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**LOW ALTITUDE, HIGH SPEED PERSONNEL PARACHUTING:
MEDICAL AND PHYSIOLOGICAL ISSUES**

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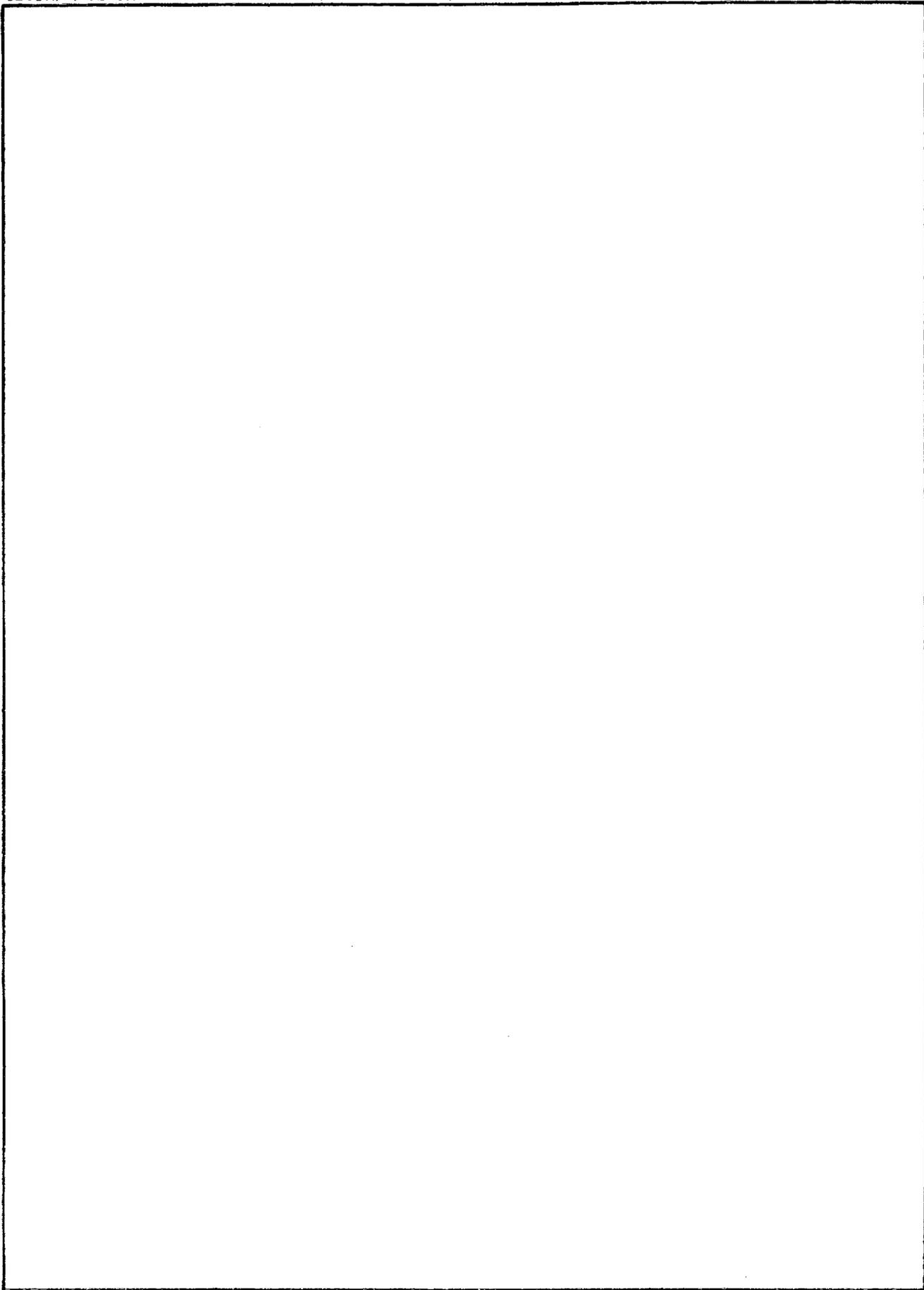
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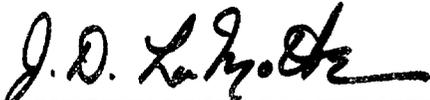
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Introduction

The purpose of this report is to provide an overview of the medical and physiological factors which influence the design and use of personnel parachutes at low altitude and high jump speeds. For the purpose of this report, low altitude is defined as 300 feet above ground level (AGL) and high speed is defined as 250 knots indicated air speed (KIAS).

Any injury received by a military parachutist due to a parachute system design flaw is unacceptable in terms of operational readiness and combat capability. Such injuries should be entirely preventable by detailed attention to systems design which thoroughly assesses the potential for injury at each step in the design and intended use of a particular parachute system.

There are no well-documented, experimentally proven human tolerance limits to the accelerations imposed during parachuting. Previously summarized estimates are based on analyses of accident data, data from acceleration sled experiments, and experience derived from high performance aircraft crew escape (ejection seat) systems (Bennett et al., 1976).

Methods and discussion

Several conditional factors are known to influence the limits of human tolerance to the forces generated during the deployment and inflation of the parachute system. For the purposes of this report, these forces will be referred to as "opening forces" unless otherwise noted. The known factors are:

- 1) Application and distribution of force to the torso;
- 2) Alignment of the torso and head-neck axis to the resultant deceleration force vector of the canopy;
- 3) Magnitude, rate of onset, and dwell time of the snatch and opening forces, and;
- 4) Angular and radial accelerations associated with 1-3 above.

These conditional factors are critical and must be explicitly considered at the earliest possible phase during the research, development, test, and evaluation (RDTE). To ignore these issues places the combat and system materiel developers in possible jeopardy during later stages of the development and

acquisition cycle. For example, to preclude an adverse Health Hazard Assessment (AR 40-10) after considerable resources have been expended, appropriate medical consultation should be included throughout the early phases of system research and development so that hazards can be identified and corrected without causing program delays or setbacks.

Human tolerance to opening shock is limited by man's capability to absorb and dissipate decelerational forces without sustaining significant injury. Optimum torso and head-neck axis alignment to parachute opening shock exists when the resultant force vector created by the parachute system (defined by an imaginary line drawn from the canopy apex to the confluence point of the suspension lines) coincides with the longitudinal +Gz axis of the parachutist.

The probability of injury to the parachutist resulting from opening forces increases in proportion to the degree to which the torso and head-neck axis alignment diverges from the optimal alignment defined previously. When the parachutist is in the optimal alignment and remains in that orientation throughout the period of force application, the bulk of the force is transmitted vertically down the spinal column, which has its greatest load carrying capacity in this position.

When there is divergence from the optimal alignment, particularly in the neck region, the mechanical strength of the spine and associated tissues is lower and injury may occur at lower levels of applied force. This is especially true if rotational or shearing forces are applied to the neck at the time of maximal load application (i.e., opening shock). The applicability of experimentally derived acceleration tolerance limits to personnel parachute research has been commented on by Ewing from Dahnke, Palmer, and Ewing, 1976:

Many of the tolerance limits described in scientific literature are derived from experiments performed on human subjects and primates who are restrained in rigid seats with rigid head rests and specific restraint systems. In most cases, these (platforms and restraint systems) are used only experimentally and not operationally. These data are of limited value in some cases and of no value in others because of the restriction on relative movement of the head, base of the neck, torso, and pelvis obtained with the rigid seat and restraint systems. This is not the case with the parachutist, who is not re-

stricted in his movements except by the parachute harness itself, and by the limitations of motion of those body segments due to the inherent characteristics of the human body.

Figure 1 shows the pattern of torso response to snatch and opening canopy forces for four hypothetical positions of torso alignment. In case A (back to canopy), the torso realignment to the +Gz axis produces hyperflexion of the neck, i.e., chin down, head forward. In case B (feet to canopy), the extreme misalignment of the torso to the force vector causes severe rotational acceleration of the head and neck, coupled with extreme hyperflexion, i.e., chin down, head forward. In case C (feet to canopy), again extreme misalignment produces severe rotational acceleration of the head and neck, but in this example resulting in extreme hyperextension. Case D (chest to canopy), results in hyperextension of the head and neck. Alignment which results in neck hyperextension has a tremendous proclivity to produce neck and spinal cord injury, especially when accompanied by angular or rotational acceleration.

The prediction of torso alignment during low altitude, high speed personnel parachute operations is problematic at best. Atmospheric turbulence is often great, creating tremendous difficulty for the parachutist predictably to achieve an optimal torso and head-neck alignment upon exit from the aircraft.

Equipment loads carried by the jumper create aerodynamic instability which also hampers the parachutist's attempt to achieve the optimal alignment. In addition, the aerodynamic forces created by the aircraft configured for parachutist deployment will be significantly altered from those produced in normal flight and may contribute to jumper instability upon departure from the aircraft.

Results and discussion

A review of US Air Force data recorded by the Air Force Deputy Inspector General for Inspection and Safety for the time period 1971 to 1979 reveals a total of 672 noncombat ejections in which 107 individuals (16 percent) received injuries. These records show that 32 percent of the injuries were associated with forced deployment of the canopy by a ballistic spreader device; the remainder were associated with conventional canopies. The majority of the injuries involved the head and neck (46 percent), shoulder (35 percent), upper leg (21 percent), and thorax (18 percent); see Table 1.

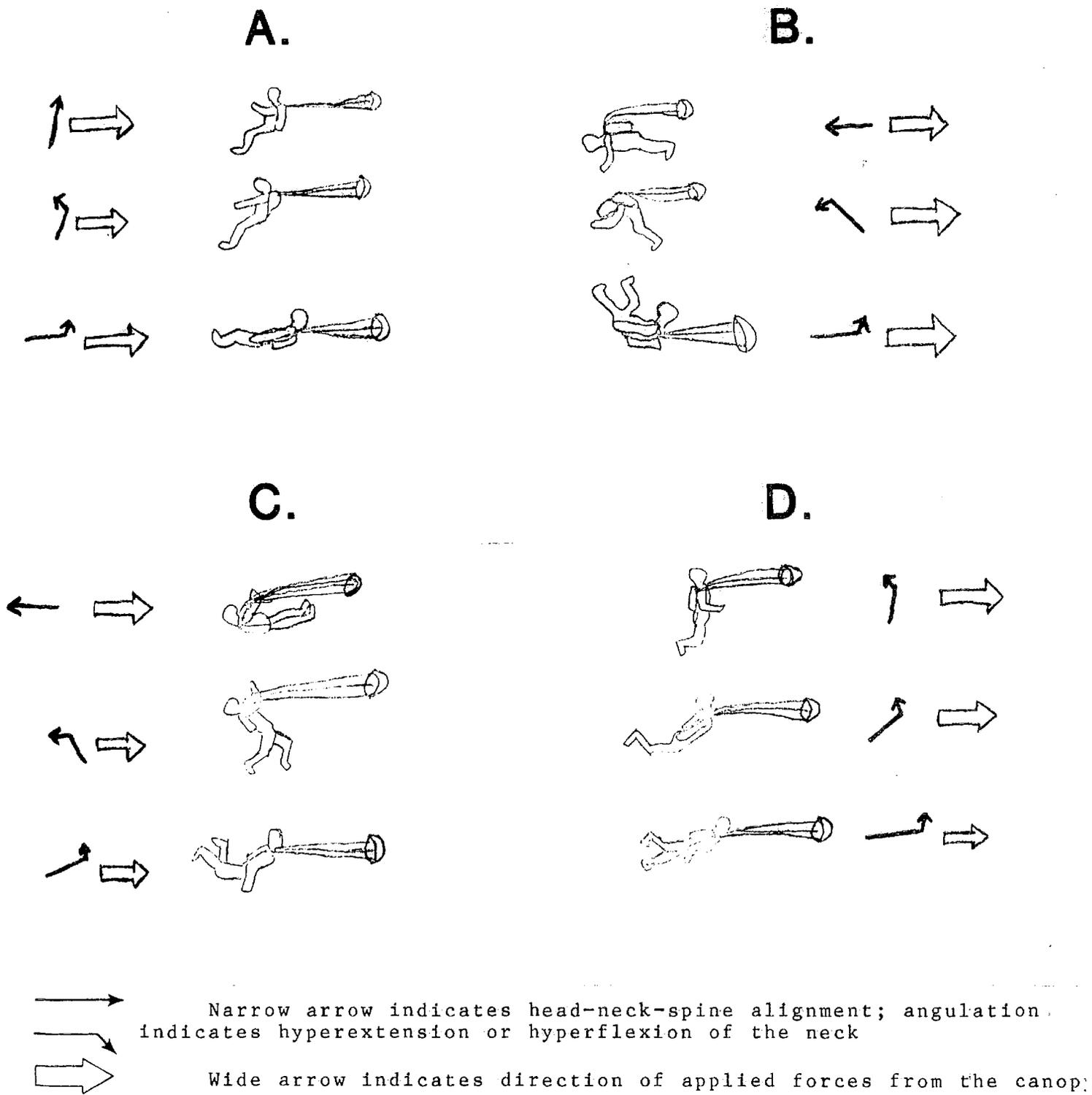


Figure 1. Pattern of torso response to snatch forces.

Table 1

Injuries resulting from parachute opening shock
US Air Force (1971-1979)*

Location	Number	Percent
Neck	49	46
Shoulder	37	35
Upper leg	22	21
Thorax	19	18
Face	13	12
Upper arm	12	11
Buttocks	9	8
Pelvis	5	5
Back	4	4
Lower arm	2	-
Ribs	2	-
Abdomen	1	-
Kidney	1	-
Teeth	1	-
Eye	1	-
Skull	1	-

* Note: Most individuals received multiple injuries.

The experience from the above noted ejection injury data is not strictly comparable to that of troop parachuting. However, some useful generalizations may be drawn from the interpretation of the data. First, the single largest category of injuries occurred to the head and neck, demonstrating the relative vulnerability of this anatomical region to parachute opening forces. Second, ejection from disabled aircraft results in random torso alignment to the force vector created by the parachute system. Therefore, one might assume that many of the recorded injuries may have been prevented if the proper means to align the parachutist with the mean force vector existed and functioned correctly. Third, a large proportion of the ejections occurred at low altitude and relatively fast velocities (250-350 KIAS) and in that respect are comparable to the issue at hand.

Using the Anatomic Index of Severity (Dahnke, Palmer, and Ewing, 1976) one finds that the neck injuries have an effective mortality probability of 10 percent while that of shoulder injuries is 0 percent. Because of the relative susceptibility of the human head/neck complex to mechanical injury, human tolerance to parachute opening shock should be estimated based on the known tolerances of the head/neck complex (i.e., the head/neck complex

represents the weak link and is the limiting factor in defining the limits of human tolerance to parachute opening forces). Human tolerance for the linear accelerative forces of parachute opening based upon neck tolerance has been proposed by Ewing (Dahnke, Palmer, and Ewing, 1976); see Table 2.

Conditions or system designs which cause or allow violent changes in direction, e.g., rapid oscillations coupled with secondary angular or radial accelerations, must be assumed to have lower tolerance limits than those listed in Table 2. These tolerance limits are proposed for healthy, physically fit military parachutists and apply only for acceleration loads carried through the risers to the parachute harness system. Loads applied directly to the head, neck, or other body parts are not considered. These proposals do not consider the time history, the pulse shape, or the duration of the opening shock and, therefore, do not provide a complete description of human tolerance to parachute opening shock.

Table 2

Acceleration tolerance criteria for single parachute opening shocks applied through the risers to the harness

Body acceleration directions	Tolerance limits measured to the torso
+Gx (eyeballs in)	15 G
-Gx (eyeballs out)	35 G
+Gy (eyeballs left)	15 G
-Gy (eyeballs right)	15 G
+Gz (eyeballs down)	25 G
-Gz (eyeballs up)	20 G

The normal range of motion of the neck without incurring injury is flexion 54-67 degrees, extension 61-93 degrees, lateral flexion 41 degrees, and rotation 73-76 degrees (Bennett et al., 1963, Buck et al., 1959). Whiplash injuries due to hyperextension of the head as a result of "rear-end" automobile impact can be compared to hyperextension injuries occurring during parachute opening with torso misalignment. Hyperextension injuries are more likely to have serious consequences than are the forward and lateral flexion injuries since there is no anatomical "block" to limit motion (in contrast to the chest and shoulders which limit flexion range of motion in the forward and sideways directions). Parachutists not stabilized in the optimal position may experience angular and radial accelerations which can cause severe motion of the neck with possible injury. The same mispositioning may result in increased susceptibility to

injury from the resultant linear acceleration previously described.

Angular acceleration has been studied in nonhuman primates and found to produce central nervous system injury in both restrained and nonrestrained subjects (Malone et al., 1969, Ommaya et al., 1970). Direct studies involving carefully instrumented human volunteers with unrestrained head and neck have shown no adverse effects at 38 rad/sec head angular velocity or with head angular accelerations of 2,675 rad/sec obtained with sled accelerations of 15 -Gx (Ewing et al., 1969, Ewing and Thomas, 1975). At the present time no other data exists which allows better definition of human tolerance to angular acceleration. Therefore, these figures represent the known tolerable angular acceleration limits for the human head; obviously, this database is grossly incomplete.

A number of human factor issues remain almost totally unexplored, both in terms of operational significance and possible solutions. Probably the most significant factor is to determine how the parachutist can move from the troop compartment of the aircraft to the open ramp (or door) and predictably exit so as to attain the optimal body alignment each time. In this regard, the optimal jump posture has yet to be determined. The design of the equipment which the parachutist will carry on his body must be carefully considered since it will create aerodynamic flows which in turn will influence the jumper's ability to attain and hold the optimal body alignment. Whether to include a reserve parachute in the system must be considered--would there be time to use it when jumping from 300 feet? If included, should it be manually activated or automatically triggered?

Conclusions

The critical factor limiting parachuting at low altitude and high speed is the limited capability of the neck to absorb and dissipate acceleration forces generated by parachute opening shock without sustaining injury. Currently, our knowledge of the neck's full tolerance to such forces is quite limited. The complexity of the tissues composing the human spine and associated structures presents a dynamic enigma from the biomechanical perspective. Attempts to recreate this dynamic function with instrumented dummies have achieved only crude success. Similar problems occur when instrumented cadavers are used in acceleration research experiments. In either case, the interaction of living tissues cannot be closely duplicated, or measured, in the dynamic experiment.

It must be borne in mind that the tolerance recommendations