U.S. ARMY PUBLIC HEALTH COMMAND (Provisional)
5158 Blackhawk Road, Aberdeen Proving Ground, Maryland 21010-5403

EPIDEMIOLOGICAL REPORT NO. 12-HF-27G0ED-11

PRELIMINARY COMPARISON OF THE T-11 ADVANCED TACTICAL PARACHUTE SYSTEM WITH THE T-10D PARACHUTE, FORT BRAGG, NORTH CAROLINA, JUNE 2010-NOVEMBER 2011

Injury Prevention Report 30-48a

PHC FORM 432-E (MCHB-CS-IP), SEP 10

ACKNOWLEDGEMENTS

There were many Soldiers and civilians who made this investigation possible. We would like to thank Mr Tyson Grier for his assistance in the early part of the investigation and for training the data collectors. LTC Robert Malsby (82nd Airborne Division Surgeon) provided insights, guidance, and networking in the early stages of preparation for the project. LTC Michael Sassano (XVII Airborne Corps Surgeon) provided us with information on airborne operations in XVIII Airborne Corps and sponsored our briefing with COL Michael Smith (XVIII Airborne Corps G-3). COL Michael Smith was instrumental in approving XVIII Airborne participation in the project, thus providing us with the support we needed to start. Dr. Ellen Segan and Mr. Tommy Brown (XVIII Airborne Corps Science Advisors) got the project back on track after it temporarily faltered and assured that the operations order for the project was completed. Mr. Earl Jefferson (Ground Liaison Officer, XVIII Airborne Corps) provided us with information on the flight manifests and flash reports, spent time educating us on airborne operations in the XVIII Airborne Corps, and assured that we received the flight manifests. CPT King Cooper and MSG Todd Winhoven (82nd Airborne Division, G-3 Air) provided us with suggestions on injury risk factors and assured we had drop zone access, flash reports, and updates on planned airborne operations. CW3 Thompson (Corps Parachute Officer, XVIII Airborne Corps), CW4 Lewis (Division Parachute Officer, 82nd Airborne Division), Mr. Nick Weidler (Natick T-11 Project Manager), and Mr. Terence (Sean) Hensey (NCI, New Equipment Trainer representing PM Soldier Equipment) provided invaluable insight into the procedures involved with parachute packing. This data collection work was funded through the Office of the Assistant Secretary of the Army (Installations, Energy and Environment) and conducted under contract W74V8H-04-D-0005 Tasks 0517 and 0568.

REPORT DOCUMENTATION PAGE	*Form Approved OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From – To)*
December 2011	INTERIM	June 2010 to November 2011

4. TITLE AND SUBTITLE PRELIMINARY COMPARISON OF THE T-11 ADVANCED TACTICAL PARACHUTE SYSTEM WITH THE T-10D PARACHUTE, FORT BRAGG, NORTH CAROLINA, JUNE 2010-NOVEMBER 2011	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) Joseph J Knapik, Ryan Steelman, Kyle Hoedebecke, Bria Graham, Shawn Rankin, Kevin Klug, Stanley Proctor, Bruce H Jones	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) US Army Institute of Public Health, Aberdeen Proving Ground MD Concurrent Technology Corporation, Fayetteville, NC	8. PERFORMING ORGANIZATION REPORT NUMBER 12-HF-27G0ED-11
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Defense Safety Oversight Council, Military Training Task Force, Pentagon, Virginia	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT: Approved for public release; distribution is unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT:
This preliminary report compares injury rates between the older T-10D parachute and the newer T-11 parachute. Data were systematically collected on jump operations performed by the 82nd Airborne Division (Fort Bragg, North Carolina) using these parachutes from June 2010 to November 2011. Data on injured jumpers included injury diagnosis, anatomical location, and how the injury occurred. Operational data from flight manifests and flash reports included the date and time of the jump, type of parachute, type of jump (administrative/non-tactical (Hollywood) or combat load), unit involved, drop zone, entanglements, Soldiers' rank, jump order (order in which the Soldiers exited the aircraft), door side (right, left, tailgate), and aircraft type. Temperature, humidity, and wind speed were obtained using a Kestrel® Model 4500 pocket weather tracker. There were a total of 63,487 jumps resulting in 678 injured Soldiers for a crude injury incidence of 10.7/1,000 jumps. There were 59,370 jumps (94%) with the T-10 and 4,117 jumps (6%) with the T-11. Most injuries (85%) with a known injury mechanism were associated with ground impact. In univariate analysis, risk of injury with the T-10 was 11.1/1,000 jumps, and that with the T-11 was 5.3/1,000 jumps (risk ratio (T-10/T-11)=2.08, 95% confidence interval=1.35-3.13, p<0.01). Other factors that independently increased injury risk included night jumps, combat loads, higher wind speeds, higher temperatures, and entanglements. After controlling for these factors in a multivariate analysis, injury risk was still higher for the T-10 parachute when compared to the T-11 (odds ratio (T-10/T-11)=1.64, 95%confidence interval=1.05-2.50, p=0.03). Most of the reduction in T-11 injury risk occurred during night jumps with combat loads, but there were very limited T-11 data under these conditions (941 jumps). There was only one nighttime combat loaded T-11 injury and that injury was a fatality. The difference in injury rate between parachutes during daytime and administrative/non-tactical operations was much more modest (risk ratio (T-10/T-11)=1.30, 95%confidence interval=0.84-2.20, p=0.24). Because of the relatively small number of T-11 jumps, caution is advised in interpreting injury differences between parachutes. It is strongly advised that additional data be collected on the T-11 under a more comprehensive spectrum of operational conditions before conclusions are reached on the injury reduction effectiveness of the T-11 parachute.

15. SUBJECT TERMS: Flight manifest, flash reports, administrative/non-tactical, Hollywood, combat load, drop zone, entanglements, rank, door position, tailgate, C130 Hercules, C17 Globemaster, C23 Sherpa, C160 Transall, CH47 Chinook, UH60 Blackhawk, C212 CASA, temperature, humidity, wind speed, parachute landing fall, PLF, tree landing, static line, safety

16. SECURITY CLASSIFICATION OF: UNCLASSIFIED			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESONSIBLE PERSON Dr. Joseph Knapik
a. REPORT Unclassified	b. ABSTRACT Unclassified	c. THIS PAGE Unclassified			19b. TELEPHONE NUMBER *(include area code)* 410-436-1328

Standard Form 298 (Rev.8/98)
Prescribed by ANSI Std. Z39.18

Department of the Army
US ARMY PUBLIC HEALTH COMMAND
5158 BLACKHAWK ROAD
ABERDEEN PROVING GROUND MD 21010-5403

MCHB-IP-DI

EXECUTIVE SUMMARY
EPIDEMIOLOGICAL REPORT NO. 12-HF-27G0ED-11
PRELIMINARY COMPARISON OF THE T-11 ADVANCED
TACTICAL PARACHUTE SYSTEM WITH THE T-10D PARACHUTE,
FORT BRAGG, NORTH CAROLINA, JUNE 2010-NOVEMBER 2011

1. INTRODUCTION AND PURPOSE.

a. The Military Training Task Force (MTTF), of the Defense Safety Oversight Council (DSOC) works to decrease injuries during military training activities. Each year the MTTF prioritizes a number of projects directed at training-related injury reduction. In 2010, the MTTF funded a project for the United States Army Institute of Public Health and Concurrent Technology Corporation to compare injury rates between the older T-10D parachute and the newer T-11 parachute. The project began on June 2010 with the cooperation of the XVIII Airborne Corps and 82nd Airborne Division at Ft Bragg, North Carolina.

b. Due to a fatality associated the T-11 parachute, all jumps with the T-11 parachute were suspended in June 2011. At that point, only about 4,000 T-11 jumps had been conducted by the 82nd Airborne Division. The Army-wide suspension was lifted in August 2011 but as of November 2011, the 82nd Airborne Division had not resumed T-11 jumps. Because the DSOC funding ends in December 2011, this is a preliminary report on the project and an analysis of the data collected to date. The major purpose of this report is to provide preliminary information on differences in injury rates between the T-10D and T-11parachutes while controlling for other factors known to influence injury rates during airborne operations.

2. METHODS.

a. From 17 June 2010 to 3 November 2011, injury and operational data were systematically collected on jump operations performed by the 82nd Airborne Division at Fort Bragg, North Carolina, while they used T-10D and T-11 parachutes. For each jump operation, one or more investigators were present on the drop zone and recorded each injured Soldier’s initial injury diagnosis, anatomical location of the injury, and how the injury occurred. The initial diagnosis was provided by a medic or physician’s assistant. If the injured Soldier was evacuated to the hospital, a physician obtained a final diagnosis and anatomical location from medical records.

b. Operational data were collected from routine reports (flight manifests and flash reports) issued by the 82nd Airborne Division. These data included the date and time of the jump, unit involved, drop zone, parachute type, entanglements, Soldiers' rank, jump order (order in which the Soldiers exited the aircraft), door side (right, left, tailgate), aircraft type, and type of jump. Entanglements were physical contact between two or more jumpers that interfered with a normal parachute descent. Type of jump could be administrative/non-tactical (Hollywood) or combat loaded. Weather data (temperature, humidity, and wind speed) were obtained by the on-site investigators using a calibrated Kestrel® (Nielsen-Kellerman Co.) Model 4500 pocket weather tracker.

c. Cumulative injury incidence was calculated as Soldiers with one or more injuries divided by the total number of jumps multiplied by 1,000 (injuries/1,000 jumps). The chi-square test of proportions was used to assess the univariate association between injuries and parachute systems, operational data, and weather data. Risk ratios (RR) and 95% confidence intervals (95%CI) were calculated. Backward stepping multivariate logistic regression was used to assess the association between injuries and these factors in combination. Odds ratios (OR) and 95%CI were calculated.

3. RESULTS. There were a total of 63,487 jumps resulting in 678 injured Soldiers for a crude injury incidence of 10.7/1,000 jumps. There were 59,370 jumps (94%) with the T-10D and 4,117 jumps (6%) with the T-11. Most injuries (85%) with a known injury mechanism were associated with ground impact. In univariate analysis, risk of injury with the T-10D was 11.1/1,000 jumps, and that with the T-11 was 5.3/1,000 jumps (RR [T-10/T-11]=2.07, 95%CI=1.35-3.16, p<0.01). Other factors that independently increased injury risk included night jumps, combat loads, higher wind speeds, higher temperatures, and entanglements. After controlling for these factors in a multivariate analysis, injury risk was still higher for the T-10D parachute when compared to the T-11 (OR [T-10/T-11]=1.64, 95%CI=1.05-2.50, p=0.03). Most of the reduction in injury risk for the T-11 occurred during night jumps with combat loads; there was limited T-11 data under these conditions (941 jumps) collected over very few days. There was only one night time combat loaded T-11 injury and that injury was a fatality. The difference in injury incidence between parachutes during daytime and administrative/non-tactical operations was much more modest (RR [T-10/T-11]=1.30, 95%CI=0.84-2.20, p=0.24).

4. CONCLUSIONS AND RECOMMENDATIONS. The present investigation found that the T-11 parachute had a lower injury incidence than the T-10D parachute, even after accounting for a number of other injury risk factors including night jumps, combat load, wind speed, temperature, humidity, entanglements, aircraft, and drop zone. However, most of the injury reduction occurred during night jumps with combat loads and the differences in injury rates during daytime administrative/non-tactical operations was considerably less. Because of the small number of T-11 jumps, extreme caution is advised in interpreting injury differences between parachutes. It is strongly recommended that additional data on the T-11 be collected under a more comprehensive spectrum of operational conditions before conclusions are reached on the injury reduction effectiveness of the T-11 parachute.

CONTENTS

EPIDEMIOLOGICAL REPORT NO. 12-HF-27G0ED-11
PRELIMINARY COMPARISON OF THE T-11 ADVANCED
TACTICAL PARACHUTE SYSTEM WITH THE T-10D PARACHUTE,
FORT BRAGG, NORTH CAROLINA, JUNE 2010-NOVEMBER 2011

1. REFERENCES. Appendix A contains the scientific/technical references used here.

2. INTRODUCTION AND PURPOSE.

a. In 2003, the Secretary of Defense directed the Department of Defense to reduce preventable mishaps or injuries. The Under Secretary of Defense for Personnel & Readiness responded by establishing the Defense Safety Oversight Council (DSOC) which chartered nine task forces to develop recommendations to achieve this objective. One of these task forces was the Military Training Task Force (MTTF), which worked to decrease injuries during military training activities. Each year, the MTTF prioritized a number of projects directed at training-related injury reduction. In 2010, the MTTF funded a project to have the United States (US) Army Institute of Public Health (AIPH) and Concurrent Technologies Corporation (CTC) examine the effectiveness of a parachute ankle brace (PAB) for reducing injuries in operational airborne units. Previous studies had shown that the PAB reduced ankle injuries by about half during basic airborne training at Fort Benning, Georgia.[1] However, the operational airborne community saw little need for the PAB since the new T-11 Advanced Tactical Parachute System (ATPS) was soon to be fielded and anecdotal information suggested it would substantially reduce injury incidence. Based on this feedback, the MTTF approved a refocus of the airborne injury reduction effort to compare injury rates between the older T-10 parachute and the newer T-11 parachute. The basic project design was to collect injury and operational data on the T-10 parachutes while they were still being used by the 82nd Airborne Division (Fort Bragg, North Carolina) and then collect the same data on the new T-11 parachutes as they were phased into the inventory.

b. The AIPH worked with the 82nd Airborne Division to understand the operational training environment and how to collect the data to determine if there were differences in injury rates between the T-10D and T-11 parachute systems. The DSOC provided funding to CTC for personnel who would observe parachute operations by the 82nd Airborne Division. These personnel were trained by the AIPH to systematically acquire data on injuries sustained during airborne training jumps as well as environmental and operational conditions that were likely to affect injury rates. Data collection began in June 2010 and a preliminary report[2] was published in December 2010.

c. On a night jump on 25 June 2011 there was a total malfunction of a T-11 parachute. The jumper with the malfunction did not activate his reserve parachute resulting in his death. All jumps with the T-11 parachute were suspended while an investigation was undertaken. A Safety Investigation Board charged with looking into the incident determined the failure of the T-11 was "caused by a combination of debris retained within the chute and improper packing. The two mistakes combined to create a situation where the debris, coupled with a partially blocked 'air channel' resulted in a torn canopy that could not properly inflate. The board determined that a number of T-11s packed for use at Bragg had similar issues". The board made a number of recommendations and on 1 August 2011 the Army-wide suspension on T-11 jumps was lifted. The board allowed Fort Bragg to follow their own plan for resumption of T-11 use. As of mid-November 2011 no additional jumps with the T-11 parachute had been conducted by the 82nd Airborne Division. When the suspension had been initiated, only about 4,000 jumps with the T-11 had been completed.

e. The funds from the contract with the DSOC will be exhausted in December 2011. CTC requested that AIPH provide a preliminary analysis of the data collected to date to close out this contract. Thus, the major purpose of this report is to provide preliminary information on differences in injury rates between the T-10D and T-11parachute while controlling for other known airborne injury risk factors.

3. AUTHORITY. Under Army Regulation 40-5,[3] the US Army Center for Health Promotion and Preventive Medicine (now the AIPH) is responsible for providing program evaluations and epidemiological consultation services related to injury prevention and control. This project was approved and funded by the DSOC in an effort to determine the injury-reduction effectiveness of the new T-11 parachutes compared to the older T-10D parachutes. The project was reviewed by the AIPH Human Protection Office employing the criteria of the Council of the State and Territorial Epidemiologists[4]. It was determined that this project constituted public health practice. The CTC requested an analysis of the data from June 2010 to November 2011and AIPH agreed to provide this analysis.

4. BACKGROUND. Since military airborne training operations were initiated in the U.S. Army shortly before World War II, physicians and scientists have worked with the operational community to enhance safety and increase the probability that Airborne Soldiers arrive on the ground ready for their operational missions. These efforts coupled with continuous improvements in parachute technology, aircraft exit procedures, and ground landing techniques appear to have substantially reduced the number of injuries over time.

a. Injury incidence in Airborne Operations. Table 1 displays investigations that have examined military airborne injuries and provides injury definitions, military units involved, methods of injury data collection, and crude injury incidences for these investigations. Studies are arranged by year and in groups that include investigations in airborne basic training, operational units, single jump operations, and combat operations. Early estimates of military parachuting injury rates in the World War II era were 21 to 27/1,000 descents.[5, 6] A summary of studies conducted after this time (up to

1998) indicated that airborne injuries averaged about 6/1,000 jumps.[7] Nonetheless, different injury definitions, dissimilar methods of data collection, and diverse operational conditions can result in widely different injury rates as illustrated in Table 1.[8-11] For example, Soldiers of the 82nd Airborne Division in late 2010 at Fort Bragg, North Carolina had an airborne injury rate of 11/1,000 jumps,[12] compared to the historical average of 6/1,000 jumps noted above.[7] Soldiers in the 82nd Airborne Division conduct many jumps under night conditions with combat loads, factors known to increase injury risk.[1, 6, 12-15] The two studies of injuries during combat operations show some of the highest airborne injury rates recorded.[16, 17]

Table 1. Military Static Line Airborne Injury Incidences

Group	Study	Injury Definition	Group, Location, Date (if available in article)	Collection of Injury Data	Jump Conditions (if specified)	Crude Injury Incidence (injuries/jumps = injuries/1,000 jumps)
Airborne Basic Training	Tobin et al. 1941[5]	Injuries recorded by training battalion	501st and 502rd Parachute Battalion, Parachute School, Ft Benning GA, Aug 1940 to Aug 1941	Personnel records		121/4,490= 27.0/1,000[a]
	Pozner 1946[18]	Not clear	3rd Parachute Training Unit, British, Jan 1944 to Jun 1945	Consolidated accident statistics		190/66,408= 2.9/1,000[b]
	Hallel & Naggan 1975[14]	Paratrooper who received medical treatment on drop zone or several days following jump	Mixed basic course and refresher course, Israeli	Punch cards identifying injuries on drop zone		723/83,718= 8.6/1,000[a]
	Pirson & Verbiest 1985[15]	Not clear	Basic jump course; some Soldiers in refresher training, Belgium, 10-year period	Accident reports identifying injuries on the drop zone		5/1,000 [c]
	Lowdon & Wetherill 1989[19]	Fractures, head injuries, dislocations, and others	Training Services Parachute Training Airfield near Oxford, British, 6-year period	Emergency room records, 6 years		205/51,828 = 4.0/1,000
	Pirson & Pirlot 1990[20]	Not clear	Paracommando basic course, Belgium, Feb 1985 to Mar 1988	Not clear		53/15,043= 3.5/1,000
	Bar-Dayan et al. 1998[21]	Casualty that prevented further jumps for at least 2 days	Parachute training, with minority of jumps for refresher course or maneuvers, Israel	Accident reports completed by physicians		388/43,542= 8.9/1,000
	Amoroso et al. 1998[22]	Any musculoskeletal or traumatic condition between aircraft exit & exiting the drop zone resulting in inability to clear the drop zone, or diagnosed in medical clinic or hospital ER	Airborne School, Ft Benning, GA	Drop zone with follow-up at hospital/emergency room and patient medical records		35/3,674= 9.5/1,000

Group	Study	Injury Definition	Group, Location, Date (if available in article)	Collection of Injury Data	Jump Conditions (if specified)	Crude Injury Incidence (injuries/jumps = injuries/1,000 jumps)
	Knapik et al. 2008[8]	Questionnaire item asking if student injured during jump week	Airborne School, Ft Benning GA, June 2005 to January 2006	Questionnaire responses		119/6,708= 17.7/1,000
	Knapik et al. 2008[1]	Physical damage to the body recorded on updated injury report	Airborne School, Ft Benning GA, April 2005 to December 2006	Drop zone injuries reported by medics with follow up at clinic/hospital		596/102,784= 5.8/1,000
Operational Units	Essex-Lopresti 1946[6]	Causalities reported by the medical officer on the drop zone	British 6th Airborne Div, January to November 1944	Drop zone		437/20,777= 21.0/1,000
	Neel 1950[23]	Time loss injuries	82nd Airborne Division, Ft Bragg, NC, 1946-1949	Not clear		1,018/174,220= 5.8/1,000
	Roche 1960[24]	Events causing hospitalization and time loss from duty	101st Airborne Division, 1956 to 1959	Injury statistics from 101st Airborne Division		1,206/355,886= 3.4/1,000
	Hadley & Hibst 1984[25]	Injury resulting in loss of duty for 1 day or more	82nd Airborne Division, Ft Bragg, NC, Fiscal Year 1979 to 1980	Not clear		117/186,717= 0.6/1,000
	Lillywhite 1991[13]	Parachute injury seen by medical personnel on the drop zone	5th Airborne Brigade, British	Medical personnel on drop Zone		379/34,236= 10.9/1,000
	Farrow 1992[26]	Injury requiring evacuation from drop zone, withdrawal from exercise, duty restriction, or hospitalization	Parachute Battalion Group, Australian, Mar 1987 to Dec 1988	Injuries recorded on a standard Field Medical Report		63/8,823= 7.1/1,000
	Kragh et al. 1996[9]	Acute anatomical lesion resulting in a duty restriction as a result of parachuting	3rd Ranger Battalion, Ft Benning GA, USA, 55-month period	Medical records of unit Soldiers		163/7,569= 21.5/1,000
	Craig & Morgan 1997[27]	Injury from time boarding aircraft to ground impact and identified by ER staff as due to parachuting	Fort Bragg NC, USA, May 1993 to December 1994	Emergency room records		1,610/200,571= 8.0/1,000
	Schumacher et al. 2000[28]	Parachute-related injury that limited duty for 1 or more days	3d Ranger Battalion, Ft Benning GA, USA, October 1996 to December 1997	Database containing all sick call and emergency room visits		210/13,782= 15.2/1,000
	Craig & Lee 2000[29]	Injury from time boarding aircraft to ground impact and identified by ER staff as due to parachuting	XVIII Airborne Corps, Ft Bragg NC, USA, May 1994 to April 1996	Emergency room records		1,972/242,949= 8.1/1,000

Group	Study	Injury Definition	Group, Location, Date (if available in article)	Collection of Injury Data	Jump Conditions (if specified)	Crude Injury Incidence (injuries/jumps = injuries/1,000 jumps)
	Hay 2006[30]	Injury requiring evacuation from drop zone, admission to medical facility, withdrawal from exercise, or duty restriction	3rd Battalion, Royal Australian Regiment & A Field Battery, Jan to Dec 2004	Audit of unit medical records	Daylight jumps only	21/1,375= 15.3/1,000
	Hughes & Weinrauch 2008[31]	Injuries recorded in unit medical records	4th Battalion Royal Australian Regiment, Feb 2004 to Feb 2005	Audit of medical records		28/554= 50.5/1,000
	Knapik et al. 2011[12]	Any physical damage to the body seen by the medical personnel on the drop zone.	82nd Airborne Division, Ft Bragg NC, Jun-Dec 2010	Direct recording on drop zone followed up with medical records, where available		242/23,031= 10.5/1,000
Single Jump Operation	Timboe 1988[10]	Injuries treated by medical personnel on the drop zone	Elements of 82nd Airborne parachuting into Ft Irwin, March 1982	Drop zone injuries	Early morning jump, combat loads, rough landing zone, high winds	158/1,780= 88.8/1,000
	Kragh & Taylor 1996[9]	Concussions, fractures, contusions, sprains, strains, lacerations	1/75th Ranger Battalion, jump onto Ali Al Salem Airfield, Kuwait, Dec 1991	Drop zone injuries recorded by medical personnel	Night jump, combat loads, high winds (10-13 knots), airfield and rocky desert drop zone	71/475= 149.5/1,000
	Craig et al. 1999[11]	Injury from time Soldier boarded aircraft until exiting the drop zone	US and British units jumping at Ft Bragg NC, May 1996	Drop zone injuries recorded by medical personnel, or at emergency room	Low visibility, ground fog, winds did not exceed 8 knots, temp=55^{0}F	US 67/3,066= 21.9/1,000 British 49/1688= 29.0/1,000
	Buxton et al.2006[32]	Not clear	British and French parachute operation	Not clear		41/740= 55.4/1,000
Combat Operations	Miser et al. 1995[17]	Any injury reported by the Ranger during an interview	2nd Battalion, 75th Ranger Regiment, jump onto Panama Airfield (Operation Just Cause), Dec 1989	Interview	Night jump, combat load, airfield drop zone	252/486= 518.5/1,000
	Kotwal et al. 2004[16]	Physical damage to the body as a result of parachuting, from aircraft exit to release of parachute harness on ground	75th Ranger Regiment; 4 combat jumps: 2 in Iraq (Operation Iraqi Freedom) & 2 in Afghanistan (Operation Enduring Freedom), 2001 to 2003	Ranger electronic medical database	Winds 1-8 knots, night jumps, combat loads, 40-60^{0}F	76/634= 120.0/1,000

[a]Injury incidence cited by authors is incorrect
[b]Includes deaths
[c]This is the incidence cited in the article but the article does not provide numerators or denominators
Abbreviations: Ft=Fort, Jan=January, Feb=February, Mar=March, Jun=June, Dec=December, GA=Georgia, NC=North Carolina, CA=California, ER=emergency room, USA=United States of America, F=Fahrenheit.

b. Parachute Systems

(1) One of the major improvements in airborne operations has been progress in parachute technology. Military parachutes designed for intentional jumps from aircrafts were designed as “T” type parachutes, with the “T” understood to mean “troop” by mid-WWII. The first parachute actually used by the soldiers of first US Army airborne test platoon in 1941 was the T-4. The T-4 system was designed as a ripcord parachute but it was modified by the test unit for static line deployment. The T-4 had a 15-foot static line, a pack tray that did not totally encompass the parachute canopy, and was difficult to don and doff. The T-4 was followed by the T-5 which was designed from the start for static line deployment. The T-5 was used during most of WWII and had a very severe opening shock. The T-7 followed, and by the end of WWII the T-7 had a single point release system that could easily collapse the parachute canopy once the jumper had landed. All early parachutes had 28-foot flat circular canopies (when inflated) with 22-foot (T-4 and T-5) or 24-foot (later T-5 and T-7) diameter reserve parachutes. The T-4, T-5, and T-7 were all canopy first opening systems, although it was generally assumed that a safer system with less opening shock might be devised by having the canopy risers (canopy suspension lines) deploy first. Canopy deployment with all these early parachutes could be erratic depending on winds and the aircraft slip stream.[33, 34]

(2) In 1952, the T-10 began to replace the T-7 and by 1954, the T-10 implementation by the US Army was completed. The T-10 has served as the main US Army personnel parachute system since this time.[33] With the T-10 the risers came out first, followed by the canopy. This allowed jumpers to fall below the aircraft slip stream before the canopy deployed and this reduced the opening shock. The T-10 system had a 26-foot inflated parabolic canopy, a total weight of 44 lbs, and was rated for a maximum load (jumper and equipment) of 350 lbs. The T-10 was designed and developed when the estimated average load of the soldier and his equipment was about 300 pounds.[17, 35] However, soldier body weights and combat loads have progressively increased since the 1950’s.[17, 36-38] One study of 624 Rangers who jumped into Panama during Operation Just Cause (19 December 1989) found that 24 (4%) carried loads that exceeded the maximum allowable.[17] During airborne operations in Afghanistan in 2001 and in Iraq in 2003, average loads ranged from 327 to 380 pounds.[16]

(3) The need for a new parachute system to accommodate the greater Soldier loads was recognized in 1994 and work between this time and 2010 lead to the development and implementation of the T-11 Advanced Tactical Parachute System. The T-11’s rate of descent is 19 ft/sec (5.8 m/sec), compared to the T-10’s rate of 22 ft/sec (6.7 m/sec). Crude estimates of the kinetic energy (KE=1/2 mass X velocity^2) on ground impact for the two parachute systems are in Table 2.

Table 2. Estimates of the Kinetic Energy (KE=1/2 mass X velocity^2) of the T-10D and T-11 Parachutes on Ground Impact

Parachute	Soldier Mass (kg)	Velocity (m/sec)	Kinetic Energy (Joules)
T-10	80	6.7	1796
T-11	80	5.8	1346

(4) Because of its shape (modified cruciform), the T-11 oscillations are highly dampened and the parachute becomes vertically stable very soon after deployment [35,39]. The T-11 reserve parachute has characteristics similar to the main parachute and the aerodynamics are such that if both the main and reserve parachutes are deployed they do not interfere with each other. However, because of the large canopy, the T-11 likely has more lateral drift, less free air space on mass tactical jumps, and a greater drag hazard once the jumper has landed. The T-10D and T-11 parachutes are shown in Figure 1.

Figure 1. The T-10D (top) and T-11 (bottom) Parachutes

(5) One previous study compared the T-11 parachute to the T-10.[40] This investigation involved Soldiers at the US Army Airborne School (USAAS) who performed their first jump with the T-11, although 7% performed their first jump with the T-10 and second with the T-11. In this investigation only daytime, administrative/non-tactical jumps were considered. Injury rates were 44% lower with the T-11 compared to the T-10. However, the incidence of tree landings were over 5-fold greater with the T-11, presumably because of the greater drift potential of the T-11 due to its larger canopy. No studies to date have compared the T-10D and T-11 systems under a wide spectrum of operational conditions (e.g., night jumps, combat loads, higher winds), or considered other risk factors that might influence injury rates.

c. Airborne Injury Risk Factors. Studies on other factors that influence airborne injury rates are shown in Table 3. Early studies identified high wind speeds, night jumps, heavy loads, and rough landing zones as increasing injury risk.[6, 14] Later studies identified such extrinsic risk factors as smaller diameter canopies, fixed wing aircraft (verses rotary wing), extra equipment (combat loads), and higher temperatures. Intrinsic risk factors examined included female gender, older age, greater body weight, lower upper-body muscular endurance, lower aerobic fitness, and prior injuries.[8, 12, 13, 15, 20, 29, 41, 42] Many studies only carried out univariate analysis of these risk factors while a few[1, 8, 12, 13] performed multivariate analysis that allowed identification of independent risk factors and determined their interactions.

Table 3. Military Static Line Parachute Injury Risk Factors

Investigation	**Injury Case Definition; Soldiers or Military Unit; Year of Data Collection**	**Jumps**	**Risk Factor**	**Strata**	**RR[b]**	**95% Confidence Interval**
Essex-Lopresti, 1946[6]	Any injury recorded on drop zone; British Airborne Division; 1944	20,777	Wind speed Time of day Aircraft Body Weight	16–20/0–5 mph Day/Night (0–10 mph winds) Plane/Balloon (0–15 mph winds) >70/<70kg	3.3 1.2 1.6 [cd]	2.0–5.5 0.9–1.8 0.8–3.4 [c]
Hallel and Naggan, 1975[14]	Any injury recorded on drop zone and hospitalizations several days after jump; Israeli paratroopers; no dates provided	83,718[e]	Time of day Drop zone Training	Night/Day Rough/Sand Refresher Course/Basic Course	2.4 3.2 2.0	2.1–2.9 2.5–4.1 1.3–3.1
Hadley and Hibst, 1984[25]	Injuries before canopy deployment with at least one day of limited duty; US airborne division; 1979–1980	186,717	Aircraft exit	No staggered exit/staggered exit	13.2[f]	0.8-234.0[f]
Pirson and Verbiest, 1985[15]	Severe and moderate injuries(contusions, abrasions excluded) from accident reports; male Belge airborne trainees, soldiers in refresher courses, and soldiers on maneuvers; 1974–1983	201,977	Parachute Wind speed Time of day Aircraft Equipment Temperature Humidity	22/28 m^2 canopy (balloon) 22/28 m^2 canopy (airplane) 18/0–7 mph Night/Day (balloon) Plane/Balloon (day jumps, no equipt) Yes/No (airplane, day jumps) >24/<24°C 100/40%	8.3 3.7 5.0 4.1 3.1 1.6 1.7[g] 1.0[g]	7.6–9.0 3.4–8.9 [c] 3.7–4.6 2.8–3.4 1.5–1.8 [c] [c]

Investigation	Injury Case Definition; Soldiers or Military Unit; Year of Data Collection	Jumps	Risk Factor	Strata	RR[b]	95% Confidence Interval
Pirson and Pirlot, 1990[20]	No injury definition; Belge airborne trainees; 1985–1988	14,356 to 15,043	Body weight Body height	82 to 87/58 to 63 kg 1.86–1.90/1.62–1.67 m	2.0 1.3	0.6–6.7 0.2–7.8
Lillywhite, 1991[13]	Any physical damage to the body recorded on drop zone; British Airborne Brigade; prior to 1989	34,236	Aircraft Time of day Equipment Wind speed Wind Bearing Number Exiting Wedge[h]	Plane/Helicopter Plane/Balloon Helicopter/Balloon Night/Day (plane) Night/Day (helicopter) Yes/No (plane) Yes/No (helicopter) 14–15/0–2 mph Rear/Other Directions 65–90/1–22 Yes/No	7.3 11.2 1.6 1.3 41.2 10.4 26.9 4.7[g] 1.4 2.5 [cd]	2.7–23.5 5.9–24.2 0.5–5.1 0.9–1.9 3.8–449.5 2.6–41.6 2.8–257.4 [c] 1.2–1.8 1.9–3.3 [c]
Farrow 1992[26]	Physical damage to the body requiring evacuation from drop zone, withdrawal from exercise, duty restriction, or hospitalization; Australian Parachute Training School; 1987-1988	8,886	Equipment Exits	Yes/No Simultaneous/Not Simultaneous	4.1 2.1	2.3-7.3 1.2-3.5
Kragh et al.,1996[9]	Physical damage with duty restriction; US Army Airborne Ranger; no dates provided	7,948	Time of day Drop zone	Night/Day (field and landing strip) Landing Strip/Field (day) Landing Strip/Field (night)	1.9 2.4 2.7	1.4–2.7 1.1–5.2 1.8–4.0
Amoroso et al., 1997[42]	Lower extremity injury requiring restricted duty US Army Safety Center data; 1985–1994	NA[ei]	Gender	Women/Men	2.0[k]	1.4–3.0[k]
Craig et al., 1997[27]	ER visits resulting from airborne activities; 18th Airborne Corps, Ft Bragg, NC; 1993–1994	200,571	Age	<18–29/≥29 years	2.2	1.9-2.5
Amoroso et al., 1998[22]	Ankle inversion sprains; US airborne trainees; no dates provided	3,674	Ankle brace	No/Yes	6.9	0.9-56.1
Schumacher et al., 2000[28]	Any ankle injury with duty limitation; US Army Airborne Rangers;1994–1997	13,782	Ankle brace	No/Yes	2.9	1.4-6.1
Craig and Lee, 2000[29]	ER visits resulting from airborne activity; XVIII Airborne Corps, Ft Bragg, NC; 1994–1996	242,949	Gender Age	Women/Men >39/17–29 years	1.4 1.4	1.1–1.7 1.2–1.5
Hay 2006[30]	Injury requiring evacuation from drop zone, admission to medical facility, withdrawal from exercise, or duty restriction: 3rd Battalion, Royal Australian Regiment & A Field Battery, Jan-Dec 2004	1,375	Equipment	15 kg/None 40 kg/None	1.1 2.9	0.3-3.7 1.0-2.7

Investigation	Injury Case Definition; Soldiers or Military Unit; Year of Data Collection	Jumps	Risk Factor	Strata	RR[b]	95% Confidence Interval
Knapik et al. 2008[1]	Physical damage to the body reported by medics with follow up at clinic/hospital; Airborne School, Ft Benning GA, Apr 2005 to Dec 2006	102,784	Ankle Brace Wind Speed Time of Day Equipment	No/Yes 10-13/0-1 knots Night/Day Yes/No	1.2 1.9 2.3 1.7	1.0-1.4 1.4-2.6 1.8-2.8 1.4-2.0
Hughes & Weinrauch 2008[31]	Injuries recorded in unit medical records; 4th Battalion Royal Australian Regiment; Feb 2004 to Feb 2005	554	Landing Zone Body Weight	Land/Water ≥100/≤70 kg	4.3 2.5	1.8-10.1 0.6-10.5
Knapik et al. 2008[8]	Questionnaire item asking if student injured during jump week; Airborne School, Ft Benning GA; Jun 2005 to Jan 2006	6,708	Time in Service Dominate Hand Smoking Age Height Weight Body Mass Index Push-ups Sit-Ups 2-Mile Run Airborne Recycle Ankle Brace Exit Problems Prior Injury	>4 years/≤1 year Left/Right Yes/No ≥30/17-19 yrs 186-211/152-173 cm 84-129/48-72 kg 25.9-40.8/17.4-23.0 kg/m^2 10-55/78-120 repetitions in 2 min 83-120/40-65 repetitions in 2 min 14.1-21.0/9.5-12.7min Yes/No No/Yes Yes/No Yes/No	4.1 1.3 1.1 3.3 2.0 2.8 1.7 2.1 1.3 2.9 2.1 1.7 2.8 3.5	3.1-5.3 0.6-2.6 0.7-1.8 1.7-6.7 1.1-3.7 1.4-5.6 0.9-3.2 1.0-4.5 0.7-2.5 1.4-6.1 1.2-3.7 1.1-2.7 1.3-6.2 2.2-5.4
Knapik et al. 2011[12]	Physical damage to the body reported by medics on the drop zone with follow up at clinic/hospital; 82nd Airborne Division, Ft Benning GA; Jun to Dec 2010	23,031	Time of Day Equipment Wind Speed Temperature Aircraft Humidity Exit Door Jump Order Military Rank Entanglements	Night/Day Yes/No 11-12/0-1 knots 91-104/37-50 deg F Fixed Wing/Rotary Wing 81-92/20-40 % Side/Tailgate 46-51/1-5 Enlisted/Officer Yes/No	2.6 3.2 2.2 5.4 11.3 1.7 12.3 1.4 1.1 65.6	2.0-3.4 2.5-4.2 1.1-4.5 1.7-17.4 1.6-81.0 1.1-2.8 8.0-18.8 0.4-5.8 0.9-1.2 43.1-99.8
Knapik et al. 2011[40]	Physical damage to the body recorded on operational reports; Airborne School, Ft Benning GA, Apr 2005 to Dec 2006	30,755	Parachute	T-10/T-11 (daytime, no equipment)	1.8	1.0-3.1

[a] Numerator is factor with higher risk; variables in parenthesis are conditions under which risk factor was calculated.
[b] RR=risk ratio.
[c] Cannot calculate from data given in article.
[d] Risk appears to be elevated based on data presented in article.
[e] Free fall jumps made up less than 5% of total descents.
[f] There were 7 injuries from 95,823 jumps before and 0 injuries from 90,894 jumps after the staggered exit. Risk ratios and 95% confidence intervals calculated by substituting 0.5 for zero cell.[43]
[g] Estimated from graph in article.
[h] The wedge is additional equipment on independent parachutes released just before the jumpers.
[i] NA=not applicable. Cohort study comparing men and women without jump denominators.
[j] Non-simultaneous doors include rear ramps, single side aircraft jumps, and balloon descents.
[k] Not risk ratios but rather the odds ratio and 95% confidence interval for odds ratio.
Abbreviations: US=United States, equipt=equipment, Ft=Fort, NC=North Carolina, GA=Georgia, Jan=January, Feb=February, Apr=April, Jun=June, Dec=December

5. METHODS. The 82nd Airborne Division of the XVIII Airborne Corps is an airborne infantry unit garrisoned at Ft Bragg, North Carolina. Its mission is to, within 18 hours of notification, strategically deploy, conduct parachute assaults, and secure key objectives for follow-on military operations in support of US national interests. The Division regularly conducts jump operations to keep Soldiers trained for Airborne forcible entry missions. From 17 June 2010 through 3 November 2011, injury and operational data were systematically collected by the investigators on jump operations conducted by the 82nd Airborne Division.

a. Jump Operations. For all Airborne training jumps, Soldiers donned either T-10D or T-11 parachutes and were seated on fixed-wing or rotary-wing aircraft. Prior to loading the aircraft, their names, ranks, and location in the jump order were recorded on a jump manifest. After the Soldiers had completely boarded, the aircraft departed for the drop zone. Along with the jumpers, the aircraft had a team normally consisting of a primary jumpmaster (PJ), assistant jumpmaster (AJ), and a minimum of two safeties. The PJ and AJ were usually the last two jumpers to exit the aircraft, while the safeties remained onboard and returned with the aircraft to the departure airfield. These individuals had responsibility for the safety of all on-board jump personnel. During flight, Soldiers were seated until the jumpmaster issued the command to stand up. At this point, the jumpers stood up and attached the static lines of their parachutes to a cable in the aircraft and awaited further commands from the jumpmasters for their door. Once the Air Force turned over control of the paratroop door to the jumpmasters, the jumpmasters verified specific geographic land marks and ground markings to ensure the aircraft was on the proper approach into the drop zone. Once this was confirmed, the jumpmaster then instructed the first jumper to stand-by in the door. Once the aircraft reached its Aerial Release Point, the jumpmaster issued the command “GO.” On this command, the jumpers exited the aircraft in quick succession. As each jumper exited, the static line pulled open the main parachute, providing the canopy that slowed the jumper’s descent. On contact with the ground, the jumpers executed a parachute landing fall (PLF) to break the impact of the landing.[7, 30] After landing, and while lying on the ground, the jumper collapsed the parachute canopy using a quick release device on the parachute harness. The jumper then stood up, bundled the parachute, and prepared for the follow-on operation.

b. Injury Data.

(1) During all airborne operations, the drop zone safety officer (DZSO) was the individual on the ground who had responsibility for all actions and the safety of all personnel on the drop zone. The DZSO was located at the Personnel Point of Impact of the drop zone, the location where the first jumper should land. Depending on the number of Soldiers involved in the airborne operation, there were from 1 to 6 ambulances located on the drop zone near the DZSO. Each ambulance had 2 to 4

Army-trained medics, and for larger operations a physician's assistant (PA) was present. Once all Soldiers who had jumped were on the ground, the ambulances drove across the drop zone and provided medical care to injured jumpers. They returned injured jumpers to a collection point near the DZSO.

(2) For each jump operation, one or more investigators were present on the drop zone. Once an injured Soldier was brought to the collection point, the investigators recorded the Soldier's name, initial injury diagnosis, anatomical location of the injury, and how the injury occurred. The initial diagnosis was provided by the medic or PA. If the injury was minor, the Soldier could be released on the drop zone by the medic or PA, but usually Soldiers were taken to a hospital or clinic for follow-up care. Once in the hospital, the medical care provider who saw the Soldier generated a record in the Armed Forces Health Longitudinal Technology Application (AHLTA) that included a more detailed diagnosis and anatomical location. For all Soldiers evacuated to the hospital, a physician examined the AHLTA record and provided a final diagnosis and anatomical location for the injury. For the purposes of this investigation, if the Soldier was released on the drop zone, the final diagnosis and anatomical location were those obtained on the drop zone. If the Soldier was taken to the hospital the final diagnosis and anatomical location were those determined by the physician from the AHLTA record. During operations with larger numbers of Soldiers, an additional medic was stationed at the hospital to record injuries and to assure that all data were captured. An injury was defined as any physical damage to the body, seen by the medic or PA on the drop zone, from the time the Soldier was seated in the aircraft until the time the Soldier completed the parachute landing and removed the parachute harness on the ground.

c. Operational Data.

(1) Planned jump operations were published in a document called the "air letter". The air letter contained the projected date and time of the jump, unit involved, drop zone, projected number of jumpers, aircraft, and other information. This allowed the investigators to be on-site for each of the jumps. After the jump operation was completed, a "flash report" was issued that contained information on the actual time of the jump, parachute type (T-10D or T-11), unit, entanglements, and some data on injured jumpers. From the time of day and visual operations of the drop zone, investigators could determine if the jump had occurred in daylight (day) or after dark (night). Information on entanglements was obtained from a narrative section on the flash report. Entanglements involved physical contact between two or more jumpers that interfered with a normal parachute descent. From the narrative description on the flash report, it was possible to determine if the jumpers were able to disentangle before ground contact or if they remained entangled to the ground. Injury data on the flash report was used to augment information obtained on the drop zone and to ensure all injuries were captured.

(2) As Soldiers loaded onto the aircraft, a jump manifest was created. The jump manifest contained information on the Soldiers' rank, name, jump order (order in which the Soldiers exited the aircraft), door side (right, left, tailgate), aircraft type, and the type of jump. Type of jump could be administrative/non-tactical (Hollywood) or combat load. For an administrative/non-tactical jump operation, Soldiers were dressed in Army combat uniforms, advanced combat helmets, and T-10D or T-11 parachutes with appropriate attached reserve parachutes. For combat loaded jumps, the Soldiers additionally wore weapons containers (for rifles), and rucksacks. The rucksacks and weapons containers were attached to the jumpers' harnesses by quick release straps and a lowering line. The lowering line served to drop the rucksack and container about 15 feet below the Soldier's body while remaining attached to the Soldier. The quick release was activated about 100 feet before ground contact.

(3) Weather data were obtained by the on-site investigators using a calibrated Kestrel® Model 4500 pocket weather tracker (Kestrel® is a registered trademark of Nielsen-Kellerman Co.). As each aircraft came over the drop zone, investigators recorded the ground dry bulb temperature, humidity, and wind speed. The lowest and highest wind speeds were obtained from 3 minutes prior to the aircraft passing over the drop zone until all jumpers had landed.

(5) Most jumps were conducted on drop zones at Fort Bragg but, during the period of this investigation, three jump operations were conducted at other locations. Other locations included Charleston, West Virginia (Clute drop zone); Little Rock Air Force Base, Arkansas (Little Rock drop zone); and the Joint Readiness Training Center (JRTC), Fort Polk, Louisiana (Geronimo drop zone). No flash report was filed for the operation at the JRTC and thus little operational data were available.

d. Data Analysis. A de-identified database was created that had one jump on each line along with operational data, weather data, and injury information (the latter, if one occurred). Data analysis was performed using Predictive-Analytic Software, Version 18.0.0. To determine injury incidence, the numerator was the number of injured Soldiers and denominator was the number of jumps. Cumulative injury incidence was calculated as Soldiers with 1 or more injuries divided by the total number of jumps and multiplied by 1,000 (injuries/1,000 jumps).

(1) The chi-square test of proportions was used to assess the univariate association between the operation/weather data (covariates or potential risk factors) and all injuries. Risk ratios (RR) and 95% confidence intervals (95% CI) were calculated by comparing the injury risk at a baseline level of the variable (indicated with a RR=1.00) to the risk at other levels of the variable. Covariates (risk factors) that were significantly ($p<0.10$) associated with injury incidence in the univariate analysis were included in a backward stepping multivariate logistic regression. In the multivariate analysis, simple contrasts with the baseline level of a variable (odds ratio (OR)=1.00)

were compared to the risk at other levels of the same variable. The dependent variable in the logistic regression was the presence or absence of an injury.

(2) Injury risk by parachute type (T10 or T-11) was also stratified on all variables that were retained in the multivariate model. RRs (T-10/T11), 95%CI, and chi-square statistics were calculated. Because of the relatively small number of T-11 jumps and the possibility of confounding, Mantel-Haenszel procedure was also used. The Mantel-Haenszel procedure combined ORs for the two parachutes. If there was a common OR the procedure calculated it; if there was no common OR because of an interaction, the procedure produced a weighted average of the separate ORs.[44]

6. RESULTS.

a. During this investigation, the Soldiers of the 82nd Airborne Division made a total of 63,487 jumps resulting in 678 injuries for a crude injury incidence of 10.7/1,000 jumps. Table 4 shows the types of injuries and the anatomical locations. Forty-three percent of injuries (n=288) involved the lower body and 55% (n=373) involved the upper body. The most common injury/anatomical location combinations were closed head injuries/concussions (n=225), ankle fractures (n=48), ankle sprains (n=43), low back strain (n=25), low back fracture (n=19), hip contusions (n=18), knee sprains (n=18), low back sprains (n=16), low back pain (n=16), head contusions (n=13) and shoulder strains (n=11). These combinations accounted for 67% of all injuries.

Table 4. Injuries by Type and Anatomical Location

Injuries and Locations	**N**	**Proportion (%)**
Injury Type		
Closed Head Injury/Concussion	225	33.2
Fracture	98	14.5
Sprain	85	12.5
Contusion	84	12.4
Pain (not otherwise specified)	72	10.6
Strain	65	9.6
Abrasion/Laceration	27	4.0
Dislocation	12	1.8
Muscle/Tendon Rupture	7	1.0
Impingement	2	0.3
Fatality[a]	1	0.1
Anatomical Location		
Head	249	36.7
Ankle	101	14.9
Lower Back	75	11.1
Knee	35	5.2
Upper Arm	34	5.0
Shoulder	31	4.6
Hip	25	3.7
Pelvis	19	2.8

Injuries and Locations	N	Proportion (%)
Multiple	16	2.4
Neck	15	2.2
Foot	14	2.1
Thigh	13	1.9
Face	9	1.3
Lower Arm	7	1.0
Elbow	7	1.0
Calf/Shin	6	0.9
Chest	5	0.7
Hand	4	0.6
Finger	3	0.4
Upper Back	3	0.4
Ear	2	0.3
Abdomen	2	0.3
Toe	1	0.1
Wrist	1	0.1
Fatality[a]	1	0.1

[a]No further information was available at the time of this report

b. There were 22 entanglements in the 63,487 jumps, resulting in an entanglement incidence of 0.35/1,000 jumps. Eighteen were entanglements to the ground, and four were freed before ground contact. There were 8 injuries associated with these entanglements (36%), with 7 of the 8 injuries involving entanglements to the ground and one of the 8 freed before ground contact.

c. Table 5 shows the events associated with the injuries experienced by the Soldiers. In 71% of the injury cases (n=479), it was possible to determine the event. Early in the investigation, these data were not systematically collected, accounting for many of the missing events. When events could not be determined later in the project, it was because the Soldier was not sure how the injury had happened or because the investigators could not interview the Soldier before the Soldier was evacuated to the hospital. Most injuries were associated with ground impact and inability to execute a proper PLF. These included landing on uneven ground, on harder surfaces, because of drop zone obstructions (i.e., logs, rocks), or because of improper PLF procedures. Ground impact injuries, static line injuries, tree landings, entanglements, problems with exit procedures, and parachute risers accounted for 99% (472 of 479) of the known events associated with injury.

Table 5. Events Associated with Injuries

Events	N	Proportion of All Categories (%)	Proportion (%) of Known Activities (unknowns removed)
Ground Impact (PLF Problems)	408	60.2	85.2
Static Line	37	5.4	7.7
Tree Landing	8	1.2	1.7
Entanglement	8	1.2	1.7
Aircraft Exits	6	0.9	1.3
Parachute Risers	5	0.7	1.0
Landed on Equipment	3	0.4	0.6
Dragged by Parachute on Ground	2	0.3	0.4
Lowering Line	1	0.1	0.2
Parachute Malfunction (fatal)	1	0.1	0.2
Unknown	199	29.4	---

Abbreviation: PLF=parachute landing fall

d. Table 6 shows the univariate associations between injury risk and the covariates. Higher injury risk was associated with the T-10D parachute, night jumps, combat loads, higher wind speeds, high dry bulb temperatures, higher humidity, C17 Globemaster or C130 Hercules aircrafts (compared to the other aircraft), exits through doors (compared to tailgates), the Geronimo drop zone, and entanglements. Entanglement incidence with the T-10D parachute was 0.34/1,000 jumps and with the T-11, 0.49/1,000 jumps (RR [T-10/T-11]=0.69, 95%CI=0.16-2.97, p=0.62).

Table 6. Univariate Associations between Risk Factors and Airborne Injury Incidence

Variable	Level of Variable	Jumps (n)	Injury Incidence (cases/1,000 jumps)	Risk Ratio (95%CI)	Chi-Square p-value
Parachute Type	T-10	59,370	11.1	1.00	<0.01
	T-11	4,117	5.3	0.48 (0.32-0.74)	
Time of Day	Day	39,608	8.5	1.00	<0.01
	Night	23,879	14.4	1.70 (1.46-1.97)	
Jump Type	Administrative/Non-Tactical	34,019	7.0	1.00	<0.01
	Combat Load	29,468	14.9	2.12 (1.81-2.48)	
Lowest Wind Speed	0-1 knot	41,943	9.7	1.00	
	2-5 knots	16,355	9.8	1.01 (0.84-1.21)	<0.01
	6-11 knots	3,185	16.3	1.68 (1.26-1.11)	
Highest Wind Speed	0-1 knot	4,687	9.8	1.00	
	2-4 knots	21,956	7.8	0.79 (0.71-0.93)	
	5-7 knots	21,715	9.3	0.94 (0.69-1.30)	<0.01
	8-10 knots	10,395	14.0	1.43 (1.03-2.00)	
	11-17 knots	2,730	20.5	2.09 (1.42-3.08)	
Dry Bulb Temperature	24-50 degrees F	10,958	7.7	1.00	
	51-70 degrees F	14,551	11.0	1.43 (1.10-1.87)	0.03
	71-90 degrees F	24,991	10.7	1.39 (1.09-1.78)	
	91-104 degrees F	8,330	9.6	1.25 (0.92-1.70)	

Variable	Level of Variable	Jumps (n)	Injury Incidence (cases/1,000 jumps)	Risk Ratio (95%CI)	Chi-Square p-value
Humidity	17-40%	15,451	9.4	1.00	<0.01
	41-60%	17.949	12.3	1.31 (1.07-1.62)	
	61-80%	19,782	8.4	0.89 (0.72-1.12)	
	81-97%	5,528	10.3	1.10 (0.81-1.49)	
Aircraft	C130 Hercules (fixed wing)	40,313	11.4	1.00	<0.01
	C17 Globemaster (fixed wing)	16,955	11.9	1.05 (0.89-1.23)	
	C23 Sherpa (fixed wing)	2,751	3.3	0.29 (0.15-0.56)	
	C160 Transall (fixed wing)	784	7.7	0.67 (0.30-1.50)	
	C212 CASA Aviocar (fixed wing)	73	0.0	-----	
	CH47 Chinook (rotary wing)	1,644	1.2	0.11 (0.03-0.43)	
	UH60 Blackhawk (rotary wing)	967	0.0	-----	
Aircraft Exit Door	Left	28,279	10.8	1.00	<0.01
	Right	28,334	11.7	1.09 (0.93-1.27)	
	Tailgate	4,468	2.5	0.23 (0.13-0.42)	
Jump Order	1-5	11,140	11.7	1.00	0.42
	6-10	10,221	11.3	0.97 (0.76-1.25)	
	11-15	9,930	10.5	0.90 (0.98-1.26)	
	16-20	9,100	9.8	0.84 (0.64-1.10)	
	21-25	8,417	11.4	0.98 (0.75-1.27)	
	26-30	7,143	11.1	0.95 (0.72-1.25)	
	31-35	3,066	6.2	0.53 (0.32-0.86)	
	36-40	1,914	8.9	0.76 (0.46-1.23)	
	41-45	1,521	11.2	0.96 (0.58-1.58)	
	46-52	883	11.3	0.97 (0.51-1.84)	
Military Rank	Junior Enlisted (E1-E4)	33,393	11.3	1.00	0.29
	Senior Enlisted (E5-E9)	20,614	11.0	0.97 (0.82-1.14)	
	Warrant Officer	633	9.0	0.84 (0.37-1.86)	
	Junior Officer (O1-O3)	6,482	8.3	0.73 (0.55-0.97)	
	Field Grade Officer (O4-O8)	781	12.8	1.12 (0.60-2.11)	
Drop Zone	Sicily	41,002	10.2	1.00	<0.01
	Luzon	8,291	7.8	0.78 (0.60-1.01)	
	Normandy	5,550	12.3	1.20 (0.93-1.54)	
	Nijmegen	2,334	13.3	1.30 (0.90-1.86)	
	Holland	3,477	6.9	0.67 (0.44-1.02)	
	Geronimo	1,654	35.1	3.42 (2.61-4.49)	
	Rock Air Force Base	700	8.6	0.84 (0.37-1.87)	
	Salerno	291	17.2	1.68 (0.70-4.02)	
	Clute	115	0.0	-----	
	Saint Mere Eglise	73	0.0	-----	
Entanglement	No	63,465	10.6	1.00	<0.01
	Yes	22	363.6	34.48 (19.61-58.82)	

Abbreviations: F=Fahrenheit, 95%CI=95% confidence interval

e. Table 7 shows the results of the backward stepping multivariate logistic regression analysis. There were 58,830 jumps (93%) that had complete data and could be included in the analysis (logistic regression required complete data on all variables). Independent risk factors for injuries included the T-10D parachute, night jumps, combat loads, higher wind speeds, higher dry bulb temperatures, and entanglements.

Table 7. Multivariate Associations between Risk Factors and Airborne Injury Risk

Variable	Level of Variable	Jumps (n)	Odds Ratio (95%CI)	Wald Statistic p-value
Parachute	T-10	54,713	1.00	Referent
	T-11	4,117	0.61 (0.40-0.95)	0.03
Time of Day	Day	36,726	1.00	Referent
	Night	22,104	1.34 (1.06-1.69)	0.02
Jump Type	Admin/Non-Tactical	31,550	1.00	Referent
	Combat Load	27,280	1.95 (1.56-2.44)	<0.01
Highest Wind Speed	0-1 knot	4,503	1.00	Referent
	2-4 knots	20,451	1.23 (0.85-1.77)	0.27
	5-7 knots	21,222	1.40 (0.98-2.01)	0.07
	8-10 knots	10,395	2.67 (1.82-3.92)	<0.01
	11-17 knots	2,259	2.81 (1.72-4.57)	<0.01
Dry Bulb Temperature	37-50 degrees F	10,958	1.00	Referent
	51-70 degrees F	14,551	1.71 (1.29-2.27)	<0.01
	71-90 degrees F	24,991	1.56 (1.21-2.01)	<0.01
	91-104 degrees F	8,330	1.78 (1.27-2.48)	<0.01
Entanglement	No	58,808	1.00	Referent
	Yes	22	56.05 (22.57-139.19)	<0.01

Abbreviations: Admin=administrative, F=Fahrenheit, 95%CI=95% confidence interval

Table 8 shows injury incidence with parachute type stratified on time of day, type of jump, highest wind speed, dry bulb temperature, and entanglements. In all cases but one (highest dry bulb temperature), injury incidence tended to be higher with the T-10D parachute compared to the T-11. Compared to the T-10D, the T-11 injury rates were lowest during night jumps and with combat loads; there were more modest differences during daytime and administrative/non-tactical jumps. Results for wind speed and dry bulb temperature were mixed. There were only two entanglements with the T-11, none resulting in injury.

Table 8. Injury Risk with Parachute Type Stratified on Other Injury Risk Factors

Variable	Strata	T-10		T-11		Risk Ratio T-10/T-11 (95%CI)	Chi-Square p-value	M-H Odds Ratio (95%CI)	M-H p-value
		Jumps (n)	Injury Incidence (cases/ 1,000 jumps)	Jumps (n)	Injury Incidence (cases/ 1,000 jumps)				
Time of Day	Day	36,432	8.6	3176	6.6	1.30 (0.84-2.02)	0.24	1.92(1.24-2.94)	<0.01
	Night	22,938	14.9	941	1.1	14.03 (1.97-99.78)	<0.01		
Type of Jump	Admin/Non-Tact	30,843	7.1	3176	6.6	1.07 (0.68-1.67)	0.77	1.72 (1.11-2.65)	0.01
	Combat Load	28,527	15.4	941	1.1	14.45 (2.0-102.69)	<0.01		
High Wind Speed	0-1 knot	4,687	9.8	0	0.0	-----	-----	1.93 (1.26-2.96)	<0.01
	2-4 knots	20,621	7.9	1,335	6.0	1.32 (0.65-2.68)	0.44		
	5-7 knots	19,808	9.9	1,907	2.6	3.77 (1.56-9.16)	<0.01		
	8-10 knots	9,571	14.3	824	10.9	1.31 (0.67-2.56)	0.43		
	11-17 knots	2,679	20.9	51	0.0	-----	0.30		
Dry Bulb Temp	37-50 deg F	10,430	7.8	528	5.7	1.37 (0.43-4.31)	0.59	2.02 (1.31-3.09)	<0.01
	51-70 deg F	13,542	11.5	1,009	4.0	2.91 (1.08-7.82)	0.03		
	71-90 deg F	22,654	11.3	2,337	5.1	2.19 (1.23-3.91)	<0.01		
	91-104 deg F	8,087	9.5	243	12.3	0.75 (0.25-2.43)	0.66		
Entangle-ment	No	59,350	10.9	4,115	5.3	2.04 (1.34-3.12)	<0.01	2.09 (1.37-3.19)	<0.01
	Yes	20	400.0	2	0.0	-----	0.26		

Abbreviations: Admin/Non-Tact=Administrative/Non-Tactical, Deg F=Degrees Fahrenheit, Temp=Temperature, 95%CI=95% Confidence Interval, M-H= Mantel-Haenszel

7. DISCUSSION.

a. Comparison of Parachutes

(1) The present investigation found that the cumulative injury incidence was 52% lower with the T-11 (univariate analysis) compared to the T-10D parachute. Even after accounting for other injury risk factors including time of day, type of jump, wind speeds, temperature, and entanglements, in the multivariate logistic regression, the injury risk was still lower with the T-11. The reduced injury risk may at be attributed at least in part to the slower descent rate of the T-11 and the subsequent reduced impact energy on ground contact. Despite the lower injury rate, stratifying injury risk on parachute type and other injury risk factors revealed some important nuances. It would initially appear that most of the T-11 injury reduction effectiveness occurred during night jumps and with combat loads. This seemed very favorable since operational scenarios of the 82nd Airborne Division envision night jumps with combat loads and these data suggested that there could be reductions in injury rates in combat operations. However, the T-11 nighttime combat loaded jumps were conducted during a few consecutive days when a large number of Soldiers participated in a Joint Forces Access Exercise (JOAX) involving a large number of planes and jumps. There were only 941 T-11 jumps during this exercise and only one T-11 injury during the JOAX. That injury was the single fatality. There is a considerable body of literature indicating that jumps with combat loads and jumps at night result in increase injury risk.[1, 9, 12, 13, 15] It is highly unlikely that the T-11 actually has a lower injury rate in nighttime jumps with combat loads,

compared to daytime administrative non-tactical jumps. It is more likely that the lower injury risk might be attributed to the small number of jumps and the statistical uncertainty associated with small sample sizes. The Mantel-Haenszel procedure (Table 8) suggested that the combined injury risk for both parachutes was 1.9 times higher at night and 1.7 times higher with combat loads. Thus, considerable caution should be exercised in interpreting this information until additional T-11 data can be obtained.

(2) We conducted one previous investigation with the T-11 parachute at the US Army Airborne School.[40] In this investigation, basic airborne trainees performed their very first jump (for 7% it was their second jump) with the T-11 and all subsequent jumps with the T-10D. Because the T-11 jump was a daytime, administrative/non-tactical jump, the T-10D was compared to the T-11 under these conditions only. The overall injury risk was 44% lower with the T-11. In the present investigation, injury risk during daytime, administrative/non-tactical jump was 23% lower with the T-11, a smaller risk reduction. Presumably because of the low number of T-11 jumps, this 23% difference was not statistically significant and this again emphasizes the need to collect more T-11 jumps to increase the statistical power of the comparison.

b. Overall Injury Incidence.

(1) The overall crude injury incidence in the present study was almost identical to that of our previous investigation (10.7 versus 10.5 injuries/1,000 jumps).[12] This might be expected at least partially because the investigation involved the same cohort and 36% of the data (23,031 jumps) was the same. The overall crude injury rate of 10.7/1,000 jumps was similar to the incidence of 10.9/1,000 jumps reported in a study of a British operational unit where the investigator defined and collected injuries in a manner almost identical to the present investigation.[13] Another British study that collected data in a similar manner during WWII had a much higher injury incidence of 21.0/1,000 jumps,[6] but these data were obtained at a time when military airborne techniques and equipment were in an early stage of development. In studies where more restrictive injury definitions were used (e.g., time loss injuries, hospital visits), incidences of 0.6 to 51/1,000 jumps have been reported. When all injuries and jumps were combined in the studies with restrictive injury definitions (6,408 injuries in 1,192,446 jumps) the incidence was 5.4/1,000 jumps.[9, 23-30] Injury incidences in basic airborne training (post-1950) have ranged from 4 to 10/1,000 jumps. When all jumps and injuries were combined in these basic training studies (2,000 injuries in 300,589 jumps) the incidence was 6.7/1,000 jumps.[1, 14, 15, 19-22] The variations in injury incidences may be attributed not only to differences in injury definitions and training experience, but also to the risk factors that likely differ in the different investigations.

(2) Four previous reports have involved Soldiers and drop zones at Ft Bragg, North Carolina.[11, 12, 27, 29] One study[11] reported an injury incidence of 24.6/1,000 jumps for a single jump operation with troops jumping at night with combat loads. If only night

jumps with combat loads and T-10 parachutes were considered in the present study, the overall injury incidence was 16.1/1,000 jumps, a 35% lower incidence. Two other studies[27, 29] surveyed parachute injuries at Ft Bragg from May 1993 to December 1994 and from May 1994 to April 1996. The crude injury incidences were 8.0 and 8.1 /1,000 jumps in the two periods, respectively. When only T-10 jumps onto Ft Bragg drop zones were considered in the present investigation the injury incidence was 10.4/1,000 jumps, a higher injury rate. However, the two previous studies at Fort Bragg[27, 29] only obtained injuries that were seen in the emergency room at the Fort Bragg Womack Army Community Hospital. In the present investigation, injuries were also obtained on the drop zone, some of which were not evacuated to the hospital. If only T-10 injuries occurring on Ft Bragg drop zones which were evacuated to hospitals and clinics in the present investigation were included (n=526) the injury incidence was 9.2/1,000 jumps, somewhat similar to, though slightly higher than, the two earlier studies.[27, 29]

c. Events Associated with Injury.

(1) Only four studies have actually reported events associated with military parachuting injuries,[12, 23, 26, 29] although others have provided speculation and anecdotal observations on how injuries might occur.[6, 45-47] When events were reported in three of these previous studies,[23, 26, 29] the categories for the events differed from those in the present investigation. Nonetheless, these previous studies provide at least some basis for comparison. Neel[23] reported on 140 parachute injury cases within the 82nd Airborne Division at Fort Bragg in 1946. At least 61% of injuries were associated with ground impacts and 6% were associated with aircraft exits. Farrow[26] provided details on all 63 injuries experienced by the Australian Parachute Battalion Group from March 1987 to December 1988. The battalion jumped from C130 Hercules and C7 Caribou (tailgate exit) aircraft using T-10 parachutes. Ground impacts, exit procedures, and tree landings accounted for 59%, 10%, and 6%, respectively, of activities associated with injury. This compares with 85%, 2%, and 2%, respectively, in the present investigation. In our previous investigation[12] these values were 75%, 11%, and 4%, respectively.

(2) By far, the event associated with the largest number of injuries was ground impact. To reduce the number of ground impact injuries, PLFs were introduced into the American Army in 1943. Weekly injury reports issued at the Fort Benning, Georgia Parachute School in 1943 suggested that injuries were trending downward before the PLF became Airborne doctrine, but injuries were definitely reduced just after introduction of the PLF.[33, 48, 49] PLFs as executed today require that, prior to ground contact, the Soldier keep feet and knees together, with hips and knees slightly flexed. The Soldier makes ground contact with the balls of the feet, then rapidly distributes the kinetic energy of the impact through the body by falling sideways and allowing the feet, calves, thighs, buttocks, and back to progressively make contact with the ground.[7, 30] This sequence of events can be made difficult or impossible if the ground is uneven or has obstructions. Under these conditions, soldiers may not be able to keep their legs

and knees together or to make the required rapid series of ground contacts across the body. Wind conditions can exacerbate problems by causing parachute oscillations that result in greater impact energy. Winds from the front can force a Soldier into a rear PLF which is very difficult to properly execute.

(3) Craig and Lee[29] reported on altitude injuries at Ft Bragg from May 1994 to April 1996 (24 months). Altitude injuries were defined as those occurring from aircraft exit to just before ground impact. They reported that 6% of all parachute injuries were of this type and that the incidence was 0.46/1,000 jumps. In the present investigation, if T-10 injuries associated with static lines, exit procedures, entanglements, and parachute riser injuries were combined, they would account for 8% of all injuries (54 of 656 T-10 injuries). However, Craig and Lee[29] only reported on injuries that were seen in the emergency room at the Fort Bragg Womack Army Medical Center. If only altitude injuries that were evacuated to the hospital were considered in the present investigation, these would be 7% of all injuries (43 of 582 injuries), for an incidence of 0.68/1,000 jumps. This is 1.5 times higher than the Craig and Lee study.[29]

(4) Static line problems accounted for the second largest number of injuries in the present investigation. The 82nd Airborne Division requires that all static line problems be listed on flash reports. The incidence of static line injury in Craig and Lee's study[29] was 0.15/1,000 (37 in 242,949 jumps) while the incidence of T-10 static line injuries evacuated to the hospital in the present investigation was more than 3 times as great, 0.47/1,000 jumps (30 in 63,4871jumps). Injuries of this type occur when the static line is not properly handed to the safety, if the safety does not properly clear the static line, or if the parachutist's arm is wrapped around the line on aircraft exit. Proper training in static line management and attention to detail when handing off the static line to the safety can reduce injuries of this type. Jumpmaster training should emphasize key elements in static line management so jumpmasters can recognize and rapidly correct situations where static line injuries might occur.

d. Injury Risk Factors. In the present investigation, support was provided for the classic military airborne risk factors since higher injury incidence was associated with higher wind speeds,[1, 6, 12, 13, 15] night jumps,[1, 6, 9, 12-15] and combat loads.[1, 12, 13, 15] We also replicated results from our previous investigation[12] of risk factors for Airborne injuries (discussed below), as would be expected since some of the same data was used.

(1) Entanglements.

(a) The T-10D entanglement incidence of 0.35/1,000 jumps in the present study was substantially lower than the incidence of 0.87/1,000 jumps reported in Airborne School training at Fort Benning, Georgia.[1] The lower incidence may reflect the higher level of experience among the 82nd Airborne Division Soldiers. The primary cause of high altitude entanglements is assumed to be weak and simultaneous exits from opposite sides of the aircraft such that the aircraft slip stream forces jumpers towards each other as their parachutes deploy. Hadley and Hibst[25] studied a procedure called the controlled alternating parachute exit system (CAPES) in which jumpers exited the 2 sides of the aircraft at slightly different times (e.g., a 1-sec delay). This resulted in a substantial decrease in high altitude entanglements from 0.71/1,000 jumps in the year before the procedure was employed to 0.19/1,000 jumps in the year that the procedure was first instituted. In practice, jumpers have a difficult time maintaining the 1-sec separation. If a Soldier rushes the door or hesitates slightly, this can disrupt the timing and still result in simultaneous exits from both sides of the aircraft.

(b) When an entanglement occurred, there was a high probability of an injury. Eight of the 22 entangled jumpers were injured (36%) and all but one of the entanglement-related injuries occurred among jumpers who remained entangled to the ground. It should be remembered that the number of entanglements was small. Nonetheless, the large proportion of injuries associated with the entanglements supports the training practice of instructing Soldiers to disentangle as soon as possible.

(c) There was a tendency for the T-11 to have a larger entanglement incidence than the T-10, although this difference was not statistically significant (0.34 versus 0.49/1,000 jumps, RR=1.44, 95%CI=0.34-6.17, p=0.62). Our previous investigation[40] at the USAAS at Ft Benning suggested just the opposite, that entanglement incidence was lower with the T-11. However, this latter finding may have been an artifact: in that investigation, the T-11 was used primarily on the first training jump and more time than usual was allowed between jumper aircraft exits and this may have reduced the risk of entanglements. Hypothetically, the T-11 could either increase or decrease entanglement risk. The larger canopy of the T-11 would reduce free airspace between jumpers during descents and might elevate entanglement risk. On the other hand, the longer deployment time of the T-11 (6 sec, versus 3 sec for the T-10) may allow jumpers to fall further below the aircraft slip stream possibly reducing the risk of high altitude entanglements. How these and other factors might affect T-11 entanglements will have to await further data on the new parachute.

(2) Wind Speed. A number of previous studies had shown that higher injury incidence was associated with higher wind speeds[1, 6, 12, 13, 15] and wind speed was an independent injury risk factor in the present investigation. Winds increase the horizontal velocity vector of the jumper and increase ground impact velocity when added to the vertical velocity vector. High winds can also drag Soldiers on the ground after they land and before they have time to collapse their parachute canopies and this situation can also increase injury risk. While jumpers are in the air, high winds can push the parachutist away from pre-planned drop zones into obstacles, rougher terrain, or trees. Tree landings are especially hazardous, since a collision with a tree can be followed by an uncontrolled ground impact if the parachutist falls from the tree. In the present investigation, there were 8 injuries associated with tree landings but because there is no routine collection on the overall number of tree landings by the 82nd Airborne Division, we cannot calculate the risk of injury from tree landings.

(3) Combat Loads and Night Jumps.

(a) A number of studies have shown that combat loads increase injury risk[1, 12, 13, 15] and this was an independent injury risk factor in the present investigation. Extra equipment increases descent velocity resulting in greater impact energy on ground contact. Since the extra equipment is lowered on a strap before ground impact and arrives on the ground before the jumper, the equipment may also create a landing zone hazard. It has also been hypothesized that combat loads may increase the risk of entanglements.[41] However, in the present investigation, there was no difference in entanglement incidence between administrative/non-tactical jumps and combat load jumps (0.35/1,000 jumps and 0.34/1,000 jumps, respectively).

(b) Another classic airborne injury risk factor is night jumps[1, 9, 12-15] and this was an independent injury risk factor in the present study. During night jumps, Soldiers have reduced ability to see the ground, to perceive distance and depth, and to appreciate the direction of horizontal drift. These and other factors possibly contribute to less controlled landings, reduced ability to see obstacles on the drop zone, and higher injury rates.

(c) In the present study, night jumps with the T-11 actually tended to have a lower risk than jumps during the day and all of these night jumps were with combat loads (Table 8). However, it must be remembered that there were only 941 T-11 night jumps, and in comparison with T-11 day jumps the results are equivocal (RR=(T11 day jumps/T11 night jumps)=6.22, 95%CI=0.84-46.19). This again emphasizes the need for more T-11 data that include more night jumps and jumps with combat loads.

(4) Temperature and Humidity. Higher temperature was an independent risk factor for injury, but humidity alone had a minimal and inconsistent influence on injury incidence. These data are generally in consonance with our previous study using some of the same data as in the present study.[12] The finding is also in consonance with a study that examined the influence of temperature and humidity on injury rates during Belgium (Belge) Airborne training.[15] Assuming a standard pressure of 1013.25 millibars and dry air (gas constant=297 J/kg*K), the density of air would decrease about 11% as the temperature increased from 40 to 95 degrees Fahrenheit (from 1.272 to 1.146 kg/m^3). The less dense air may result in faster descent velocities and this could influence injury rates. However, it should be noted that there was no dose-response in the present data as might be expected if air density alone was the causative factor for the higher injury risk. The largest decrease in injury risk occurred between the two lowest temperature categories and there was little change in risk in subsequent temperature categories.

(5) Aircraft and Exit Doors.

(a) The present study found that the C17 and C130 aircraft were associated with higher injury incidences than the other aircraft examined. However, the type of aircraft was not an independent risk factor in the multivariate analysis. There are several possible explanations for this. First, jumps from C23, C160, CH47, UH60 and C212 were all daytime administrative/non-tactical jumps, and jumps of this type had a lower injury rate in the present investigation and in other studies.[1, 12, 13, 15] Second, jumps from the C17 and C130 aircraft were all conducted at 800 feet above ground level (AGL), while jumps from the C23, were conducted at 1200 to 1500 feet AGL, and all jumps from CH47, UH60, and C212 aircraft were conducted at 1500 feet AGL. Higher jump altitudes may have allowed jumpers to achieve better canopy control and provide more time to prepare for landing. Third, CH47, C23, and C212 jumps were conducted off the tailgate of the aircraft and not out of side doors like the C130 and C17. In tailgate exits, jumpers hooked their static lines to starboard-side anchor cables utilizing a reverse or upside-down bite on the static-line with their left hand. This could have reduced potential static line injuries because it was less likely that a jumper's hand or arm could be routed around the static-line. The distance between where the jumper released grip on the static line and the point where his feet left the aircraft increased significantly with tailgate exits. Finally, in rotary wing aircraft (CH47, UH60) jumpers have more space during exits and during descents, less probability of entanglements, and can better concentrate on landing procedures. Thus, some combination of time of day, higher jump altitudes, less probability of static line problems, and better jumper spacing during descents may explain the lower injury rates in the C23, CH47, UH60, and C212 aircrafts.

(b) When only T-10D, daytime, administrative/non-tactical jumps were considered, injury incidences for the C17, C130 and C160 (i.e., side-door aircraft) were 11.8, 7.7 and 7.7/1,000 jumps, respectively (RR(C17/C130)=1.54, 95%CI=1.07-2.23). The reason for the higher injury incidence in the C17 is not clear but there are several facts to consider. First, jumpers have more experience with the C130 as most jumps are conducted from this aircraft. In the present investigation, 65%, 26% and1% of jumps were conducted with the C130, C17 and C160, respectively. When C17 are employed, they are often used on larger operations with more jumpers involved, although this factor alone (i.e., number of jumpers) did not influence injury rates in the present investigation. Second, the C17 is a jet powered aircraft while the C130 and C160 are propeller driven. Jumpers exiting the C17 have to deal with a larger air wash from the jets. The entanglement incidence was slightly higher with the C17 than with the C130 suggesting that the wash may have had some effect on aircraft exits (0.45 versus 0.29/1,000 jumps, RR=1.57, 95%CI=0.61-4.05). Third, there are differences in the jump platforms for exiting the aircraft. The C17 has a recessed door and the wind is not felt until the jumper exits, while with the C130 the jumper exits from a platform that is extended beyond the door. How these factors might affect injury rates is not clear.

(c) Previous studies[12, 13] have compared jump injury rates between fixed wing and rotary aircraft and found that fixed wing aircraft had higher injury risk. As noted above, all jumps from rotary wing aircraft in the present investigation were administrative/non-tactical daytime jumps. If only T-10D administrative/non-tactical, daytime jumps were considered, injury rates in the present investigation were 7.8/1,000 jumps with the fixed wing aircraft and 0.8/1,000 jumps for the rotary wing aircraft (RR (fixed/rotary)=10.13, 95%CI=2.52-40.77), in consonance with the previous investigations.[12, 13]

(6) Drop Zone.

(a) Previous literature indicated that airborne drops onto sand were less hazardous than jumps onto rougher terrain,[14] or onto dirt landing strips with uneven and unimproved areas around the landing area.[9] Ninety-six percent of jumps covered by this report occurred at drop zones at Fort Bragg. These were Sicily, Luzon, Normandy, Holland, Nijmegen, Salerno, and Saint Mere Eglise. Overall, there were some modest differences in injury incidence among these areas with Holland having the lowest injury incidence and Salerno the highest. Drop zone was not an independent injury risk factor in the multivariate analysis and much of the small differences in injury rates might be accounted for by other factors. Sicily and Holland drop zones have a mixture of sandy and hard-packed soil with sparse grass and other low lying vegetation. There is a hard packed dirt airstrip down the middle of Sicily and Holland and both are surrounded by dense pine forests. Additionally, Holland is located on top of a ridgeline with sloping sides and an Airfield Seizure Training Facility adjacent to the Landing Strip. Normandy and Salerno have similar terrain with the exception of a no Flight Landing Strip (FLS). Nijmegen drop zone is much narrower than the others, with prominently hilly terrain on the northern side. Nijmegen does have a dilapidated and overgrown FLS which is no longer serviceable. Lastly, Luzon drop zone is located on Camp Mackall, which is on the western side of the Fort Bragg reservation. It also has a FLS and its trailing edge borders a heavily traveled state highway. These drop zones have all undergone terrain changes in the last twenty years due to construction to control erosion.

(b) Four percent of jumps occurred at drop zones off Fort Bragg including Clute, Little Rock, and Geronimo. Jumps at Clute drop zone were performed as part of the 64th Annual Convention of the 82nd Airborne Division in Charleston, West Virginia. Jumps at Little Rock drop zone were conducted as part of the Little Rock Air Force Base Air Show near Little Rock, Arkansas. Jumps at Geronimo drop zone were part of an airborne insertion into the Joint Readiness Training Center (JRTC) at Fort Polk, Louisiana. The single operation at Geronimo involved a night jump with combat loads from C130 (92% of jumps) and C17 (8% of jumps) aircraft. This was the first time an

Airborne brigade combat team had conducted an operation of this size into the JRTC and the unfamiliarity with the drop zone paired with the nighttime combat loaded operation may have contributed to the high casualty rate.

8. CONCLUSIONS AND RECOMMENDATIONS. The present investigation found that the T-11 parachute had a lower injury incidence than the T-10D parachute after accounting for a number of other injury risk factors including night jumps, combat load, wind speed, temperature, humidity, entanglements, aircraft, and drop zone. However, most of the injury reduction occurred during night jumps with combat loads and the differences in injury rates during daytime administrative/non-tactical operations was much more modest. Because of the small number of nighttime combat loaded T-11 jumps, extreme caution is advised in drawing inferences from the data collected here. It is strongly recommended that additional data on the T-11 be collected during the full spectrum of operational conditions before conclusions are reached on the effectiveness of the T-11 parachute for reducing injuries.

9. POINTS OF CONTACT. Dr. Joseph Knapik (DSN 584-1328) joseph.knapik@us.army.mil

JOSEPH KNAPIK, ScD
Research Physiologist
Injury Prevention Program

APPROVED:

Bruce Jones, MD, MPH
Program Manger
Injury Prevention Program

APPENDIX A
REFERENCES

1. Knapik, J.J., S. Darakjy, D. Swedler, P. Amoroso, and B.H. Jones. Parachute ankle brace and extrinsic injury risk factors during parachuting. *Aviation, Space and Environmental Medicine*. 79:408-415, 2008.
2. Knapik, J.J., R. Steelman, K. Hodedbecke, T. Grier, B. Graham, K. Klug, S. Rankin, S. Proctor, and B.H. Jones. *Military Airborne Training Injuries and Injury Risk Factors, Fort Bragg North Carolina, June-December 2010*. Aberdeen Proving Ground MD: US Army Public Health Command, Technical Report No. 12-HF-17G072-10, 2011.
3. *Preventive Medicine*. Washington DC: Headquarters, Department of the Army, Technical Report No. 40-5, 2007.
4. Hodge, J.G. An enhanced approach to distinguishing public health practice and human subjects research. *Journal of Law, Medicine and Ethics*. Spring:2-19, 2005.
5. Tobin, W.J., L.J. Cohen, and J.T. Vandover. Parachute Injuries. *JAMA*. 125:318-321, 1941.
6. Essex-Lopresti, P. The hazards of parachuting. *British Journal of Surgery*. 133:1-13, 1946.
7. Bricknell, M.C.M., and S.C. Craig. Military parachute injuries: a literature review. *Occupational Medicine*. 49:17-26, 1999.
8. Knapik, J.J., A. Spiess, D. Swedler, T. Grier, S. Darakjy, P. Amoroso, and B.H. Jones. Injury risk factors in parachuting and acceptability of the parachute ankle brace. *Aviation, Space and Environmental Medicine*. 79:689-694 2008.
9. Kragh, J.F., P.J. Amoroso, B.H. Jones, and R.D. Heekin. Parachuting injuries among Army rangers: a prospective survey of an elite airborne battalion. *Military Medicine*. 161:416-419, 1996.
10. Timboe, H.L. Mass casualty situation: Gallant Eagle 82 airborne operations: a case report. *Military Medicine*. 153:198-202, 1988.
11. Craig, S.C., D. Zugner, J.J. Knapik, and M.C.M. Bricknell. Parachuting injuries during operation Royal Dragon, Big Drop III, Ft Bragg, North Carolina, May 15/16, 1996. *Military Medicine*. 164:41-43, 1999.
12. Knapik, J.J., R. Steelman, T. Grier, B.H. Graham, K. Hoedebecke, S. Rankin, K. Klug, S. Proctor, and B.H. Jones. Military parachuting injuries, associated events, and injury risk factors. *Aviation, Space and Environmental Medicine*. 82:797-804, 2011.
13. Lillywhite, L.P. Analysis of extrinsic factors associated with 379 injuries occurring during 34,236 military parachute descents. *Journal of the Royal Army Medical Corps*. 137:115-121, 1991.
14. Hallel, T., and L. Naggan. Parachute injuries: a retrospective study of 83,718 jumps. *Journal of Trauma*. 15:14-19, 1975.
15. Pirson, J., and E. Verbiest. A study of some factors influencing parachute landing injuries. *Aviation, Space and Environmental Medicine*. 56:564-567, 1985.
16. Kotwal, R.S., D.E. Meyer, K.C. O'Connor, B.A. Shahbaz, T.R. Johnson, R.A. Sterling, and R.B. Wenzel. Army Ranger casualty, attrition and surgery rates for

airborne operations in Afghanistan and Iraq. *Aviation, Space and Environmental Medicine*. 75:833-840, 2004.
17. Miser, W.F., W.A. Lillegard, and W.C. Doukas. Injuries and illness incurred by an Army Ranger unit during Operation Just Cause. *Military Medicine*. 160:373-380, 1995.
18. Pozner, H. Parachutists. *Journal of the Royal Army Medical Corps*. 86:208-217, 1946.
19. Lowden, I.M.R., and M.H. Wetherill. Parachute injuries during training descents. *Injury*. 20:257-264, 1989.
20. Pirson, J., and M. Pirlot. A study of the influence of body weight and height on military parachute landing injuries. *Military Medicine*. 155:383-385, 1990.
21. Bar-Dayan, Y., J. Shemer, and Y. Bar-Dayan. Parachute injuries: a retrospective study of 43,542 military jumps. *Military Medicine*. 163:1-2, 1998.
22. Amoroso, P.J., J.B. Ryan, B. Bickley, P. Leitschuh, D.C. Taylor, and B.H. Jones. Braced for impact: reducing paratrooper's ankle sprains using outside-the-boot braces. *Journal of Trauma*. 45:575-580, 1998.
23. Neel, S.H. Medical aspects of military parachuting. *The Military Surgeon*. 108:91-105, 1951.
24. Roche, C.A. Of men, medicine and military parachuting. *Military Medicine*. 125:512-521, 1960.
25. Hadley, A.T., and J.D. Hibst. Reduction of military high-altitude parachute entanglements using the controlled alternating parachute exit system. *Aviation, Space and Environmental Medicine*. 55:65-68, 1984.
26. Farrow, G.B. Military static line parachute injuries. *Australian and New Zealand Journal of Surgery*. 62:209-214, 1992.
27. Craig, S.C., and J. Morgan. Parachuting injury surveillance, Fort Bragg, North Carolina, May 1993 to December 1994. *Military Medicine*. 162:162-164, 1997.
28. Schumacher, J.T., J.F. Creedon, and R.W. Pope. The effectiveness of the parachute ankle brace in reducing ankle injuries in an airborne ranger battalion. *Military Medicine*. 165:944-948, 2000.
29. Craig, S.C., and T. Lee. Attention to detail: injuries at altitude among U.S. Army military static line parachutists. *Military Medicine*. 165:268-271, 2000.
30. Hay, S.T. Parachute injuries in the Australian Airborne Battle Group in 2004. *Australian Defense Force Health*. 7:73-77, 2006.
31. Hughes, C.D., and P.C.L. Weinrauch. Military static line parachute injuries in an Australian commando battalion. *Australian and New Zealand Journal of Surgery*. 78:848-852, 2008.
32. Buxton, N., D. Gilliam, M. House, and D. Kean. Injuries caused by parachute risers during foreign military parachuting. *Military Medicine*. 171:1057-1058, 2006.
33. Richards, G. *World War II Troop Type Parachutes Allies: U.S., Britian, Russia*. Atglen, PA: Schiffer Publishing Limited, 2003.
34. Weeks, J. *Airborne Equipment. A History of Its Development*. New York, New York: Hippocrene Books, Inc., 1976.
35. US Army Test and Evaluation Command. *Operational Test Agency Evaluation*

Report (OER) for the Advanced Tactical Parachute System (ATPS) Milestone C-Type Classification. Alexandria VA: US Army Test and Evaluation Command, Technical Report No., 2009.
36. Knapik, J.J., and K. Reynolds. *Loads carried in military operations: A review of historical, biomechanical and medical aspects*. Washington DC: Borden Institute, Technical Report No., 2010.
37. Knapik, J.J., M.A. Sharp, S. Darakjy, S.B. Jones, K.G. Hauret, and B.H. Jones. Temporal changes in the physical fitness of United States Army recruits. *Sports Medicine*. 36:613-634, 2006.
38. Dubik, J.M., and T.D. Fullerton. Soldier overloading in Grenada. *Military Review*. 67:38-47, 1987.
39. Allen, K. *Final Test Report for the Developmental Test of the Advanced Tactical Parachute System*. Yuma Proving Ground AZ: Yuma Test Center, Technical Report No. YPG 06-136, 2006.
40. Knapik, J.J., B. Graham, R. Steelman, K. Collier, and B.H. Jones. The Advance Tactical Parachute System (T-11): Injuries during basic military parachute training. *Aviation, Space and Environmental Medicine*. 82:935-940, 2011.
41. Knapik, J.J., S.C. Craig, K.G. Hauret, and B.H. Jones. Risk factors for injuries during military parachuting. *Aviation, Space and Environmental Medicine*. 74:768-774, 2003.
42. Amoroso, P.J., N.S. Bell, and B.H. Jones. Injury among female and male parachutists. *Aviation, Space and Environmental Medicine*. 68:1006-1011, 1997.
43. Fleiss, J. *Statistical Methods for Rates and Proportions*. New York: John Wiley and Sons, 2003.
44. Kahn, H.A., and C.T. Sempos. *Statistical Methods in Epidemiology*. New York: Oxford University Press, 1989.
45. Davis, W.R. Parachute injuries: their prevention. *Military Medicine*. 129:1071-1076, 1964.
46. Kiel, F.W. Hazards of military parachuting. *Military Medicine*. 130:512-521, 1965.
47. Davidson, D.J. A review of parachuting injuries. *Injury*. 21:314-316, 1990.
48. Lord, C.D., and J.W. Coutts. A study of typical parachute injuries occurring in two hundred and fifty thousand jumps at the parachute school. *Journal of Bone and Joint Surgery (American)*. 26:547-557, 1944.
49. Lord, C.D., and J.W. Coots. Typical parachute injuries. A study of those occurring in 250,000 jumps at the parachute school. *JAMA*. 125:1182-1187, 1944.