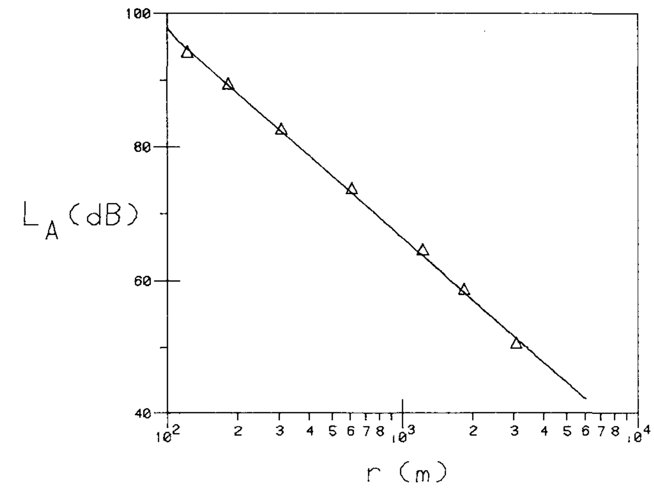

Fig. 1 Linear fit of sound levels for Boeing 737-100/200 aircraft.

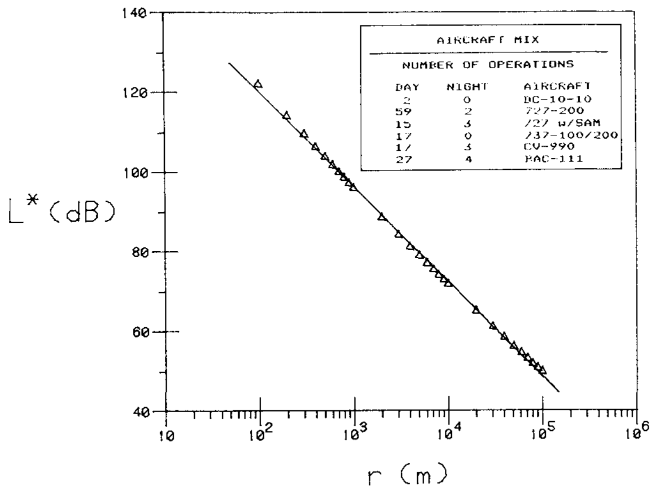

Fig. 2 Linear fit of sound levels from multiple aircraft.

It has been found that an excellent approximation for $L_k^*(r)$ is given by the same form as Eq. (2), i.e.,

$$L_k^*(r) = c_{1,k}^* - c_{2,k}^* \log_{10}(r) \tag{5}$$

where the composite coefficients $c_{1,k}^*$ and $c_{2,k}^*$ will depend upon the mixture of aircraft on trajectory k. The quantity $L^*(r)$ represents the sound level of an "equivalent source" at distance r, which delivers the same total weighted power density as the combination of individual sources at that distance. An example of the quality of the least-square-error fit is shown in Fig. 2.

With the coefficients $c_{1,k}^*$ and $c_{2,k}^*$ calculated for each trajectory, the equivalent level L^* at any point on the ground is found by summing over all the trajectories:

$$L^* = 10 \log_{10} \sum_{k=1}^{N_t} 10^{L_k^*/10} \tag{6}$$

Since the time-of-day weighting has already been included in L_k^* and, hence, L^*, the expression for $L_{\text{d-n}}$ becomes

$$L_{\text{d-n}} = 10 \log_{10} \sum_{t=1}^{N} 10^{L_t^*/10}/N \tag{7}$$

Calculation of $c_{1,k}^*$, $c_{2,k}^*$, and $L_{\text{d-n}}$ is relatively fast compared with summing the power densities of every source at each time sample to get $L_{\text{d-n}}$.

Table 1 Noise level coefficients for commercial aircraft[a]

Aircraft	c_1	c_2
DC-8-30	164.02	31.06
DC-9 w/SAM	146.76	26.13
DC-10-10	150.81	30.32
707 w/SAM	138.77	24.81
720	143.92	22.95
727-200	142.57	23.68
727 w/SAM	124.83	18.92
737-100/200	159.35	31.04
737 w/SAM	149.60	27.72
747-200	144.19	26.20
L-1011	140.75	25.75
A-300	179.76	41.60
BAC-111	154.88	28.44
VC-10	144.74	23.64
CV-990	164.17	29.42

[a]Computed for landing thrust levels, 3-deg glide slope.

Conclusion

The method of using composite noise coefficients reduces the number of calculations needed to determine $L_{\text{d-n}}$ at any point on the ground, as compared with more straightforward methods. For simulations of aircraft noise where many aircraft are involved, a considerable savings in computation time can be achieved. While the method has been demonstrated for the measure $L_{\text{d-n}}$, it is applicable to any measure that adds effects from separate sources via power density addition.

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Airplane Designer's Checklist for Occupant Injury Prevention

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Introduction

ALTHOUGH the design techniques for injury protection are maturing, there are a large number of bewildering specification requirements that confront a designer of pilots' seats and cabins. Design engineers are educated and oriented toward vehicle construction and components. After graduation, they enter industry and acquire organizational assignments. Design engineers become responsible for some subset of the aircraft, such as structures, control systems or equipment, but not all of them. Each design group, together with their supporting analysts and staff groups, have improved their designs by research on operational usage. Gathering data on injuries is especially difficult because the operational usages are usually mishaps, crashes, and emergency egresses.

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A set of engineering procedures for injury prevention has been presented in the "Aircraft Crash Survival Design Guide."[1]

Many engineers are required to accomplish elements of the cockpit design. The resulting cockpit arrangement may not provide a habitable design unless the conflicting requirements are resolved. A new method, presented here, is called an "inverted checklist," and highlights the consequences of an inadequate design. The word "inverted" means that the injury is assumed to have occurred, and its causes are yet to be determined. This reverse chronological analysis is used by aircraft accident investigators who are charged with examining wreckage in the field and postulating possible causes.

A methodical inverted checklist is presented in Table I for head-to-toe injuries. A corresponding list of topics includes helmet size, seat positioning, seat stroking, torso restraints, survivable volume, and other important design variables.

Forehead

Injury to the frontal cranium and face can be lethal. A human forehead can contact a stationary object in the cockpit for a variety of reasons, see Fig. 1, position (1). (Numeral in parentheses in this Note are circled positions in Fig. 1.) A large strike radius (2) increases the possibility of head contact injury. One possible cause is failure of the reel lock.[2] Failure of the reel-to-structure mounting hardware has the same effect (3 and 4). Head contact will also occur if other structures fail, such as a seat rail (5), lap belt attachment (6), or a seat-to-floor attachment (7). In some cases, forehead contact can occur below ultimate failure if the structures or restraints exhibit large deflections. A long torso harness having a low modulus of elasticity will permit large torso deflection.

Neck

Neck injury is closely related to head motion because head forces and accelerations are transmitted to the cervical spine and its muscle systems. A direct rearward-acting force to the head can be reacted by a properly adjusted headrest. A suddenly applied positive horizonal acceleration can snap the head backward and cause severe injury to the upper two cervical spine segments at position (9). A faulty head rest or a maladjustment will aggravate this condition.[3] The seat must be adjusted to place the pilot's eye in the "design position" with a subtended angle, ϕ equal to 15 deg or greater. A head rest must be adjusted accordingly.

Hyperextension of the neck can occur during the initial phase of ejection. As the head enters the airstream, windblast on the face and helmet produces neck rotation. At high dynamic pressure, drag force is very high (10). Severe conditions occur at low altitude and high velocity. An ill-fitting helmet or loose chinstrap becomes a small parachute in the windblast and magnifies forces transmitted to the neck. Injury to the cervial spine can also induce injury to the spinal cord, which is especially dangerous. Helmet design, fit, and proper adjustment is an important aspect of injury prevention.[4]

Clavicle

A shoulder harness should be designed so the belt load resultant will not be directly imposed on a shoulder or collar bone. The torso belt loads (12) produce a resultant (13). Since the forward belt webbing attaches to a lap belt buckle, only the rear webbing angle can be controlled by design. The reel (3) should be located high to lessen the resultant.[5]

Rib

A mislocated upper torso restraint can cause excessive load on the rib cage. A single diagonal belt for a passenger seat presents an especially difficult problem compared to a dual-webbing design.[1] Passengers range in size from children to large adults. The design problem is further complicated by the fact that passengers may be elderly and frail.[6] Webbing must be wide and thick to distributed the load over a large area of the sternum and ribs. Thin and narrow webbing may be prone to "roping" (rolling and folding), which concentrates the belt load.

Backbone

In an upward ejection seat a person may suffer back injury if the force exceeds the occupant's tolerance to that compressive force.[7] The negative z-interial force (11) is also experienced by a seated occupant is a flat crash. In both cases, the human spine acts like a tree trunk and supports all the

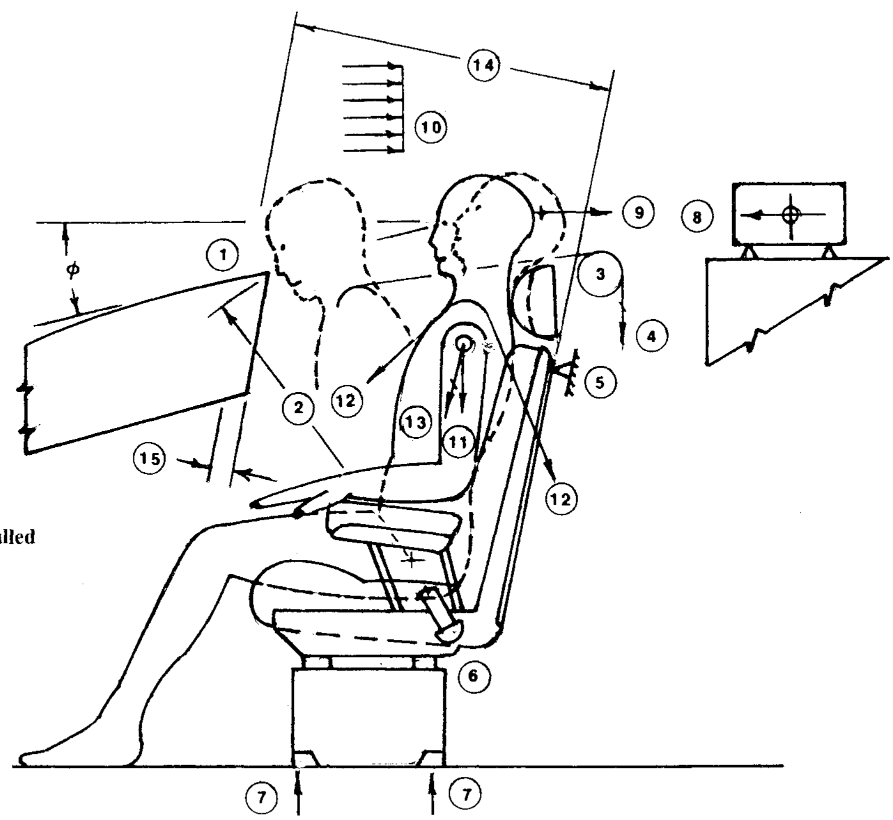

Fig. 1 Cockpit design (numerals in circles are called positions in the text).

Table 1. Designer's "inverted checklist"

Injury	Condition	Possible cause	Specification
Frontal Cranium	$-G_x$ deceleration	Maladjusted torso harness Faulty reel lock	USARTL-TR-79-22 D MIL-R-8236 D
Cervical spine	$+G_x$ acceleration Windblast (ejection)	Inadequate head rest Faculty helmet chinstrap	MIL-S-9479 B MIL-H-22995 A
Clavicle fracture	$-G_x$ crash	Mislocated torso anchor	MIL-S-58095
Rib fracture	$-G_x$ deceleration	Maladjusted torso harness	USARTL-TR – 79-22 D
Lumbar spine	$-G_z$	Inadequate seat stroke Excessive ejection force Insufficient ejection stroke	MIL-S-58095 MIL-S-9479 B MIL-S-9479 B
Pelvic fracture	$-G_x$	Mislocated lap belt anchor	FAR 25.785
Femur fracture	windfall	Inadequate leg restraint	NADC-79201-60
Humerus fracture	windfall	Inadequate arm restraint	NADC-79201-60
Hand	contact	Inadequate strike envelope	MIL-STD-1290
Patella	contact	Column stowage malfunction	MIL-STD-882 A
Shoulder	contact	Insufficient ejection envelope	MIL-STD-1333 A
Occipital skull	contact	Inadequate stowage	FAR 25.787

weight above it. At any point, say in the lumbar spine, the weight of the torso, neck, head, helmet, and any other clothing and body-mounted equipment, will exert a compression in the backbone. Each vertebrum will suffer compression stress, and each intervening disc will be proportionately shortened.

Decreasing the acceleration by increasing the pulse time is really the only method of reducing the load. For an ejectee, the designer seeks maximum seat travel and long-rime rocket burn. This is completely analogous to landing gear descent energy absorbtion by low-load, long-stroke oleos.

During structure crushing, seat stroke is obtained by plastic deformation of the material between man and earth surface. Ordinarily, this structure consists of the seat pan, seat legs, floor, and sub-floor structures. In some helicopter energy absorbing seats, the pan and seat back is suspended from the ceiling with tension wires instead of the conventional compression legs. The suspension design is very effective when there is more head room than available stroking distance below.

Hip

An inertial load imposed on an unrestrained human could cause impact with objects in the surrounding cabin. To prevent trauma injury, motion is restrained by use of lap belts and shoulder harnesses. Although restraints raise the overall probability of injury prevention, there is an upper limit of human tolerance to pelvic fracture. A lap belt should be positioned to ride high on an occupant's hip bone (over the illiac crest) and yet maintain a prescribed angle with the seat pan.[1,8] If the lap belt is attached to the floor instead of the seat, there is a likelihood that the vertical component of the crash load crushes the seat legs causing the lap belt to go slack. During the subsequent horizontal deceleration, the occupant could then "submarine" under the lap belt, causing abdominal or back injury.

Limbs

When a person is ejected form an airplane, every exposed surface is subject to the aerodynamic forces. Experience has shown that these forces are unsteady, and human limbs that are unrestrained will oscillate and beat violently. Windflail injuries affect every limb bone and joint. A big flight boot becomes a large drag force which produces combined bending and torsion in the thigh bone. Stresses in human longbones have often caused tibia and femur fractures. Prevention of limb injuries can be obtained by use of the limb restraint equipment.[9-12]

Hand

In an emergency situation, a hand is likely to be injured because of its large strike radius.[13] The design dilemma is that a pilot must be able to reach knobs, levers, and controls all about. These same controls must therefore be designed to be free of sharp edges and as "soft" as possible to prevent trauma. Wearing gloves can act as padding and also prevent severe burns in post-crash fires.

Knee Cap

The larger the pilot, the greater the probability of contact trauma during ejection. A ninety-five percentile male, about 6 ft. 3 in., risks hitting objects on the way out during ejection.[14] Failure of control column stowage or an inadequate ejection envelope (15) will result in severe injury to the patella.

Shoulder

Shoulder injury is a possibility if the ejection envelope is too small. Position (14) is the dimension of an ejection envelope in the left-hand side view. The corresponding dimension in the rear view should be sufficiently broad to allow a ninety-five percentile male clothed with a flight suit, to clear all obstacles with a margin.[15]

Back of the Head

Seat and restraint designs are for naught if an occupant is held safely while an object behind him jars loose. An equipment item that is not adequately anchored becomes a flying missile during a crash [see position (8)]. Loose items in the cabin can come from *any* direction.[8] Equipment mounting criteria must ensure that *x, y, z* components in both plus and minus magnitudes are great enough to prevent failure.

Conclusions

Not all crashes are survivable nor are all emergency egress attempts likely to be successful. There are upper limits to each individual's human tolerance. In spite of this, it is possible to strive for greater possibility of survival by improved design. A new form of engineering analysis is available in the form of an inverted checklist. By predicating an injury to some portion of the body, the possible causes can be reckoned and then methodically eliminated.

Acknowledgments

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Errata

High-Lift Airfoil Design from the Hodograph

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IN the above paper, Eq. 23 and the two Equations that follow it were printed incorrectly. The correct Equations appear below.

$$\Delta\xi_1 = \int_0^{\eta_{20}} K\begin{pmatrix}\sin\\ -\cos\end{pmatrix}\Theta\cdot d\eta_2$$

$$\Delta\eta_1 = \int_0^{\eta_{20}} K\begin{pmatrix}\sin\\ \cos\end{pmatrix}\Theta\cdot d\eta_2 \tag{23}$$

where

$$K = \sqrt[4]{\frac{(\xi_{20}-k_2)^2+\eta_2^2}{[(\xi_{20}^2-\eta_2^2-1)^2+4\eta_2^2\xi_{20}^2][(\xi_{20}-k_1)^2+\eta_2^2]}}$$

and

$$\Theta = \frac{1}{2}\left[\tan^{-1}\frac{\eta_2}{\xi_{20}-k_1}+\tan^{-1}\frac{\eta_2}{\xi_{20}-1}+\tan^{-1}\frac{\eta_2}{\xi_{20}+1}-\tan^{-1}\frac{\eta_2}{\xi_{20}-k_2}\right]$$

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