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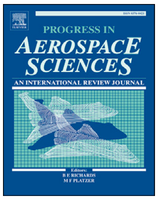

Advances in crash dynamics for aircraft safety

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ABSTRACT

This paper studies the ability of the fuselage's lower lobe to absorb the energy during a crash landing, where the introduction of the composite materials can improve the crash survivability thanks to the crushing capability of structural parts to limit the effects of deceleration on the occupants. Providing a protective shell around the occupants and minimizing the risks of injuries during and immediately after the crash in the post-crash regime is a safety requirement.

This study consists of: (1) numerical and experimental investigations on small components to verify design concepts using high performance composite materials; (2) analyses of full scale crashes of fuselage lower lobes.

This paper outlines an approach for demonstrating the crashworthiness characteristics of the airframe performing a drop test at low velocity impact to validate a numerical model obtained by assembling structural components and materials' properties previously obtained by testing coupons and sub-elements.

1. Introduction

Crashworthiness is the ability of an aircraft structure and its internal systems to protect occupants from injury in an event of crash. Specifically, it means that the integrity of the passenger cabin should be maintained, that the accelerations the passengers are subjected to should be survivable in case of a crash, and that fires should be prevented.

Human tolerance to impacts has been studied for many years and a number criteria have been developed to predict injury [1,2]. A well-known criterion is the head injury criterion (HIC):

$$HIC = max\left[\frac{1}{t_2 - t_1}\int_{t_1}^{t_2} a(t)dt\right]^{2.5}(t_2 - t_1) \tag{1}$$

where a is the linear acceleration of the center of mass of the head expressed as a multiple of the gravitational acceleration ($g = 9.81\ m/s^2$), t is the time in seconds, and $t_2 - t_1$ is the time interval. The HIC is the maximum value of this moving average during the duration of the impact and is limited to 1000 when $t_2 - t_1 = 36\ ms$ or to 700 when $t_2 - t_1 = 15\ ms$. This criterion predicts brain injury while accounting only for the linear acceleration when it is known that angular accelerations have a significant effect. One of many criteria for mild traumatic brain injury (MTBI) is based on P, the power of the loads applied to the head. $P = m\bar{a}\cdot\bar{v} + \overset{a}{I}\bar{\alpha}\cdot\bar{\varpi}$ where m is the mass, $\bar{a}$ is the linear acceleration vector, $\bar{v}$ is the linear velocity vector, $\overset{a}{I}$ is the inertia tensor, $\bar{\alpha}$ is the angular acceleration and $\bar{\varpi}$ is the angular velocity. The Head Impact Power (HIP) injury criterion introduced by Newman can be written as:

$$HIP = m\left(a_x v_x + a_y v_y + a_z v_z\right) + I_{xx}\alpha_x\omega_x + I_{yy}\alpha_y\omega_y + I_{zz}\alpha_z\omega_z \tag{2}$$

where m is the mass of the head and I_{xx}, I_{yy}, and I_{zz} are its principal moments of inertia. In Ref. [3], m = 4.2 kg, $I_{xx} = 0.0140$ kg.m^2, $I_{yy} = 0.0187$ kg.m^2, and $I_{zz} = 0.0172$ kg.m^2. Slightly different values are used in other publications [4].

Eiband [5] summarized previously available test results dealing with the effect of acceleration on the whole body. A typical chart for the effect of acceleration in the vertical direction on a seated occupant (Fig. 1) shows that for durations under 0.03 s, no injuries were reported for uniform accelerations below 18 G.

To prevent or limit injury to the spine, CS Part 25.562c [7] stipulates that the lumbar load should not exceed 1500 pounds.

The Dynamic Response Index (DRI) developed Air Force Wright Laboratory to estimate the probability of compression fractures in the lower spine due to acceleration in a pelvis-to-head direction [8,9]. Fig. 2 shows a single degree of freedom model of a seated human with a mass m connected to a seat by spring k and dashpot c.

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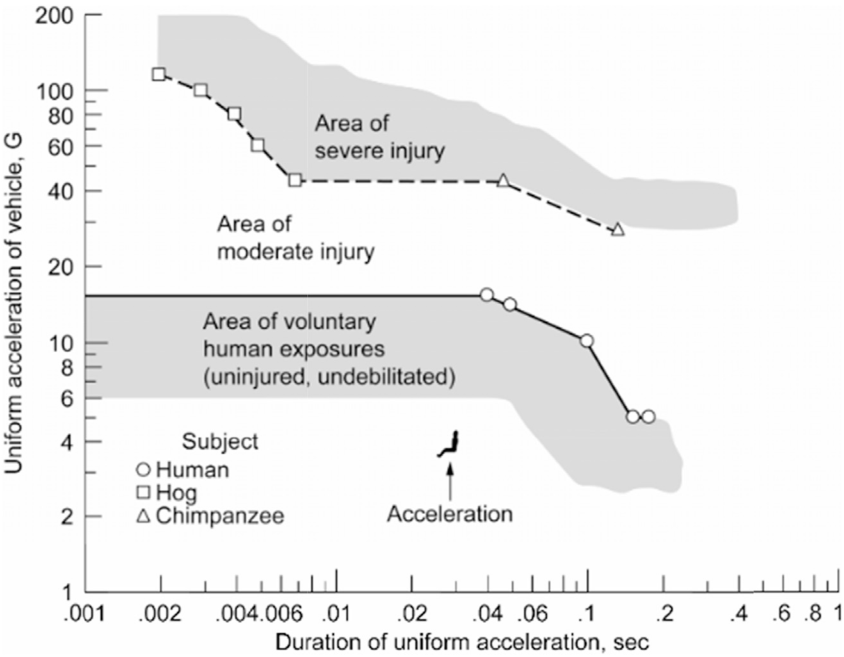

Fig. 1. Lawrence et al. [6].

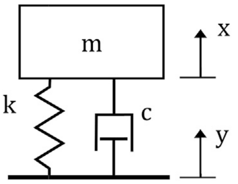

Fig. 2. Spring-mass model for the Dynamic Response Index.

The relative motion δ, the difference between x, the displacement of the body and y, the displacement of the seat, is governed by:

$$\frac{d^2\delta}{dt^2} + 2\zeta\omega\frac{d\delta}{dt} + \omega^2\delta = \frac{d^2y}{dt^2} \tag{3}$$

Given the input acceleration $\frac{d^2y}{dt^2}$, one can determine the maximum deflection δ_{max} and calculate the Dynamic Response Index:

$$\mathrm{DRI} = \delta_{max}\omega^2/g \tag{4}$$

where g is the acceleration of gravity. The DRI is used to evaluate the potential for spinal injury during aircraft crashes [10–13] and also in the operation of high speed marine craft [14]. In this model, the natural frequency $\omega = \sqrt{k/m}$ and the damping ratio $\zeta = c/(2\sqrt{km})$ are taken to be 52.9 rad/s and 0.224 respectively. As the maximum DRI value increases from 20 to 23, the spinal injury rate increases from 16 to 50%.

A typical section of the fuselage for a transport aircraft include frames, stringers and skin, the passenger floor, the cargo floor and struts or stanchions. During a crash landing, the kinetic energy should be dissipated in a controlled way by the crushing of the structure below the passenger floor. Energy is dissipated by stanchions connecting the frames and beams on the cargo floor (Fig. 3), by longitudinal sine wave beams below the subfloor beams (Fig. 4) or sine wave beams below cargo floor beams (Fig. 5).

In another design (Fig. 6), cargo floor beams are connected to the frames while the bottom frame of the fuselage is replaced by a splice plate [18]. A special honeycomb shaped material is inserted between the cargo floor and the clip plate for dissipating energy during a crash (see Fig. 7).

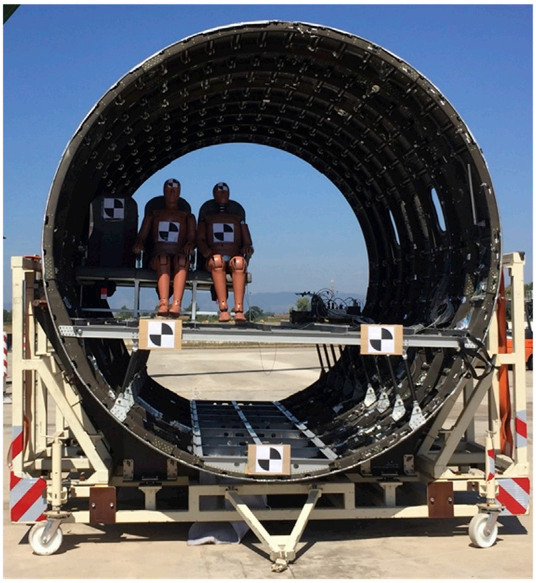

Fig. 3. Typical fuselage section of transport aircraft.

The height of the sub-cargo structure in helicopters and light fixed-wing aircraft is typically in the range of 200 mm [19]. For wide-body transport aircrafts category provides significantly more distance between the cargo floor and the ground is of the order of 600 mm [19]. Assuming a constant deceleration a, the crushing distance is given by $x = V^2/(2a)$. If the initial velocity v is 30 ft/s and the acceleration is 20 times the acceleration of gravity, the crushing distance is 0.7 ft or 213 mm. The necessary space is not available in helicopters and small aircraft. In that case the landing gear and the seats must dissipate a significant part of the kinetic energy.

In the following, Section 2 describes previous research dealing with structural elements such as frames, struts and sine wave beams. It also presents an overview of tests of full size aircraft and fuselage sections, the facilities where these tests are conducted and the software used for the simulation of these tests. Section 3 reports how the aircraft safety agencies advice the compliance with the structural requirement. Section