

## Research Article

### Numerical Simulation of Helicopter Cockpit Seat subjected to Crash Impact

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**Abstract:** Sikorsky S-61 or better known as “Nuri” had served the Malaysian aviation sector for the past four decades. It is mainly used for transportation, combat search and rescue purposes. However, there were Nuri helicopter crashes or accident cases reported during its operation period which involved loss of its occupants. The pilot survivability rate can be improved provided that the vertical impact loading on the helicopter is reduced during the crash accident. Utilization of an energy absorbing pilot seat or cockpit structure maybe one of the approaches to minimize the impact shock exerted to the occupants. However, the shock or maximum acceleration of the cockpit/pilot seat has to be first determined before a thorough design scheme can be undertaken. In this study, a vertical crash event of the Nuri pilot seat from 500 feet altitude was simulated and the maximum acceleration rate was determined using MSC PATRAN/LS-DYNA. The pilot survivability was determined by comparing the result with human tolerance criteria data available in other published works. From the result, it was found that the maximum acceleration of the Nuri pilot seat was 584.4g at 19.63 milliseconds, thus it can be concluded that the survivability aspect of the pilot is fatal when compared to other published works.

**Keywords:** Crash, aircraft, aerospace, finite element analysis, impact

## INTRODUCTION

The S-61 A-4 helicopter is manufactured by Sikorsky, and the first version was built in 1957. Its operation in the United State of America Naval began in 1961 and now is widely served other nations security forces such as British Arms Forces, Italian and Brazilian Navy and Japan Maritime Self Defense Force (Jackson, 2005, King and Lombardo, 1997). Sikorsky S-61 A-4 or known as Nuri in Royal Malaysian Arms Forces (RMAF), is a twin-engine class helicopter which is mostly utilized as a transport aircraft and had been first purchased by Malaysian Government in 1968. From that historical date, the Nuri helicopter had become one of the useful modes of transportation for the RMAF. Generally, the main usage of Nuri helicopter is for transportation and it can carry about 31 passengers and four crews. Moreover, Nuri helicopter also could be used for rescue operation from remote area by using hoist (by mean of winching). Although Nuri helicopters had served the RMAF for the few decades, it also involved in several crash cases since its inception to RMAF in 1968. About 18 cases of Nuri crashes had been reported since 1969 till 2007 (Bernama, 2007). Apart for the defence sector, other similar S-61 Sikorsky variants are used in the offshore

and maritime operation by commercial transportation company in Malaysia. Therefore, this study focuses on the crash impact simulation behavior of the Nuri cockpit and pilot seat structure, in order to gain a better understanding on the contributing factors that may improve the survivability of the occupants.

## LITERATURE REVIEW

Acceleration is defined as rate of change of velocity of an object over period of time. It can be divided into few types: positive, negative and gravitational acceleration. An object moves faster in positive acceleration while moves slower in negative acceleration. Negative acceleration is known is deceleration. Gravitational acceleration on an object is due to gravity force. In addition, for impact related acceleration or known as “shock”, it can be expressed in unit of “g” or “G”, where this represents the ratio of object’s acceleration to gravitational acceleration at sea level. Shanahan (2004) reported that acceleration which occurs during a crash or impact can be described in crash triangular pulse. It was reported that this triangular crash impulse simplifies the calculations for most of the aircraft and automobile crashes. Impact acceleration tends to produce mechanical stress in short

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duration, however potentially traumatic the object or human.

**Human tolerance curve:** Human tolerance of a restrained individual to sudden acceleration or also known as human tolerance curves was developed by Eiband (1959). It was the compilation of data from

human tolerance experiments on live volunteers done by Colonel John Stapp. The outcomes of the studies can be shown in Fig. 1 to 3. These data represents the boundary area of uninjured, moderate injury and severe injury of human subjected to Gz acceleration force. It is noted that, this experiments performed using human volunteers and animals on rigid seats, well-designed

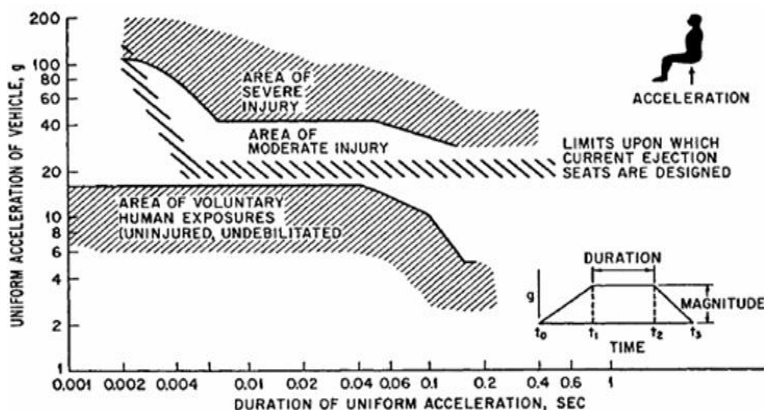


Fig. 1: Eiband Curve for +Gz (Eiband, 1959)

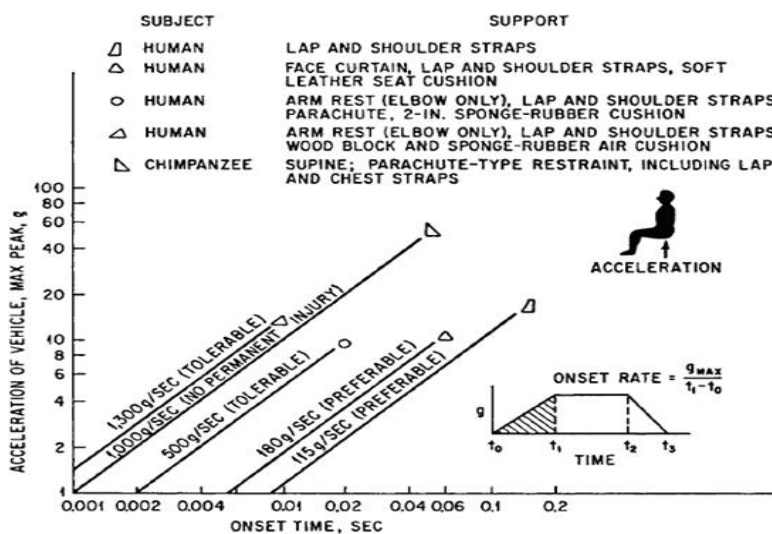


Fig. 2: Effect of rate of onset for +Gz (Eiband, 1959)

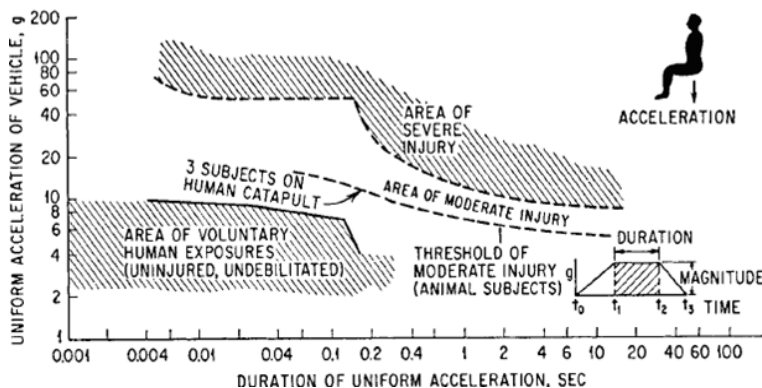


Fig. 3: Eiband Curve for -Gz (Eiband, 1959)

Table 1: Human tolerance criteria (Shanahan, 2004)

Direction of accelerative force	Occupant's inertia response	Tolerance level
Accelerative force	Response	
Headward (+Gz)	Eyeballs down	20-25 G
Tailward (-Gz)	Eyeballs up	15 G
Lateral Right (+Gy)	Eyeballs left	20 G
Lateral Left (-Gy)	Eyeballs right	
Nack to chest (+Gx)	Eyeballs out	45 G
Chest to back(-Gx)	Eyeballs in	45 G

body supports with minimum slack in hardness. Most research works pertaining to occupant and helicopter crash response (Jackson *et al.*, 2002; Viano and Lau, 1998; Hu *et al.*, 2009) relate their findings with the results obtained by Eiband (1959). Shanahan (2004) also have tabulated from their findings (Table 1) the predicted human tolerance area for other axes of acceleration forces, which uses occupant's eyeballs response correlation with the impacting acceleration (in g).

**Tolerance to abrupt acceleration:** According to Shanahan (2004), development of crashworthiness or protective system design standards warrants a clear understanding of human tolerance to abrupt acceleration and factors affecting it. Factors affecting human tolerance to abrupt acceleration can be categorized as extrinsic and intrinsic. Extrinsic factors, which are associated with characteristics of crash pulse and design of seating and restraint system, can be further classified into 5 factors. These are namely: magnitude of acceleration; direction of the acceleration; duration of acceleration; rate of onset; position and availability of restraint or support system. On the other hand, intrinsic factors are related to the person/subject impacted upon, such as: age of subject; health of subject; sex of subject and physical condition of subject. Intrinsic and extrinsic factors are independent of each other.

**Numerical study in crashworthiness structures:** Bisagni (2002) reported that crash tests performed on subfloor and intersection structural elements exhibits good energy absorbing capability in the subfloor structure. The value of absorbed energy and crush force efficiency are found to be 23 kN and 0.66 respectively based from the PAM-CRASH analysis made at the intersection elements and sub floor structure. The numerical results agree well with the experimental values obtained especially regarding general behaviour and specific numerical values. Most important observation made is the structural collapse mechanism of the numerical results matches near to the behaviour of the crash tests. It was further noted that good structural failure predictions could be obtained using detailed geometrical model with suitable material property data.

A Lagrangian numerical approach to water modeling was developed by Hughes *et al.* (2007) in predicting the crashworthiness of helicopters onto water. Based on the numerical results findings, he has concluded that initial stage of water impact could be captured using the proposed approach. Size of the element used in refining the mesh affect the capturing accuracy of the fluid response and imparted loading. Besides that the process of obtaining pressure time histories becomes an uphill task when there is separation between water and skin element due to contact instability. Since the element and contact instability affects traces obtained, the pressure results should not be used to gauge the accuracy of numerical values obtained. Nevertheless, he has suggested future recommendation for two limitations with regards to the existing metallic design that were discovered in this research. Firstly, to maximize the skin deflection without failure to enable transmission of the loading to other energy absorbing components. Secondly, to design intersection joints which could degrade the stiffness based on the type of surface impacted upon.

Luo Cheng *et al.* (2007) have conducted numerical simulation of the fuel tank crashing with the aid of CAD, CAE and FEM commercial code. Simulation was carried out with two structural arrangement, namely fuel tank with and without protection frame, to obtain the dynamic response behavior and crashworthiness parameters. Large lateral deformation, experienced by fuel tank without protection frame when it crashes onto rigid ground, is not good for crashworthiness of structure. On the other hand, fuel tank with protection frame remains its original shape perfectly with effective reduction in peak stress. It was indeed observed that protection frame helps to absorb and dissipate energy significantly during impact.

**Simulation model development:** The Nuri helicopter was chosen as test model for the simulation work due to its availability. The Nuri cockpit and pilot seat structure were modelled using Solidworks 2007. Measurement of the primary Nuri cockpit and pilot seat frame structures was measured in situ at an air force facility. Solid works 2007 was chosen due to its user friendly features and its compatibility with finite element pre-processing package MSC PATRAN. It can be saved in IGES (\*.igs) format which can be exported to MSC PATRAN for pre-processing phase of the model (Fig. 4).

Simplification in meshing process was done to reduce the duration taken for simulation where the mid-surface of the helicopter were modelled as a shell element. LS DYNA solver was used in the post-processing stage of the numerical model development. Two types of element were chosen to mesh the model; there are co-triangle (CTRIA3) and quadrilateral (CQUAD4) shell elements. The total elements in the model were 65967 including the cockpit and pilot seat structure and the ground as shown in Fig. 4b.

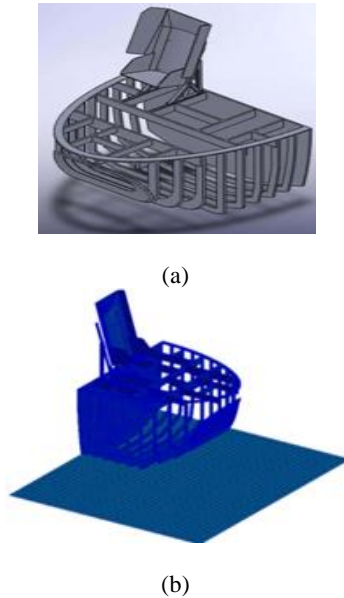


Fig. 4: Development of cockpit and pilot seat structure (a) SolidWorks 2007, (b) MSC PATRAN

**Material model, load and boundary condition:** In this project, two types of materials models were selected from LS-DYNA library; MAT\_RIGID (TYPE 20) and MAT\_PIECEWISE\_LINEAR\_PLASTICITY (TYPE 24). TYPE 20 was applied to the surface plane which represents the ground section, while TYPE 24 was applied for the cockpit and pilot seat elements. The Nuri helicopter cockpit materials structure is typically manufactured using Aluminium Alloy 7075-T6 and Aluminium Alclad 7075-T6. The pilot seat primary holding structure is made from aluminium alloy 2024-T3 whereas the pilot seat rail is constructed from 4130 steel. The material data properties for all aluminum

alloy materials were adopted from research works of Abotula and Chalivendra (2010) and Murat Buyuk *et al.* (2009). Johnson-Cook material failure model was also selected to simulate the deformation of aluminum alloy structures during high speed drop impact due that the model in principle, can handle non-linear problems and complex contact conditions. The rigid boundary condition for the model is the plate element which represents a flat ground surface. Single point constrains which does not have any translational and rotational displacement was applied to the elements in the plate. For impact simulation, automatic general contact was chosen in the LS-DYNA configuration.

## RESULTS AND DISCUSSION

This section focuses on the simulation results to determine the maximum g impact at the pilot seat subjected to vertical impact crash from 500 feet of altitude. It also includes deformation analysis, relationship between displacement, velocity and acceleration with time.

**Deformation analysis:** Figure 5 depicts the initial condition of Nuri's cockpit and pilot seat before vertical impact crash occurs where the ground section is represented by square plane under the structure. Theoretically, kinetic energy is at maximum level just before the cockpit reaches ground. The cockpit structure is basically designed to absorb and distribute the impact energy in order to minimize the transmitted shock to pilot seat and subsequently to the pilot. However, not all forces or energy are well distributed without any proper damping or shock absorbing component.

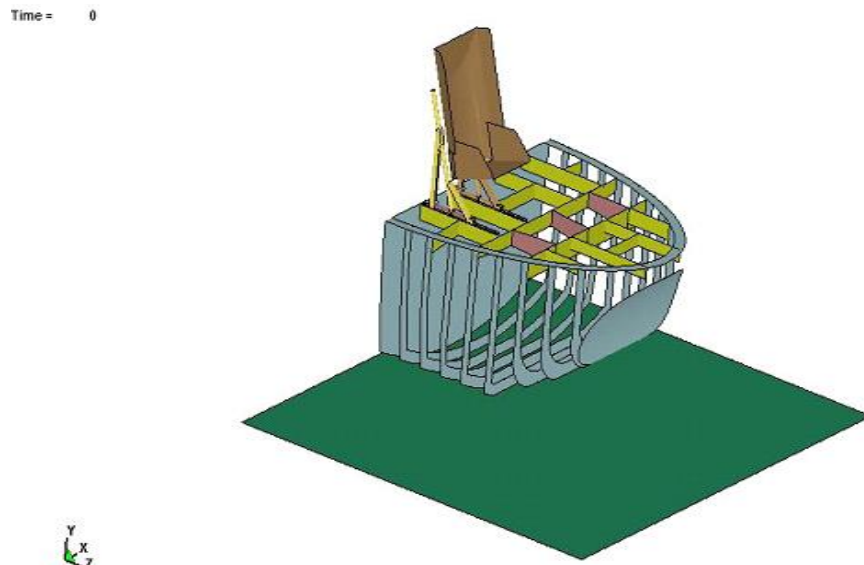


Fig. 5: Initial condition of Nuri's cockpit and pilot seat before crash event

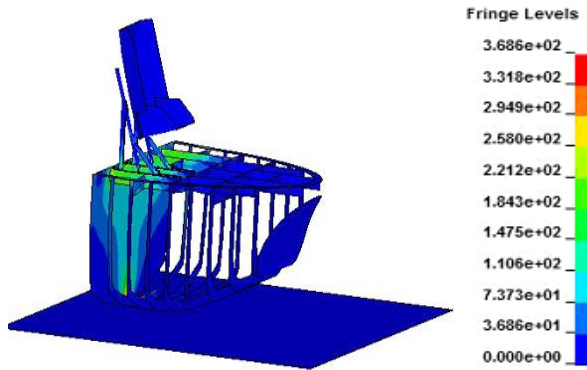


Fig. 6: Cockpit and pilot seat condition at 2.2 milliseconds of crash time

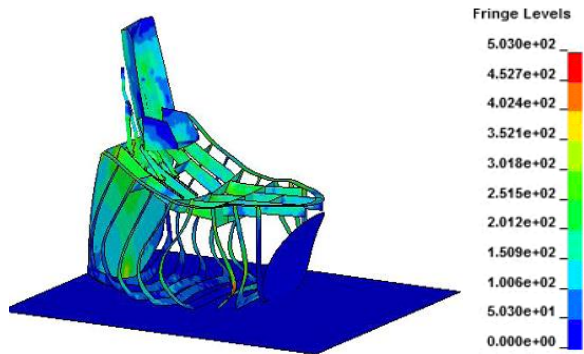


Fig. 7: Cockpit and pilot seat condition at 10 milliseconds of crash time

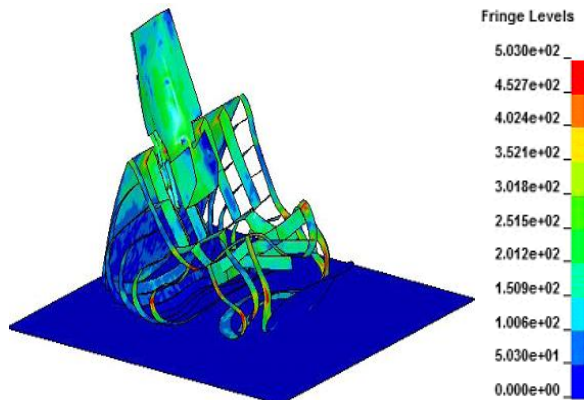


Fig. 8: Cockpit and pilot seat condition at 17.04 milliseconds of crash time

Figure 6 to 9 depict the deformation simulation of cockpit and pilot seat subjected to vertical impact crash. At 2.2 milliseconds, the structure touches the ground as shown in Fig. 6. However at 10 milliseconds, the cockpit structure began to deform as shown in Fig. 7. It can be observed on cockpit structure that the impact forces are mostly distributed to the rib of the cockpit structure.

Simultaneously, the overall pilot seat structure however remains intact and secure without major deformation. From Fig. 8, it was found that the

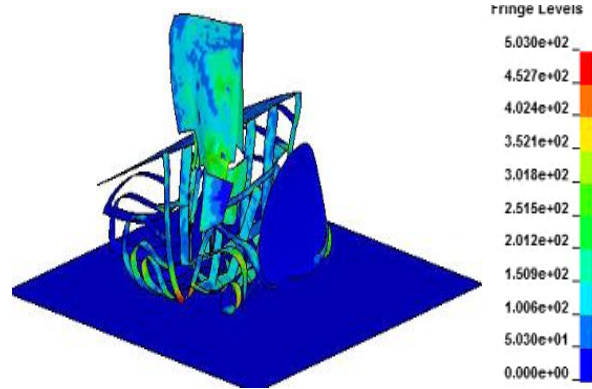


Fig. 9: Cockpit and pilot seat condition at 49.63 milliseconds

simulated acceleration was estimated to be  $5.73 \times 10^6 \text{ mm/s}^2$  at 17.04 milliseconds. Pilot seat are now seen to deform extensively during this moment. Fig. 9 presents the structure of cockpit frame and pilot seat deformation phase at 49.63 milliseconds. It is found that maximum displacement (y-direction) of the seat structure is at 1203 mm whereas at this moment, it can be classified as total failure or wreckage for the crash event.

**Effects of crash impact to pilot seat:** 4 nodes at the pilot seat pan have been chosen to investigate its displacement, velocity and acceleration behavior during the crash impact. These chosen nodes are depicted in Fig. 10.

The nodes displacement in vertical (y axis direction) over time history curve is depicted in Fig. 11. It was observed that all nodes (A, B, C, D) experienced same displacement behavior from 0 second to 10 milliseconds. However, from 10 milliseconds onwards, higher displacement is observed for node A when compared to other nodes. Node A shows the highest displacement of 1203.32 mm at 50 milliseconds due to its location, which is the nearest point to the pilot seat pan-cockpit support structure. At this moment, it is assumed that the maximum impact force from the cockpit is transferred or distributed to the pilot seat pan. Figure 12 depicts velocity vs time history curve of the selected nodes. It is found that, all nodes experienced negative velocity values before 50 milliseconds due to the cockpit de-acceleration effect. At 50 milliseconds, almost all nodes recorded zero velocity which translate the pilot seat pan has stop de-accelerating and is totally static at this point. However, it starts to move constantly toward positive y direction after 50 milliseconds which imply that the pilot seat structure bounced back due to impulse force effect upon hitting the ground. Fig. 13 depicts the relationship between acceleration of pilot seat over time. It can be concluded that the acceleration tends to stable at zero value after 50 milliseconds. All simulated results from Fig. 11 and Fig. 13 exhibited similar



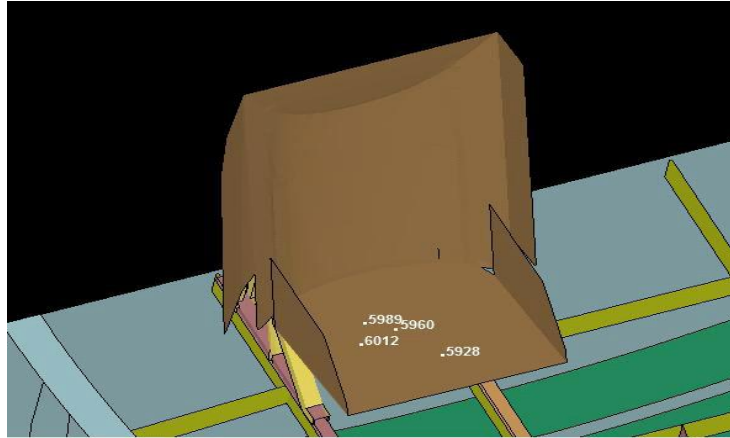


Fig. 10: Nodes at pilot seat

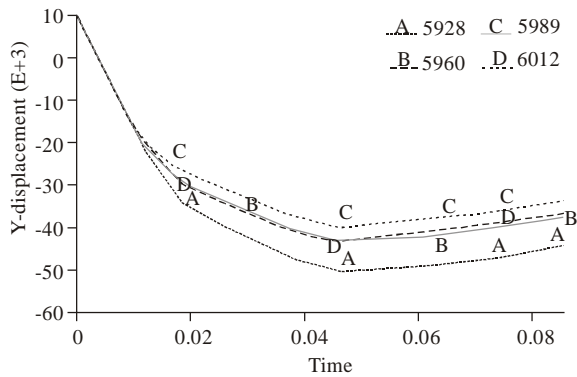


Fig. 11: Pilot seat pan vertical displacement and time history curve of crash event

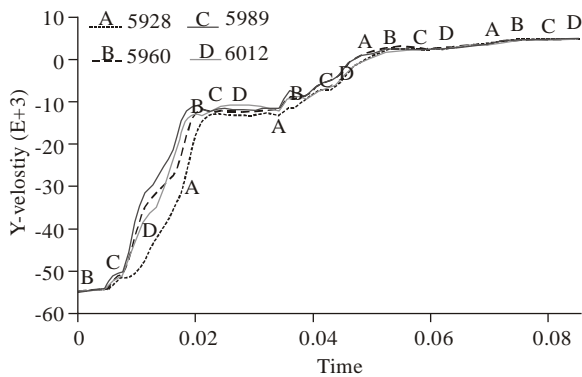


Fig. 12: Pilot seat pan velocity and time history curve of crash event

history curve trends as other published work by Jackson *et al* (2002), which have utilized finite element code MSC DYTRAN to validate their experimental works.

**Comparison of pilot seat and pilot seat support crash response:** Figure 14 shows the selected nodes at pilot seat support for comparative study on pilot seat pan-support structure impact forces. Node 115461 was selected for the support section due to its location near

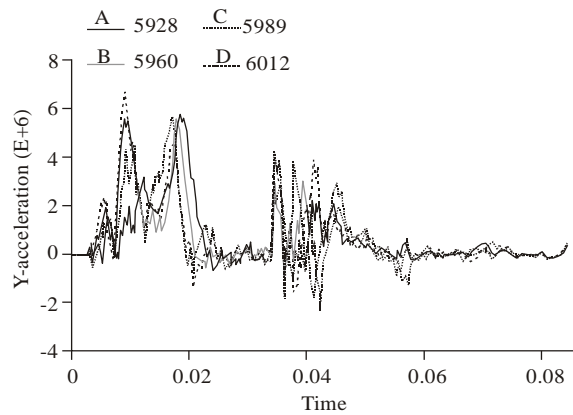


Fig. 13: Pilot seat pan vertical acceleration and time history curve of crash event

to the main cockpit beam structures. For pilot seat pan, node 6012 was chosen randomly. From Fig. 15, the maximum acceleration for node 115461 was found higher than node 6012. This can be attributed to impact force was transmitted first to node 115461 prior ascending to node 6012. At the same time, pilot seat support functions as preliminary impact forces absorber or damping mechanism for the seat pan. From the result, the pilot seat support endures maximum impact acceleration of  $8.25 \times 10^6 \text{ mm/s}^2$  or 841.6 g, whereas it is simulated about  $5.73 \times 10^6 \text{ mm/s}^2$  or 584.4 g (at 19.63 milliseconds time event) will be exerted to the pilot seat. The maximum impact forces transmission from the support to seat pan was delayed by 9.54 milliseconds. It can be noted that the maximum impact value measured at pilot seat indicates that the pilot will likely to be severely injured at this level when compared with the human tolerance curve (Fig. 1). It is also observed that the cockpit structure shape, pilot seat, material selection can play a significant role in the new energy absorbing capability of helicopter cockpit design in order to increase the pilot survivability.

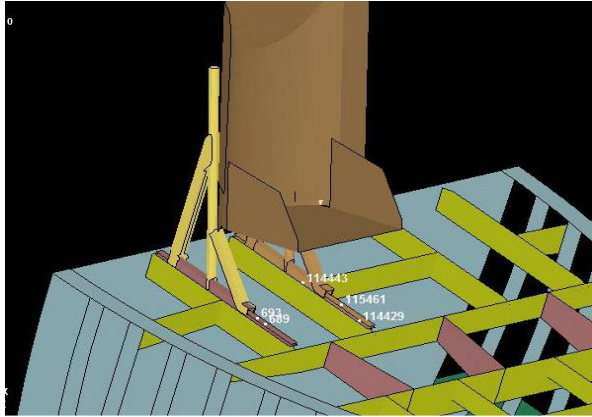


Fig. 14: Nodes at pilot seat support

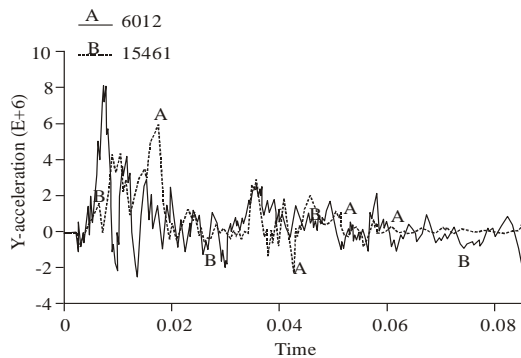


Fig. 15: Comparison of vertical acceleration at pilot seat (node 6012) and pilot seat support (node 115461)

### CONCLUSION

The crash impact to the Nuri helicopter pilot seat from 500 feet altitude was examined using the finite element solver LS-DYNA. From the simulated cockpit & pilot seat model, the following conclusions can be made concerning to this study:

- Finite element simulation shows the extreme deformation of the pilot seat during the vertical crash with maximum shock of 584.4 g at 19.63 milliseconds.
- From the survivability graph, the value of 584.4 g at 19.63 milliseconds shows that the Nuri cockpit seat does not provide any substantial crashworthiness mechanism or capability to absorb the shock exerted to the occupant from vertical drop of 500 feet.

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