Biodynamics of Aviation Stresses on The Vertebral Column

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Introduction

THE vertebral column of a human body is structurally comprised of rigid bony vertebrae, cartilaginous intervertebral discs with ligament attachements, and forms an elastic system capable of a dynamic response. The inorganic and organic constituents of this structure offers high compressive tensile stiffness. Flexion, compression and expansion which are the properties of this structure mainly depend upon its elasticity and damping qualities. These properties in turn provide a man with postural stability, lateral and rotational bending. The convex – concave arrangement of various intervertebral discs of the structure contributes greatly to the overall spinal elasticity and thus dynamically maintain the centre of gravity in a man.

The rate of onset of acceleration during the initial application of force (*e.g.* ejection), together with the associated elastic properties of the human body and seat structure can cause an acceleration overshoot. This, sometimes increases the inertial loading on the spine resulting in spinal compression and subsequent fracture.

In the ejection seat assembly, when a man is ejected out, the elastic qualities of the seat pack and cushions will also contribute to the dynamic overshoot of acceleration.[4] The forces generated by the ejection cartridges and applied to the ejection seat get modified significantly as a result of internal dynamics of the man-seat system. The safety criteria, for the ejection forces have to be based on the dynamic response of the human subject. Von Gierke[3] had suggested the use of dynamic response index for ejection type of forces. This concept is being used in the USAF and is now being adopted by the RAE and NATO countries.[2]

Dynamic Response Index and its Determination

The dynamic response index which is being currently introduced is based on a single mass spring model with a damping element. The displacement of the system on the application of a force is given by

$$\frac{d^2\delta}{dt^2} + K\omega_n \frac{d\delta}{dt} + \omega^2{}_n = \frac{d^2z}{dt^2} \qquad (1)$$

where δ is the compression of the spring in feet, K, the damping ratio of the model, ω_n is its undamped natural frequency in radians/sec and $\frac{d^2z}{dt^2}$ is the Z axis acceleration.

The DRI is given as –

$$DRI = \frac{\omega^2{}_n \ \delta \max}{g} \qquad (2)$$

The values of K and ω_n for a model equivalent to the human body have been estimated to be –

$$K = 0.224 \text{ and}$$

$$\omega_n = 52.9 \text{ rad/sec}$$

$$DRI = 86.9\ \delta \max \qquad (3)$$

DRI and Safety Criteria

Table I gives the DRI values against percentage risk of injury on ejections in the U.S.

Table I

Simple forces		Complex forces	
DRI	*Risk of injury*	*DRI*	*Risk of injury*
18.0	5%	17.0	5 – 20
20.4	5 20%	19.0	20 – 50
23	50%	22.0	50

The DRI values obtained from δ max determined by computer from the G-profile are compared against the injury potential given in Table I.

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DRI Criteria for Repeated Shocks

A comprehensive approach to use the D.R.I. concept to cover all types of forces similar to those experienced in Aviation has been made by Allen[1] based on large number of experimental data collected from various sources. For D.R.I. values between 15 to 20 the data available from ejections have been used *viz* 5% injury risk for D.R.I. of 18.

In the studies conducted at Loughborough University of Technology on body impedance on male subjects, D.R.I. values of 6 were found to be very uncomfortable for 20 shocks for 1 hour per day. Experiments at Srivenham, using army personnel as subjects showed D.R.I. values of 2 and above to be causing considerable discomfort for pseudorandom vibrations (0–8Hz) with 18 shocks per minute and 20 mts per day.

It was observed that in two out of eight incidents of voilent uncontrolled aircraft manoeuvres with Mirage aircraft have given rise to spinal fractures. The manoeuvres gave 4 main oscillations with peak G ranging between 8 — 12 g. It is therefore concluded that 4 shocks of D.R.I. value of 9 could give rise to 25% injury risk. Based on the aircrew reaction to aerobatics it is proposed that 5 D.R.I. for 75 times per day and 7 D.R.I. for 5 per day could be taken as criteria for "severe discomfort." The above information is presented in a comprehensive manner in figure 1 and can be used for the assessment of spinal injury and discomfort in case of Aviation Stresses.

REFERENCES

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2. Dynamic Response Index : MIC-S-9179B (USAF) 24 Mar 1971.
3. Henzel, JH, Mohr, GC and Von Gierke, HE : Reappraisal of Biodynamics Implications of human ejections. Aerospace Med. 39, 231, 1968.
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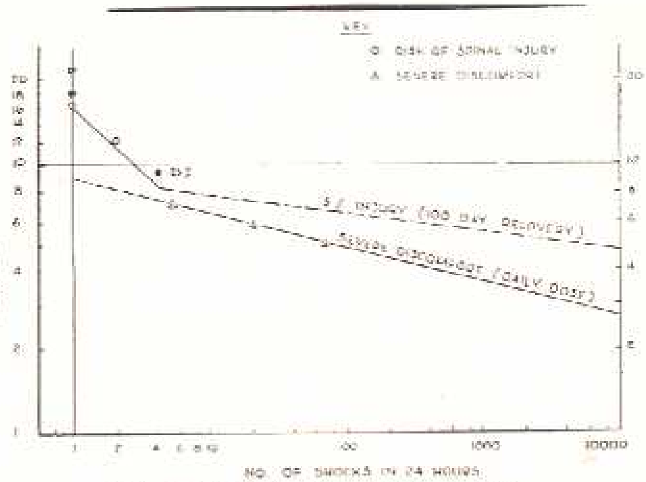

FIG 1 SHOCK DATA AND PROPOSED LIMITS