PHYSIOLOGICAL AND PSYCHOLOGICAL RESPONSE MODELLING OF THE HELICOPTER PILOT THROUGH VIBRATION SIMULATION

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Abstract

This research focuses on the integrated simulation of helicopter-pilot system to predict pilot's physiological and psychological responses to the vibration. This paper describes the approach of integration of helicopter structural model to the aerodynamic forcing function and to the pilot-seat model. The physiological and psychological responses at 5 Hz are calculated based on vibration transmission ratio of the pilot's body segments. The pilot's Physiological responses including heart rate, highest blood pressure, lowest blood pressure, respiration rate and saliva secretion quantity are presented. Tired eyes, irritation, dizziness, yawning, sleepiness and headache as psychological reactions are provided. The integrated simulation approach of helicopter-pilot system can be used for pilot health and comfort assessments, helicopter structural and cockpit and seat design.

1. INTRODUCTION

One of the extreme conditions exists in man-made environments is the vibration[1]. Long-term exposure to vibration can affect human health, safety, comfort, performance and working efficiency [1-6].It cannot be supposed that a complicated and intelligent system as the human body responds to the vibration in a simple way and the responses cannot be predicted easily [7]. The complexity of the human body system is because of its physical, physiological, psychological characteristics. In addition, the interaction between physiological and psychological features makes the modelling of human behavior more difficult[5].

Running vibration experiments to measure the human responses is expensive, time consuming and risky for the human body. Additionally, few computer-aided programs are available for predicting human's responses to the vibration [5, 8, 9]. Therefore, modeling of the human behavior through an integrated approach of vibration simulation is proposed in this research. The helicopter pilot works in a dynamic environment and experiences different maneuvers including take-off, level flight with different speeds, landing, etc. These different working missions can cause changes in pilot's physical, physiological and psychological responses due to changing in the exposure to the vibration.

The aim of this paper is to model the physiological and psychological responses of the helicopter pilot through the changes in physical characteristics of the pilot's body in different flight conditions. In other words, the pilot's responses are modeled based on physical parameters created by the vibration. There are few organized studies for modeling the human behavior through mathematical equations such as Kubo, Terauchi [5] that evaluate the physiological and psychological parameters based on the vibration transmissibility of the body segments. However many previous research have investigated the measurement and analyzing of human vibration and its effects on health, comfort, ride quality, etc. Kubo's study uses a synthetic vibration model to predict the psychological and physiological human feedbacks, this paper is used in this research.

2. METHODOLOGY

In order to simulate the vibration on the pilot's head, chest, abdomen, thigh and the lower leg in the different flight conditions, an integrated approach has been used. The integrated approach considers two steps of simulation of forced vibration at the cabin floor through modelling of helicopter structure and aerodynamic forcing function. In the next step the forced vibration is required to be integrated to the pilot-seat model.

2.1. Simulation of forced vibration at the cockpit floor

First, a finite element method (FEM) model of 349 Gazelle helicopter is developed in ABAQUS as given in Figure 1.

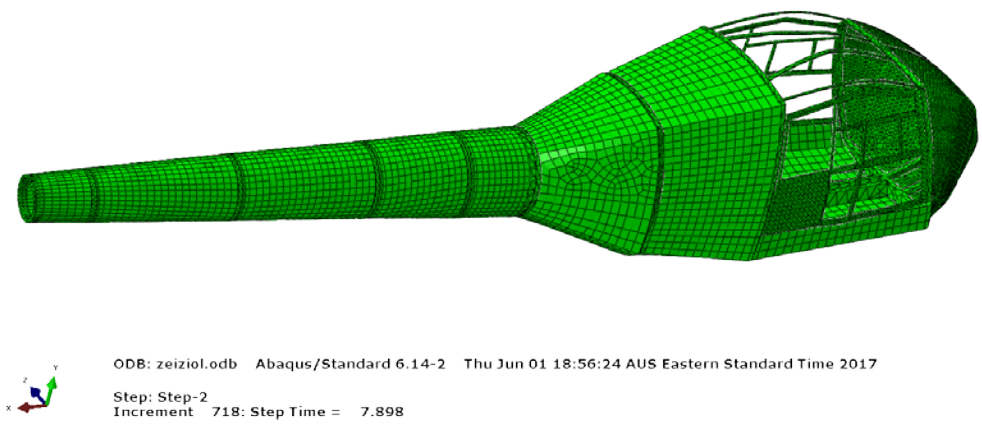


Figure 1: 3D FEM model of Gazelle helicopter developed in ABAQUS

The structural model replicates the full-scale helicopter model with its primary and secondary components. More information on the model, its dimension, material, basic vibration characteristics and natural frequencies can be found in [10].

In the next step, the forcing function acting on the main rotor of the helicopter as the main source of vibration of helicopter needs to be determined. The forces and moments on the rotor hub are in forms of Fourier series that is a function of blade azimuth angle (Ψ) [11].When the forces and moments are transferred from rotating frame to non-rotating frame or the shaft plane (s) only the loads which are harmonics of number of blades (3 blades in this case) will remain and the relationship can be written as Equation 1.

$$\{F_{hub}\}_s = F_{hub0} + \sum_{n=-\infty}^{+\infty} \{A_{3n}\cos\,(3n\Psi) + B_{3n}\sin(3n\Psi)\} \quad (1)$$

Where n is the harmonic number, F_{hub0} is the mean hub load, A_{3n} and B_{3n} are harmonic coefficients. The forcing function for a single flight condition is extracted from literature [11] and the characteristics of the corresponding flight condition are as given in Table 1.

Flight condition	V3101
Altitude(m)	306.2
Load factor	1.0
Advance ratio	0.14
Advancing tip Mach number	0.73

Table 1: the characteristics of flight condition for simulation ([11]

The forcing function of flight condition is applied to the helicopter structural model in ABAQUS and the vibration at the cockpit floor, at the pilot seat location is obtained.

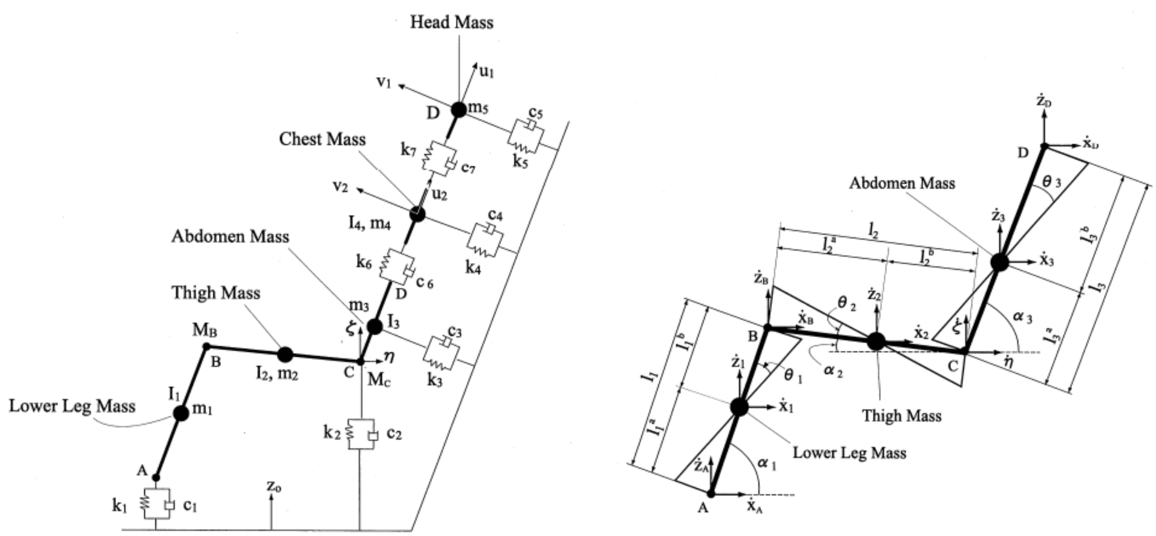
The vibration frequencies up to 5 Hz can be problematic to the human body because they match with the natural frequency of the internal body organs and makes resonance. Since this range of vibration frequency is common in the helicopter cockpit, only the single frequency of 5 Hz has been considered for the simulation in this paper.

2.2. The pilot-seat model

The corresponding amplitude of the vibration at 5 Hz frequency is integrated to two dimensional human vibration model that is introduced by Kubo, Terauchi [5] that considers the body as 5 segments including, “the head, chest (from the upper point of breast stone to the third lumbar vertebra), abdomen(from the third lumbar vertebra to the trochanteric point), thigh and lower leg” [5, 12], as given in Figure 2.The head, chest and abdomen are connected to each other through spring and dampers, however the abdomen, thigh and lower leg with the joints. More information on the basic model can be found in [5].

The vibration of the cabin floor is transmitted to the body from the feet and the seat pan. Kubo’s model is modified for a seated pilot with medium weight of 80 kg and height of 185 cm.The equations of motion of proposed human model are formulated and the mathematical model is developed in MATLAB. The displacement of the cabin floor obtained from the integration of aerodynamic forcing function and the helicopter structural model is applied to the model as shown as z_0 , in Figure 2.

The integration procedure is considered for a single flight condition as explained in Table 1, and the displacement and velocity at the cabin floor along with feet and seat pan location are imported as the input to the human body.



a) mass spring damper representation of the system

b)abdomen, thigh and lower leg

Figure2: Two dimensional the human-seated model [5]

2.3. Physiological and psychological parameter modelling

Based on Kubo's research, physiological reactions including heart rate, highest blood pressure, lowest blood pressure, respiration rate and saliva secretion quantity for a seated person exposed to 5 Hz vibration can be formulated as Equation 2 to 6 [5].

$$\boldsymbol{Y_{heart\ rate} = 2.338 + 0.054X_1 + 0.200X_2 - 1.351X_5} \quad (2)$$

$$\boldsymbol{Y_{highest\ blood\ pressure} = -0.812 + 2.055X_1} \quad (3)$$

$$\boldsymbol{Y_{lowest\ blood\ pressure} = 0.634 - 0.088X_1 - 0.175X_2 + 0.750X_5} \quad (4)$$

$$\boldsymbol{Y_{respiration\ rate} = 2.550 - 0.212X_2 - 0.083X_3 - 0.692X_5} \quad (5)$$

$$\boldsymbol{Y_{saliva\ secretion\ quantity} = 0.159 - 0.280X_1 - 0.423X_3 + 1.362X_5} \quad (6)$$

Psychological reactions of tiredness, yawing, sleepiness, tired eyes, absent-mindedness, irritation, loss of patience, distracted attention, headache, backache, dizziness, nausea and stiff shoulders for a seated person exposed to 5 Hz vibration are available formulas [5].Some of the equations are as (7) to (12) [5].

$$\boldsymbol{Y_{tired\ eyes} = -364.568 + 234.968X_1 + 59.181X_2} \quad (7)$$

$$\boldsymbol{Y_{irritation} = -34.528 + 36.232X_1} \quad (8)$$

$$\boldsymbol{Y_{dizziness} = -44.854 + 47.534X_1} \quad (9)$$

$$\boldsymbol{Y_{yawning} = -108.989 - 16.744X_2 + 114.285X_5} \quad (10)$$

$$\boldsymbol{Y_{sleepiness} = 69.861 - 69.960X_1} \quad (11)$$

$$\boldsymbol{Y_{headache} = -284.713 + 32.515X_1 + 16.151X_2 + 171.099X_5} \quad (12)$$

In which X is the transmission ratio (the ratio of output acceleration at the body segments to the input acceleration at the cockpit floor). X_1 represents the transmission ratio of the head, X_2 is the transmission ratio of the chest, X_3 is the transmission ratio of the abdomen, X_4 is of the thigh and X_5 is of the lower leg. In the following the results of psychological and physiological response of the pilot model to 5Hz vibration are provided.

3. RESULTS AND DISCUSSION

The results on pilot's physiological responses to the cockpit floor vibration are obtained through simulation of vibration transmission ratio of the pilot's body segments. The vibration transmission ratio indicates how the body segments are able to absorb the input vibration. If the vibration transmission ratio of a body segments is higher than "1" then the body segments has amplified the vibration. It is possibly because of the fact that the frequency of excitation force to the body is equal or in the vicinity of the natural frequency of the body organs. The vibration transmission ratios of the pilot's body segments during the flight condition (V3101) are simulated. All of obtained ratios [13] are higher than one, which verifies the fact that 5 Hz is the natural frequency of majority of body organs especially internal organs.

The equations on the physiological responses indicate the ratio of changing variables after being exposed to vibration. The simulated physiological response of the pilot during the flight condition of simulation (V3101) is given as Figure 3.

As can be seen in Figure 3, due to the transmitted vibration to the pilot's body the pilot's heart rate increased (20%). The cabin vibration has induced an increase in pilot's highest and lowest blood pressure and the respiration rate, and only saliva secretion quantity has experienced a small reduction (0.02%). The results on physiological responses are similar to values found by[5].

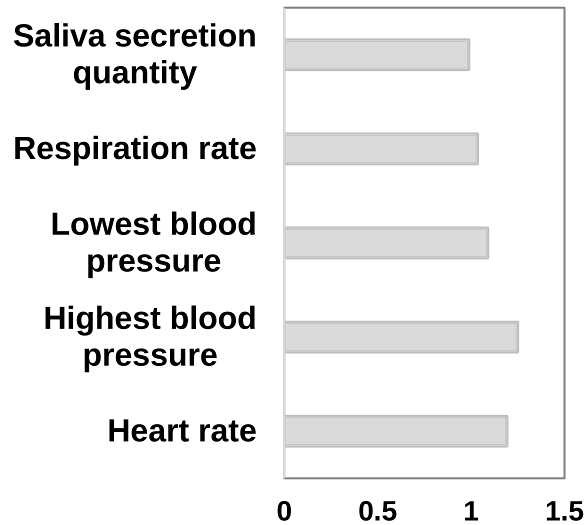


Figure 3: Simulated pilot's physiological reactions

The evaluated psychological reactions including tired eyes, irritation, dizziness, yawning, sleepiness and headache of the pilot are presented in Table 2. The values represent the transition of feeling of the psychological responses that is based on semantic differential method. In other word "0"value indicates there is no difference between psychological reaction before and after being exposed to vibration. The values can be positive or negative as showing increase or decrease in the psychological variables.

Psychological reaction	Tired eyes	Irritation	Dizziness	Yawning	Sleepiness	Headache
Values	12.30785	1.795071	2.79948	-2.6869	-0.27485	5.457131

Table 2: The results on pilot's psychological responses during the simulated flight condition

These psychological factors indicate transition of tiredness feeling. The results illustrate that the pilot has an extremely feeling of tired eyes and headache, however there is a less predicted feeling of the sleepiness and yawning reactions. The results are consistent with literature [5]. Therefore this integrated approach of simulation can be used as a powerful tool especially at the design stage, to have a comprehensive assessment of the helicopter-pilot system.

4. CONCLUSION

The approach of integrated simulation of helicopter-pilot system to predict the psychological and physiological response of the pilot is proposed in this research. This model has the capability of integration of aerodynamic forcing function for different maneuverers to the helicopter structural model and to the pilot-seat model. So, the structural vibration, the vibration at the seat, vibration at the pilot's body, and pilot's physiological and psychological reactions can be simulated comprehensively. This model can provide designers with information on structural seat design when the helicopter and its cockpit design is in early stages. Moreover, it can be used to examine some abnormal conditions like unbalance and out of track of the main rotor head that can be applied to the structural model and its effects on the pilot's responses.

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