Crash Analysis of an Aircraft Fuselage under Belly Landing

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Abstract*— Belly landing occurs when an aircraft lands without deploying its landing gear due to pilot error or mechanical failure. In the present work crash analysis of the fuselage under such belly landing is studied by numerical simulation using LS-DYNA software. In this study both the effect of sinking speed and the effect of different terrain properties on energy absorbing capacity is considered. Fuselage structure was modelled using LS-DYNA to simulate the crash analysis of the fuselage under vertical drop. The fuselage section similar to Boeing 737 aircraft was dropped at 7m/s and 10m/s on a rigid surface as well as on water and the deformations of fuselage were noted for each case and the energy absorbed by each of the components of the fuselage was evaluated. From the result obtained, it shows that frame and skin plays important roles in absorbing energy under crash.

Index Terms— ***belly landing, fuselage, crashworthiness, LS-DYNA, water impact***

I. INTRODUCTION

In the history of aviation accidents, belly landing does occur when pilot forget to extend the landing gear or due to mechanical failure while touchdown. A report by Bond [1] cited that Emirates plane EK521 crash-landed at Dubai International Airport speculated due to pilot error. The pilot decided to abort the landing because of a wind shear and the aircraft eventually landed with its belly and caused a massive fire. Moreover in the case of aircraft with engine failure, the emergency situation may lead the pilot to ditch on a nearby water body/marshy lands such as the case of well-known Hudson aircraft crash in 2009 where US Airways Flight 1549 made an emergency belly landing on the Hudson river [2].

There are many risks in performing belly landing such as the aircraft may be in fire, flip over or even disintegrate. Moreover the impact of belly landing in the absence of landing gear and hence the shock absorber may lead to entire kinetic energy being transferred to the structure and the passengers, which may be dangerous and prove fatal. Federal Aviation Administration (FAA) came out with strict regulations and requirements that need to be implemented by aircraft manufacturers to ensure the safety of passengers under unexpected incident. For example, during crash landing there is a limit imposed on the deceleration pulse at the passenger seat that need to be meet by the aircraft manufacturers (Heimbs [3]). To avoid this impact energy passing to the passengers the structure below the passenger compartment need to be designed to absorb the entire kinetic energy. Thus one needs to study the impact of the fuselage structure on different terrains such as rigid, soft soil and water bodies to know the energy absorbing capability.

Experimental study of such fuselage structures under impact on different terrains is very costly. A typical experimental drop test is reported by Xiaochuan et al [4], in which the fuselage was lifted to a height of 2.5m above the platform using four cables that is attached on the upper side of the fuselage section. High speed camera was used to record the dynamic image of the test and later it was used to get the impact velocity. The impact caused the sub floor structures deformed and struts buckled locally. The cargo beams were broken due to the joint between cargo floor and frames are pulled out. These experiments are very costly to realize and repeat, hence one need to use the modern simulation tool such as LS-DYNA to simulate the impact and repeat many times to arrive at the best optimized structure that can absorb the maximum energy during belly landing. Xiaochuan et al [4] has also carried out such a simulation and validated with their experimental test.

Figure 1 : Fuselage Drop test[4]

Adams and Lankarani [5] has carried out an experimental and a simulation study of a B737 fuselage section impact on rigid surface using LS-DYNA software. While Xue et al [6] analyzed the structural deformation of fuselage under crashworthiness in terms of peak loads, deformation mode, energy absorption and structural integrity. Recently Wang Yonghu et al. [7] has carried out an experimental and numerical study of water impact investigations for aircraft crashworthiness. Tay et al [8] studied crash simulations of aircraft fuselage section in water impact and compared with solid surface impact. Very recently Edwin and Karen [9] has carried out crash testing and simulation of complete Cessna 172 aircraft model using LS-DYNA in studying pitch down impact onto soft soil. It can be found that considerable studies have been carried out on the impact of aircraft on land whereas only few studies are reported on impact on water. Thus in this work, simulation of a B737 type fuselage section belly landing on both rigid wall and water is carried out using LS-DYNA software.

II. GEOMETRY OF THE FUSELAGE

In this study only fuselage section was modelled rather than the whole aircraft components. Furthermore, this study focuses on the energy absorption by the fuselage only and the material selection has been reduced to perfectly plastic type. The model of the fuselage consists of skin, frames, stringers, passenger floor and struts as shown in figure 2.

The model was developed using Solidworks which consist of skin, Z-shaped frame and U-shaped stringers. Joints, fastener, doublers and other elements were ignored to keep the geometry simple. The diameter and thickness of the fuselage skin are 2m and 0.2 cm respectively while the passenger floor was placed around one third from the bottom of fuselage skin. Three frames were modelled with thickness of 0.2cm and the fuselage is 1m length as shown in figure 3.

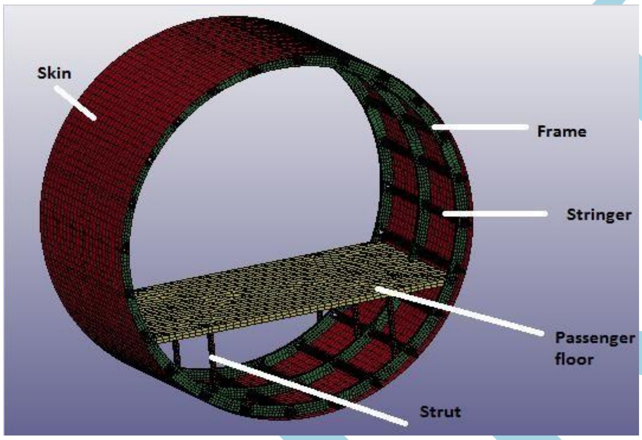

Figure 2 : Fuselage components

III. MATERIAL SELECTION

The LS-DYNA model made up of approximately 141539 nodes and 264413 elements. Shell elements were used at fuselage skin, frames, and supporting beams. Solid element was used at passenger floor due to its large thickness. Simplified Johnson-Cook model, MAT98 of LS-DYNA were used and the details are provided in Table 1. Plastic Kinematic, MAT003 of LS-DYNA was used for cabin floor.

Table 1: Material of fuselage section

Component	Density (kg/m^3)	Elastic modulus (GPa)	Effective failure strain (%)
Skin	2796	71	15
Frame	2796	71	8
Stringers	2770	71	15
Struts	2796	71	8

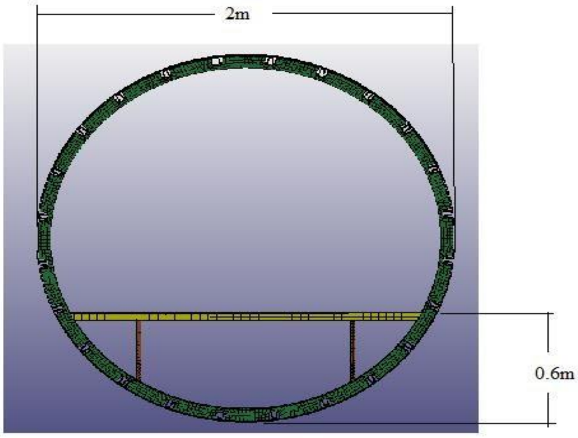

Figure 3 : Fuselage dimension

Since the fuselage was exported to LS-DYNA from Solidworks, the parts need to be connected with each other through Automatic Single Surface contact. This type of contact is normally use in crashworthiness studies because it is reliable and accurate. To simplify the model, all the fuselage parts were combined to one part using part set. Velocity of 7 m/s was defined in Y direction and the fuselage section was dropped vertically to ground. Later, the velocity was increased to 10m/s to study the effect of changing velocity of the fuselage.

IV. VALIDATION

The result from an experimental test conducted by Xiaochuan et al [4] at velocity of 9.14 m/s is used to validate the simulation done in this work. In the simulation, the fuselage was dropped vertically on a rigid surface at a velocity of 10 m/s. Although the parameters used are different for both cases, the experimental result was used for qualitative validation. The result from the test shows that the sub floor structures deformed, some of the materials of the frame deformed plastically and struts buckled. One can note that deformation pattern for both the simulation (Fig. 4) and experiment (Fig. 5) are very similar. Moreover, the simulation produced a plastic hinge on the deformed frame exactly similar to that of experimental results. In both the experimental and simulation, the lower part of the fuselage almost hit the passenger floor as shown in Figs. 4 & 5. Thus in both cases, the structure undergo similar plastic deformation to absorb the impact energy.

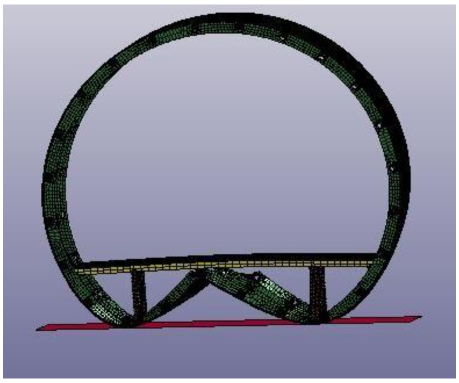
Figure 4 : LS-DYNA simulation (V= 10 m/s)

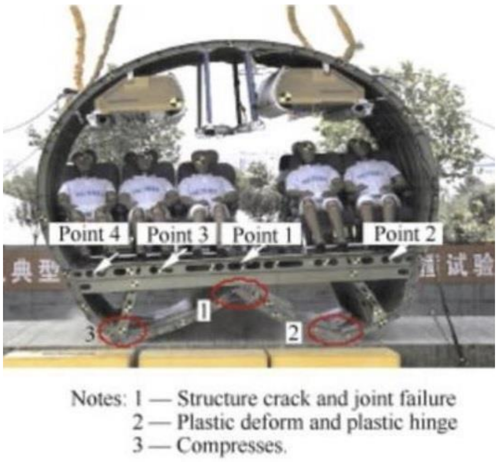

Figure 5 : Experimental result[4] (V= 9.14 m/s)

V. EFFECT OF IMPACT VELOCITY

Fig. 6 shows the deformation pattern of the fuselage for an impact velocity of 7 m/s. Fig. 7 gives the dissipation of kinetic energy with time and it can be seen it dissipates completely at t = 43 ms. When the fuselage hit the ground, the kinetic energy slowly dissipated into another form of energy such as heat and it is absorbed by the inner part of the structure. It can be seen from Fig.8 that frame absorb most of the energy followed by skin. Passenger floor, struts, and stringer contribute little parts in absorbing the energy. The result pattern is similar to a study done by Xue et al. [8] that showed energy absorbed by the frames are much larger than other parts. Therefore, frame plays important roles in absorbing energy during the impact.

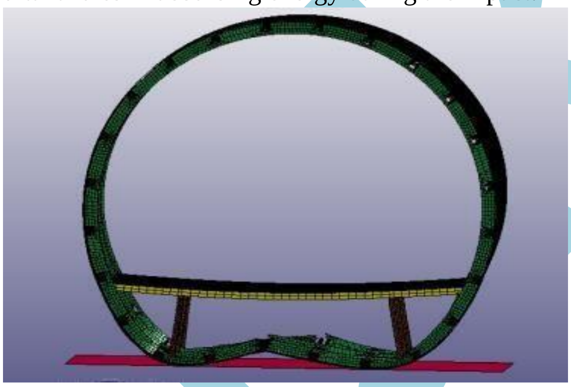

Figure 6 : Deformation for Impact at V=7m/s on rigid surface

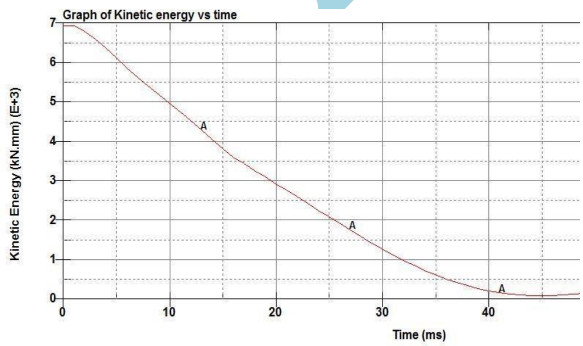

Figure 7 : Kinetic energy vs time for V =7 m/s on rigid surface

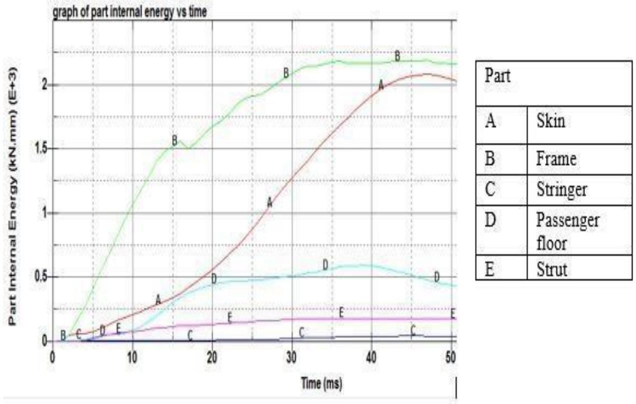

Figure 8 : Part internal energy vs time for V= 7 m/s on rigid surface

Moreover it was found that the deformation is larger when the impact velocity is high. It can be seen from Fig. 4 that the lower part of the fuselage almost hit the passenger floor when the velocity increased to 10m/s as compared to the deformation at 7 m/s (Fig. 6). There are also some differences in internal energy absorbed by each part as the velocity is increased as shown in Fig.9. Initially, frame absorbs most of the energy but starting 28 ms after the crash, the skin takes the lead by absorbing most of the remaining energy. Thus proper skin materials selection are required to make sure the aircraft can absorb maximum energy or separate elements that can absorb the energy need to be added. For example, as proposed by Martin and Arokkiaswamy [10], an additional structure such as crash tubes that are fixed onto the ski structure can absorb the energy and can also prevent the aircraft structure from damage under crash landing.

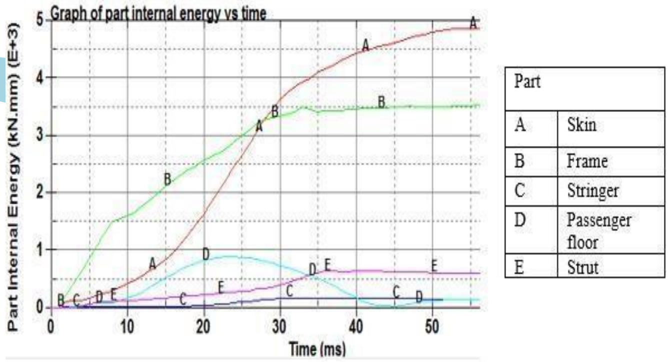

Figure 9 : Part internal energy vs time for V= 10 m/s on rigid surface

VI. WATER CRASH MODELLING

A shell box with dimension of 2500mm x 1500mm x 500mm was used as container holding water. The water modeling was done using Smooth Particle Hydrodynamics (SPH) method. Fluid is represented from a set of moving particles and each SPH particle denotes an interpolation point on which all the properties of the fluid are known. Automatic Node to Surface contact was defined to make sure fuselage is in contact with the water. The same contact was also defined for container to water surface. Control SPH was added to define the general control parameters needed for calculation. MAT_NULL was used to define the material of water.

The fuselage was dropped into water at a velocity of 7m/s and the resulting deformation pattern is as shown in Fig 10. In landing on rigid surface, the kinetic energy goes to zero at 43ms as shown in Fig. 7, but for the case of landing on water, little amount of kinetic energy is still left as shown in Fig. 11. Thus the kinetic energy in water landing was not fully absorbed by the fuselage structure as compared to that of landing on rigid surface. Moreover in water landing as compared landing on rigid surface (Fig. 8), there is difference in internal energy absorbed by each part (Fig. 12) and again frame absorbs most of the energy.

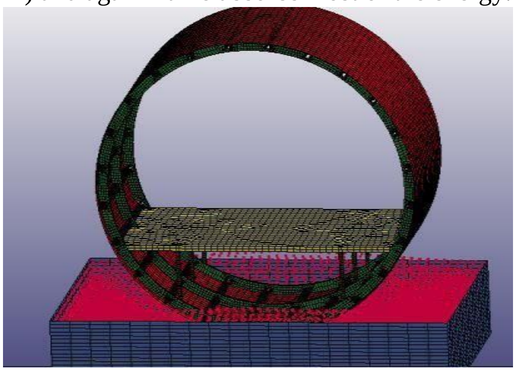

Figure 10 : Crash on water surface

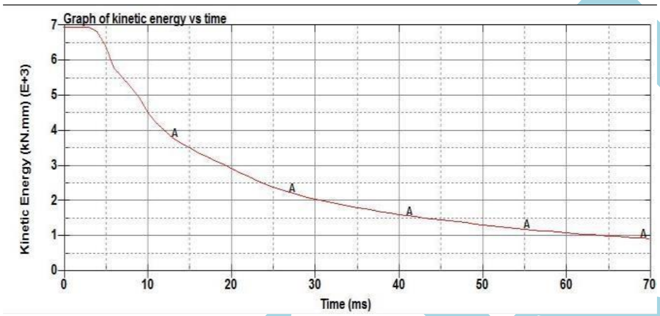

Figure 11 : Kinetic energy vs time for V= 7m/s on water

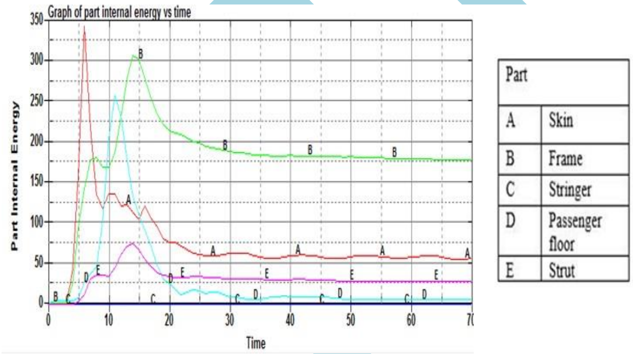

Figure 12 : Part internal energy vs time for V=7m/s on water

VII. CONCLUSION

Crash simulation of belly landing of an aircraft fuselage section in rigid and water surface has been studied using LSDYNA software. The role of each part of fuselage in absorbing the energy is clearly brought out both for solid and water surface impact. It was found that frame absorb most of the energy followed by the skin. Passenger floor, struts, and stringer contribute little parts in absorbing the energy. The energy absorbed by the fuselage structure for impact on water is less than the energy absorbed for impact on rigid surface.

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