Dynamics and Impact Biomechanics Modeling and Analysis of Aircraft Takeoff and Landing Process

Shenglong Dai, Kehua Lia and Wei Zhu[a]

Department of Aviation Medicine, the Naval Medical Center of PLA, Second Military University, Shanghai, 200433, China

[a]email: zhuwei512@126.com

Keywords: Dynamic impact; Simulation; Biomechanics modeling; Takeoff ; Aircraft

Abstract: The dynamic process of takeoff and landing of an aircraft is modeled and analyzed, which provides a technical basis for the impact biomechanics research of the crew in the aircraft, so that the mechanism of damage to human tissues or organs in the process of impact can be studied in depth. Modeling provides detailed data support for subsequent simulation studies, especially for head damage during takeoff and landing of aircraft.

1. Introduction

Albert I. King, a damage biomechanics expert at Wayne State University's Bioengineering Center and academician of the National Academy of Engineering, defines impact biomechanics as "impact biomechanics, a science related to injury control. It studies how to prevent human tissues or organs from impacting by controlling the flying environment [1-6].

The aim of impact biomechanics is to protect the passengers of vehicles from serious injury at a cost that the public can bear. The basis of impact biomechanics is engineering mechanics and physiology and pathology of human body system. In the 1970s, traffic accident injuries have developed into the first major hazard threatening personal injury, and aviation and aerospace accidents occur from time to time [7-12]. Therefore, to take effective measures to avoid accidents and ensure personal safety has become the focus of attention of developed countries in the world. Many scholars have devoted themselves to the research in this field. After decades of efforts, a lot of achievements have been achieved and a new discipline, impact damage biomechanics, has been gradually formed. Based on the above reasons, this paper studies the biodynamics of the take-off and landing process of aircraft to provide theoretical support for the safety of pilots and crew.

2. Modeling of Aircraft Ski-jump Takeoff Process

We assume that the takeoff environment is windless; the initial aircraft state is static, the runway level, and the takeoff end of the runway tilts upward. In order to better understand the performance of the aircraft, takeoff is divided into two stages: the first stage is the deck flat acceleration process, and the second stage is the acceleration takeoff and departure process.

Phase 1: flat acceleration process on the runway.

The first stage is the flat acceleration process on the runway. Considering the aircraft as a lumped mass, the dynamic equation is

$$\begin{cases} T\cos(\theta_0+\varepsilon)-(D+F_R)=\dfrac{W}{g}\dfrac{dv}{dt} \\ L+T\sin(\theta_0+\varepsilon)+N-W=0 \end{cases} \tag{1}$$

Where, W is aircraft weight, T is engine thrust, F_R is rolling friction, N is deck reaction force, respectively, $\{L,D\}$ representing air lift and air resistance. θ_0 is the pitch angle, the angle between the body longitudinal axis reference line and the deck, ε is the setting angle of the starting force thrust, and the angle between the direction of thrust and the body longitudinal axis reference line.

DOI: 10.25236/icbsis.2020.051

Integrate the two sides of equation (1), we get

$$\int T\cos(\theta_0+\varepsilon)ds-\int(D+F_R)ds=\frac{W}{g}\int_0^{v_t} v\,dv \tag{2}$$

Assuming that there is no Thrust Vectoring Control (TVC), the angle between the tail jet and the longitudinal axis of the body is very small, and the thrust remains constant along the horizontal plane, the effective mean of thrust can be defined as:

$$\overline{T}\equiv\frac{1}{L_{Deck}}\int_0^{L_{Deck}}T(s)\cos(\theta_0+\varepsilon)ds \tag{3}$$

Among them, L_{Deck} is the length of the runway in which the plane accelerates straight at this stage.

So at the end of the runway, the equation (2) can be written as following equation (4) according to the dynamic characteristics and the principle of kinetic energy conversion.

$$\overline{T}L_{Deck}-\int(D+F_R)ds=\frac{1}{2}\frac{W}{g}v_I^2 \tag{4}$$

The second item is very small, it can also be written as

$$\overline{T}L_{Deck}\approx 1.02\times\frac{1}{2}\frac{W}{g}v_I^2 \tag{5}$$

And its biggest velocity can be achieved at the last stage can be solved as

$$v_I=\sqrt{\frac{2}{1.02}g\frac{\overline{T}}{W}L_{Deck}} \tag{6}$$

Phase 2: Accelerating takeoff.

When the aircraft enters the ski deck surface, the final acceleration equation is:

$$\begin{cases} T\cos(\theta_0+\varepsilon)-(D+F_R)-W\sin\theta_{Deck}=\dfrac{W}{g}\dfrac{dv}{dt} \\ (L+N)+T\sin(\theta_0+\varepsilon)-W\cos\theta_{Deck}=\dfrac{W}{g}\dfrac{v^2}{R} \end{cases} \tag{7}$$

Among them, $R(s)$ is the radius of deck curvature, $\theta_{Deck}(s)$ is the angle between the tangent of deck surface and the horizontal plane. During the take-off, the average effective thrust is assumed as $\overline{T}_{SJ}$, and the thrust vector angle of the launch force is the same as that of the horizontal deck.

$$\overline{T_{SJ}}=\frac{1}{S_{SJ}}\int_0^{S_{SJ}}T(s)\cos(\theta_0+\varepsilon)ds \tag{8}$$

$$\overline{R}=\frac{1}{1-\cos\theta_f}\int_0^{S_{SJ}}\sin\theta_{Deck}ds \tag{9}$$

Phase 3: Deceleration landing process

The mechanical model of deceleration process is as follows:

$$m_1\frac{d^2x}{dt^2}=F_e-2T_e\sin\theta-F_f-D \tag{10}$$

$$\sin\theta=\frac{x}{(x^2+h^2)^{\frac{1}{2}}} \tag{11}$$

$$D=\frac{1}{2}C_x\rho\left(\frac{dx}{dt}\right)^2S_0 \tag{12}$$

Among them, m_1 is the mass of the aircraft, x is the taxiing distance, F_e is the thrust, T_e is the resistance, θ is the angle between the resistance and the original equilibrium position, F_f is the runway friction, D is the air resistance, S_0 is the forward projection area of the wing, the distance from the center line to the side pulley.

If the thrust is closed then it can also be simplified as

$$m_1 \frac{d^2x}{dt^2} = -2T_e \sin\theta - D \tag{13}$$

$$m_1 \frac{d^2x}{dt^2} = -2T_e \sin\theta - \frac{1}{2}C_x\rho(\frac{dx}{dt})^2 S_0 \tag{14}$$

Where T_e can be solved as

$$T_e = \begin{cases} k_1(x_1 - 2x_2) & x_1 > 2x_2 \\ 0 & x_1 < 2x_2 \end{cases} \tag{15}$$

$$x_1 = \sqrt{x^2 + h^2} - h \tag{16}$$

$$\sin\theta = \frac{x}{h + x_1} = \frac{x}{\sqrt{x^2 + h^2}} \tag{17}$$

3. Simulation method of mechanical response of head and neck

The dynamic characteristics of the aircraft and the analysis of the force process on the crew's head and neck are developed in two simulation environments respectively. In the Simulink platform of the MATLAB environment, the modeling and Simulation of the dynamics of the block lock padlock are carried out. The simulation results are used as the input of the dynamic response of the head and neck of the abques platform, and the finite element simulation of the head and neck is carried out in the abques environment.

Function module composition can be divided into four modules，such as dynamic model of aircraft, finite element model of head and neck，analysis module and model validation，see figure 1.

As for the verification of the model, including the verification of the dynamic model of the aircraft padlock and the verification of the fidelity of the head and neck modeling, the simulation results are compared with the experimental data by using the experimental data of 2066 standard of the U.S. Army and the human body collision data of NBDL, and the model parameters are optimized to reflect the real response as much as possible.

4. Finite Element Simulation of Head and Neck Mechanical Response

The finite element modeling of the head and neck of passengers mainly includes three parts: head, cervical vertebra and upper trunk. According to the geometric shape and size of the object, the model is constructed and simplified by modularization method as following figure 2 and figure 3.

Conclusion

The dynamic response of the crew's cervical spine and head under backward and forward impact is analyzed and drawn by means of finite element method. The acceleration and response curve of the crew's head and neck under horizontal impact can be obtained, and then the response curve of the crew's head and neck under impact can be estimated. The possible injury to the crew's head and neck provides basic technical data for flight safety.

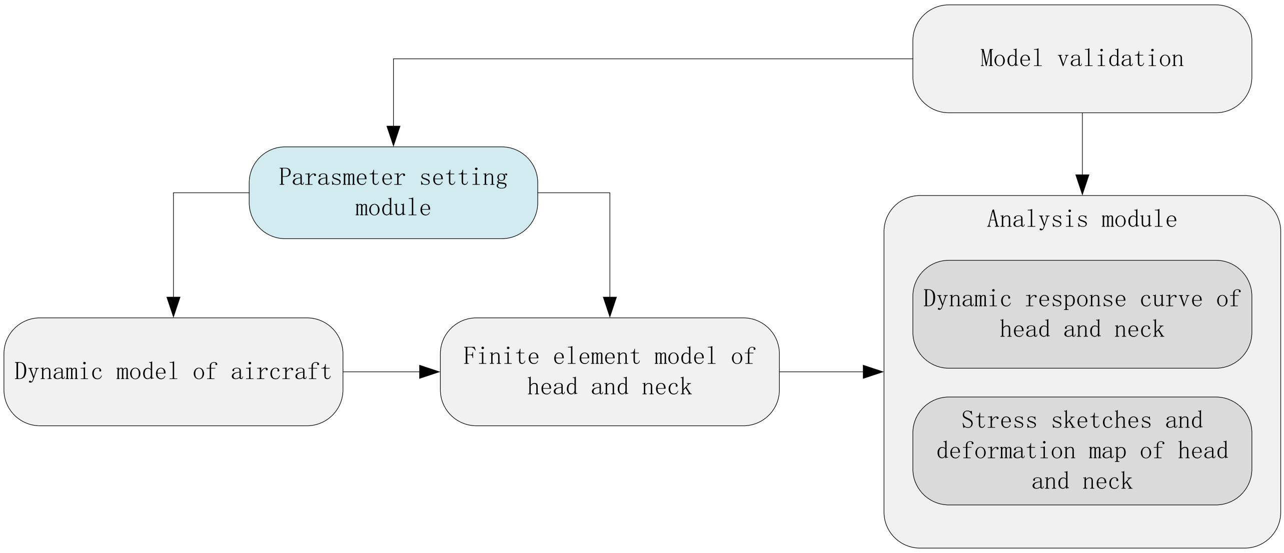

Figure 1. Simulation flow chart of mechanical response of crew's head and neck during takeoff and landing of aircraft

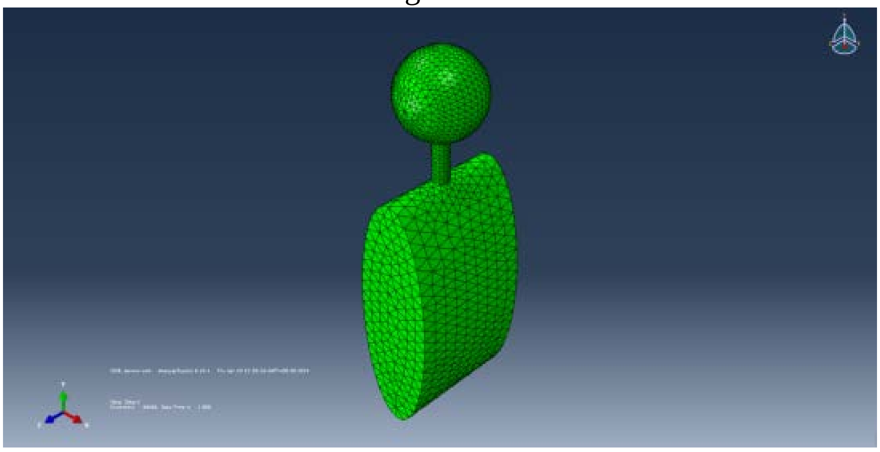

Figure 2. Finite element modeling of head and body

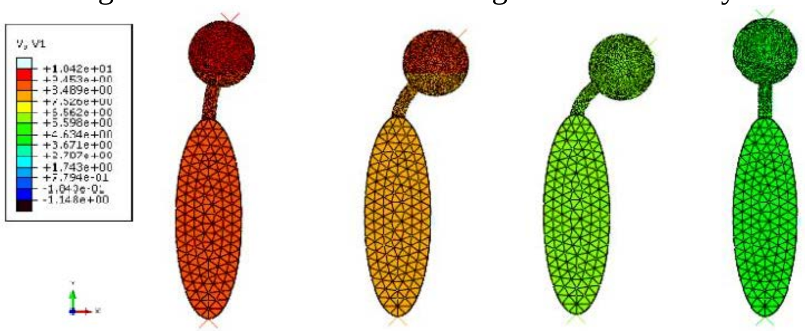

Figure 3. Head and neck biomechanics simulation animation demonstration process

References

[1] L.O. Chua, Memristor-the missing circuit element. IEEE Trans. Circuit Theory 18 (5) (1971) 13.

[2] D.B. Strukov, G.S. Snider, D.R. Stewart, R.S. Williams. The missing memristor found, Nature 453 (7191) (2008) 4.

[3] T. He, J.M. Tour, Electronics: The fourth element, Nature 453 (7191) (2008) 2.

[4] M.Di. Ventra, Y.V. Pershin, Experimental demonstration of associative memory with memristive neural networks, Neural Netw. 23 (7) (2010) 6.

[5] G.A. Gibson, S. Musunuru, J. Zhang, An accurate locally active memristor model for s-type

negative differential resistance in nbox, Appl. Phys. Lett.

108 (2) (2016) 023505.

[6] G.A. Gibson, S. Musunuru, J. Zhang, Nanocsale memristor device as synapse in neuromorphic systems, Nano Lett. 10 (4) (2010) 5.

[7] K. Norris, B.J. Choi, J. Zhang, Trilayer tunnel selectors for memristor memory cells, Adv. Mater. 28 (2) (2016) 7.

[8] H. Kim, S.P. Adhikari, C. Yang, Memristor bridge synapse-based neural network and its learning, Neural Netw. 23 (9) (2012) 10.

[9] Y.M. Banadaki, M.J. Sharifi, General spice models for memristor and application to circuit simulation of memristor-based synapses and memory cells,

J. Circuits Syst. Comput. 19 (2) (2010) 18.

[10] Z. Zeng, A. Wu, Anti-synchronization control of a class of memristive recurrent neural networks, Commun. Nonlinear Sci. Numer. Simul. 18 (2) (2013)13

[11] Guo, B. Z., & Zhao, Z. L. (2011). On the convergence of an extended state observer for nonlinear systems with uncertainty. Systems & Control Letters, 60, 420-430.

[12] Han, J. Q. (2009). From PID to active disturbance rejection control. IEEE Transactions on Industrial Electronics, 56, 900-906.