Mark A. Lowry,[1] M.D.; Paul F. M. Mellen,[2] M.D.; and Victor W. Weedn,[3] M.D., J.D.

Ejection Seat Aircraft Fatalities in the United States Military, 1966 to 1990

REFERENCE: Lowry, M. A., Mellen, P. F. M., and Weedn, V. W., **"Ejection Seat Aircraft Fatalities in the United States Military, 1966 to 1990,"** *Journal of Forensic Sciences*, JFSCA, Vol. 39, No. 5, September 1994, pp. 1153–1160.

ABSTRACT: When a military jet aircraft becomes incapable of controlled powered flight, the aircrew has the alternative of initiating the ejection sequence. In a majority of cases the ejection sequence is successful in extracting the aircrew from probable death. However, in a minority of cases the ejected aircrewmember does not survive. We analyzed 57 autopsy cases from 1966 to 1990 of military aircraft fatalities in which ejection was initiated. These cases were analyzed for injury patterns, age, rank, military branch, type of aircraft, and circumstances surrounding the ejection. The majority of fatalities occurred during "out-of-envelope" ejections and were associated with extreme whole-body trauma. Drowning fatalities were associated with relatively minor traumatic injury. Parachute malfunctions resulted in extreme total-body decelerative injuries. The remainder of the fatalities were due to man-seat separation failure, human error, and unfortunate circumstances. Two cases of hangman's type cervical neck fracture were observed during high-speed ejection.

KEYWORDS: pathology and biology, ejection seat, aviation pathology, aircraft accident investigation, military aviation

Many hazards are inherent to military aviation. The evolution of ejection seat-equipped aircraft has allowed for the survival of hundreds of airmen who were facing death from an impending crash. A tremendous investment of time, money, and engineering has transpired since the first automated ejections in the 1940s [*1–4*].

The most recent generation of ejection seats are capable of multiple modes of operation, depending upon factors such as airspeed, aircraft attitude, and altitude at time of ejection [*5–7*].

The U.S. military safety centers have published survival rates of 75 to 90 percent of the aircrew who eject from aircraft [*8–9*]. Therefore, only a minority of aviators fail to survive once they choose to eject from a stricken aircraft.

Received for publication 31 March 1993; accepted for publication 15 March 1994.

[1]CPT, MC, FS, USA, Department of Pathology, Walter Reed Army Medical Center, Washington, D.C.

[2]MAJ, MC, FS, USA, Office of the Armed Forces Medical Examiner, Armed Forces Institute of Pathology, Washington, D.C.

[3]LTC, MC, FS, USA, Office of the Armed Forces Medical Examiner, Armed Forces Institute of Pathology, Washington, D.C.

The opinions or assertions contained herein are the private views of the authors and are not to be construed as official or as reflecting the views of the Department of the Army or the Department of Defense.

The ejection sequence may vary in the many makes of ejection seats available but does have certain commonalities.

Ejection seats are equipped with a lower ejection handle and depending on the make of the seat, may have an upper handle (Fig. 1). Once armed, briskly pulling on the handle will initiate ejection. After the handle is pulled, an explosive cartridge will rapidly propel the seat up twin rails out of the aircraft. This is followed by the ignition of a rocket motor that further propels the seat clear of the airframe. A small drogue parachute will then deploy to stabilize the seat. This extracts a larger main parachute which will then inflate. Some models have a ballistic spreader gun that assists this inflation. Following inflation of the main parachute, the ejectee will separate from the seat and descend to surface impact.

Each make of ejection seat has individual design parameters for operation and safe delivery of the crewmember to the ground and is termed "the envelope of operation."

The primary physical parameters that determine this "envelope" are the aircraft's height above ground, nose attitude, bank angle, sink rate and airspeed at the time of ejection. The term "out of envelope" is used to designate circumstances that are beyond the performance capabilities of the ejection seat to operate fully, that is, for the seat to clear the aircraft, the ejectee to separate from the seat, and the parachute to have full inflation with deceleration prior to surface impact. Many of the modern ejection seats can accomplish this entire sequence in less than 5 seconds at zero airspeed and zero altitude with wings level [14].

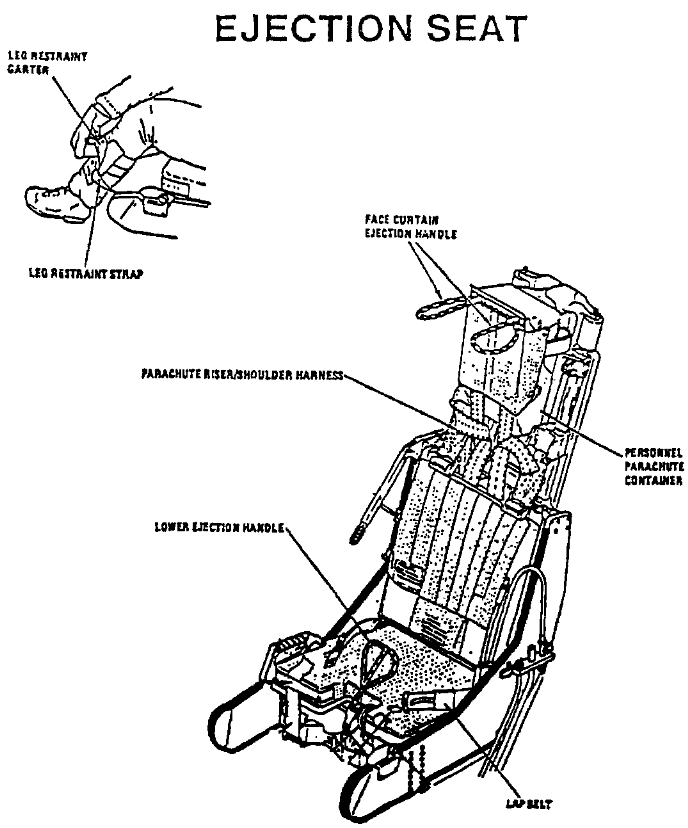


FIG. 1—*Example of ejection seat with upper and lower handles. (Modification of Figure 1-7, NATOPS Flight Manual, AV-8A and TAV-8A Aircraft, NAVAIR 01-AV8A-1, 1978, pp.* [1] *25.)*

Methods

The case files of the Armed Forces Institute of Pathology were searched via computer for aviation fatalities occurring between 1966 and 1990 in which the ejection sequence had been initiated.

Seventy-nine cases were initially identified. Of these, eleven records were irretrievable, nine contained toxicology only, and two cases were miscoded (no ejection had been initiated). This allowed for the examination of 57 autopsy cases of aircrewman who suffered fatal injury during the ejection sequence.

The recovered files were analyzed for age, rank, branch of service, aircraft type, injury patterns, and the time point in the ejection sequence at which the fatal injury/injuries occurred.

Results

Injury patterns did not correlate with age, branch of service, or aircraft type. A correlation of the type and degree of injury was observed with the time point in the sequence at which injury occurred [Fig. 2 and Table 1].

Out of Envelope

The vast majority of fatalities (28/57 cases) occurred during "out-of-envelope" ejections. These fatalities sustained extreme whole-body trauma with nonsurvivable injuries. All of these cases had major head injuries, as well as numerous thoracic, abdominal, and extremity injuries. Documentation of spinal injuries tended to underrepresented due to the absence of whole-body X-rays and/or spinal dissections in some of the earlier cases.

Initiation Phase

One ejectee failed to leave the aircraft after pulling the ejection handle at the exact instant of impact. He suffered whole-body trauma and fragmentation.

In-Rail and Rocket Ascent Phase

Two cases of high-speed ejections resulted in "hangman's-type" C2 vertebral fractures, which were caused by the wind buffeting of the aviators' helmets. The accident board had determined that one of the aviators had a loose-fitting helmet, which contributed to the injury.

One ejectee fell to his death because he was not strapped to his parachute harness and ejection seat. He suffered massive deceleration injuries similar to those observed in the parachute-malfunction group.

Man-Seat Separation Phase

There were three cases of within-envelope ejections in which the aviator failed to separate from the ejection seat. Impacting the ground in contact with a 200 lb ejection seat resulted in whole-body trauma, particularly head injury. All three fatalities sustained cranial eviscerations, one with complete decapitation.

Parachute Descent Phase

One fatality occurred when the seat struck the ejectee following man-seat separation, resulting in a basilar skull fracture and a T4 vertebral fracture.

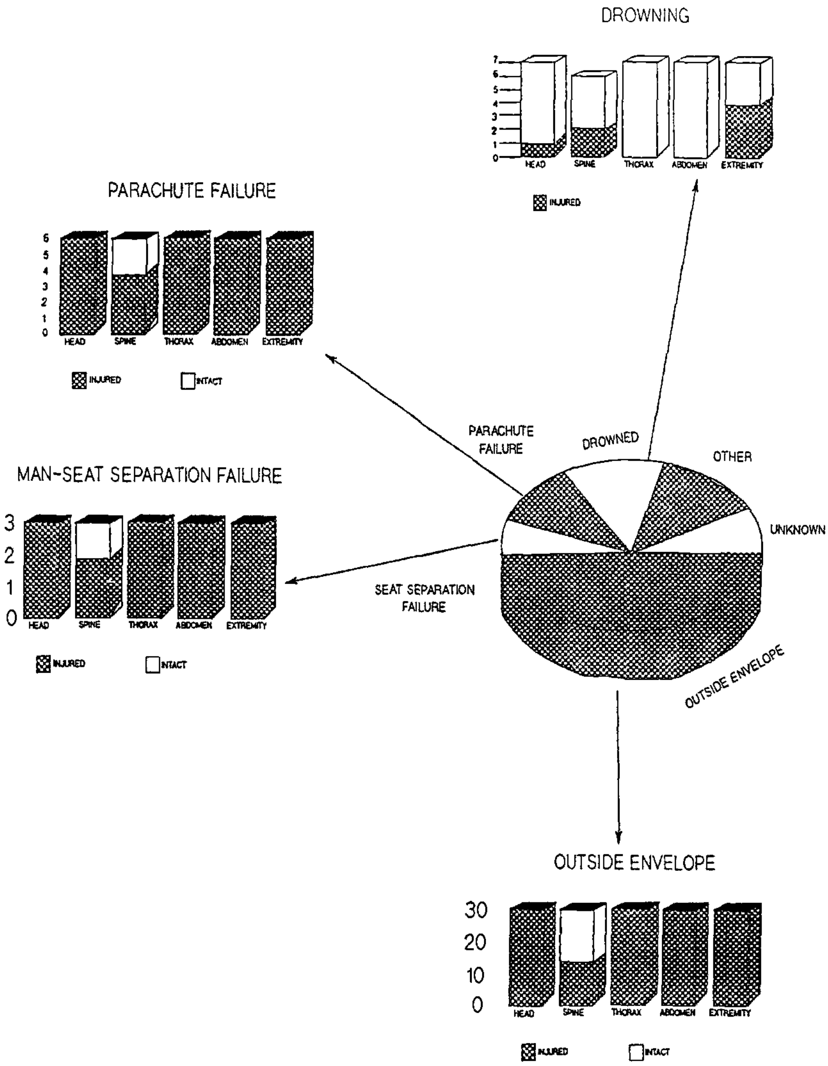


FIG. 2—*Graphic representation of major anatomic injury patterns in relation to the moment in the ejection sequence during which fatal injury was incurred.*

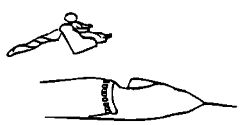
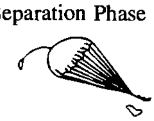
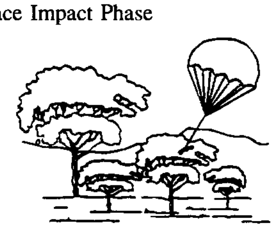
One case of strangulation-type asphyxiation occurred when the aviator became entangled in twisted parachute risers.

In six instances the ejectees experienced failures or malfunctions of their parachutes, resulting in extreme deceleration injuries to the head, thorax, spine, abdomen, and extremities.

Surface Impact Phase

Drowning comprised the second largest group of deaths (7/57 cases). None of the individuals had sustained injuries that were inherently fatal. Three had extremity injuries

TABLE 1—*Ejection sequence summary.*

Ejection Sequence	Circumstances & Injuries	#	%
Out-of-Envelope	Out-of-Envelope Massive Whole Body Trauma	28	49%
Initiation Phase 	Failed To Leave Aircraft: Whole Body Fragmentation	1	2%
Ascent Phase 	High Speed Ejection: Flail Injury & C-2 Vertebral Neck Fractures	2	3%
	Not Strapped To Seat: Extreme Decelerative Injuries	1	2%
Man-Seat Separation Phase 	Failed To Separate From The Seat: Whole Body Trauma, Particularly Massive Head Trauma	3	5%
Parachute Descent Phase 	Struck by Seat After Separation: Basilar Skull Fracture, T4 Vertebral Fracture	1	2%
	Entangled In Parachute Risers: Pulmonary Edema, Ligature Marks On Neck	1	2%
	Failure of Parachute Deployment: Extreme Whole Body Decelerative Injuries	6	10%
Surface Impact Phase 	Drowned: Pulmonary Edema, Temporal Bone Hemorrhage; Non-Lethal Spinal, Extremity, Head Injuries	7	12%
	Entangled in Tree: Pulmonary And Cerebral Edema	1	2%
	Struck Head On Ground: Closed Head Injury	1	2%
	Uncertain Circumstances 4/5 With Whole Body Trauma	5	9%

(2 with femur fractures). Two sustained nonlethal spinal injuries, one of whom had a postauricular contusion and was probably unconscious at water impact.

One aviator died of positional asphyxia after he landed upside down in thick jungle foliage and dropped his extrication knife, which was not attached to a lanyard.

One aviator died of closed-head injury incurred during parachute landing.

Unknown/Uncertain

Five cases were uncertain due to incomplete, inconclusive, or absent aircraft accident board records, prohibiting correlation with the circumstances surrounding the ejection. Four of the five aviators had suffered total-body injuries similar to the "out-of-envelope" fatalities.

Toxicology

Postmortem toxicologic data was available for review in 45 cases. In six cases postmortem alcohol was present in levels consistent with putrefaction. There was no evidence of premortem alcohol in any cases. In three cases there was evidence of prescribed medications (antihypertensive medication in two cases and a nonsteroidal anti-inflammatory medication in one case). No one had evidence of mind-altering or illicit drug use. In no case was medication use determined to be contributory to the mishap.

Discussion

This paper has analyzed a subset of aviators who died following ejection from their aircraft over the time period 1966 to 1990. Numerous historical papers have analyzed the earlier generation of aircraft ejections that occurred prior to the mid-1960's [*10–13*].

The investigation of an aircraft mishap is a multidisciplinary process. Military air mishap investigation boards are composed of senior aviation officer, safety officer, engineering officer or maintenance officer, and a flight surgeon [*14,15*]. When a fatality is involved, the assistance of a forensic pathologist is requested.

When escape systems are involved, caution must be used in attributing an injury or fatality to a "malfunction" of the ejection seat. Our study found that almost half of all the fatalities were incurred in "out-of-envelope' ejections, that is, ejections that were initiated beyond the seat's design capability to successfully extract the ejectee. These fatalities were associated with extreme whole-body trauma [*16–18*].

The remaining cases were a combination of human error, mechanical failure, and unfortunate circumstances. Many of these cases could be isolated to the time point in the sequence at which the fatal injury occurred.

The deaths of the aviator who was not strapped to his parachute harness and the aviator who died suspended upside down after losing his extrication knife are examples of preventable human error.

The pathologic findings associated with parachute malfunction are similar to the decelerative injuries that have been described in military and sport parachuting accidents [*19–21*].

Significantly, the drowning fatalities had relatively minor traumatic injuries when compared with the other groups. When combined with the water environment, however, these injuries may have contributed to their deaths. Other investigators had recognized this hazard, leading to the adoption of salt water-activated life preservers [*22–24*].

High-speed ejections are associated with flail injuries. These injuries represent a subtype of "out-of-envelope" ejections, which were described separately in this study because of their unique injury patterns. Two of the ejectees in this series suffered C2 vertebral dislocation fractures when they ejected at greater than 450 knots indicated airspeed. Also associated were limb dislocations at the knees, elbows, and shoulder girdle. Aviators are indoctrinated with the ideal speeds at which ejection should occur; however, an emergent situation may preclude slowing the aircraft. In response to this, investigators have described the biomechanical aspects of restraint devices designed to reduce these injuries [*25–30*].

The absence of whole-body X-rays and spinal cord dissections in some of the cases were frustrating deficits that contributed to the underepresentation of spinal injuries in this study. Numerous papers have documented vertebral fractures in both surviving and nonsurviving ejectees. The evaluation of spinal injuries in ejectees is an active area of research in the aviation community. Spinal injuries have been attributed to various causative factors, that is, parachute-opening shock, parachute riser contact, improper alignment at the time of ejection, and helmet buffeting [31–40].

Negative toxicologic findings in military aircraft fatalities is not surprising as medication use is strictly monitored by the flight surgeons. Postmortem production of alcohol from putrefaction emphasizes the importance of a complete analysis for volatiles to rule out artifact.

Complete, thorough autopsies to include full-body X-rays, spinal cord dissections, and toxicological analysis will provide the aircraft accident board with informative injury-pattern data. Determinations as to causative factors for injuries/fatalities should not be made without an accurate account of the events surrounding an ejection. Coordination with the investigation team will facilitate the identification of causative factors [41].

Acknowledgment

The authors wish to acknowledge the criticisms and suggestions offered by Frederick C. Guill, M.E.A. during the final draft of this manuscript.

References

[1] Guill, F. C., "Ascertaining the Causal Factors for "Ejection Associated" Injuries," *Aviation Space and Environmental Medicine,* Vol. 60, Supplement, 1989, pp. B44–71.
[2] Martin-Baker Aircraft Company, "The History and Development of Martin-Baker Escape Systems," Martin-Baker Aircraft Company Limited, Higher Denham, England, 1989, pp. 2–56.
[3] Mason, J. K., "The Pathology of Fatal Inadvertant Ejection from Aircraft," *Journal of Forensic Sciences,* Vol. 16, No. 1, 1969, pp. 7–15.
[4] McCarthy, G. W., "USAF Take-Off and Landing Ejections, 1973–85," *Aviation Space and Environmental Medicine,* Vol. 59, No. 2, 1988, pp. 359–362.
[5] NATOPS Flight Manual, F14A Aircraft, Naval Air Technical Services Facility, Philadelphia, 1990.
[6] NATOPS Flight Manual, AV-8A and TAV-8A, Naval Air Technical Services Facility, Philadelphia, 1978.
[7] NATOPS Flight Manual, AV8B, Naval Air Technical Services Facility, Philadelphia, 1989.
[8] "United States Navy Emergency Escape" Summary, Naval Safety Center, Aeromedical Division, NAS Norfolk, 1989, pp. 1–3.
[9] Delgado, R., "USAF Ejection Summary 1 Jan -31 Dec 1982," USAF Ejection Escape Experience, 1983, pp. 16–19.
[10] Sandstedt, P., "Experiences of Rocket Seat Ejections in the Swedish Air Force: 1967–1987," *Aviation, Space, and Environmental Medicine,* Vol. 60, 1989, pp. 367–373.
[11] Smiley, J. R., "R.C.A.F. Ejection Experience 1962–1966," *Aerospace Medicine,* Vol. 39, 1968, pp. 619–622.
[12] Collins, T., Sawyer, C., Ferrari, V., and Shannon, R., "Five-Year Injury Experience in Escape from USAF Ejection Seat Equipped Aircraft," *Aerospace Medicine,* Vol. 39, 1968, pp. 627–632.
[13] Smiley, J. R., "RCAF Ejection Experience; Decade 1952–1961," *Aerospace Medicine,* Vol. 34, 1964, pp. 125–129.
[14] *U.S. Naval Flight Surgeon Aircraft Mishap Investigation Pocket Reference,* Naval Safety Center Aeromedical Division, NAS Norfolk, Virginia, 1989.
[15] Arny, S., *United States Army Aviation Handbook,* Society of the United States Army Flight Surgeons, Ft. Rucker, Alabama, 1989.
[16] Gable, W., "Pathology Patterns in Aircraft Accident Investigation," *Aerospace Medicine,* Vol. 68, 1984, pp. 638–640.
[17] Shannon, R., "Analysis of Injuries Incurred During Emergency Ejection/Extraction Combat and Non-Combat," *Aerospace Medicine,* Vol. 41, 1970, pp. 798–803.
[18] Chubb, R., Davidson, W., and Gable, W., "The Pathology of Ejection Failure," *Aerospace Medicine,* Vol. 34, 1963, pp. 1050–1054.
[19] Mellen, P. F. and Sohn, S., "Military Parachute Mishap Fatalities, A Retrospective Study," *Aviation Space and Environmental Medicine,* Vol. 61, No. 7, 1990, pp. 1149–1152.
[20] Snyder, R. G., "Human Tolerances to Extreme Impacts in Free Fall," *Aviation Medicine,* Vol. 34, 1963, pp. 695–705.

[21] Simson, L. R., "Chin-Sternum-Heart Syndrome: Cardiac Injuries Associated with Parachuting Mishaps," *Aerospace Medicine,* Vol. 11, 1971, pp. 1214–1217.
[22] Balfour, A. J. and Ground, K. E., "An Unsuccessful Ejection," *Aviation Space and Environmental Medicine,* Vol. 51, 1980, pp. 1050–1051.
[23] Pittman, J. C., Kaufman, W. C., and Harris, C. E., "Physiologic Evaluation of Sea Equipment," *Aerospace Medicine,* Vol. 40, 1969, pp. 378–381.
[24] Balfour, A. J., "No Drowning Mark Upon Him," *Aviation Space and Environmental Medicine,* Vol. 54, 1983, pp. 1021–1022.
[25] Reader, D. C., "Problems of Ejection from Aircraft. Restraint Harness Design," *Journal of the Royal Society of Medicine,* Vol. 68, 1975, p. 721.
[26] Fleming, C., "Ejection Problems and Injuries, Their Causes, Effects, Treatments and Suggestions for Preventable Measures," *Aviation Space and Environmental Medicine,* Vol. 50, No. 8, p. 829–833.
[27] Engin, A. E., "Passive Resistive Torques about Long Bones Axes of Major Human Joints," *Aviation Space and Environmental Medicine,* Vol. 50, 1979, pp. 1052–1057.
[28] Schneck, D. J., "Studies of Limb-Dislodging Forces Acting on an Ejection Seat Occupant," *Aviation Space and Environmental Medicine,* Vol. 51, No. 3, 1980, pp. 256–264.
[29] Combs, S. P., "Mechanism of Extremity Injuries Occurring During Ejection from F-4 Aircraft," *Aviation Space and Environmental Medicine,* Vol. 51, No. 9, 1980, pp. 1074–1076.
[30] Lyons, T. J. and Ficke, A. J., "Cases from the Aerospace Medicine Resident's File. Case 17. An Aviator with Multiple Compression Fractures of the Spine Secondary to High Speed Ejection," *Aviation Space and Environmental Medicine,* Vol. 58, No. 3, 1987, pp. 379–381.
[31] Griffin, C. R., "Proceedings: Problems of Ejection from Aircraft. Spinal Ejection Injuries," *Proceeding of the Royal Society of Medicine,* Vol. 68, 1975, pp. 722–723.
[32] Rotondo, G., "Spinal Injury After Ejection in Jet Pilots: Mechanism, Diagnosis, Follow-up, and Prevention," *Aviation Space and Environmental Medicine,* Vol. 46, No. 6, 1975, pp. 842–848.
[33] Kaplan, B. H., "Method of Determining Spinal Alignment and Level of Probable Fracture During Static Evaluation of Ejection Seats," *Aerospace Medicine,* Vol. 45, No. 8, 1974, pp. 942–944.
[34] Kazarian, L., Beers, K., and Hernandez, J., "Spinal Injuries in F/FB 111 Crew Escape Systems," *Aviation Space and Environmental Medicine,* Vol. 50, 1979, No. 7, pp. 829–833.
[35] Rowe, K. W. and Brooks, C. J., "Head and Neck Injuries in Canadian Forces Ejections," *Aviation Space and Environmental Medicine,* Vol. 55, No. 4, 1984, pp. 313–315.
[36] Hazzard, R. C., "Retro-Hyperflexion Luxation; Mechanism of Cervical Spinal Cord Contusion Injury During Ejection Sequence," *Aviation Space Environmental Medicine,* Vol. 52, 1981, pp. 625–626.
[37] Hearon, B. F., Thomas, H. A., and Roddin, J. H., "Mechanism of Vertebral Fracture in F/FB 111 Ejection Experience," *Aviation Space and Environmental Medicine,* Vol. 53, No. 5, 1982, pp. 440–448.
[38] Guill, F. C. and Herd, G. R., "An Evaluation of Proposed Causal Mechanisms for "Ejection Associated" Neck Injuries," *Aviation Space and Environmental Medicine,* Vol. 60, Supplement, 1989, pp. A26–47.
[39] Rotondo, G., "Vertebral Lesions Caused by Ejection with the Catapultable Seat," *Riveria Medicina Aeronautica y Spaz,* Vol. 37, 1967, pp. 71–88.
[40] Ewing, C. L., "Non-Fatal Ejection Vertebral Fracture, U.S. Navy Fiscal Years 1959 through 1965: Costs," *Aerospace Medicine,* Vol. 42, 1971, pp. 1226–1228.
[41] Guill, F. C., "What the Aircrew Automated Escape System and Aircrew Life Support System Equipment Designers Need from the Investigating Medical Officer and Pathologist," *Aviation Space and Environmental Medicine,* Vol. 60, Supplement, 1989, pp. B1–10.

Address requests for reprints or additional information to
Mark A. Lowry, CPT, MC, FS, USA
Dept. of Pathology
Womack Army Medical Center
Ft. Bragg, NC 28307