ABSORPTION OF ENERGY EXPLOITATION DURING IMPACT OF AIRCRAFT

A. Žiliukas, N. Fiodorova

VGTU Antanas Gustaitis Aviation Institute, Lithuania. E-mail: antanas.ziliukas@ktu.lt

Received 20 04 2004, accepted 26 07 2004

Antanas ŽILIUKAS, Prof Habil Dr
Date and place of birth: Zarasai, Lithuania, 1940
Education: Kaunas Polytechnic Institute; Mechanical Engineering Diploma (1963), Doctor Sc. Eng. Degree (1968), Doctor Habilitus Degree in Eng. (1989).
Fields of research: Mechanics of Solids, reliability of structures.
Present position: Head of Department of Mechanics of Solids, Professor of Kaunas University of Technology, and member of Lithuanian Academy of Science.
Publications: monographs:"Fracture of structures", "Energomechanics" and textbooks: "Mechanics of deformable bodies" (I – 1994, II – 1995), "Technical diagnostics and reliability of aircraft", 150 scientific papers.

Nina FIODOROVA
Date and place of birth: Vilnius, 1980.
Education: Faculty of Transport Engineering of Vilnius Gediminas Technical University 2003, bachelor's degree.
Fields of research: Aviation mechanics.
Present position: Post - graduate student at VGTU Antanas Gustaitis Aviation Institute.
Experience: Paper at the scientific conference AVIATION – 2003.

Abstract. The article shows the variation of stopping distance as a function of deceleration and velocity change derived from the standard Newtonian equations for assumed constant acceleration. Note that the time to stop is equal for all three triangular deceleration-time pulses but that the stopping distances are not. Minimum stopping distance is achieved with a rectangular pulse, and hence it is the most desired pulse shape from a consideration of deceleration from maximum velocity at a given deceleration level in the shortest possible distance.

Keywords: aircraft, impact, energy, velocity, stopping distance.

Introduction

Crashworthiness technology can be extended beyond simple concepts by simulation of the crash phenomena. Additional sets of impact conditions may appear critical for certain specific systems, and these require examination as well. Analytical models, scale models, and full-scale tests may simulate these conditions.

Complex interactions of crash, inertial, and structural forces, which contribute to the structural distortion and the acceleration environment experienced in a crash, can be observed [1]. Dissipation of the potential and kinetic energy of the aircraft can be studied for conditions that exist in the crash sequence. Structural distortion with subsequent ruptures, volumetric reductions, and penetration of occupied spaces can be assessed and estimates of the acceleration levels on critical components and occupants obtained.

In terms of fidelity, the dynamic testing of full-scale structures most closely approximates actual crash conditions, especially if the components of velocity and impacted surface conditions can be realistic simulated in the early design stages of a new aircraft; full-scale testing is untimely and costly. In fact, the testing of full-scale airframes has been confined to the development of technology rather than the development and improvement of design.

1. Dissipation of kinetic energy during impact

Relationships among the kinetic quantities of position, velocity, and acceleration form the basis for the study of dynamic phenomena.

By Newtonian Law, force (*F)* is a product of a mass (*m)* and an acceleration (*a*):

$$F = ma = m\frac{dv}{dt}, \tag{1}$$

where v is velocity and
t is time.
From equation (1), we get:

$$F = m\frac{dv}{ds}\frac{ds}{dt} = mv\frac{dv}{ds}. \qquad (2)$$

Multiplying F by elementary shift *(ds)* and integrating in the change limits of a shift, we get:

$$\int_{s_1}^{s_2} Fds = \int_{v_1}^{v_2} mvdv = \frac{1}{2}mv_2^2 - \frac{1}{2}mv_1^2 \qquad (3)$$

A shift in kinetic energy $T = \frac{1}{2}mv^2$ is equal to work $W = \int_{s_1}^{s_2} Fds$.

Then using the equation (3), when a speed descends from v_0 to *v* during impact (after impact speed is equal to zero), we can note:

$$\int_0^s Fds = \frac{1}{2}mv_0^2 - \frac{1}{2}mv^2 \qquad (4)$$

An ideal impact is shown at Fig 1. At Fig 1b we see a force and shift change dependence.

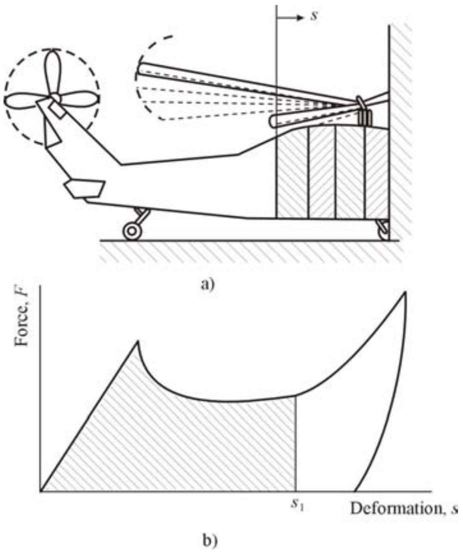

Fig 1. Kinetic energy descending during impact
a – chart of an impact;
b – a force and a shift interdependence.

At Fig 1b, hatched area is quantity of the kinetic energy before shift s_1, that is

$$\int_0^s Fds = \frac{1}{2}m(v_0^2 - v_1^2)$$

But during impact, a complicated process takes place and the absorption of energy depends on a shift decrement. We can look at the structure system like at a foam or a honeycomb [3].

An ideal schema for the porous composite of deformation is shown in the Fig 2.

An area under force and shift shows an energy absorption quantity:

"1" – elastic zone;
"2" – plastic zone;
"3" – bounced aircraft zone.

If we know an aircraft slippage distance on the ground till stopping,

$$Fs = \frac{1}{2}mv_0^2 \qquad (5)$$

where,

$$v_0 = \sqrt{\frac{2Fs}{m}} \qquad (6)$$

When an aircraft is moving slowly on a horizontal surface, force is

$$F = mG \qquad (7)$$

where m is a frictional coefficient and
G is weight.
Then speed

$$v_0 = \sqrt{\frac{2mGS}{G/g}} = \sqrt{2gms} \qquad (8)$$

where *g* – freewheeling dip of acceleration.

A change of work and kinetic energy, when speed is $v_f = 0$, are evaluated like:

$$-mGs = \frac{1}{2}\frac{G}{g}\left[v_f^2 - v_0^2\right] \qquad (9)$$

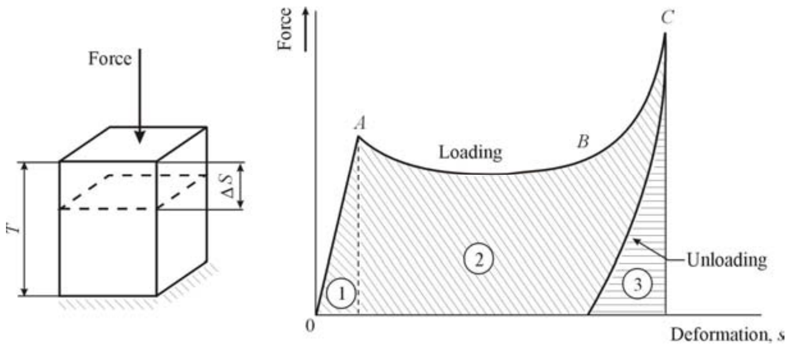

Fig 2. Force and shift interdependence of porous composite

From this

$$v_f = \sqrt{v_0^2 - 2gms} \tag{10}$$

and

$$v_0 = \sqrt{v_f^2 - 2gms} \tag{11}$$

But a slippage is not horizontal, and then speed is:

$$v_0 = \sqrt{v_f^2 - 2gms(m\cos q \pm \sin q)} \tag{12}$$

where q - a corner with horizontal (for slippage uphill the sign + applies; for slippage downhill, the – sign).

For example, slide distance of an airship is 350 m, residual speed is $v_f = 80\,\text{km/h}$, and frictional coefficient is $m = 0{,}7$. Evaluating speed (n_0) by the formula (11), we get $v_0 = 260\,\text{km/h}$.

2. Stopping distance

Subject to change of speed, a medium deceleration of an airship may be formulated as:

$$v_0^2 - v_f^2 = 2g\bar{L}s \tag{13}$$

where *s* is stopping distance and

$\bar{L}$ is medium deceleration.

Then stopping distance is:

$$s = \frac{v_0^2 - v_f^2}{2g\bar{L}} \tag{14}$$

According to this formula, we can notionally find a stopping distance till crash. Calculation data is listed at figure 3.

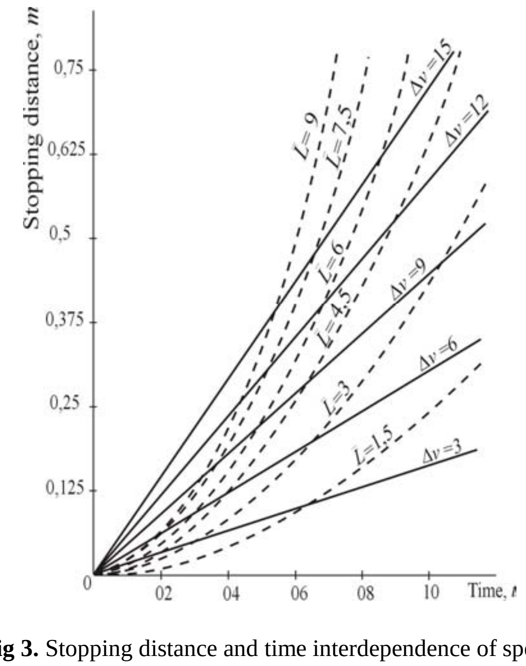

Fig 3. Stopping distance and time interdependence of speed change and deceleration level

A rate of deceleration may be rectangular, triangular or have an another form [2]. Rate of deceleration with a triangular form is shown in Fig 4.

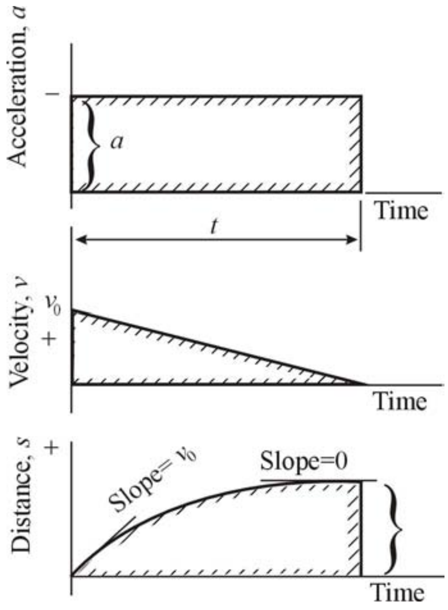

Fig 4. Rate of deceleration with a rectangular form

Here

$$t = v_0 / a,\quad v_0^2 = 2as,\quad s = \frac{1}{2}\frac{v_0^2}{a}$$

Rate of deceleration with a triangular form is shown in Fig 5.

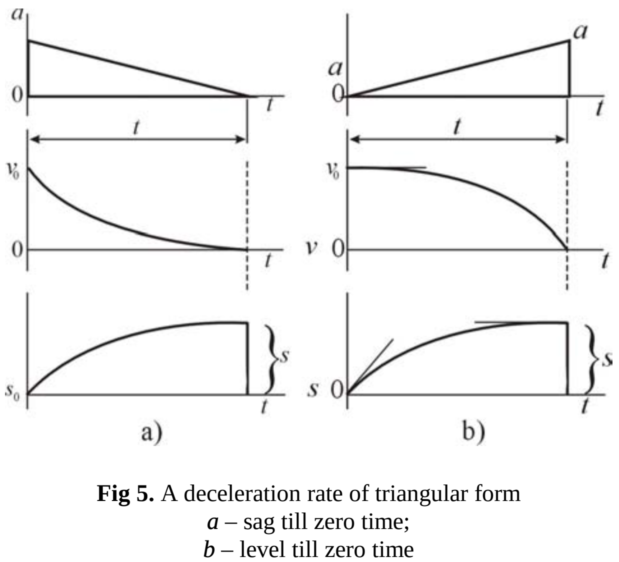

Fig 5. A deceleration rate of triangular form
a – sag till zero time;
b – level till zero time

In Fig. 5 a, computational dimensions are noted as:

$$\frac{1}{2}at = v_0,\ t = \frac{2v_0}{a},\ s = \frac{1}{3}v_0 t = \frac{2}{3}\frac{v_0^2}{a}$$

In Fig. 5 b, computational dimensions are noted as:

$$\frac{1}{2}at = v_0,\ t = \frac{2v_0}{a},\ s = \frac{2}{3}v_0 t = \frac{4}{3}\frac{v_0^2}{a}$$

Rate of deceleration with a symmetrical triangular form is shown in Fig 6.

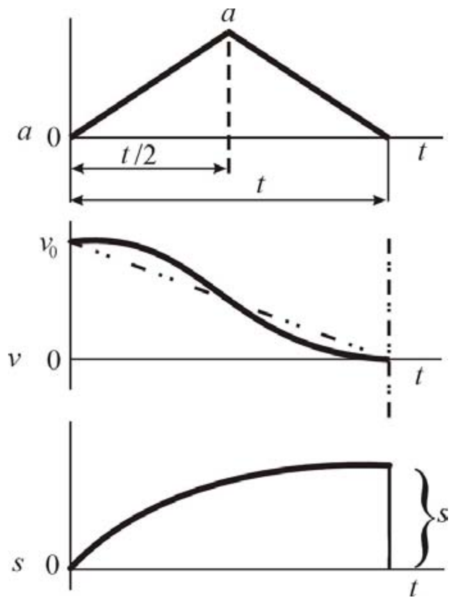

Fig 6. Rate of deceleration with a symmetrical triangular form

In Fig 6 a, computational dimensions are noted as:

$$\frac{1}{2}at = v_0, \; t = \frac{2v_0}{a}, \; s = \frac{1}{2}v_0 t = \frac{v_0^2}{2}$$

When speed is final, $v_t = 0$, the characteristics of the rate of deceleration various forms are calculated thus.

When deceleration rate is rectangular (Fig 7).

Term $\quad t = \frac{v_0}{gL}$;

Deceleration $\quad L = \frac{v_0^2}{2gs}$;

Stopping distance $\quad s = \frac{v_0^2}{2gL}$ or $s = \frac{gLt^2}{2}$.

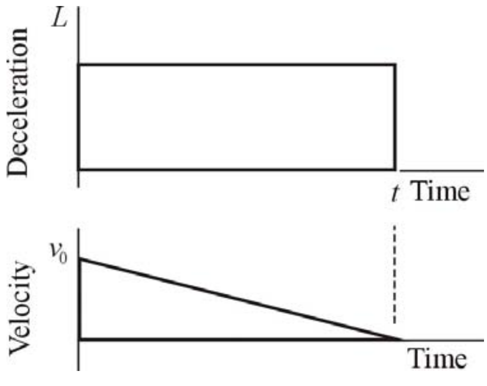

Fig 7. Rate of deceleration with a rectangular form

When the rate of deceleration is triangular form No 1 (Fig 8):

Term $\quad t = \frac{2v_0}{gL}$;

Deceleration $\quad L = \frac{2v_0^2}{3S}$;

Stopping distance $\quad s = \frac{2v_0^2}{3L}$ or $s = \frac{gLt^2}{6}$.

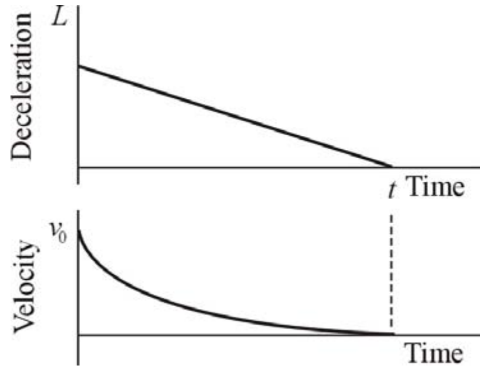

Fig 8. Rate of deceleration with a triangular form (No 1)

When the rate of deceleration is triangular form No 2 (Fig 9):

Term $\quad t = \frac{2v_0}{gL}$;

Deceleration $\quad L = \frac{v_0^2}{gs}$;

Stopping distance $\quad s = \frac{v_0^2}{gL}$ or $s = \frac{gLt^2}{4}$.

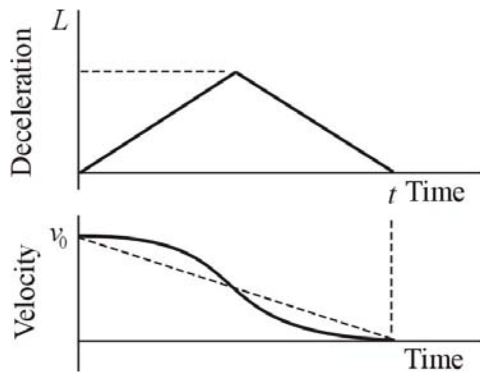

Fig 9. Rate of deceleration with a triangular form (No 2)

Term $\quad t = \frac{2v_0}{gL}$;

Deceleration $\quad L = \frac{4v_0^2}{3s}$;

Stopping distance $\quad s = \frac{4v_0^2}{3L}$ or $s = \frac{gLt^2}{3}$.

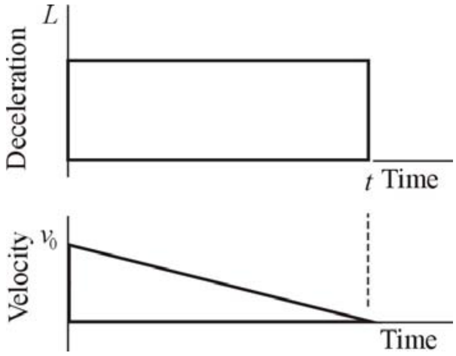

Fig 10. Rate of deceleration with a triangular form (No 3)

Term $$t = \frac{1{,}57 v_0}{gL};$$

Deceleration $$L = \frac{0{,}7854 v_0^2}{gs};$$

Stopping distance $$s = \frac{0{,}7854 v_0^2}{gL}$$ or

$$s = \frac{gLt^2}{p}.$$

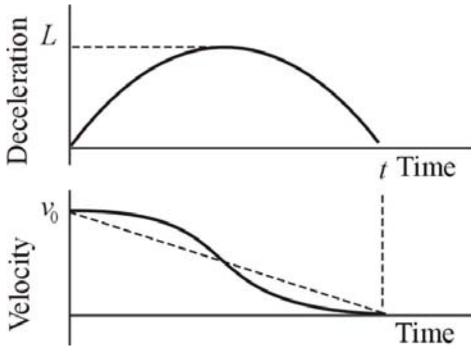

Fig 11. Rate of deceleration with a half-sine form

A dependence of the following equations is shown in the Fig 12.

In Fig 12 we can see that stopping distance is shortest when a rate of deceleration has a rectangular form.

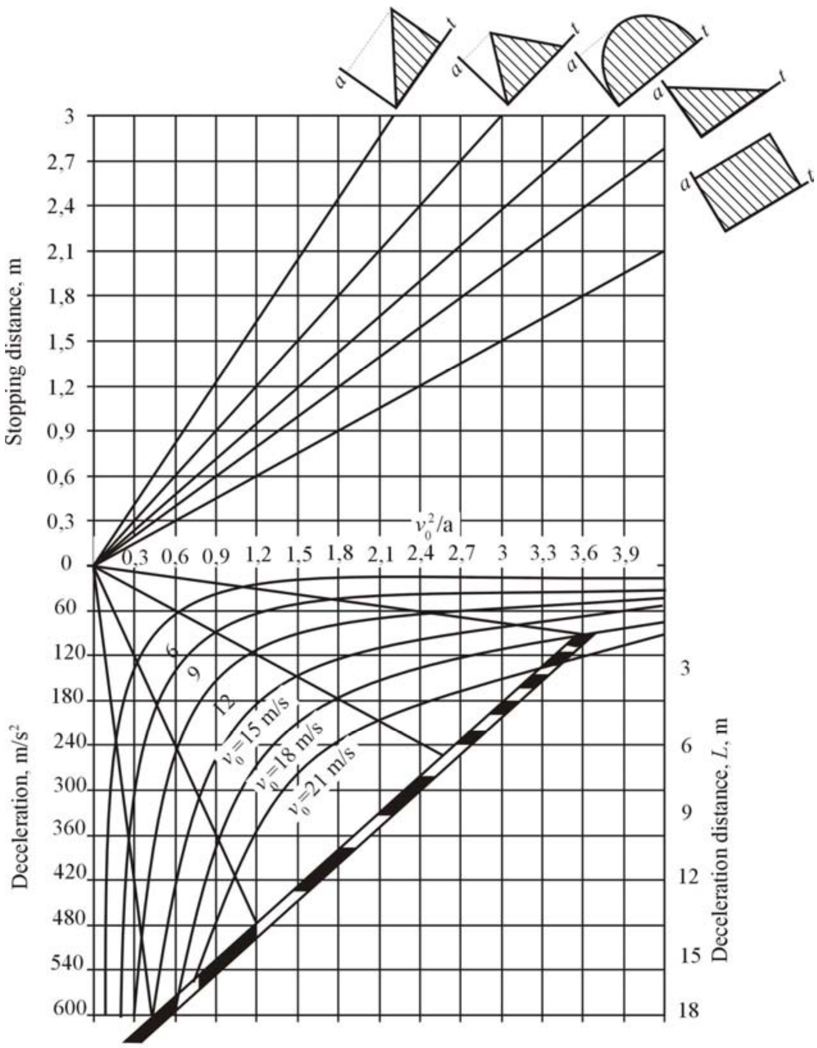

Fig 12. The dependences of the velocity, the deceleration and the distance on the time

Conclusions

1. The time to stop aircraft is possible in the three deceleration-rate forms: triangular, rectangular, and half-sine.
2. Minimum stopping distance is achieved with the rectangular pulse and hence it is the most desired pulse shape from a consideration of deceleration from maximum velocity at a given deceleration level in the shortest possible distance.

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