb) pilot. However, since the vast majority of injuries experienced are minor (i.e. cuts and bruises), the relative risks of serious injury or death are not clear.

¹² CT114010 June 1985

¹³ Older systems used different firing mechanisms.

¹⁴ CT114048 September 1997 (serious injury, occupant weight 75 kg)

CT133266 August 1994 (fatal injuries, occupant weight 95.8 kg)

CT114048 September 1997 (serious injury, occupant weight 75.9 kg)

Ejection evaluation

The following review of ejection injury potential with respect to weight of the ejectee addresses different phases of the ejection event individually. Each phase has its own unique features, and weight of the ejectee has a different influence depending on the phase. The following phases of the ejection will be considered:

- a) Firing of seat:
 - i. acceleration forces;
 - ii. impact on cockpit structure or canopy; and
 - iii. other (inertial reel retraction and loose objects).
- b) Windblast and tumbling:
 - i. windblast; and
 - ii. tumbling and seat trajectory.
- c) Person-seat separation;
- d) Opening shock;
- e) Landing forces:
 - i. descent rate; and
 - ii. horizontal velocity and terrain.
- f) Post-landing factors

Firing of seat

Acceleration forces

Dynamic loading of the body during an ejection involves complex interactions. Work has been done to model this system and to establish safe limits from a design perspective (5), but variability in acceleration forces on the body due to posture and aircraft manoeuvring influences the likelihood of injury. The amount of acceleration experienced by the occupant varies with: temperature; total weight of the seat assembly and occupant; altitude; and aircraft attitude. The acceleration forces on the body may exceed those produced by the seat through dynamic overshoot. Appropriate seat cushions, posture, effective inertial reel haulback, and a tight strap-in

help deal with dynamic overshoot. Probability of ejection egress injuries will be considerably reduced by well-designed, properly used restraint systems.

CF experience: Ejection acceleration has caused injuries such as vertebral fractures, or knee and shoulder flail, which are consistent with the experience of other militaries. Incidence of injury in this phase, including vertebral fracture, appears to depend on individual circumstances rather than weight. A review of USN ejections did not identify a correlation between incidence of acceleration-induced back injury and weight or build (3)¹⁵. However, under-reporting of fractures¹⁶ and inaccurate cause assignment make it difficult to make valid claims regarding the effect of weight on incidence of this injury (4, 15). 11 of 53 CT133/144 ejectees sustained some sort of vertebral fracture^{17/18}.

Influence of weight: In theory, weight of the occupant is a determining factor for the amount of force to which an ejectee will be exposed. Increased mass reduces occupant acceleration and is an advantage as long as the seat will fire the occupant clear. Main concerns from an injury perspective are lightweight individuals or those with tall slim build that may be at higher risk of spinal fracture, but the literature does not clearly identify risk of low weight (3)¹⁹.

Impact on cockpit structure

The size and anthropometrics of the ejectee combined with posture and limb positioning in relation to the cockpit structures dictate the likelihood of injury on exit. Anthropometric extremes are rarely a factor in injury (10). CF pilots are anthropometrically screened to ensure that major incompatibility is ruled out, so only minor injuries are likely (depending on limb position). Poor body position and unfavourable ejection conditions are responsible for most egress injuries (10). If the aircraft canopy does not clear correctly, it is extremely important that the pilot's head height be below the top of the headbox or canopy ram to prevent head contact with the canopy and consequent spinal and neck injury.

CF experience: Minor injuries from the inertia reel retraction are common. Surface damage to knees, shins or arms and minor burns to the back of the legs are not unusual (14, this CT133/CT114 review).

¹⁵ ...but did find that height was a risk factor for spinal fracture, and weight predisposes aircrew to more serious injuries when there is an injury. The author discusses that this may not be a valid result. No attempt was made to correct for posture or aircraft parameters.

¹⁶ Undisplaced compression fractures of the spine are often asymptomatic and may not show on early x-ray.

¹⁷ It can be difficult to distinguish seat acceleration fractures from those received on ground impact.

¹⁸ Unless otherwise stated, figures given pertain to the present CT133/114 review of accidents since 1970.

¹⁹ Edwards found that neither weight nor physique was related to incidence of back injury in a review of 199 USN ejections from Jan 89 - Dec 93.

Influence of weight: There is no indication that weight predisposes the occupant to this type of injury; although, anthropometrics theoretically do.

Other

Other influences such as forces from the inertial reel or loose articles in the cockpit have injury potential. One occupant of a CT133 is believed to have been struck by an unsecured camera and was likely unconscious during the ejection event²⁰.

Windblast and tumbling

Windblast

As the body moves into the airstream it is exposed to: ram pressure force (q); windblast induced movement of limbs (referred to as flail: throwing them against objects or forcing them past natural movement limits); and, objects or equipment thrown against the body. The amount of damage is heavily dependent upon the airspeed of the aircraft at time of ejection. Posture and angle of exposure of the limbs and head to the windblast will affect flail injury.

The ram air pressure itself rarely causes anything but minor soft tissue injury (1). The main problem is flail injury, which results from the differential decelerations on extremities and pulsating force as the body tumbles. Dynamic pressures in an ejection can overcome muscular effort to restrain the limbs and head (this is the reason for leg garters and similar extremity restraints). Equipment such as the helmet can "catch" the windstream and put large forces on the head and neck and/or remove the helmet. Clothing can be torn, boots may be removed, and visors are often stripped away. Proper fit reduces the chance of these equipment effects.

CF Experience: Low speed ejections entail decreased likelihood of major flail injury and only superficial injuries have been observed for CT133/CT114 ejections since almost all have been below 250 knots (14, this CT133/CT114 review)²¹. There are a number of cases where forces on the helmet and chinstrap, or oxygen mask have caused minor injury.

Influence of weight: There is no indication of, or reason to expect an effect of ejectee weight on the probability of windblast injury.

Tumbling and seat trajectory

The amount of tumbling depends on a number of variables including airspeed and manoeuvring of the aircraft at the time of ejection. Tumbling may cause injury in

²⁰ CT133363 September 1984

²¹ Only 5 of 53 CT133/CT114 since 1970 have ejected at 300 KIAS or more. There is no windblast injury reported in any of the 53 other than minor contusions or abrasions.

itself, or it may play a role in seat interference. Tumbling is influenced by the pilot's mass-moment-of-inertia (MMI) and the centre of gravity (CofG) of the occupant and seat-person combination. Both MMI and CofG vary with weight. Pilot weight is correlated with size, so there may be other aerodynamic effects. The complex relationship among size, MMI, CofG, and seat trajectory is not fully established.

In theory, high spin rate can develop in high altitude ejections that may in themselves be fatal (1). This is a very unlikely event.

CF experience: Ejectees often report tumbling²², but no injuries from the tumbling motion itself are reported. Accident data does not demonstrate an association between weight and windblast or tumbling injury. Increased tumbling or change in trajectory may be contributing to seat interference, but the historical data does not demonstrate a clear relationship between severity of tumbling and weight.

Influence of weight: There are indications that weight and body size could be a factor in tumbling but the exact nature of the influence is not known. People on the small or large end of the scale may be more likely to tumble.

Seat-person separation

CT133/ CT114 seat interference during ejection is probably caused by seat instability (post-ejection tumbling) and inadequate separation of the seat and ejectee. The relative movement of the seat and the person/parachute depends upon factors such as: aircraft manoeuvring at time of ejection; airspeed; altitude; sink rate; person orientation relative to the windblast; MMI, and CofG. Direct contact with the seat during or following seat-person separation can cause injury. Depending on the relative trajectory of the seat and person/parachute, the seat may cause fouling or tangling of the deploying parachute.

CF Experience: There are occasional reports of ejectees being struck by the seat (14, this CT133/CT114 review). Seat-parachute interference has led to one fatality in the CT133/CT114 and two serious injuries since 1970 (discussed above in Accident Review section).

Influence of weight: Tumbling and person trajectory are discussed above. Weight may influence the function of the seat-person separator (the mechanism which acts to move the seat and person apart). In theory, a larger mass occupant in the seat will accelerate less since the force of the "butt-snapper" is constant. This could reduce distance or separation from the seat.

Opening shock

Opening shock is a measure of the deceleration experienced by the ejectee following deployment of the parachute. Factors that interact to produce opening shock include:

²² It is interesting to note that sensation of tumbling may not always indicate that there was tumbling. Ejectees have reported tumbling when witnesses in other aircraft report stable flight (5).

suspended weight; altitude of deployment; velocity at which deployment occurs (either velocity of aircraft at ejection or terminal velocity achieved during free-fall); porosity of the parachute; effective area of the parachute; and, air density. A large opening shock may injure the ejectee. Asymmetrical inflation of the parachute may cause high-localised stresses on risers or canopy and cause failure.

Airspeed is the largest contributing factor to opening shock. Altitude also plays a role in determining opening shock because of its effect on freefall velocity, and because opening shock is affected by true air speed (TAS) not indicated air speed (IAS). For instance, a pilot who is in freefall at 2000 feet will be travelling at approximately 100 KTAS (about 5 G opening shock), whereas at 40 000 feet, freefall velocity will be twice as high: 200 KTAS (10-15 G opening shock)(2). However, should the pilot exit the aircraft at 300 KIAS (s)he will experience 20 to 25 G opening shock (1). High altitude escapes are much more likely to cause damage to the body or to the escape system. Time over which the parachute deploys is also an important factor since the duration of the acceleration impulse determines injury. Counter-intuitively, larger parachute canopies generally produce a smaller opening shock since deployment time tends to be longer (1, 2).

Weight of the pilot and equipment is a factor in the arrested velocity (once the parachute is deployed and is supporting the load). The amount of deceleration or opening shock the body experiences is the difference between the starting velocity and the arrested velocity. Smaller masses undergo a greater deceleration since the arrested velocity is lower. The risk of injury is theoretically greater for lighter individuals. However, the effects of airspeed and altitude generally dwarf these differences.

The sudden deceleration (jolt) may cause injury by the harness, or movement of limbs and striking by objects. If the body is tumbling it may not be in a straight line along the axis of the jolt. The angular forces depend on the orientation and velocity of the body with respect to the terminal velocity under the parachute. Body position and tight harness straps reduce the chances of injury due to dynamic overshoot.

CF experience: The force of the deceleration is communicated to the body via the harness. It is common for ejectees to experience minor bruising and abrasions (14, this CT133/CT114 review). In 485 ejections that occurred in the CF between 1952 - 1987, there was only one reported case of parachute failure due to opening shock at high altitude (15)²³.

Influence of weight: Although weight is a factor (since deceleration of lighter people will be slightly greater, there is a corresponding greater chance of injury) it is minor, because force on the parachute system during deployment is mainly determined by velocity and altitude.

²³ A premature deployment at high altitude CF100762 1959 (and possibly CF8623333 1956).

Landing forces

Descent rate

Vertical descent rate is a function of: the mass suspended by the parachute; canopy size and other attributes; and, altitude. Larger parachutes decrease landing descent rate. Table 2 is taken from the U.S. Navy Flight Surgeon's Manual (1).

Table 2. Relationship between weight, canopy size, and descent rate.

PILOT AND EQUIPMENT WEIGHT	RATE OF DESCENT	
	24 FOOT MARTIN-BAKER	28 FOOT NB-7, 8, 9
127 kg (280 lb)	25 ft/sec	22 ft/sec
72.5 kg (160 lb)	20 ft/sec	17.5 ft/sec

Increasing parachute canopy size will reduce the descent rate; however, this may increase opening shock (depending on opening time) or cause other problems. If the larger canopy has slower deployment to reduce opening shock, the slower deployment may increase risk in low altitude ejections. Larger parachute size may also increase the chances of seat-parachute interaction.

Weight is a predisposing factor for injury in non-ejection descents (9). The Operational Research 1997 study of CT133/CT114 ejection (6) suggested a linear relationship between weight and injury potential. For example, an increase in pilot weight from 84 kg (185 lb) to 97.6 kg (215 lb) increases the chance of any injury on landing by 50%²⁴. However, given that the vast majority of landing injuries are minor (muscle and joint strains and limb fractures), this figure does not reflect risk of serious or fatal injury.

Important factors in determining the injury potential of a descent force are: the distance and time over which the body decelerates (more distance and more time leads to greater attenuation of the impact force); deceleration pulse shape; deceleration direction; and, physical characteristics of the person. Impacts of +20 Gz for 0.1 seconds are considered safe (1). In theory a 104 kg (230 lb) landing weight with a 24' parachute will produce a 20 G impact even with a very conservative stopping distance of 1.4 ft (6). Since the human body is somewhat flexible there is some inherent absorption of the force. A good landing technique will optimise impact attenuation and probably has more influence than weight on the forces experienced by

²⁴ This study looked at pilot weight only, not landing weight, which is influenced by RSSK deployment or non-deployment.

the body (6). The terrain can also have a large influence by absorbing some of the force.

In theory pilots who retain the RSSK on landing increase their suspended weight by an additional 15 or 16 kg thereby increasing impact velocity. The location of the extra weight may be more of a factor than the absolute increase in weight. The position of the un-deployed RSSK changes posture and predisposes the body to lumbar compression fractures on landing. Carriage of equipment has been demonstrated to predispose injury in non-ejection parachute descents (7).

CF experience: The small numbers do not permit a correlation analysis, but it appears that the RSSK is un-deployed in many occasions where there are landing injuries, including lumbar compression fractures or back strain. There does not seem to be as much of a link to lower limb fractures as one would expect if the weight alone were the risk factor. The current review of CT133/CT114 ejections found that the heaviest pilot in a successful in-envelope ejection (97.6 kg (215 lb)) experienced only a mild knee sprain on landing (RSSK was deployed).

Horizontal velocity (wind) and terrain

Horizontal velocity is dictated by windspeed and swinging (oscillation) of the person suspended under the parachute. Studies of non-ejection parachute descents indicate that windspeed is a factor associated with increasing injury (7). Appropriate landing position and technique help to dissipate landing forces.

Landing on hard or very irregular surfaces, encountering objects such as trees, rocks, water or cliffs, can play a large role in landing injury.

CF experience: Windspeed on ground impact is not available in most accident reports and no review of landing windspeed with respect to landing injury was possible.

Influence of weight: Heavier weight does increase the likelihood of injury on landing. Unfamiliarity with landing technique and the inability of the pilot to choose landing conditions and terrain probably have a larger role in determining injury.

Post-landing factors

Post-landing factors can have enormous influence on injury or survival of an ejection. Examples of post-landing factors include: impacting objects while being dragged by the parachute; water landings; fire; injury during rescue efforts; and, hypothermia. There is no indication that this category has been a problem for the CF in recent years. This review revealed no serious injury or fatalities from post-landing factors. Continued safety in the post-landing phase depends upon life support and survival equipment such as the automatically inflating life preserver and a good SAR system.

Conclusions

There are many influences on the probability of injury in an ejection. Aircraft parameters such as airspeed, altitude, and manoeuvring at time of ejection play a large role in injury potential and, whenever possible, pilots should attempt to optimise these before ejection.

Biomedical analysis and accident review suggests heavy weight is not a significant risk factor for major injury or deaths although further study is recommended to clearly establish the influence of mass and body size on tumbling and seat-person separation. This analysis does not support a pilot weight restriction of 90 kg (190 lb) or less (1 CAD HQ 300130Z JAN 99). It should be stressed that engineering concerns may apply that are outside the scope of this review. This analysis indicates that a more effective strategy would be to focus on preventing injuries through improved equipment, procedures, and training²⁵.

There are four phases in the ejection sequence where ejectee weight has some influence:

- a. Acceleration injury: lightweight individuals are more at risk of acceleration injury. Training to ensure proper strap-in and optimal posture on ejection could result in reduced risk for all;
- b. Seat-separation: heavy weight may play a role in reducing the distance produced by the “butt-snapper”. It is not yet clear what role weight plays in tumbling and how tumbling can influence seat-separation, but light weight may be more of a concern than heavy. Work to modify seat stability and reduce seat interference from an engineering perspective is the most logical approach;
- c. Opening shock: lightweight individuals are more at risk of opening shock injury. It appears that parachute systems that spread the force out over a greater time will reduce this risk; and,
- d. Landing injury: heavyweight individuals are more at risk owing to higher descent rates. Landing technique can make a large difference in dissipating impact energy. Larger parachute canopies can reduce the rate of descent.

Review of accident data indicates a potentially troublesome pattern of seat-interference, but there is no evident correlation to ejectee weight.

²⁵ Not discussed here is expanding the performance envelope of the ejection system which could save lives (since out-of-envelope ejections were not considered).

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Annex A: **Data from CF CT133 and CT114 ejections, 1970-1998**

Data for this table was collected from Canadian Forces CT133 and CT114 accident reports from 1970 - 1998. The table reads across two pages. Ejections outside the envelope feasible for survival, or where no ejection was attempted, are highlighted in grey.

CT133 Ejection Data

Tail #	Date	Crew Posn	Injury level	Seat Interference	Weight (kg)	Height (cm)	Age (yrs)	speed at ejection (KIAS)	Alt at ejection (FT/AGL)	Injury: seat firing	Injury: windblast tumbling
133266	27 Aug 94	front	fatal	severe - seat/parachute	95.8		40	?	5000		
133352	17 Oct 91	front	fatal								
	17 Oct 91	rear	fatal								
133315	07 Apr 87	front	fatal								
	07 Apr 87	rear	fatal								
133363	14 Sep 84	front	minor	seat contacted chute	84	182	33	160	500	contusion on left elbow	
	14 Sep 84	rear	fatal	severe - seat/chute	88	170	33	160	500		
133069	21 Sep 82	front	fatal		76.5	?	34				
	21 Sep 82	rear	minor	seat/man separation delayed due to arming key strain/damage	76	175	35	180	4500	compression fracture T10 and T11; minor trauma to left elbow	
133639	28 Jun 82	front	fatal		93						
133442	14 Feb 81	front	serious		77.2	182	32	120	800	bruising to kneecaps	
133405	21 Aug 80	front	minor		78.5	179	37	140	1500	graze from strap on neck; abrasion to elbows; abrasion on shins	
	21 Aug 80	rear	minor		77	180	26	140	1500	abrasion on shins; abrasion on right knee; graze from strap on neck	
133453	20 Feb 74	front	fatal								
	20 Feb 74	rear	fatal								
133603	18 Sep 73	front	minor		68	183	24	260	13000	abrasion to both knees	
133520	18 Sep 73	front	minor		61	173	25	280	12000	various small bruises	bruising under chin from chin strap (helmet pulled off), laceration behind right ear
133292	17 Jul 70	front	minor		66.7						

CT114 Ejection Data

Tail #	Date	Crew Posn	Injury level	Seat Interference	Weight (kg)	Height (cm)	Age (yrs)	speed at ejection (KIAS)	Alt at ejection (FtAGL)	Injury: seat firing	Injury: windblast tumbling
114156	10 Dec 98	left	fatal								
114048	25 Sep 97	left	serious	parachute tangled with seat - incomplete inflation	75	?	32	130	850	possible: fracture of L1	
	25 Sep 97	right	minor	seat struck back of helmet	75	?	28	130	850		
114079	21 Mar 94	left	minor	struck twice by seat	77	179	36	130	1000	possible: neck and calf injury	
	21 Mar 94	right	minor		87	171	32	130	1000		
114018	22 Oct 92	left	minor		74.5	175	24	200	400	lower back strain	
	22 Oct 92	right	minor		79.5	180	24	180	700	torn muscle and haematoma on lower third of left calf	bruise from mask
114073	14 Aug 92	left	minor		84.5	183.8	23	120	800	linear abrasion to neck consistent with retraction of ballistic inertial reel; superficial contusions/abrasions on posterior calves; strain of left trapezius and sternomastoid (looking right on firing)	
	14 Aug 92	right	serious	parachute chute tangled with seat - incomplete inflation	75.9	179.9	28	120	700	superficial contusions/abrasions to posterior calves of both legs + singeing of hair	possible: abrasions to left forearm and right upper arm
114077	01 May 91	left	minor		84.9	182	33	120	300	bruises to calves	
	01 May 91	right	minor		70	175	30	120	300	minor compression fracture T10	
114001	26 Feb 91	left	minor	parachute panels damaged by seat contact	68	177.8	23	slow	350		abrasion to neck from dog tag chain
	26 Feb 91	right	minor		84	180	28	slow	350		abrasions from nape strap; laceration on right side of chin due to mask
114169	21 Aug 90	left	fatal		72	167	30	110	300		
	21 Aug 90	right	minor	seat contacted canopy	60	167	28	110	300	single marks on legs; possible: T12 vertebral fracture	abrasion on arm from harness
114098	03 Sep 89	left									

(page 17 continued)

Tail #	Date	Injury: opening shock	Injury: seat interact	Injury: ground landing	RSSK deploy	Wt (kg) (RSSK+ harness)	Comments
114156	10 Dec 98			fatal impact	na		outside envelope - air lock fasteners not done-up
114048	25 Sep 97			fracture of L1; neck sprain; sprain of left ankle; bruising on shoulders and chest from harness straps and QRB	no		
	25 Sep 97			low back strain	yes		
114079	21 Mar 94	sternal contusion from QRB; superficial pelvic and thigh injury from harness	possible: neck and calf injury; foot abrasion		yes		
	21 Mar 94	sternal contusion; neck abrasion due to parachute riser; petichae on right shoulder			yes		
114018	22 Oct 92			possible: lower back strain	no		
	22 Oct 92	superficial injury from harness (perhaps caught in trees)		laceration on chin from branches	yes		
114073	14 Aug 92	sternal contusion			yes		
	14 Aug 92	sternal contusion		fracture of L1, L2 and L3 and associated soft tissue contusions; possible: linear abrasions from chin strap and helmet	no		
114077	01 May 91			possible: minor injuries from blunt trauma	no		
	01 May 91			possible: minor injuries from blunt trauma	no		
114001	26 Feb 91				yes		
	26 Feb 91			ankle sprain; possible: contusion above right eyebrow	no		
114169	21 Aug 90				na		student struck by aircraft - received fatal head injury
	21 Aug 90				no		
114098	03 Sep 89				na		no apparent attempt to eject

Tail #	Date	Crew Posn	Injury level	Seat Interference	Weight (kg)	Height (cm)	Age (yrs)	speed at ejection (KIAS)	Alt at ejection (FtAGL)	Injury: seat firing	Injury: windblast tumbling
114110	03 Sep 89	left	minor		77.7	178	36		425	burn on right leg; other minor injuries	facial abrasions from oxygen mask
114129	17 Jun 89	left	minor	possible	86	175	28		5000	compression fracture of L1; minor bruising to left calf	
114010	25 Jun 85	left	minor		97	179	35	100	100	compression fracture of T12	
114165	25 Jun 85	right	fatal		109	186	47	100	50		
	22 Sep 79	left	none	parachute damaged by seat contact	77	177.8	20	280	630		
	22 Sep 79	right	minor	parachute damaged by seat contact	81	174	31	280	1100	lumbar compression fractures	
114158	15 Nov 79	left	none	parachute damaged by seat contact	70	175	21	250	10600		
114057	24 Nov 78	left	none	seat caused extensive damage to parachute			22	140	6800		
	24 Nov 78	right	none	parachute damaged by seat contact			23	140	6800		
114125	13 Jul 78	left	minor	parachute damaged by seat contact	84	174	35	330	8500	compression fracture of D12 and L1; contact with canopy caused forehead grazes and fracture of ulnar styloid plus various contusions	
114118	03 May 78	left	fatal		70	177	32	300	40		
114082	16 Jul 77	right	minor		73	170	28	180	400	burn on back of lower legs	bruise
114088	16 Jul 77	right	minor		82	180	33	200	800	various contusions on the legs; burn to posterior right leg	contused areas consistent with harness
114132	24 Jan 77	left	none	suspected-struck in head	68	179	31	130	800		
114138	14 Sep 76	left	minor	parachute damaged by seat contact + struck in head	72.6	178	24	350	6000	compression of T6	various small contusions and abrasions from mask and chin strap
114138	14 Sep 76	right	minor		68	178	23	350	6000		superficial abrasion and contusion to lip/nose/chin
114028	31 May 76	left	fatal		83	190	20	100	80		
	31 May 76	right	fatal		79.5	180	25	100	50		
114123	11 May 76	left	minor		84	188	25	125	920	compression of L1	
	11 May 76	right	minor		72.5	177.8	28	125	820	compression fracture T12, L1, L2, L3	left facial abrasion
114029	12 Aug 75	left	minor		80.8	176.5	31	130	2100		
	12 Aug 75	right	none		88.5	175	28	130	2100		

(page 19 continued)

Tail #	Date	Injury: opening shock	Injury: seat interact	Injury: ground landing	RSSK deploy	Wt (kg) (RSSK+ harness)	Comments
114110	03 Sep 89				no		water landing
114129	17 Jun 89				yes		
114010	25 Jun 85			mild sprain of right knee	yes		
	25 Jun 85			fatal injury	na		outside envelope
114165	22 Sep 79				yes		
	22 Sep 79			possible: lumbar compression fractures	yes - hanging by one strap		
114158	15 Nov 79				yes		
114057	24 Nov 78				yes		
	24 Nov 78				yes		
114125	13 Jul 78	hematomas from straps			yes		canopy did not jettison
114118	03 May 78			fatal injuries	na		outside envelope
114082	16 Jul 77				yes		water landing
114088	16 Jul 77				yes		canopy did not jettison
114132	24 Jan 77				no		
114138	14 Sep 76	abrasions from parachute harness	10 cm diameter contusion on back of left leg		yes		
114138	14 Sep 76	parachute harness abrasions			yes		
114028	31 May 76			fatal	na		outside envelope
	31 May 76			fatal	na		outside envelope
114123	11 May 76				yes		
	11 May 76	sternal contusion		chin laceration from QRB	no		
114029	12 Aug 75			very minor back injuries	yes		
	12 Aug 75				yes		

Tail #	Date	Crew Posn	Injury level	Seat Interference	Weight (kg)	Height (cm)	Age (yrs)	speed at ejection (KIAS)	Alt at ejection (ft/AGL)	Injury: seat firing	Injury: windblast tumbling
114074	21 May 75	left	minor	parachute damaged by seat contact	71.7	177.8	23	300	3800	many petechiae of upper face and nosebleed probably due to negative G; abrasions on shins	
	21 May 75	right	minor		88.5	177.8	36	300	3800	subconjunctival hemorrhages and petechiae consistent with negative G;	very minor contusions/abrasions
114137	26 Feb 74	left	minor	parachute damaged by seat contact							
	26 Feb 74	right	minor								
114016	19 Dec 73	left	minor	parachute damaged by seat contact	65.8	175	22	100	7500		
114136	22 Aug 73	left	fatal								
	22 Aug 73	right	minor		68	171.5	25		2500	compression of L1	
114179	14 Jul 73	left	minor		91.6						
114183	10 Jun 72	left	fatal								
114127	20 Mar 72	left	fatal		68	177.8	23				
114086	03 Dec 71	left	minor								
114130	08 Oct 70	left	minor								
	08 Oct 70	right	minor								
114133	17 Aug 70	left	serious								

(page 21 continued)

Tail #	Date	Injury: opening shock	Injury: seat interact	Injury: ground landing	RSSK deploy	Wt (kg) (RSSK+ harness)	Comments
114074	21 May 75	minor abrasions from straps			yes		
	21 May 75	contusions on thighs from parachute straps			yes		water landing
114137	26 Feb 74						data not found
	26 Feb 74						data not found
114016	19 Dec 73				no		details on injury not found
114136	22 Aug 73			fatal injuries	na		did not eject
	22 Aug 73				yes - snagged		
114179	14 Jul 73						data not found
114183	10 Jun 72				na		no ejection attempted
114127	20 Mar 72						data not found
114086	03 Dec 71						outside envelope + data not found
114130	08 Oct 70						data not found
	08 Oct 70						data not found
114133	17 Aug 70						data not found

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14. ABSTRACT

(U) This review was undertaken in Jan 1999 in response to growing concern over Canadian Forces CT133 and CT114 aircraft ejection safety. Occupant weight was a suspected risk factor for serious injury or death during an ejection. A review of literature and examination of all CT133 and CT114 accident reports from 1970-98 was done to investigate occupant weight as a risk factor during all phases of ejection (firing of the seat, windblast and tumbling, seat-person separation, opening shock, landing forces, and post-landing factors). Heavy weight does not appear to be a significant risk factor for major injury or death from a biomedical perspective, although further study is recommended to clearly establish the influence of mass and body size on tumbling and seat-person separation. Heavy weight does lead to higher descent rates and possibly associated landing injury, although our data cannot establish this, nor can it rule out influence of inadequate training in landing technique. Light weight may be a risk factor with respect to injury associated with acceleration, tumbling and opening shock. It should be noted that there may be engineering concerns regarding these specific ejection systems that are outside the scope of this review.

La présente étude a débutée en janvier 1999 à la suite d'une inquiétude croissante quant à la sécurité des dispositifs d'éjection des appareils CT133 et CT114 des Forces canadiennes. On suspectait alors le poids de l'occupant de constituer un facteur de risque dans les cas de blessures graves ou de décès durant l'éjection. Un examen de la documentation disponible et de tous les rapports d'accidents des CT133 et CT114 pour la période 1970-1998 a été entrepris afin de déterminer si le poids de l'occupant constituait un facteur de risque dans l'une quelconque des phases de l'éjection (mise à feu du siège, souffle aérodynamique et culbutage, séparation du passager et du siège, choc à l'ouverture, choc à l'atterrissage et facteurs intervenant après l'atterrissage.) Un poids élevé ne semble pas, d'un point de vue biomédical, apparaître comme un facteur de risque significatif en matière de blessures graves ou de décès mais une étude plus approfondie semble souhaitable afin de déterminer l'influence de la masse et de la taille du corps sur le culbutage et la séparation du passager et du siège. Un poids élevé entraîne de fait une vitesse de descente plus élevée et joue peut-être un rôle dans certaines blessures à l'atterrissage bien qu'il n'ait pas été possible d'établir ce dernier fait à partir de données disponibles et ou d'écarter l'hypothèse d'une formation aux techniques d'atterrissage inadéquate. Un poids faible peut également constituer un facteur de risque au regard des blessures associées à l'accélération, au culbutage et au choc à l'ouverture. Il convient de noter qu'il est possible que les dispositifs d'éjection en question présentent des problèmes de conception se trouvant hors du champ de la présente étude.

15. KEYWORDS, DESCRIPTORS or IDENTIFIERS

(U) aircrew; ejection; CT133; CT114, weight; life support equipment