On Retaining the Seat Pack after Ejection when Landing in Trees

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Abstract

Current air force training dictates that ejectees from high-performance aircraft mitigate landing injury hazards by letting the survival equipment in their seat packs fall to the end of an 8 metre lanyard while they are still descending under parachute. The exception is when they will land in trees and are told to retain the seat pack for the protection it offers against tree branches. Proposed automated seat pack deployment systems would protect aircrew from the landing injuries frequently seen when circumstances prevent them from deploying it themselves, though this would also deny the option to retain the seat pack for tree landings. This study reviews aeromedical literature and analyses Canadian Forces ejection tree landing injuries. It finds that, contrary to current doctrine, tree landing injury profiles with retained seat packs are not better and may be worse than those with deployed seat packs. Automated seat pack deployment is recommended.

Résumé

La formation actuelle des membres de la force aérienne prévoit que les membres d’équipage qui s’éjectent des avions à hautes performances limitent les risques de blessures à l’atterrissage en larguant l’équipement de survie contenu dans leur paquetage de siège au bout d’une sangle de 8 mètres pendant leur descente en parachute. Une exception est faite lorsqu'ils atterrissent dans des arbres et, dans ce cas, on leur enseigne de conserver le paquetage de siège qui offrirait une certaine protection contre les blessures infligées par les branches. Les systèmes proposés de déploiement automatique du paquetage de siège auraient l'avantage de réduire les risques de blessures à l'atterrissage lorsque les circonstances empêchent le déploiement manuel, mais ne permettraient pas de conserver le paquetage en cas d'atterrissage dans les arbres. La présente étude passe en revue la documentation aéromédicale et analyse les cas de blessures à l'atterrissage dans les arbres survenus dans les Forces canadiennes. Ses conclusions sont que, contrairement à la doctrine actuelle, le fait de conserver le paquetage de siège n'améliore pas le profil des blessures lors de l'atterrissage dans les arbres et semble même aggraver les risques par rapport au déploiement du paquetage. Il est donc recommandé d'implanter systématiquement le déploiement automatique du paquetage de siège.

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Executive summary

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John A. Steele; DRDC CORA TM 2010-238; Defence R&D Canada – CORA; November 2010.

Introduction: Current air force training dictates that ejectees from high-performance aircraft mitigate landing injury hazards by letting the survival equipment in their seat packs fall to the end of an 8 metre lanyard while they are still descending under parachute. The exception is when they will land in trees and are told to retain the seat pack for the protection it offers against tree branches. Proposed automated seat pack deployment systems would protect aircrew from the landing injuries frequently seen when circumstances prevent them from deploying it manually, though this would also deny the option to retain the seat pack for tree landings. On the recommendation of the Board of Inquiry into the crash of CT155215, the special projects officer for aviation life support equipment at 1 Canadian Air Division Headquarters requested a study to review Canadian Forces (CF) ejection experience in order to validate the retention of seat packs for tree landings and to inform decisions on the adoption of automated seat pack deployment systems.

Results: A review of aeromedical literature showed that ground landing most often results in minor or no injuries. Minor injuries are most often to the lower extremities, though they are sometimes major and can involve the spine. Seat pack retention is a widely recognised risk factor for major leg and spinal injuries, though its role in aggravating or mitigating tree landing injury is not addressed in the literature. British aeromedical staff found injury data inconclusive on whether seat packs were better retained or deployed when landing in trees, though most British fleets are capable of automated seat pack deployment.

A review of 66 Canadian Forces ejections into trees with known seat pack statuses and landing injury profiles failed to find any evidence that seat pack retention into trees mitigates and prevents more injuries than it aggravates or causes. In fact, all central tendency measures of tree landing outcomes were better for deployed than for retained seat packs, although a Mann-Whitney U test showed deployed seat packs better at only an 80% confidence level ($p = 0.2$).

Significance: This result removes the justification for the tree landing exception to advice to deploy seat packs before landing, potentially simplifying best practise. It also indicates the value of wider fleet use of automated seat pack deployment systems to mitigate landing injury risks in other landing environments whenever ejectees lack the descent time or capacity needed to deploy their own seat pack. The Aviation Life Support Equipment Manual should also be changed to reflect these results.

Follow-up questions: Issues needing impact assessment and possible mitigation include wind-induced lanyard swing with automatic deployment at higher altitudes, the dynamics of ejectee suspension by lanyard when deployed seat packs snag in branches, and the optimal use of lanyard release in tree landings.

Sommaire

On Retaining the Seat Pack After Ejection when Landing in Trees

John Steele; DRDC CORA TM 2010-238; R & D pour la défense Canada – CARO; Novembre 2010.

Introduction : la formation actuelle des membres de la force aérienne prévoit que les membres d'équipage qui s'éjectent des avions à hautes performances limitent les risques de blessures à l'atterrissage en larguant l'équipement de survie contenu dans leur paquetage de siège au bout d'une sangle de 8 mètres pendant leur descente en parachute. Une exception est faite lorsqu'ils atterrissent dans des arbres et, dans ce cas, on leur enseigne de conserver le paquetage de siège qui offrirait une certaine protection contre les blessures infligées par les branches. Les systèmes proposés de déploiement automatique du paquetage de siège auraient l'avantage de réduire les risques de blessures à l'atterrissage lorsque les circonstances empêchent le déploiement manuel, mais ne permettraient pas de conserver le paquetage en cas d'atterrissage dans les arbres. Suivant une recommandation de la commission d'enquête sur l'accident du CT155215, l'officier des projets spéciaux pour l'équipement de survie d'aviation au quartier général de la 1er Division aérienne du Canada a demandé une étude sur les expériences d'éjection dans les Forces canadiennes (FC) en vue de valider la consigne de conserver le paquetage de siège en cas d'atterrissage dans les arbres, et de prendre une décision informée sur l'adoption des systèmes de déploiement automatique du paquetage de siège.

Résultats : une revue de la documentation aéromédicale montre que l'atterrissage en parachute ne cause, dans la plus part des cas, que des blessures mineures ou inexistantes. Les blessures mineures affectent le plus souvent les extrémités des membres inférieurs bien qu'il y ait des cas plus graves pouvant aller jusqu'à des atteintes à la colonne vertébrale. Le fait de conserver le paquetage de siège pour l'atterrissage est largement reconnu comme un facteur d'aggravation des risques de blessures aux jambes et à la colonne vertébrale. Il convient de noter que l'effet du paquetage, dans le sens de la réduction ou de l'aggravation des risques, sur les blessures subies en cas d'atterrissage dans les arbres n'est pas couvert en tant que tel dans la documentation. Les spécialistes britanniques de la médecine aéronautique ont constaté que les données disponibles ne permettaient pas de conclure que la présence du paquetage de siège était un facteur d'atténuation ou d'aggravation lors d'un atterrissage dans les arbres, bien que la plupart des avions britanniques soient équipés d'un système de déploiement automatique du paquetage.

En ce qui concerne les Forces canadiennes, une étude portant sur 66 cas d'éjection avec atterrissage dans les branches, pour lesquels l'état du paquetage et les profils de blessures étaient connus, n'a pas permis de déterminer si la présence du paquetage était un facteur d'atténuation ou d'aggravation des blessures subies. En fait, la tendance centrale est plutôt en faveur du déploiement que de la rétention du paquetage. Toutefois, le test Mann-Whitney U portant sur les bénéfices d'un paquetage déployé n'offre qu'un niveau de confiance de 80 % ($p = 0,2$).

Interprétation : ce résultat annule la justification de l'exception au déploiement du paquetage avant l'atterrissage en cas de chute dans les arbres, ce qui simplifie potentiellement la recommandation d'une pratique optimale applicable dans tous les cas. Cette conclusion élimine

en outre un argument contre la généralisation des systèmes de déploiement automatique du paquetage dans l'ensemble de la flotte. Il est clair que ce système réduit les risques de blessures dans les autres circonstances d'atterrissage, notamment lorsque la personne éjectée ne dispose pas du temps de descente nécessaire ou est dans l'incapacité de larguer manuellement son propre paquetage. Le manuel des équipements de survie aviation devrait donc être modifié pour refléter ces résultats.

Questions de suivi : un problème dont les impacts devraient être étudiés et éventuellement atténués est le balancement causé par l'action du vent sur le paquetage et la sangle lors d'un déploiement automatique à haute altitude, la dynamique de la personne qui reste suspendue au bout de sa sangle si le paquetage s'accroche dans les branches d'un arbre, et l'utilisation optimale du dispositif de largage de la sangle après un atterrissage dans les arbres.

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Table of contents

List of figures

List of tables

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1 Introduction

Since the first aircraft ejection during the Second World War, well over 10,000 aircrew lives have been saved from (most often) certain death in disabled or out-of-control high-performance aircraft. However, ejection, itself, remains risky. Though ejection survival rates in national reports are usually better than 85%, some degree of injury is the most common result. This can occur in any of five phases of the ejection experience, each with various sources of injury [1]:

1. Decision phase – comprising the time span from emergency onset to formulation of the decision to eject. Injuries can result from violent effects of mid-air collision and loss of control at high speed;

2. Ejection phase – consisting of the time required to activate the ejection handle and egress via rocket-assisted catapult from the cockpit. Bruising from the retraction of the harness to position the body for egress and spinal fracture from rapid acceleration are common as are airstream-induced flail injuries during high-speed flight egress;

3. Descent phase – beginning with rocket motor burn-out until beginning to land. Man-seat interference due to tumbling during seat separation and groin bruising due to parachute opening shock are common sources of injury.

4. Landing phase – from first contact with anything on the surface of the earth until stationary on the surface and detached from the parachute. The rapid fall speed of a rescue parachute can make ground impact injurious; and

5. Survival phase – from the end of landing to the completion of rescue. Limb injuries from earlier phases can prevent life raft entry or rudimentary survival activity, introducing other hazards.

Part of the provision for the survival phase is emergency equipment stowed in a shell under the seat cushion. The most generic term for this equipment is the personal survival pack (PSP) though in some fleets it has the technical name rigid seat survival kit (RSSK). However, it is most often simply called a seat pack. When aircrew are first suspended under parachute, the PSP remains suspended just behind their thighs until they either land or they operate the release mechanism to deploy it.[1] Once deployed, PSP components, weighing between 15 and 20 kg, fall out of their container until stopped by an 8 m long lanyard fastened to the ejectee's harness. If the ejectee believes there is a risk of contacting power lines before landing, there remains the option of disconnecting or cutting the lanyard and catching up with the equipment after landing. [2]

The decision of whether or not to deploy the seat pack can influence the type and severity of injury experienced during the landing phase. How best to minimise these injuries is the topic of this paper.

[1] The one exception is the CT156 Harvard, which provides an automatic seat pack deployment option. [2]

1.1 Problem statement

According to current Aviation Life Support Equipment (ALSE) doctrine [2], general advice to ejecting aircrew is to deploy the contents of their PSP before landing. For ground landings, this makes it easier for the ejectee to do a good parachute landing fall (PLF). For CF fleet seat packs, tension on the lanyard after PSP deployment also triggers automatic life raft inflation, an important preparatory step before landing in water. The exception to this advice is when aircrew will land in trees, for which they are instructed to keep the seat pack in place for landing to shield them from tree branch injury.[2] To ensure aircrew continue to have this option, seat pack deployment remains a manual process for most fleets. Figure 2 shows an ejectee with his PSP retained.

Figure 1. Rigid Seat Survival Kit.

Figure 2. Ejectee with RSSK lid, only.

The problem giving rise to this study is that several circumstances can make it difficult or impossible to manually deploy the seat pack. [2] [3] When this happens, certain injuries frequently result. These could be prevented through automatic seat pack deployment, though it would be at the cost of denying ejectees the option of retaining their seat packs for tree landings. No Canadian analysis has been done to confirm the benefits of retaining seat packs for tree landings.

Among the recommendations from the Board of Inquiry into the crash of CT155215 was a call for a review of CF ejection experience for analysis to validate the direction that the PSP should be retained if landing in trees. Accordingly, initiation of this study was requested by the ALSE Special Projects Officer under A3 Aerospace and Force Protection Readiness at 1 Canadian Air Division Headquarters in Winnipeg.[3] [5]

1.2 Assessment concept

[2] Several Canadian sources have separately reported that this policy arose after an ejected F-104 pilot was fatally impaled by a tree branch in a manner likely to have been prevented by a retained seat pack.
[3] This study was first reported in a letter report. [4]

This study had two principle components. The first was to review the available literature touching on ejection injuries. The conduct and results of the review and related information from outside the CF are the subject of Chapter 2. The second component was to survey available records of Canadian ejection experience for indications of adverse tree landing injury outcomes for those with retained, deployed or detached seat packs on landing. The conduct of this phase, the results of the analysis, and further discussion are reported in Chapter 3. Conclusions and recommendations are given in Chapter 4.

2 Literature review

Though the ultimate goal of the literature review was to find out what other air forces had found on the current question, the more immediate goal was to get a good understanding of the most important phenomena associated with the phases of ejection and their interrelationships. Fortunately, information was found serving both of these goals.

The review was conducted by acquiring and reading all the aeromedical literature available touching on ejection injury from initial emergency through rescue, reading for relevance to the requested study, and distilling the results.[4] The findings that pertain to the current question are presented below, beginning with general conclusions on landing injuries, moving specifically to the role played by seat packs in landing injuries, then to tree landing injuries and their relationship to seat pack status, concluding with the subject of automated PSP deployment.

2.1 Ground landing injuries

For the purposes of this study, the term "ground landing" should be understood to include every type of landing except water landings, including tree landings, which were frequently not specifically addressed in some articles although they had plainly occurred in the analysed ejection data. No PSP-related fatalities were documented in the literature. All injury rates reported are the fraction injured of those who survived through to rescue.

2.1.1 Type and frequency

Reports concerning the frequency of ground landing injury vary from 0% [6][5] to 42% [7][6,7] The most common landing injury, most often minor, is to lower limbs. [13] [19] Reported probabilities of lower limb landing injury are grouped between 4%–6% [9] [10] [12] [18] [20], 10%–11% [10] [16], and 18% [11] [13].

The reported frequency of spinal landing injury also varies widely, ranging from 1% [10] [18] [21], 3% – 4% [15] [9] [12] and 11%–12% [16] [20][8]. Without giving an estimate, Anton [19] doubts the frequency of landing spinal injury by reporting no significant differences between RAF spinal injury rates for those landing on land and those in water and the low spinal injury rate for military parachute jumps [22] [23]. However, Guill [24] writes to warn of the frequent over-assignment of spinal injuries to the egress phase, overlooking other injurious cause factors

[4] An annotated bibliography of all aeromedical articles consulted for this study, including those not referred to in the body of the study, is given after the Annex B.

[5] This study from Finland attributes no ejectee injuries to landing in 17 ejections over 34 years. Four landings in snow are specifically mentioned.

[6] Between these extremes, reports give landing injury probability estimates less than 10% [8] [9], 10%-20% [10] [11] [12], 20%-30% [13], and 30%-40% [14] [15] [16] [17].

[7] Sturgeon's 1988 research report [16] gives an analysis of the ejection phases associated with each injury suffered by 67 surviving Canadian ejectees, suggesting that 33% were injured during landing, slightly less than the 36% injured on descent and less than half the 69% injured during cockpit egress.

[8] These were two of 19 ejections during take-off or landing.

ranging between the initial event necessitating ejection through to the events of rescue. Auffret and Delahaye [25] also note the difficulty of determining the moment when spinal injury occurred. Whatever the actual spinal risk at landing, most sources indicate the greatest spinal risk from landing to be hyperflexion centred at the thoracic – lumbar transition T12–L2. [1] [12] [15] [16] [23] [25]

Pirson and Verbiest [23] and Every and Parker [12] specifically note shoulder luxation to be the most common upper limb landing injury, whose reported frequency varies from 1%–2% [9] [10] through 4%–7% [16]. Interestingly, Sandsteds [9] reports one dislocated shoulder that was set back into place by the shock of landing. Otherwise, there is fairly uniform agreement that the most common landing injuries are minor cuts, scrapes and bruises. [10] [15] [16] [18]

2.1.2 Risk factors

The landing descent velocity correlates strongly with landing injury risk. Bagian [22] reports that a 13%–23% slower descending jump parachute generates 86% fewer landing injuries. Pirson and Verbiest [23] show a 16% slower jump parachute to give 73% to 88% fewer serious landing injuries. Lewis [11] notes that simulation-based reconstructed descent velocities confirm that this also applies to rescue parachutes, which are faster falling[9], reporting that descent velocity correlated strongly with lower limb injury (t-test p=0.01), giving 7.4 m/s average fall rate when lower limbs were injured but 7.0 m/s when not. Principle causes of higher descent rates included damaged parachutes[10] and incomplete parachute inflation with low altitude ejections[11]. Higher all-up aircrew weight generates faster landing descent rates, though previous analyses of Canadian ejection data show this component of the effect on landing injuries to be weak. [14] [28] Late efforts to steer the parachute also increase landing descent speed[12] and injury risk.

Difficult (hard, uneven) terrain further increases the risk of injury. [1] [7] [18] [26] [29] while surface winds introduce additional landing hazards [1] [14] [25] [30].

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[9] A properly functioning rescue parachute already has a faster descent rating (maximum 7.3 m/s by CF requirement) [2] than a military jump chute, which is typically 80% of this value or less. [22] [23] The difference is partly due to space constraints where it is stowed in the ejection seat head box and the urgency of reaching the ground quickly when ejecting over enemy territory. [26] [25] For perspective, 7.3 m/s is experienced on the ground when stepping off a 2.7 m (9 ft) high platform, although one stepping off a tower lacks the energy absorption offered by a parachute during the landing fall.

[10] Every and Parker [12] note 3.5 times as many injuries in ejectees with missing or torn parachute panels over those with minor or no parachute damage.

[11] Lewis [11] specifically identifies low altitude ejection as increasing injury probability from 14% for ejections above 30 m, 29% below 30 m, and 36% for ejections from ground level, and Milanov [27] concurs. Their relevance to ground landing injury is inferred by the author. McCarthy [20] notes, however, that the survival rates and injury risks for ejections below 150 m during take-off and landing (based upon 22 ejections) are no worse than those for all other ejections above 150 m, and safer than other ejections below 150 m.

[12] Most rescue parachutes can be steered in a rudimentary way by shifting the load on one or more of the four risers attached to the ejectee or using steering lines built into the chute. Use of these will increase descent rates, which is not recommended below 150 m [2]. Ejectees have also mistakenly tried to “flare” a parachute just before landing to slow final descent when the parachute did not have that capability. In a recent ejection, this was modelled to actually increase the landing descent rate by 24% and 45% [3].

Also correlated with landing injury are seat pack retention [3] [14] [16] [19] and incorrectly performed parachute landing fall (PLF). [1] [7] [9] [13] [14] [25] [27] [29] Though lack of training has been asserted as a factor in badly executed PLFs [7] [25], Sturgeon [1] states that landing injury is too infrequent for PLF training to be significant, and that landing injuries appear to be directly related to seat pack retention.

2.2 Seat packs and landing injuries

The status of the seat pack has an impact on the experience of ground landing through a few mechanisms. It has been found that, once inflated, the life raft hanging 8 m below can catch the wind and cause the equipment bags to swing, sometimes wrapping the lanyard around the ejectee's legs, though the literature did not substantiate an increased landing injury hazard. [29] An able ejectee can damp the oscillations by pulling in some of the lanyard and releasing it again to prepare for landing. [2] [29] If seat pack deployment happens at the doctrinally recommended 150 m above ground level (AGL) and the descent rate is assumed to be the maximum acceptable 7.3 m/s, this leaves no more than 20 seconds for the life raft to inflate and oscillations to develop before landing.

A few different mechanisms result in the lower risk of landing injury with a deployed seat pack. Over water, a deployed seat pack promises a life raft ready to board. Over land, a deployed seat pack means the ejectee's feet are still more than 6 m up when the PSP equipment hits the ground. With lanyard tension gone, that last second of fall sees the parachute further decelerate the ejectee toward a new slower fall speed. The already stopped seat pack mass and the lower descent velocity reduce the momentum (product of mass and speed) that the ejectee must dissipate through the impulse of ground contact during the PLF.

To do a proper PLF, the ejectee should land on the balls of the feet with knees slightly bent and toes pointed 45 degrees to one side of the direction of travel, falling onto the outside of the calf and thigh and then rolling diagonally across the back. [2] As noted in 2.1.2, this proves easier to do safely without 15 – 20 kgs hanging at the buttocks.

Factors identified in the literature which can prevent manual seat pack deployment include:

a. injury disabling the ejectee (physically or cognitively)[13] [3] [9],

b. weather obscuring visible cues to time the release before landing [9],

c. too little time to find and operate the release lever [16] [19] [20] and

d. an unserviceable release mechanism[14].

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[13] Sandsteds [15] notes that 30% of ejectees had limited chance to prepare for landing due to injuries, darkness, low clouds or a parachute descent of only a few seconds.

[14] Paquet's narrative [3] of the eight most recent CF ejections notes one involving an unserviceable mechanism causing injurious landing with seat pack (CT155215) and another mechanism only operable on the third attempt.

Landing injuries specifically associated with retained seat packs include lower limbs [1] [3] [11] [19], spinal injuries [14] [16] [25], and even fractures of the pelvic girdle [29]. Sturgeon [16] describes seat pack retention as the biggest landing injury risk factor, noting that five of eight reported major landing injuries involved retained seat packs.

2.3 Tree landing injuries

References to ejectees landing in trees appeared in several studies [9] [15] [16] [17] [26][15], which reported tree landing frequencies ranging from 26% [15][16], 31% [17][17], to 1 in 3 [9][18] [16]. Specific injuries documented involving trees include a fracture of each of the olecranon (outer elbow) and collum (neck)[19] [9], a superficial injury to each of eye and shoulder [16], and mild contusions and abrasions [15].[20] If they follow a pattern, there were too few specific injury reports to make it apparent.

The more significant concern for both Sturgeon [16] and Sandsteds [9] was ejectees coming to rest suspended from the snagged parachute[21] and the difficulty of reaching the ground safely and, in combat, quickly. [17]

2.4 Tree landings and seat packs

One American [17] and three Canadian [1] [16] [15] aeromedical publications mention both tree landings and seat packs, although the only mention of interaction between seat packs and trees is when reporting the doctrine of retaining PSPs into trees. [1]

2.5 Automated seat pack deployment

Four reports make reference to automated PSP deployment, either directly or indirectly. In 1968, Shannon and Ferrari [17] advocated the employment of such a mechanism. In 1975, Auffret and Delahaye [25] noted that the most modern ejection systems have the deployment mechanism "sufficiently independent from the pilot so that he is not forced to be preoccupied with this maneuver at the last minute." Fleming [29] (1979) examines the concept of automated PSP deployment at some length, seeming to imply that it was already implemented on at least one fleet.[22] Over water, an undeployed seat pack may drown an injured / unconscious ejectee.[23]

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[15] US Navy ejections, acknowledged only in data annex case comments.
[16] Canadian air force.
[17] US air force ejections during combat over South East Asia.
[18] Swedish air force.
[19] The meaning is not certain as collum (Latin "neck") may also refer to a neck-like structure in some other part such as the femur (below the head) or mandible.
[20] Rowe and Brooks [15] mention two of eight serious injuries occurring on landing and that five of the eight landed in trees. However, one of the two landing injuries was an unprepared landing when unable to release the seat pack, suggesting it was not a tree landing.
[21] Termed "frequent" by Sandsteds.
[22] "… there were complaints that, in cases of automatic release, the inflated dinghy acted …" [29] p. 833.
[23] The currently recognised risk of a PSP retained into water is the low position of a buoyant package lifting the bottom and submerging the face.

Over land, such an ejectee will surely land more safely, though lanyard wrapping may introduce its own landing injury hazard. Finally, McCarthy's report [20], by stating that ejecting aircrew need to "confirm the deployment of survival equipment from the seat pack", implies that USAF F-4 Phantom pilots (predominant platform in the study) have automated seat pack deployment.

The most directly pertinent information on studies by other air forces came through a chance meeting during the ejection reviews of Chapter 3. The author was introduced by DFS 2-6 to a former Royal Air Force (RAF) flight safety officer now with the Department of National Defence. While visiting, he shared relevant experiences, assisted with the data review and also offered to make inquiries about the question with his contacts in Europe. A few months later, he reported that the Centre for Aviation Medicine (CAM) in Farnborough, Hampshire, United Kingdom (UK), had studied the question of seat pack retention into trees and found nothing conclusive on "the effect of pack up/pack down on injury sustained (if any) on penetration of a tree canopy." Because of this, retaining the PSP was still perceived as importing more risk than deploying it. He also reported that the RAF currently provides the option of automatic seat pack deployment on most aircraft with ejection seats, though a technician is required to change the option between manual and automatic release before take-off. [31]

2.6 Conclusions from the literature review

1. The most serious ground landing injury risks faced by ejectees are fractures and connective tissue injuries to the lower extremities and spine.

2. The most common landing injury risks that ejectees face are minor cuts, scrapes and bruises.

3. The principal risk factors for serious landing injury are descent speed, uneven ground, surface winds and retained seat packs.

4. The literature does not address the validity of seat pack retention to protect against tree branch injury.

5. The CAM in Farnborough found injury data inconclusive regarding the advantage of deploying seat packs before landing in trees.

3 Review of CF ejection experiences

The review of CF ejection experience is the heart of the work requested by the sponsor. The concept developed for the study had three components:

1. identify suitable data sources for review that capture CF ejection experience,

2. identify as many CF ejections as possible in which the ejectee landed in trees, and

3. analyse the impact of PSP status on the landing injuries each ejectee received.

Each of these components is described in the following sections, followed by the results of the analysis.

3.1 Data source identification

The Airworthiness Investigative Authority appointed under the Aeronautics Act is the Directorate of Flight Safety (DFS). [32] For this reason, DFS owns all data relevant to CF ejection events. Inquiries to DFS identified the following possible sources of data:

1. Flight Safety Occurrence Management System database;

2. Flight Safety Investigation Reports;

3. Aircraft Accident Board of Inquiry findings; and

4. Reports of Emergency Escape from Aircraft.

A description of each of these data sources and assessments of their availability and their utility for steps 2 (tree landing detection) and 3 (impact assessment of PSP status on landing injuries) are given in the sub-sections below.

3.1.1 Flight Safety Occurrence Management System

The Flight Safety Occurrence Management System (FSOMS) is used to capture and monitor CF flight safety occurrences and hazards, investigate their causes, make recommendations, identify trends, and monitor implementation of preventive measures. [33] It was established in the 1970s by incorporating all records of flight safety incidents for aircraft fleets then in service. Included in FSOMS are records of aircraft ejections and bail-outs. Queries to FSOMS by DFS staff for ejections produced incidents for 9 of Canada's 11 ejection-capable fleets[24] as shown in Table 1. The available information included summary and narrative text fields, tail number, degree of injury suffered by the ejectee (fatal, very serious, serious, minor, nil injuries), and incident latitude and longitude, in most cases.

[24] According to DFS 3-2-3, data for fleets already retired from service when FSOMS was established (eg. the F86 Sabre) was never incorporated into FSOMS.

Table 1. Ejections recorded in FSOMS for ejection-capable aircraft fleets in the CF[25]

Designation	Name	Dates	Ejections
F-86	Sabre	1953 – 1975	0*
CF100	Canuck	1953 – 1981	65
CT133	Silver Star	1954 – 2005	76
F2H-3	Banshee	1955 – 1962	0†
CF101	Voodoo	1961 – 1987	32
CF104	Starfighter	1961 – 1986	87
CT114	Tutor	1962 – present	62
CF116	Freedom Fighter	1968 – 1995	16
CF188	Hornet	1982 – present	11
CT155	Hawk	2000 – present	4
CT156	Harvard	2000 – present	1
		Total CF ejections in FSOMS:	354

*Sabre and Banshee flight safety data was never put into FSOMS because both fleets retired from service before FSOMS was established.
†Banshees were flown by the Royal Canadian Navy. [35]

Detection of tree landings is not well supported by FSOMS, since there is no field in the database to systematically capture ejection landing terrain. Narrative fields either stated or implied the terrain in perhaps 30 of the ejections listed. Approximately 90% of the incident listings included latitude and longitude of the occurrence to the nearest minute. Medical assessment was similarly unsupported with the only searchable FSOMS field pertaining to medical outcomes being the overall degree of aircrew injury, with no indications of whether injuries occurred during the landing phase.

[25] Dates are taken from [34] and then expanded to include all ejections listed in FSOMS.

3.1.2 Flight Safety Inspection Reports

The Directorate of Flight Safety produces Flight Safety Investigation Reports[26] (FSIRs) solely for the purpose of accident prevention and not for legal, administrative or disciplinary action. [36] They focus on determining exactly what happened in the course of the accident and any lessons to be learned and safety modifications to be made.

The DFS website provides FSIRs back to 1997; FSIRs older than this are held in Ottawa in either DFS transitory storage or in national archives. Among the reports online, one ejection event was noted in which the ejectee landed in trees. However, the report did not provide sufficient detail about landing injuries to support the study objectives. The detail available in FSIRs could support the identification of tree landings in Step 2, though another source would be needed for Step 3, reviewing landing injuries.

3.1.3 Board of Inquiry reports

When sufficient aircraft damage, serious injuries or death are associated with an aircraft accident[27], an aircraft accident board of inquiry (BOI) is convened by the Commander 1 Canadian Air Division (1 Cdn Air Div). This BOI constitutes a review and accountability process separate and independent of the DFS investigation, although it will make use of DFS findings to determine cause factors and inform decisions potentially affecting the management of everything from capabilities to careers. Because of their potential reach, BOI findings and recommendations are designated Protected B. [38]

As with FSIRs, the results from BOIs earlier than 2000 are not generally available and can only be systematically obtained from government archives. Once obtained, BOI findings would include all the information needed to identify tree landings and all available medical information on ejectee injuries. As with FSIRs, they could support detection of tree landings (step 2) and assessment of PSP impact on landing injuries, though their limited availability would impose some constraints on the process.

Members of the aeromedical community in Winnipeg and Toronto believed that, since the medical components of most BOIs were conducted by aeromedical personnel at the Canadian Forces Environmental Medicine Establishment (CFEME) in Toronto, these components might well be more easily accessed from local DRDC Toronto storage, and that review of the files held there might fairly rapidly yield a body of tree landing and injury data, depending upon how easily CFEME medical staff could incorporate this interesting component task into already full schedules. In support of this prospect, tree landing likelihood estimates were generated using geographic coordinates from FSOMS and current satellite imagery, so that file review could be prioritised to support the identification of tree landing ejections as quickly as possible. Accordingly, ejection lists sorted within each fleet into descending tree landing likelihood were sent to the CO of CFEME to guide the process of BOI review in Toronto, as available person-hours enabled it to go forward.

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[26] According to DFS 3, prior to 1999, FSIRs called Flight Safety Boards of Inquiry.
[27] An event involving a CF aircraft that is not caused by enemy action.

3.1.4 Reports of emergency escape from aircraft

In its current form, the Report of Emergency Escape from Aircraft is a 24 page questionnaire catalogued as form DND 1056. It is intended to capture the ejectee's experience of every aspect of the event germane to flight safety, from the circumstances that led to ejection through to rescue, as well as follow-up information from flight surgeons (ejectee injuries by phase of ejection and indications from ALSE equipment condition), ALSE technicians (handling the equipment), and unit commanders (currency of aircrew training and aircraft management). Specific information solicited includes a free text "description of events from emergency to rescue", "Did the survival kit deploy properly?" with related details and "Describe the ground characteristics at touchdown, e.g., grain field, pasture, swampy, mountainous, timberland, desert, jungle, deep snow, etc." with related details. (See Annex A for a summary of the information collected by DND 1056 forms.)

Having a predictable format, these reports promised fairly rapid location of every relevant detail for tree landing detection. If consistently completed, the medical assessment tallying injuries by phase of occurrence would also support the injury analysis phase. However, until the completeness and detail of the information was known, there remained a possibility of having to resort to use of BOI records either archived or potentially available in Toronto.

Personnel with DFS at NDHQ acknowledged having a substantial collection of DND 1056 reports including some from the 1950s. However, the person responsible for ensuring such reports are completed with every such escape over the past 20 years works at the Aerospace Engineering Test Establishment (AETE) in Cold Lake. Therefore, it was unclear how complete the collection in Ottawa would be and whether a more complete collection was held at Cold Lake.

A further limitation of the DND 1056 forms is that they are not completed posthumously and would exclude fatal ejections. However, most such ejections are "out of envelope" (i.e., the flight parameters at ejection are beyond designed ejection system capabilities). Examples of this include low altitude ejections involving a high descent rate, inverted flight or supersonic flight. For this study, it was assumed that the phenomena leading to most fatal injuries were independent of PSP status on landing.

3.2 Identification of tree landings

With DND 1056 forms chosen as the best basis for comprehensive tree landing detection, plans were made to review the reports available at DFS. In preparation, DFS staff tabulated the date and platform data for the 225 available reports to support their review on location. The collection included forms for 44 RCAF ejections from F86 Sabre aircraft not found in FSOMS.[28] During 2.5 days, 194 of the 225 reports were reviewed[29] and 71 tree landings identified.[30]

[28] The only Canadian operational Banshee ejection was in 1958 and was unsuccessful. [36]
[29] The author had to catch a plane before reviewing the 32 oldest reports.
[30] Where differences are noted between the data presented here and following and that given in an earlier letter report by the same author [4], data presented here is authoritative, correcting one or more small errors in recording, interpretation and manipulation of data reported previously.

The volume and detail captured in the reports was extensive. The aircrew narrative, medical assessments and detailed questions, having evolved to a mature state over almost 60 years of use, represent a formidable body of evidence characterising in great detail specific CF ejection experiences. It is unfortunate that the entire collection exists only on paper documents held in Duotang binders, as this imposes significant overhead on data utilisation.

3.3 Impact of seat pack status on tree landing injuries

The initial plan was to review each tree landing for indications of causal relationships between seat pack status on landing (retained, deployed or detached) and the set of injuries received during landing. Causal relationships could be positive (preventing or mitigating landing injuries) as current doctrine asserts for a retained seat pack when passing through trees, or negative (causing or aggravating landing injuries) as is shown in the literature for a retained seat pack landing on open ground. How often does the retained seat pack save ejectees from trees? How often do the trees save ejectees from the retained seat pack? The conclusion was to be based upon the relative proportions and severities of seat pack status causal relationships with landing injuries.

This component of the study required appropriate interpretation of medical terminology and the application of medical judgement to possible injury mechanisms and outcome severities, necessitating assistance from the aeromedical community. This need was met by the DFS flight surgeon in Ottawa and by the commanding officer (CO) of the CFEME at DRDC Toronto. In collaboration with them, a medical assessment form was developed for use with each tree landing ejection to record landing circumstances including landing PSP status, landing injuries received, and any apparent causal relationships between the two along with the implications for the preferred PSP status for that landing injury. The form used is reproduced in Annex B with sample text to illustrate its intended use.

3.3.1 Causal relationships between seat pack status and tree landing injuries

Of the 71 tree landings identified, three reports failed to specify PSP status on landing and two lacked medical reports, leaving 66 reports usable for this study.[30] Six instances of causation between PSP status and tree landing injury were identified. Five involved retained PSPs and the sixth an incompletely deployed PSP.[31] All six involved landing injuries aggravated by the retention of the PSP.

In the course of the ejection review, the DFS flight surgeon noted that instances of retained seat packs causing or aggravating landing injuries are much easier to identify than instances of them preventing or mitigating injury. Reasons for this include the relative imperviousness of PSPs to witness marks from impact, the masking of witness marks by routine wear, and the complexity of associating them with prevented hypothetical injury. (See Annex B for more context.)

Because of these factors, the absence of evidence that retained seat packs prevented or mitigated tree landing injuries does not necessarily mean that they do not mitigate injury. All that can be said is that the strength of the preventing / mitigating effect of a retained PSP on tree landing

[31] Only one side released. The other side remained attached, presumably retaining the PSP contents.

injury is weaker than the aggregated effects confounding its reporting. For this reason, it was concluded that indications of causal relationships between seat pack status and landing injury should not form the basis for PSP management recommendations from CF ejection experience.

3.3.2 Significance of tree landing injury severity distributions

Fortunately, the data collected from DND 1056 forms also provide an adequate basis for statistical tests for significance in the differences between the distributions of landing injury severities. Since what is sought is a validation of PSP retention into trees, a suitable null hypothesis is that retained seat packs produce no better tree landing injury severity distribution than alternative seat pack statuses. A validating result would be a tree landing injury severity distribution for retained seat packs that is better than that for deployed or released seat packs with a 5% or lower probability of occurring by chance if retention was no less injurious than not retaining.

Table 2 shows how the combinations of landing injury severity and PSP status were distributed between the aircrew ejecting from a CF fleet aircraft to land in trees, survive to rescue and complete an emergency escape report.

Table 2. Counts of combinations of PSP status and tree landing injury severity.

PSP status on landing	**Severity of most serious landing injury**		
	No Injury	**Minor**	**Serious**
Retained	18 / 46 (39%)	27 / 46 (59%)	1 / 46 (2%)
Deployed	8 / 13 (62%)	5 / 13 (38%)	0
Detached*	3 / 7 (43%)	4 / 7 (57%)	0
Total	29/66 (44%)	36/66 (55%)	1/66 (2%)

*This set includes those who did not bring a seat pack with them and those who lost their seat pack when the stitching on the seat pack lanyard gave way on deployment.

Rather than retention, tree landing injury severity distribution data appear to actually favour PSP deployment. Sixty-two percent (28 of 46) of those retaining their PSP were injured on tree landing whereas only 45% (9 of 20) of those who deployed or detached were injured on tree landing. Clearly, retained seat packs are not better beyond chance than deployed seat packs and may actually be worse. That injury rates for detached and retained seat packs should be so similar when they are the two options with the least in common suggests that differences in tree landing injury severity distributions are random.

Pair-wise Mann Whitney U tests for significance[32] conducted between retained and deployed data in Table 2 show that tree landing injury severity data samples of these sizes being drawn from the

[32] The Pair-wise Mann Whitney U test permits measurement of the significance of differences between ordered data sets that are not from an equal interval scale, for which parametric statistical tests that assume normality are ruled out.

same distribution can be this different 20% of the time. Repeating the test between retained and not retained (i.e. with deployed and detached data combined) shows these two data sets could be drawn from the same tree landing injury severity distribution and still be at least this different 28% of the time. Being over the 5% threshold, the differences in landing injury severity can not be called significant.

3.4 Discussion

Thus far, the evidence presented agrees with the informally reported CAM findings in Section 2.5: CF ejection experience does not warrant concluding that one PSP status is better than the other. In that ALSE doctrine asserts that retained seat packs are better for tree landings, CF experience does not validate current ALSE doctrine and, instead, weakly supports seat pack deployment or detachment for tree landings. Other ground and water landing circumstances already clearly warrant seat pack deployment for better landing outcomes. Hence, there appears to be no injury-based empirical argument against automated seat pack deployment. If acquired, the capability can reasonably be expected to prevent more injuries and save more lives over all types of landings than current manual release systems.

Automated PSP deployment does raise other issues pertaining to landing injury. If it is to help those ejecting at low altitudes during take-off or landing, the moment of PSP deployment needs to be as soon as possible after man/seat separation. However, wind gradients are known to catch the inflated life raft and induce pendulum swing in the lanyard. During a higher altitude ejection, wrapping of the lanyard around a disabled ejectee's legs will be commonly seen. Though Fleming [29] reported that two such landings were completed safely on level ground, the impact of a leg wrapping lanyard on landing injuries, tree or otherwise, is not known, and may warrant further consideration before automated PSP deployment is adopted and training policy is adapted.

Defeat of the "cover your buttocks" argument in favour of seat pack retention into trees also re-opens the question of optimal seat pack status to consideration of all three options, although the adoption of automated deployment (for all the other benefits) would reduce this to two choices: whether to land with the seat pack lanyard still connected or to detach or cut the lanyard altogether to let the equipment fall free in hopes of catching up with it after landing. Detaching the lanyard will have two expected consequences:

1. The freshly unloaded parachute will immediately begin to decelerate the ejectee toward a new slower steady state descent rate, and

2. The possibility of the seat pack contents becoming entangled in tree branches, causing the lanyard to stop the ejectee above the ground.

The first result may offer an important advantage when the parachute is damaged or interfered with and the descent rate dangerous for anything but a water landing. In this case, the distance travelled between lanyard detachment and deceleration most of the way to a new slower steady state fall speed will be substantially more than when the parachute is operating as designed. Risk of injury is also very sensitive to landing velocity above the maximum acceptable descent rate, in which case early detachment of the seat pack to permit a damaged parachute to reach the lower descent speed may be critical if the ejectee is to survive the landing.

The second effect of detachment raises the question of whether it is good or bad to end up suspended in trees by the seat pack lanyard. As it happens, this question is also addressed by the data collected from the review of tree landing injuries.

3.4.1 Landing injury severity when coming to rest suspended in trees

One class of tree landing injury hazard raised by Sturgeon [16] and Sandsteds [9] is the process by which ejectees who come to rest suspended in trees reach the ground. Of the 66 who landed in trees, 30 (45%) came to rest fully or partly[33] suspended above the ground.[34] Table 3 gives the combinations of tree suspension and landing injury severity seen in the ejections reviewed.

Table 3. Counts of combinations of suspension and tree landing injury severity.

	Severity of most serious landing injury		
Suspension category	**No Injury**	**Minor**	**Serious**
Not suspended	14 / 36 (39%)	21 / 36 (58%)	1 / 36 (3%)
Partially, by parachute	2 / 4 (50%)	2 / 4 (50%)	0
Fully, by parachute	12 / 24 (50%)	12 / 24 (50%)	0
Fully, by lanyard	1 / 2 (50%)	1 / 2 (50%)[30]	0
Total	29/66 (44%)	36/66 (55%)	1/66 (2%)

Combining the injury data for all types and degrees of suspension shows injury frequencies of 50% for suspended but 61% for not suspended. This sample suggests that, where tree landing injuries are concerned, suspension may actually be a preferred outcome. That said, the Mann Whitney U test indicates that differences this great or greater between the two sets can occur randomly when drawn from the same distribution 39% of the time. Therefore, evidence for a lower tree landing injury severity when suspended is weak at best. In combat operations, issues of escape and evasion may also make suspension less desirable.

3.4.2 Probability of suspension by the seat pack lanyard

Of the thirteen ejectees that entered trees with seat packs deployed (Table 2), two of them came to rest suspended by their seat pack lanyards. Assuming a binomial distribution, the 95% confidence range for the single event probability is between 2.8% and 41%, indicating that lanyard suspension is a genuine possibility. Though the sample is too small to indicate much

[33] Part suspension implies touching without being free to lie fully on the ground.
[34] Shannon and Ferrari [17] found that, of the 31 ejectees over south-east Asia who landed in trees, 21 (68%) ended up at least partly suspended.

concerning injury risk, it initially appears very similar to suspension by parachute, which may be better than ground landing.

Complicating the question for CF-18 aircrew is the impending adoption of the Naval Aircrew Common Ejection Seat (NACES). It has a seat survival kit (SSK)[35] whose lanyard does not attach to the parachute harness at chest height but, rather, to the seat pack shell that remains by the ejectee's buttocks. In that case, suspension by lanyard seems likely to result in a head down position, potentially introducing other landing injury modalities.[36] The lanyard attachment point for other fleets may introduce other complications warranting lanyard detachment before the tree canopy penetration.

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[35] The shell housing the SSK is not rigid.

[36] This makes sense of a comment from a member of the USAF sharing a commercial flight with the author who indicated that USAF doctrine has the ejectee detach the seat pack lanyard for tree entry so as not to "do a face plant into the ground". It would seem their lanyard also attaches to the ejectee below the centre of gravity.

4 Conclusions and recommendations

Review of aeromedical literature and CF ejection experience has produced evidence that supports the following concluding statements.

4.1 Conclusions

1. In general, a retained PSP will cause or aggravate more landing injuries than it will prevent or mitigate.

2. When the ejection is survivable and the ejectee will land in trees, the severity of injuries received during the landing phase will most likely be minor or nil.

3. When the ejection is survivable and the ejectee will land in trees, the severity of injuries received during the landing phase is not significantly influenced by whether the PSP is retained, deployed or detached for landing.

4. Employment of a system that reliably and automatically deploys the PSP without reliance on conscious ejectee action is expected to mitigate and prevent more injuries than it causes or aggravates.

5. The body of completed questionnaires entitled "Report of Emergency Escape from Aircraft" is a valuable body of historical information germane to human factors analysis, equipment improvement, and other areas relevant to flight safety and aircrew personal safety. The data is under-exploited because it exists only in paper form.

4.2 Recommendations

1. CF aircraft fleets from which aircrew can eject should be enabled to provide automatic deployment of PSP during ejection.

2. The ALSE Manual [2] should be amended to reflect the findings of this study.

3. Follow-on work should be done to assess the impact of leg wrapping by the PSP lanyard on landing injuries for injured or unconscious ejectees, and develop recommendations regarding whether (or when) tree landings warrant lanyard detachment in preparation for landing.

4. The data contained in the DFS collection of reports of emergency escape from aircraft should be entered into a suitably designed and secured database to enable a wide range of analyses in support of flight safety.

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Annex A Report of Emergency Escape from Aircraft

The main source of CF ejection experience data was the collection of forms entitled "Report of Emergency Escape from Aircraft" held by DFS on the 11th floor of the Pearkes Building in Ottawa. They are currently catalogued as form DND 1056 and are available from http://imgapp.mil.ca/DFC2/. The forms reviewed exist only on paper, though the consistent structure of the information they capture suits them well to storage in an electronic database. Table A1 provides a summary and outline of the organisation of the form used to capture ejection phenomena.

Table A1. Summary and organisation of information captured in DND 1056 forms

Part	Source	Information Reported
A. General Information	Ejectee	Ejectee & other crew identities, where, when, why, method, weather, flight data
B. Description of Events	Ejectee	Narrative of events from emergency to rescue
C. Ejection / Bailout	Ejectee	Decision dynamics, preparations, crew sequence, posture, problems, system functionality (inertial reel, canopy, egress, seat separation, parachute, PSP deployment), descent dynamics, landing preparations
D. Landing on Land	Ejectee	Drift & orientation, sequence of events, force, terrain, suspension, footing, problems.
E. Landing on Water	Ejectee	Depth, distance to shore, water conditions, preserver & life raft inflation & function, parachute dynamics & release, immersion suit use, problems.
F. Personal Equipment	Ejectee	Type, fit, function, hazard, utility & loss (helmet, visors, O_2 mask, PSP, knife, harness, footgear, hand wear, life preserver, 'G' suit, clothing) and problems.
G. Survival	Ejectee	Size of party, conditions, injuries, area, equipment use & utility, rations, materials found, first aid, shelter, travel.
H. Rescue	WFSO	Aircraft signals use & performance (visual & electronic), rescue alerting, resources, conduct, locating, para-drop, handling, and any problems.
J. Previous Experience & Remarks	Ejectee	Previous instance specifics of ejection, parachuting, survival & rescue training & experiences; lessons learned, advice, recommendations
K. Escape Equipment	Supervisor	ALSE modification records, post-event inspections
L. Injuries	Flight Surgeon	Type, severity, location, agent and phase (before egress, during egress, descent, landing, after landing), amnesia, first aid quality, hospitalisation, return to flying duties.

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Annex B Data collection form

Shown on the next page is the data collection form developed for the review of the completed "Report of Emergency Escape from Aircraft" forms (DND 1056). The form was intended to help capture ejection parameters possibly needed to understand landing injuries, and also to capture medical judgements pertaining to causal relationships between landing injuries and PSP status.

During the review, "RSSK" was thought to be a suitably generic term for seat pack, though PSP is more generic. Therefore, where the term "RSSK" appears in the form, a generic seat pack is to be understood.

B.1 How the form was used

The data collection form has been populated with notional data to illustrate its intended use. Data for "landing tree type", "landing tree density", and "Surface" was not consistently available and ultimately did not inform the conclusions of the study. The rest of the upper portion is fairly self-explanatory, and was filled out as completely as possible for any ejection report referring to timberland, trees, bushes, etc in the responses on landing. Once started by the author, DFS 2-6 populated the middle and lower portions as supported by the available data as follows:

1. All injuries received on landing were tabulated in the blanks to the left beside 1, 2, etc.

2. Each injury was assigned a letter reflecting its severity rating from fatal to minor.

3. All the identified factors that influenced the severity of any landing injury (besides the already listed terrain, trees and landing seat pack status) are tabulated toward the right under "Other Factors" beside A, B, and C.

4. Letters are recorded inside the thick black rectangle reflecting the nature and degree of causal influence each factor had on each landing injury, according to the influence ratings legend from C – caused to P – prevented.

5. Finally, a seat pack status is chosen (if warranted) that would best have mitigated each of the landing injuries.

The author's notional data shown in the form indicates the following:

1. The ejectee suffered a fractured pelvis on landing, a very serious injury, caused by the ejection seat being tangled in the parachute lines resulting in an injuriously rapid descent to the ground. The hardness of the ground and weight of the retained seat pack aggravated the injury, though it was mitigated by tree branch contact reducing ground impact. A detached seat pack lanyard would have reduced the descent rate and mitigated the injury ground impact.

2. A deep gash in the PSP cover bears witness to a violent collision between the seat pack and tree branches, likely to have caused serious injury to the buttock, aggravated by the entangled

ejection seat, had the seat pack not been in place. This injury was best mitigated by PSP retention.

3. Minor contusions and abrasions to the head were caused by contact with trees and aggravated by the ejectee's loss of helmet during ejection. These injuries do not indicate a preferred seat pack status on landing.

B.2 Lessons learned from use of the form

The details sought on type of tree, landing tree density and surface of landing were generally not usable because the data was not routinely captured and because of their imprecise definition on the form.

In the course of the ejection review, the DFS flight surgeon noted that instances of retained seat packs causing or aggravating landing injuries are much easier to identify than instances of them preventing or mitigating injury. Capture of such mitigation relies upon a number of uncertain factors related to effects being observable and unambiguous, and the alternative outcome being reconstructed and reported.

For example, whereas the nature of specific injuries are often sufficient to conclude their causation, the only positive indications of an injury mitigated or prevented by a PSP will be witness marks on the seat pack caused by the potentially injurious impact. Seat packs (and especially the hard shells of RSSKs) can be quite resistant to acquiring impact witness marks. Even if they are acquired, these witness marks must be noticeably distinct from a background of undocumented but routine wear and tear that seat packs acquire through routine handling. Then, the flight surgeon must notice these marks, associate them with either injuries that were less severe than they could have been or else with hypothetical injuries that didn't happen, and then record these in the medical report. This sequence was thought to rely upon a degree of coincidence and a level of observation and deduction that was unlikely to be routinely undertaken by flight surgeons.

Witness marks might also be observable on trees at the landing site, though a flight safety investigator would have to observe the damage (which in most cases would only be visible by climbing the tree and looking for fresh breaks). The freshness of the breaks would have to be unambiguous, and their size and location reported with enough detail for the flight surgeon to form a clear picture of what happened. Again, this is a less likely sequence of events than those associated with assigning cause and aggravation of actual injuries. As a result, the results of the review are expected to be biased toward instances of PSP-aggravated injury and away from instances of PSP-mitigated injury, confounding a balanced causal analysis.

It was also noted that any efforts to compare the number of minor injuries received by two different ejectees will be confounded by differences in flight surgeon reporting styles. One may list seven distinct minor injuries by location while another describes "multiple contusions and abrasions". For these reasons, the only injury information included in the analysis was the degree of the most serious landing injury received.

Incident date: 31 Dec 2009 **RSSK Role in Tree Landing Injuries – Data Collection Form** FSOMS #: 99999

Aircraft: CT114923 Ejectee: **(pilot)** nav pax RSSK status on landing: **(retained)** deployed detached

Landing tree type: **(deciduous)** coniferous mixed bush unk Landing tree density: **(sparce)** dense unk

Stopped on: rock ice **(hard grd)** soft grd bog water snow tree susp'd Surface: N/A even **(uneven)** ?

Severity ratings:

A – Fatal
B – Very Serious
C – Serious
D – Minor

Influence ratings:

C - Caused
A - Aggravated
– - No influence
M - Mitigated
P - Prevented

	Landing injury descriptions (caused & prevented)	Severity	TERRAIN	TREES	RSSK	Other Factors A: Ej'n seat caught in chute	Other Factors B: Lost helmet	Other Factors C	Substantiation	RSSK status best mitigating each landing injury: RETAINED DEPLOYED DETACHED
1.	Fractured pelvis	B	A	M	A	C			Rapid descent	?? Ret Dep (Det)
2.	Punctured buttock	C		C	P	A			Deep gash in PSP cover	?? (Ret) Dep Det
3.	Contusions & Abrasions to head	D		C			A			(??) Ret Dep Det
4.										?? Ret Dep Det
5.										?? Ret Dep Det

Other notes & comments:

Seat/parachute interference caused ejection seat to be tangled in parachute lines, causing much higher descent rate than normal.

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Annotated bibliography of ejection injury articles

Abu-Ghosh, H.M., Aqqad, S.S., Abbadi, M.D., and Shahin, B.H. (1995), The Royal Jordianian air Force (RJAF) post ejection injury report of 22 cases [Abstract], *Aviat. Space Environ. Med.*, 66, 501.

– This short abstract reports RJAF ejections between 1965 and 1993. Of 22 ejections, 20 survived including only two with spinal fractures.

Anton, D.J. (1991), Injuries associated with escape from fast jet aircraft, (IAM 707) Royal Air Force Institute of Aviation Medicine, Farnborough Hampshire, United Kingdom.

– This paper focuses on the variety of impact and inertial injuries found in 'within envelope' ejections and considers their causes in order by the phase of ejection in which they occur. It does not report ejectee outcome statistics.

Auffret, R. and Delahaye, R.P. (1975), Spinal injury after ejection, (AGARD-AR-72) Advisory Group for Aerospace Research and Development, NATO.

– This paper presents ejection outcome statistics from 7 NATO air forces followed by theoretical and experimental data on spinal injury phenomena.

Bagian, J.P. (1992), Comparison of parachute landing injury incidence between standard and low porosity parachutes, *Aviat. Space Environ. Med.*, 63, 802-4.

– This paper compares military jump parachuting (not ejection) landing injury rates between standard and low porosity parachute jumps over a 3 year period. The intuitive expectation that the slower falling low porosity parachutes reduce landing injuries is confirmed with high confidence.

Beckmann, G., Endris, R., and Stömmer, P. (1984), Injury patterns resulting from non-fatal ejections from aircraft, (Translation CIS/2520.0000GE-S/GE/01/89/939) Chief Intelligence and Security, National Defence Headquarters, Canada. (Originally published 1983 in *Wehrmed. M. Schr.*, 27(8), 313-9, S.K.T. trans.)

– This paper reports the outcomes of 217 ejections (19% killed, 49% injured and 32% uninjured), and surveys the survivor injury patterns seen.

Collins, R., McCarthy, G.W., Kaleps, I., and Knox, F.S. (1997), Review of major injuries and fatalities in USAF ejections, 1981-1995, *Biomed. Sci. Instrum.*, 33, 350-3.

– This short paper reports trends in annual USAF ejection, fatality and major injury frequencies, with head, neck and spine injury trends.

Every, M.G. and Parker, J.F. Jr (1976), Biomedical aspects of aircraft escape and survival under combat conditions, (Office of Naval Research task NR-105-667), BioTechnology, Inc., Falls Church VA, USA.

– This paper reports combat ejection parameters for US naval aviators in South-East Asia, contrasting those recovered with those captured as POWs and later returned. It gives injury

severity outcomes for the 106 POWs later returned (53% major, 25% minor and 23% no injuries) and tabulates their injuries by location and phase. Includes a thorough treatment of flail injuries.

Fleming, C. (1979), Ejection problems and injuries: their causes, effects and treatments, and suggestions for preventive measures, *Aviat. Space Environ. Med.* 50(8), 829-33.

– This paper reports lessons learned from Israeli Air Force ejection experience during the 1973 Yom Kippur war, including the pros and cons of automatic seat pack deployment.

Guill, F.C. (1989), Ascertaining the causal factors for "ejection-associated" injuries, *Aviat. Space Environ. Med.*, 60(10 Suppl.), B44-71.

– This paper was motivated by concern for the frequency and growing credence of erroneous medical conclusions on US Navy ejection injury causation. It offers a catalogue of potentially injurious mechanisms by phase to improve the basis for correct determinations. Specific problems identified include speculative attribution of pre- and post-egress spinal injury to the rocket catapult phase, imprecise injury description, and failure to correlate injuries with ALSE equipment damage.

Hennings, E.J. (1998), Mishap data evaluation of current naval aircraft 1987 – 1996, (NAWCWPNS TP 8332) Naval Air Warfare Center Weapons Division, China Lake, CA, USA.

– An analysis of 10 years of naval air mishaps with fatalities or major injuries (including non-ejection) to determine the technological advances currently in development that would most likely have saved lives. No specific mention of landing injuries, RSSKs or tree landings.

Hunt, J.C. and Johanson, D.C. (2006), Ejection mortality and morbidity: what are the odds of being killed or injured during ejection? A first look at trends [Abstract], *Aviat. Space Environ. Med.*, 77(3), 322.

– Purports to present the odds of ejection resulting in fatal, major, minor and nil injury, for ejections within and outside of envelope. This author was unable to find internal consistency within the odds reported.

Latchman, S.A. (1998), CT114 and CT133 ejection analysis, (1 CAD/CANR CORA PR 9803) 1 Canadian Air Division/Canadian NORAD Region Headquarters, Centre for Operational Research and Analysis.

– Determines that, despite a recent tragic death on landing, rescue parachute capacity does not warrant a cap on pilot nude weight of 200 lbs. Summarises the physics of landing injury.

Lewis, M.E. (2006), Survivability and injuries from use of rocket-assisted ejection seats: analysis of 232 cases, *Aviat. Space Environ. Med.*, 77(9), 936-43.

– This study from the Centre for Aviation Medicine (formerly the Institute of Aviation Medicine) presents detailed correlations between types of injuries and ejection and landing circumstances and anthropometry.

McCarthy, G.W. (1988), USAF take-off and landing ejections, 1973-85, *Aviat. Space Environ. Med.*, 59(Apr), 359-62.

– This paper analyses 22 ejections from 15 aircraft and determines that T/O and landing ejection is as safe as ejection from above 500ft and safer than other <500ft ejections.

Milanov, L. (1996), Aircrew ejections in the Republic of Bulgaria, 1953-93, *Aviat. Space Environ. Med.*, 67(4), 364-8.

– This paper reports the outcomes of 60 ejections (17% with fatal, 23% with major, 28% with minor, and 32% with no injuries) and focuses on statistical correlations between ejection injury levels and a variety of variables including data for all 60 ejections for further analysis. It attributes all ejections to failures of either flying skill (67%) or equipment (33%).

Moreno Vázquez, J.M., Durán Tejeda, M.R., and García Alcón, J.L. (1999), Report of ejections in the Spanish Air Force, 1979-1995: an epidemiological and comparative study, *Aviat. Space Environ. Med.*, 70(7), 686-91.

– This paper reports the outcomes of 48 ejections (15% with fatal, 52% with major, 23% with minor and 10% with no injuries), providing additional breakdown by fleet trends, ejection causes, injurious phases, and the impact of flight parameters, body position and decision delay.

Nakamura, A. (2007), Ejection experience 1956-2004 in Japan: an epidemiological study, *Aviat. Space Environ. Med.* 77(9), 54-8.

– The paper reports the outcomes of 140 ejections (23% with fatal, 9% with major, 68% with no major injuries), with further analysis by aircraft type, seat model, flight parameters, and reasons for fatalities.

Newman, D.G. (1995), The ejection experience of the Royal Australian Air Force: 1951-92, *Aviat. Space Environ. Med.*, 66, 45-9.

– This paper reports 84 ejections including 8% fatalities and 8% without injury, focusing on survivor injuries. The most common of 5 types of major injury was vertebral fracture (80 fractures among 29 ejectees), and the most common of 6 minor injury types was bruises/abrasions (in 64 aircrew). No mention made of trees or RSSKs.

North Atlantic Treaty Organisation (2005), Pathological aspects and associated biodynamics in aircraft accident investigation, (RTO-EN-HFM-113) Human Factors and Medicine Panel, Research and Technology Organisation, NATO.

– This lecture series addresses needed data and best practice for investigation of all aviation accidents, not just military ejections.

Paquet, J.S. (2008), Riding the rocket seat, *Flight Comment*, 2008 (2), 16-26.

– This article provides detailed descriptions of the CF's eight most recent emergency aircraft escapes (including an inadvertent ejection and a *de facto* bail-out), between May 2003 and April 2008. It includes specific mention of the gravity (but not nature) of landing injuries due to retained seat packs and examples of difficulty releasing them.

Pirson, J. and Verbiest, E. (1985), A study of some factors influencing military parachute landing injuries, *Aviat. Space Environ. Med.*, 56, 564–7.

– This study correlates injury rates for military training parachute jumps onto a grassy plain with type of non-steerable parachute, light conditions, and wind speed. Significant injury risk factors include speed of descent and higher rucksack loads.

Rowe, K.W. and Brooks, C.J. (1984), Head and neck injuries in Canadian Forces ejections, *Aviat. Space Environ. Med.*, 55, 313-5.

– This paper tabulates 77 ejection outcomes (6% fatal, 10% major, 61% minor and 22% no injuries), mission, ejection, landing and injury circumstances and frequencies for more than 10 years of flying from 1972 through 1982.

Sandsteds, P. (1989), Experience of rocket seat ejections in the Swedish Air Force: 1967-1987, *Aviat. Space Environ. Med.*, 60, 367-73.

– A detailed report of ejection phenomenology with many individual case attributes. Of 92 ejections, 9 lethal cases are detailed and the 39 of the 83 survivors with non-trivial injuries mapped according to types of injury and ejection circumstances. It includes a fuller treatment of injuries by ejection phase.

Schwartz, J.A., Woolsey, J.P. III, and Nelson, J.R. (1999), Analysis of incidents of crew ejection from selected U.S. tactical fighter aircraft, (IDA document D-2352) Institute for Defense Analyses, USA.

– This paper compares a planned light-weight variant of the Zvezda K36 (Russian) ejection seat with the competing alternative second-generation Advanced Concept Ejection System (ACES II) for the F22.

Shannon, R.H. and Ferrari, V.J. Jr (1968), USAF ejection experience in the combat environment, 1 Jan 1967-30 Jun 1968, (IAC: SR-00763, DTIC: ADD702638) Directorate of Aerospace Safety, Deputy Inspector General for Inspection and Safety, USAF, USA.

– This very interesting paper reports 102 ejection (1% fatal, 19% serious, 38% minor and 42% no injuries) and contrasts the higher altitude, speed, and success rates of combat ejections with those of non-combat ejection phenomena. (Pilots do not delay ejection decision after receiving missile attack.) The paper also touches on landing injuries, tree landings and automatic seat pack deployment. Note that the paper is mis-indexed and unavailable from DTIC, but can be ordered online from SAFE.

Sturgeon, W.R. (1988), Ejection systems and the human factor: a guide for flight surgeons and aeromedical trainers(U), (DCIEM 88-TR-16), Defence and Civil Institute of Environmental Medicine.

– This publication includes detailed illustration and analysis of ejection phenomena seen among 485 attempted Canadian ejections and bail-outs. Included are specific fleet escape system configurations, mechanisms, parameters and limitations, with practical implications of altitude and airspeed.

Sturgeon, W.R. (1988), Canadian Forces Aircrew Ejection, Descent, and Landing Injuries 1 January 1975 – 31 December 1987, (DCIEM 88-RR-56), Defence and Civil Institute of Environmental Medicine.

– This report details the known primary causes of every main injury seen in 78 attempted ejections (with 14% fatal, 24% major, 50% minor and 12% no injuries). Further analysis by ejection phase and aircraft type is also given.

Taneja, N., Pinto, L.J., and Dogra, M. (2005), Aircrew ejection experience: questionnaire responses from 20 survivors, *Aviat. Space Environ. Med.*, 76(7), 670-4.

– This article explores the subjective experience of ejection events and the advice generated for other aircrew (mostly on training) by the 20 Indian Air Force ejectees for aircrew. Phenomena mentioned include time distortion and the effect of altitude on emotions and decisions.

Trenholm, B.W. (1994), Major causes of mishap-related fatalities and major injuries 1987-1993, (NAWCWPNS TP 8190) Naval Air Warfare Center Weapons Division, China Lake, CA, USA.

– This report gives analysis of 273 naval aviation mishaps with 107 killed to identify half-a-dozen aircraft improvements needed with motivating case narratives. Ejection statistics are also given (11% killed and 30% with major injuries). Detailed but barely legible mishap data is appended.

Visuri, T. and Aho, J. (1992), Injuries associated with the use of ejection seats in Finnish pilots, *Aviat. Space Environ. Med.*, 63, 727-30.

– This paper documents 17 ejections over 33 years (with 6% fatal, 29% major, 47% minor and 18% no injuries). It concluded no injuries due to parachute landings, with note of four landings in snow. Trees are only mentioned in out-of-envelope ejections.

Werner, U. (1999), Ejection associated injuries within the German Air Force from 1981-1997, *Aviat. Space Environ. Med.*, 70(12), 1230-4.

– This paper give analysis of 85 ejections (with 2% fatal, 35% major, 48% minor and 14% no injuries) by aircraft type, escape system, and flight parameters. It finds the newer escape systems reduce severity but not number of injuries.

Williams, C.S. (1993), F-16 pilots experience with combat ejections during the Persian Gulf war, *Aviat. Space Environ. Med.*, 64, 845-7.

– This paper examines the function of the ACES II during four ejections over Iraq in which all injuries were minor.

Wright, H.L., Salisbury, D.A. and Bateman, W.A. (2000), Biomedical review of aircrew weight as a risk factor in CT 133 and CT 114 ejections, (DCIEM TM 2000-100), Defence R&D Canada – Defence and Civil Institute of Environmental Medicine.

– This study of ejection experience between 1970 and 1998 found no statistical confirmation of aircrew weight as an injury risk factor, but noted theoretical weight-based risk factors in each phase of ejection for further investigation including tumbling and man-seat separation dynamics and descent speed causing landing injuries.

List of symbols/abbreviations/acronyms/initialisms

Abbreviation	Full Form (meaning)
1 Cdn Air Div	1 Canadian Air Division
A3	(Continental staff system designation for air force operations)
ACES II	Second generation advanced concept ejection seat
AETE	Aerospace Engineering and Test Establishment
AFP Rdns	Aerospace and Force Protection Readiness
AGARD	Advisory Group for Aerospace Research and Development
AGL	Above ground level
ALSE	Aviation life support equipment
ALSEO	ALSE Officer
Aviat. Space Environ. Med.	Aviation Space and Environmental Medicine
BOI	Board of Inquiry
CAM	Centre for Aviation Medicine (was IAM)
CANR	Canadian NORAD Region
CAS Surg	Medical advisor to the Chief of the Air Staff
CF	Canadian Forces
CFAWC	Canadian Forces Air Warfare Centre
CFEME	CF Environmental Medicine Establishment
CIS	Chief of Intelligence and Security
CO	Commanding Officer
CORA	Centre for Operational Research and Analysis
CS	Chief Scientist
CT155215	Hawk jet training aircraft
DCIEM	Defence and Civil Institute of Environmental Medicine (former name of DRDC Toronto)
DComd FG	Deputy Commander, Force Generation
DFS	Directorate of Flight Safety
DND	Department of National Defence
DRDC	Defence R&D Canada
DRDKIM	Director R&D Knowledge and Information Management

Abbreviation	**Full Form (meaning)**
DTAES	Director Technical Airworthiness and Engineering Support
DTIC	Defence Technical Information Center
FSIR	Flight Safety Inspection Report
FSOMS	Flight Safety Occurrence Management System
HQ	Headquarters
IAC	Information Analysis Center
IAM	Institute of Aviation Medicine
NACES	Naval Aircrew Common Ejection Seat
NAWCWPNS	Naval Air Warfare Center, Weapons Division
NORAD	North American Aerospace Defence Command
OR	Operational Research
ORAD	OR and Analysis Directorate
PLF	Parachute landing fall
PR	Project Report
PSP	Personal survival pack
R&D	Research & Development
RAF	Royal Air Force (UK)
RCAF	Royal Canadian Air Force
RJAF	Royal Jordanian Air Force
RSSK	Rigid seat survival kit
SPO	Special projects officer
Sqn	Squadron
SSK	Seat survival kit
TM	Technical Memorandum
UK	United Kingdom
USAF	United States Air Force

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Current air force training dictates that ejectees from high-performance aircraft mitigate landing injury hazards by letting the survival equipment in their seat packs fall to the end of an 8 metre lanyard while they are still descending under parachute. The exception is when they will land in trees and are told to retain the seat pack for the protection it offers against tree branches. Proposed automated seat pack deployment systems would protect aircrew from the landing injuries frequently seen when circumstances prevent them from deploying it themselves, though this would also deny the option to retain the seat pack for tree landings. This study reviews aeromedical literature and analyses Canadian Forces ejection tree landing injuries. It finds that, contrary to current doctrine, tree landing injury profiles with retained seat packs are not better and may be worse than those with deployed seat packs. Automated seat pack deployment is recommended.

La formation actuelle des membres de la force aérienne prévoit que les membres d'équipage qui s'éjectent des avions à hautes performances limitent les risques de blessures à l'atterrissage en larguant l'équipement de survie contenu dans leur paquetage de siège au bout d'une sangle de 8 mètres pendant leur descente en parachute. Une exception est faite lorsqu'ils atterrissent dans des arbres et, dans ce cas, on leur enseigne de conserver le paquetage de siège qui offrirait une certaine protection contre les blessures infligées par les branches. Les systèmes proposés de déploiement automatique du paquetage de siège auraient l'avantage de réduire les risques de blessures à l'atterrissage lorsque les circonstances empêchent le déploiement manuel, mais ne permettraient pas de conserver le paquetage en cas d'atterrissage dans les arbres. La présente étude passe en revue la documentation aéromédicale et analyse les cas de blessures à l'atterrissage dans les arbres survenus dans les Forces canadiennes. Ses conclusions sont que, contrairement à la doctrine actuelle, le fait de conserver le paquetage de siège n'améliore pas le profil des blessures lors de l'atterrissage dans les arbres et semble même aggraver les risques par rapport au déploiement du paquetage. Il est donc recommandé d'implanter systématiquement le déploiement automatique du paquetage de siège.

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automated PSP deployment; ejection; injury mitigation; landing injuries; manual PSP deployment; personal survival pack; PSP; rigid seat survival kit; RSSK; seat pack; tree landings