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Research Article

SEMI ACTIVE CONTROL OF FIGHTER JET LANDING GEAR COMPARING WITH PID AND FUZZY LOGIC CONTROLLER EQUIPPED MAGNETORHEOLOGICAL DAMPER

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ABSTRACT

This paper associated with a fighter jet landing gears that has semi active suspension system. Aircraft landing gears are most important part of the aircraft during taxi position which must be able to reduce vibrations from runway roughness. For this purpose, Magnetorheological (MR) damper is used instead of passive damper as semi active landing gear and its damping force varies by voltage controller which is applied to electromagnetic coil. In order to determine the applied voltage, fuzyy logic controller and PID controller are designed. The performance of MR damper is shown with extensive numbers of numerical simulations. The two control methods are compared with each other. It is shown that the controllers can be applicable to the system and is shown that why the semi active systems can be more preferable.
Keywords: Aircraft landing gear, seated pilot model, MR damper, taxiing analysis, semi active control, fuzzy logic control, PID control, particle swarm optimization.

1. INTRODUCTION

The landing gears have important role during touchdown and taxi position as a intermediate part between the fuselage and runway. During taxiing, the fuselage can be induced by the landing gear because of road disturbances. Effect of vibrations on the aircraft depend on environmental conditions, landing gears structures and disturbances. The aircrafts are exposed big magnitude vibrations when they move on harsh runway. This causes big magnitude vibrations on the fuselage and it effects passenger comfort or is encountered a serious accident. For this reason, the vertical and horizontal kinetic energy must be absorbed by landing gears [1].

Semi active control of the systems have theoretical and practical area of researches. This depends on some reasons; semi active systems have reliability as well as passive systems and semi active systems need less energy than active systems. MR damper contains contrallable fluid. MR dampers reduce vibrations through absorbing energy. By this way, stability of system preserved [2-5].

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MR damper has nonlinear hysteresis characteristic. MR damper has different modelling tecnics to define nonlinear hysteresis character of MR damper. The model based on Bouc-Wen demonstrates dynamic of MR damper, although it is hard to determine parameters and it has complicated structure. Therefore, in this study the modified Bouc-Wen model is used for the model of MR damper [6].

Several mathematical models of the vehicle and aircraft systems are used for vibration analysis. For comparing the semi active system with passive and active systems, a bond graph tecnique has been used by Margolis and it has been proved optimal control strategies can be used for the applicability [7]. Semi active suspension system for 2 DOF vehicle model has been used for improving the ride comfort, road holding and rattle speed by Youn and Hac [8]. A quarter car semi active suspension system has been proposed proving the performance gains of semi active suspensions over passive suspensions by Sims and Stanway [9]. A semi active landing gear has been developed that using three different control approaches by Kruger and it has been compared the passive, active and semi active cases for a multibody aircraft model [10]. A fuzzy PID controller has been developed for landing gear to reduce acceleration transmitted to the fuselage during landing by Lin et al [11]. Choi and Wereley has proposed a sliding mode controller [12]. A semi active landing gear using 2 DOF aircraft model has been proposed that has been implemented PID controller to improve ride comfort during landing, take off and taxiing phases by Sivakumar and Haran [13]. A torsional MR damper is designed to stabilize the nose landing gear system due to the ground induced lateral excitation by Sateesh and Maiti [14].

In this study, MR damper landing gears is used to reduce aircraft vibrations during taxiing. Voltage of MR damper is determined with PID and fuzzy logic controller. The two controller methods compared with each other and controller efficiency tested in MATLAB-Simulink.

2. MATHEMATICAL MODEL

2.1. MR Damper Mathematical Model

MR damper contains piston, magnet coil, accumulator and hydraulic cylinder filled with MR fluid. MR fluid can be defined as controllable fluid which its characteristic is changeable with density of applied magnetic field. The schematic of MR damper model is shown in Figure 1.

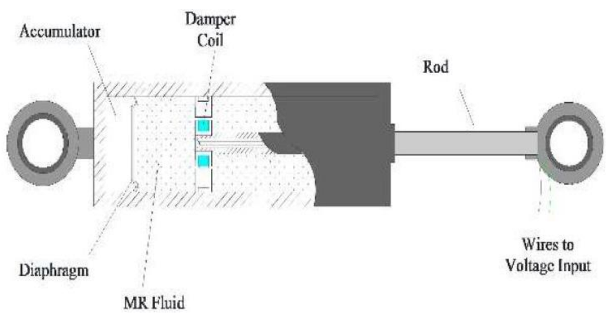


Figure 1. Model of MR damper [15]

Magnetorheological fluids are obtained that are added micron sized particle in carrier fluid. Carrier fluid contains petroleum based oils, silicon oil, kerosene, mineral oils, water, polyester etc. In generally, iron is used as magnetic particle. When magnetic field applies, arbitrary dispersed iron particles in carrirer fluid takes form dipole moment in row. Iron particles are lined up as chain form which is perpendicular to the direction of carrier fluid flow. This means velocity of carrier fluid flow decreases. If magnetic field continues this effect maintaines. When magnetic field is removed, iron particles chain is broken and carrier fluid turns back to its normal state. By this way, it can be adjusted and acquired different damping forces. Also, if current can not be applied, MR damper behaves as passive damper. This is very important property for safety as semi active system [16]. Behaviour of MR fluid is shown in Figure 2.

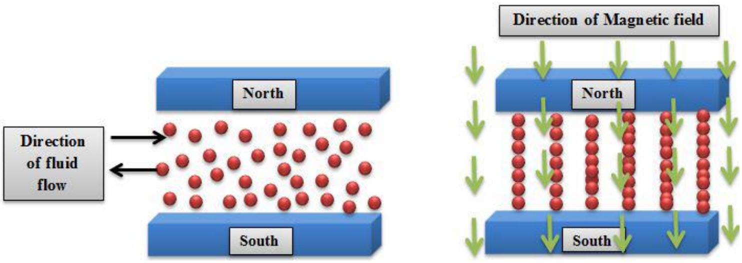


Figure 2. Behaviour of MR fluid [16]

The picture of MR fluid is shown that taken with electron microscope in Figure 3.

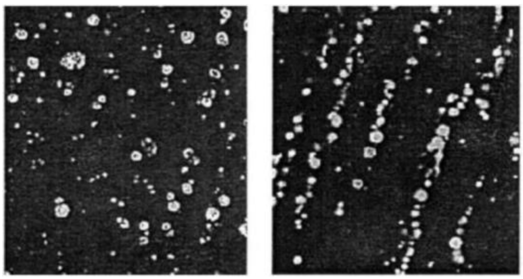


Figure 3. Taken photo of MR fluid with electron microscope (Left side iron particles states when there is no applied magnetic field, right side iron particles states when magnetic field applies) [17]

Because of its nonlinear hysteresis character, MR damper is modelled with modified Bouc-Wen approach. It contains parallel spring and series damping to Bouc-Wen model. Modified Bouc-Wen model is shown in Figure 4.

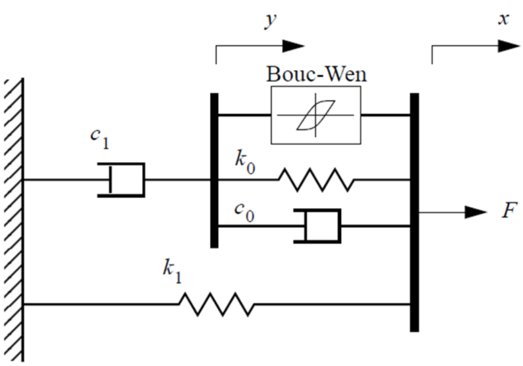


Figure 4. Modified Bouc-Wen Model [16]

Dynamic equations of modified Bouc-Wen model are given below. At two side's forces of rigid bar is equal to;

$$c_1\dot{y} = a_h z + c_0 (\dot{x} - \dot{y}) + k_0 (x - y) \tag{1}$$

in this formula, z is computable factor which is defined as;

$$\dot{z} = -\gamma |\dot{x} - \dot{y}||z|^{n-1} z - \beta (\dot{x} - \dot{y})|z|^n + A (\dot{x} - \dot{y}) \tag{2}$$

if equation (1) is range for $\dot{y}$, the following equation is obtained

$$\dot{y} = \frac{1}{c_0 + c_1}\{a_h z + c_0 \dot{x} + k_0 (x - x_0)\} \tag{3}$$

then, the total force can be defined as,

$$F = a_h z + c_0 (\dot{x} - \dot{y}) + k_0 (x - y) + k_1 (x - x_0) = c_1\dot{y} + k_1 (x - x_0) \tag{4}$$

where k_1 is accumulator spring stiffness, c_0 is viscous damping coefficient at high velocity, c_1 is decremental effect at low velocity, k_0 is spring stiffness at high velocity, x_0 is initial displacement because of accumulator stiffness which defined as k_1. Effect of giving voltage to MR damper coils can be taken into account using following equations;

$$\begin{aligned} a_h &= a_{ha} + a_{hb}\, u \\ c_1 &= c_{1a} + c_{1b}\, u \\ c_0 &= c_{0a} + c_{0b}\, u \end{aligned} \tag{5}$$

where u can be calculated with first order filter given below;

$$\dot{u} = -\eta (u - V) \tag{6}$$

in equation (6) V is defined as applied voltage to MR damper coils.

2.2. Heaviside Step Function

In the Heaviside Step Function method, the applied voltage has one of three values, 0, $V_{max}/2$ or V_{max} [18]. Mathematical expression is given in (7),

$$v = V_{max} H[(f_c - f)f] \tag{7}$$

where f_c is ideal controller force, f is MR damper force and H is Heaviside Function. Heaviside Function is expressed in (8) clearly.

$$\left.\begin{aligned} H(x) &= \frac{1}{2}(1 + \mathrm{sgn}(x)) \\ v &= \frac{V_{max}}{2}(1 + \mathrm{sgn}([f_c - f)f]) \end{aligned}\right\} \quad v = \begin{cases} 0 \\ V_{max}/2 \\ V_{max} \end{cases} \tag{8}$$

2.3 Aircraft Mathematical Model

The aircraft model is shown in Figure 5. The used aircraft model is taken from an article [19] and, seats and pilots are added to the full aircraft model in this study. M is the fuselage mass which is connected to the three masses of the front, rear left and rear right landing gears. mt_1, mt_2 and mt_3 are the front, rear left and rear right landing gear masses. mk_1 and mk_2 are the seats masses. mp_1 and mp_2 are the pilots body masses. xt_1, xt_2 and xt_3 are the vertical displacements of front, rear left and rear right tires. x is the bounce motion of the fuselage, θ and β are the pitch and roll angular position which are defined with respect to the body fixed coordinate frame. xp_1 and xp_2 are the vertical displacement of pilots bodies. xk_1 and xk_2 are the vertical displacements of pilots seats. ks_1, ks_2 and ks_3 are the stiffness of front landing gear, rear left landing gear and rear right landing gear systems. kt_1, kt_2 and kt_3 are the stiffness of front, rear left and rear right tires. ct_1, ct_2 and ct_3 are the damping of front, rear left and rear right tires, respectively. Stiffness and damping elements of pilots bodies are kp_1, kp_2, cp_1 and cp_2, respectively. Also, stiffness and damping elements of pilots seats are kk_1, kk_2, ck_1 and ck_2, respectively. F_{MR}^{f}, F_{MR}^{rr} and F_{MR}^{rl} represent the semi active control forces that are applied to the front, rear right and rear left landing gears, respectively. a and b denote the distances from center of gravity (CG) to the front and rear landing gear along x axis. c and d denote the distances between CG and rear right and rear left landing gears z direction. k and l denote the distances from CG along y direction.

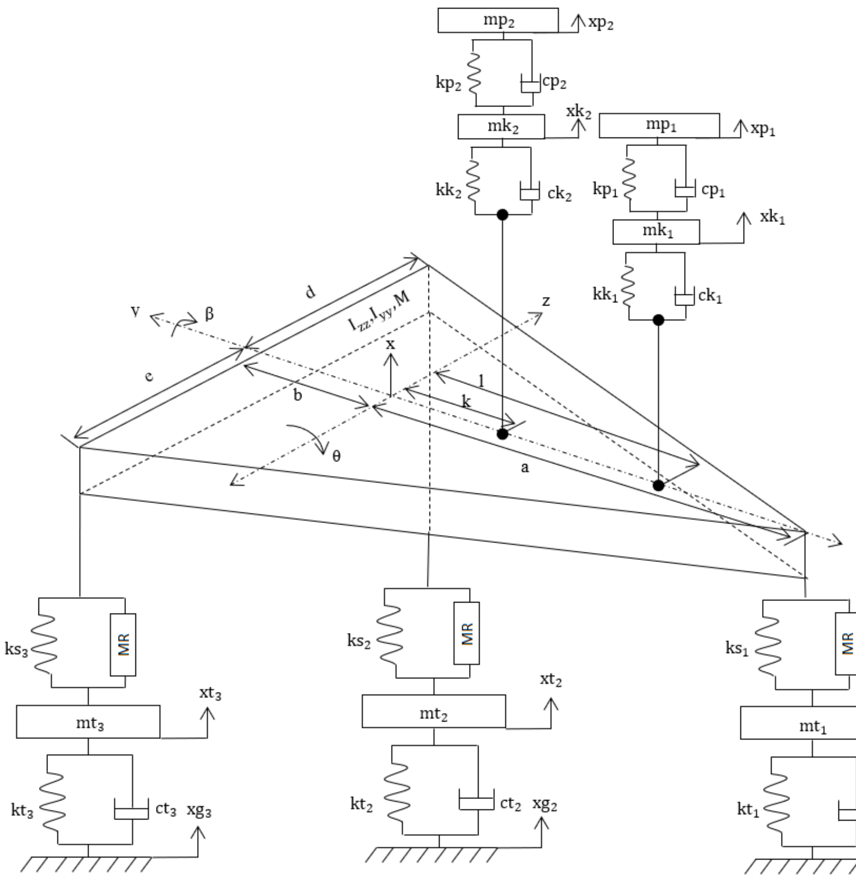


Figure 5. Aircraft physical model

Equations of motions of the aircraft is derived by Lagrange method. The general Lagrange equation can be written as,

$$\frac{d}{dt}\left(\frac{\partial E_k}{\partial \dot{q}_i}\right) - \left(\frac{\partial E_k}{\partial q_i}\right) + \left(\frac{\partial E_p}{\partial q_i}\right) + \left(\frac{\partial E_d}{\partial \dot{q}_i}\right) = Q_i \tag{9}$$

where E_k, E_p, E_d are the kinetic energy, potential energy and dissiparative energy of the system, respectively. q_i is the generalized coordinates and Q_i is the external forces of the system. Equations of motion are obtained using Lagrange methos as follows;

$$mp_1\ddot{x}p_1 + ki_1(xp_1 - xk_1) + cp_1(\dot{x}p_1 - \dot{x}k_1) = 0 \tag{10}$$

$$mp_2\ddot{x}i_2 + kp_2(xp_2 - xk_2) + cp_2(\dot{x}p_2 - \dot{x}k_2) = 0 \tag{11}$$

$$mk_1\ddot{x}k_1 + kk_1(xk_1 - x + l\theta) + ck_1(\dot{x}k_1 - \dot{x} + l\dot{\theta}) - kp_1(xp_1 - xk_1) - cp_1(\dot{x}p_1 - \dot{x}k_1) = 0 \tag{12}$$

$$mk_2\ddot{x}k_2 + kk_2(xk_2 - x + k\theta) + ck_2(\dot{x}k_2 - \dot{x} + k\dot{\theta}) - kp_2(xp_2 - xk_2) - cp_2(\dot{x}p_2 - \dot{x}k_2) = 0 \tag{13}$$

$$M\ddot{x} + ks_1(x - a\theta - xt_1) + ks_2(x + b\theta - d\beta - xt_2) + ks_3(x + b\theta + e\beta - xt_3) - kk_1(xk_1 - x + l\theta) - kk_2(xk_2 - x + k\theta) - ck_1(\dot{x}k_1 - \dot{x} + l\dot{\theta}) - ck_2(\dot{x}k_2 - \dot{x} + k\dot{\theta}) = -F_{MR}^{f} - F_{MR}^{rr} - F_{MR}^{rl} \tag{14}$$

$$I_{zz}\ddot{\theta} - a\,ks_1(x - a\theta - xt_1) + b\,ks_2(x + b\theta - d\beta - xt_2) + b\,ks_3(x + b\theta + e\beta - xt_3) - l\,kk_1(xk_1 - x + l\theta) - k\,kk_2(xk_2 - x + k\theta) - l\,ck_1(\dot{x}k_1 - \dot{x} + l\dot{\theta}) - k\,ck_2(\dot{x}k_2 - \dot{x} + k\dot{\theta}) = a\,F_{MR}^{f} - b\,F_{MR}^{rr} - b\,F_{MR}^{rl} \tag{15}$$

$$I_{yy}\ddot{\beta} - d\,ks_2(x + b\theta - d\beta - xt_2) + e\,ks_3(x + b\theta + e\beta - xt_3) = d\,F_{MR}^{rr} - e\,F_{MR}^{rl} \tag{16}$$

$$mt_1\ddot{x}t_1 + kt_1(xt_1 - xg_1) - ks_1(x - a\theta - xt_1) + ct_1(\dot{x}t_1 - \dot{x}g_1) = F_{MR}^{f} \tag{17}$$

$$mt_2\ddot{x}t_2 + kt_2(xt_2 - xg_2) - ks_2(x + b\theta - d\beta - xt_2) + ct_2(\dot{x}t_2 - \dot{x}g_2) = F_{MR}^{rl} \tag{18}$$

$$mt_3\ddot{x}t_3 + kt_2(xt_2 - xg_2) - ks_3(x + b\theta + e\beta - xt_3) + ct_3(\dot{x}t_3 - \dot{x}g_3) = F_{MR}^{rr} \tag{19}$$

3. CONTROLLER DESIGN

3.1. PID Control

PID control is used in leading endustrial control systems and many researches. It is obtained that measured value is brought to the set-value. That obtained error value is named E(t). U(t) that is controller signal, is obtained by multiplied error signal itself, derivative and integral with determined coefficient. It is shown that working principle of PID controller in Figure 6.

$$U(t) = K_P\,E(t) + K_I \int_0^t E(t)dt + K_D \frac{dE(t)}{dt} \tag{20}$$

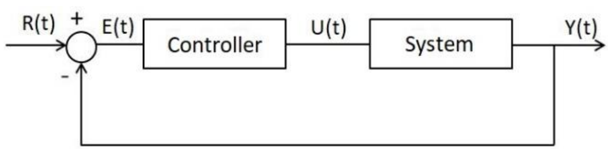


Figure 6. Working principle of PID controller

K_P, K_I and K_D are the controller coefficients of PID controller. In this study, PID controller coefficients are optimized by Particle Swarm Optimization method. Particle Swarm Optimization was presented in 1995 by Eberhart and Kennedy and they inspired by movements of birds in the sky. With this oppinion, swarm represents a number of potential solutions of the problem. In PSO algorithm, particle means each individual in search space can be adjusted dynamically based on movement of velocity and position. Position and velocity of particle represent the solution for the problem and flying directions of particles, respectively. The particle's position can be calculated, with a given fitness function. To obtain the best particle's position, two "best" values are named pbest and gbest are updated. In this way, the position of particle can be adjusted by changing its velocity dynamically toward the optimum value of calculation named global optimum, based on these two "best" values. In each calculation, velocity and position are updated for each particle [20]. Equations are shown in (21) and (22).

$$v_i^{k+1} = w\, v_i^k + c_1 rand_1^k\left(pbest_i^k - x_i^k\right) + c_2 rand_2^k(gbest_i^k - x_i^k) \quad (21)$$

$$x_i^{k+1} = x_i^k + v_i^{k+1} \quad (22)$$

Where w is inertia parameter, $c_1$and c_2 are the weight factors between [0,2]. v_i^k, x_i^k are the velocity of particle, the position of particle i in k^{th} iteration, respectively. $rand_1^k$ and $rand_2^k$ are the random numbers between [0,1]. The main procedure of PSO algorithm are shown in Figure 7.

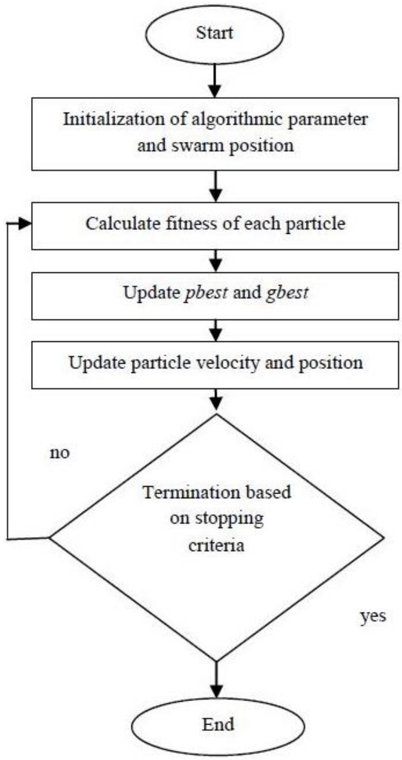


Figure 7. Steps in PSO algorithm [20]

3.2. Fuzzy Logic Control

Fuzzy logic control method is frequently used for control problems. Fuzzy logic control methods based on linguistic syntheses and it is not necessary mathematical model during controller design. Therefore, performance of controller is independent from accuracy of mathematical model. Also fuzzy logic controllers are able to cope with the nonlinearity in the system [17].

Clasic fuzzy logic controller structure has two inputs and one output. The controller inputs are displacement of top point of the MR damper (x) and velocity of top point of the MR damper (v). The output is control voltage (u) of MR damper. Fuzzy logic controller general structure is shown in Figure 8.

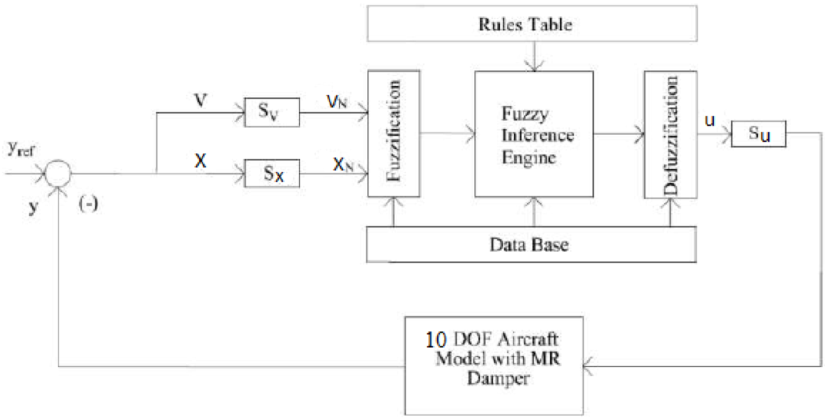


Figure 8. The fuzzy logic controller general structure [17]

Fuzzy logic controller design consists of fuzzification, inference engine and defuzzification steps. Numerical values are converted linguistic values at fuzzification step. In the second step, linguistic output value is obtained with inference engine through rule table. The linguistic values are converted to output numerical values during defuzzification. The linguistic values for inputs are symbolized as: NB, NS, NM, ZE, PS, PM, PB. NB denotes negative big, NS denotes negative small, NM denotes negative medium, ZE denotes zero, PS denotes positive small, PM denotes positive medium and PB denotes positive big, respectively. The linguistic values for output can be defined as ZE, PS, PM, PB. The input x is normalized in the range of [-1,1] and the input v normalized in the range of [-10,10]. The output is normalized in range of [0,5].

The rules table used in this study is shown in Table I. The surface of fuzzy logic controller which is designed for MR damper, is shown in Figure 9. The membership functions for the inputs and output are shown in Figure 10.

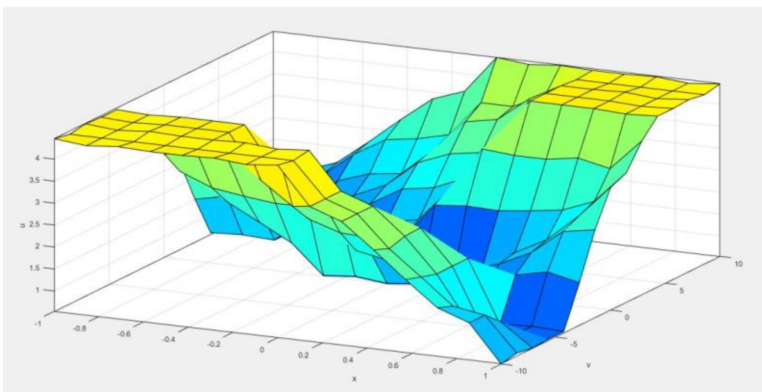


Figure 9. Surface of fuzzy logic controller

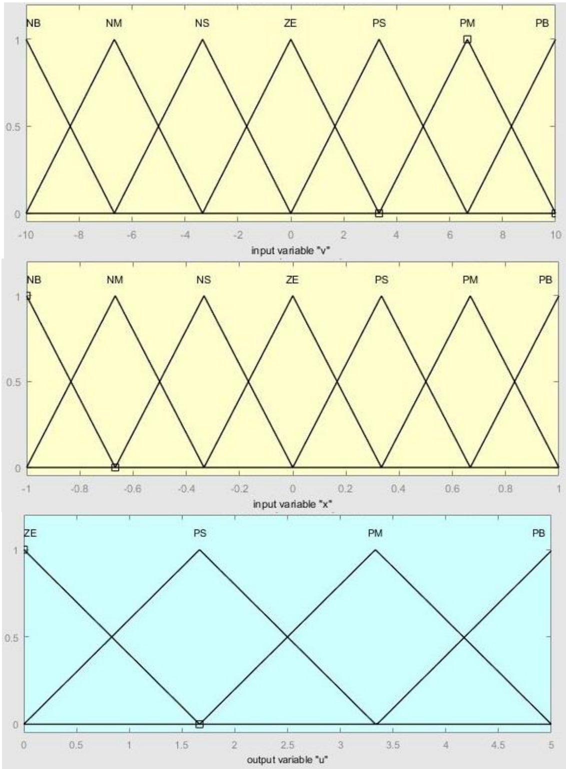


Figure 10. The membership functions for the inputs and the output

Table 1. The rule table for fuzzy logic controller [20]

	NB	NM	NS	ZE	PS	PM	PB
NB	PB	PB	PB	PM	ZE	ZE	ZE
NM	PB	PB	PB	PS	ZE	ZE	PS
NS	PB	PB	PB	ZE	ZE	PS	PM
ZE	PB	PB	PK	ZE	PS	PM	PB
PS	PO	PO	ZE	ZE	PB	PB	PB
PM	PK	ZE	ZE	PS	PB	PB	PB
PB	ZE	ZE	ZE	PM	PB	PB	PB

4. NUMERICAL SIMULATION

Mathenatical model of the ten degrees of freedom aircraft model equipped MR damper is designed and simulated via MATLAB-Simulink. The MR damper parameters [17] used in this study are given in the Appendix.

The hysteresis character of MR damper is shown in Figure 11. The MR damper in this study which is multiplied with 8 for produced force of the front landing gear and multiplied with 3 for produced force of the rear landing gears, is adjusted to adapt for the aircraft landing gears.

Frequency of input excitation is 2 Hz and the amplitude is 0.005 m. The applied voltages are 0, 2 and 4 Volt for MR dampers. Also, parameters of the aircraft model [19] are given in the Appendix.

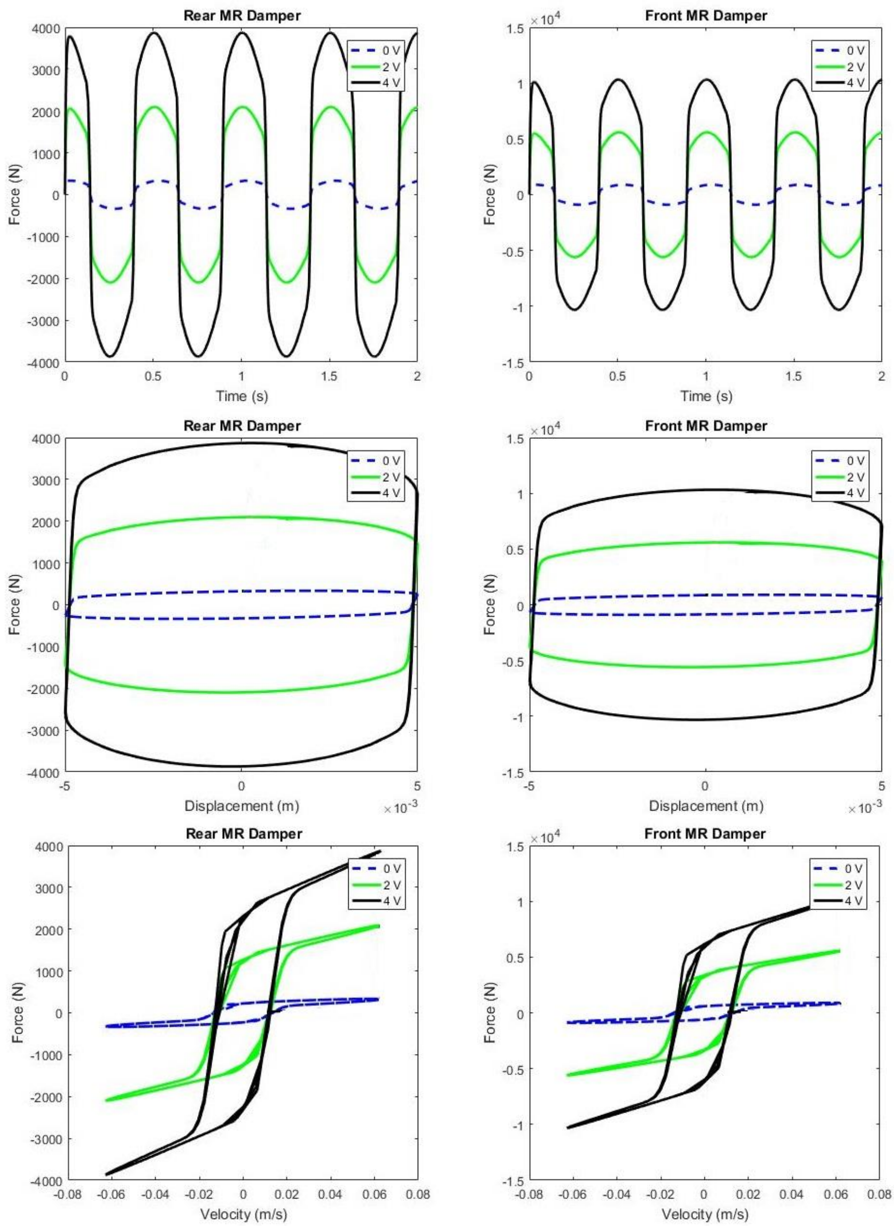


Figure 11. MR Damper dynamic behaviour

The perfomance of PID and fuzzy logic controlled cases and passive case are compared with numerical simulations. In the passive case, the voltage is not applied to MR damper. In the fuzzy logic controlled case, the applied voltage is determined by the fuzzy logic controller. In the PID controller case, the applied voltage is determined using Heaviside Step Function. Also, the road disturbances that occur when the aircraft tires are induced at different times, are given in Figure 12.

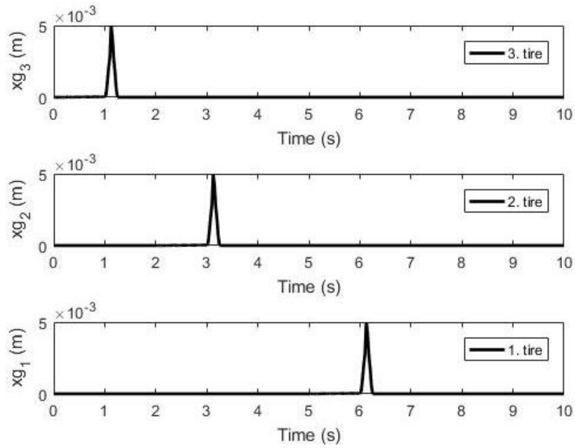


Figure 12. Road Profile

The results are given for the bounce, pitch and roll motions and accelerations for fuselage, the vertical displacements and accelerations of seats and pilots with discussions. The comparison is done between fuzzy logic control, PID control and passive case. The results are given in Figures 13-19. The solid line shows the passive case, the dotted line shows PID control case and the dashed line shows fuzzy logic control case, respectively.

For fuzzy logic controlled case, it can be shown that fuzzy logic controller recudes the bounce, roll and pitch vibrations the except pitch acceleration of the fuselage and also, reduces the seats and the pilots vibrations, as depicted. It is observed from the figures that the designed fuzzy logic controller for semi active landing gears improves the motions and accelerations of the fuselage, the seats and the pilots displacements and accelerations.

Also, for PID controlled case it can be shown that PID controller recudes the bounce and roll vibrations except the pitch motion and acceleration of the fuselage and in addition, it does not give good results for the seats and the pilots vibrations, as depicted. It is observed from the figures that the designed PID controller for semi active landing gears improves the motions and accelerations of the fuselage. But it can not affect the seats and pilots displacements and accelerations effectively.

The frequency responses of bounce, roll and pitch modes of the fuselage and vertical of the pilots and seats are shown in Figure 20, for MR 0 V case. It is known that the most critical response is peak value in frequency responses. These critical frequency responses are in the band that human body is sensitive.

The system have ten natural frequencies because of that the system is ten degrees of freedom. The mass matrix and the stiffness matrix are given in the Appendix. The natural frequencies are calculated as w_{n1}=132.4372 rad/s, w_{n2}=76.6601 rad/s, w_{n3}=76.6857 rad/s, w_{n4}=6.3914 rad/s, w_{n5}=17.2859 rad/s, w_{n6}=17.2859 rad/s, w_{n7}=16.8669 rad/s, w_{n8}=87.7418 rad/s, w_{n9}=87.8818 rad/s and w_{n10}=12.1148 rad/s, respectively.

Furthermore, applied voltages which are calculated via fuzzy logic controller and PID controller are shown in Figures 21 and 22. Maximum value of the applied voltages that is calculated via fuzzy logic controller are 0.76 V for front landing gear and 0.65 V for rear landing gears. It can be shown that the fuzzy logic voltage controllers generate constant voltage under no vibrations. The reason of this situation is the designed controller's structure. The fuzzy logic controller evaluates the input as displacement and velocity. Hence, the controller has constant voltage value when there is no vibration and in addition, there is no limit in the controller for this situation. The voltage controller of PID control is designed via Heaviside Step Function. To evaluate two controllers in same condition, V_max is chosen 0.76 V for front landing gear and 0.65 V for rear landing gears. Additionally, the selected controller voltage output range is between 0-5 V and MR damper works between 0-1 V because of the road profile. The selected road profile has not big excitation for this study. MR damper which is used in this study, has been tried adapting to working range between 0-10 V. But, because of the used MR damper characteristic gets worse the results of some displacements and accelerations.

Produced forces by MR dampers are shown in Figure 23. The MR damper forces which is produced via fuzzy logic controller are between +/- 3000 N for front landing gear, +/- 1000 N for rear landing gears, and which is produced via PID controller are between +/- 1000 N for front landing gear, +/- 500 N for rear landing gears. It can be shown the forces that are produced by fuzzy logic controller, have big magnitude than PID controller's forces. Thus, the fuzzy logic controller gives more sufficient vibration suppress.

Parameters of PID controllers that is determined by PSO algorithm are given in Table II.

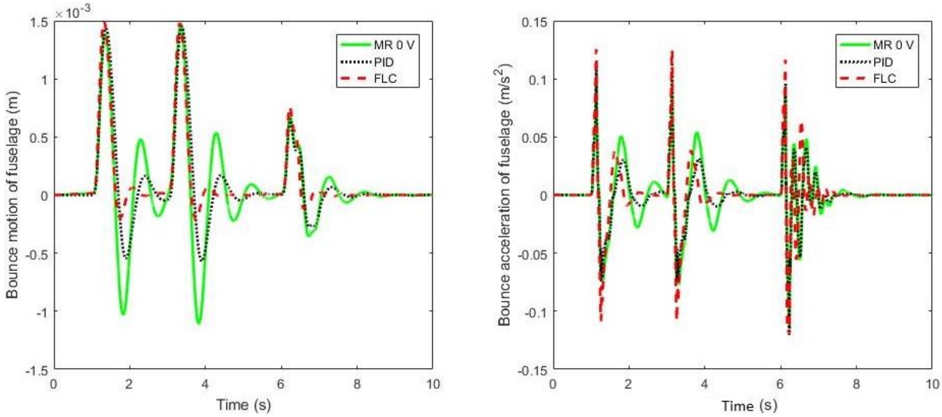


Figure 13. Bounce motion and acceleration of the fuselage

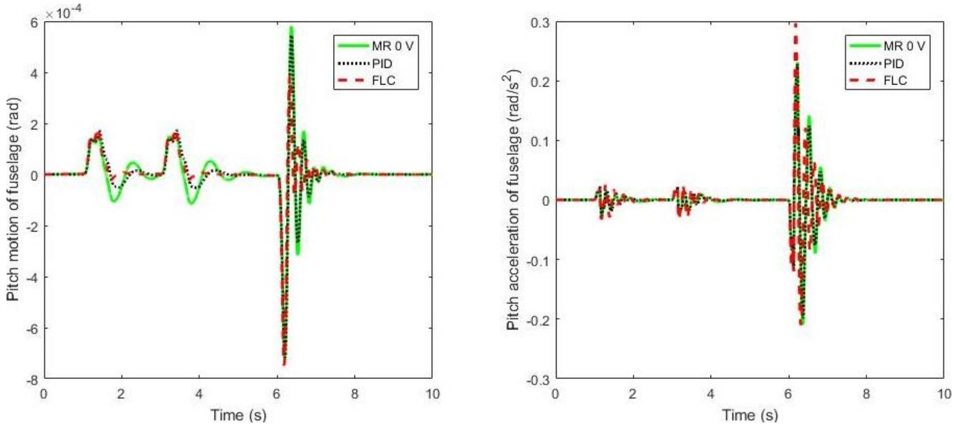


Figure 14. Pitch motion and acceleration of the fuselage

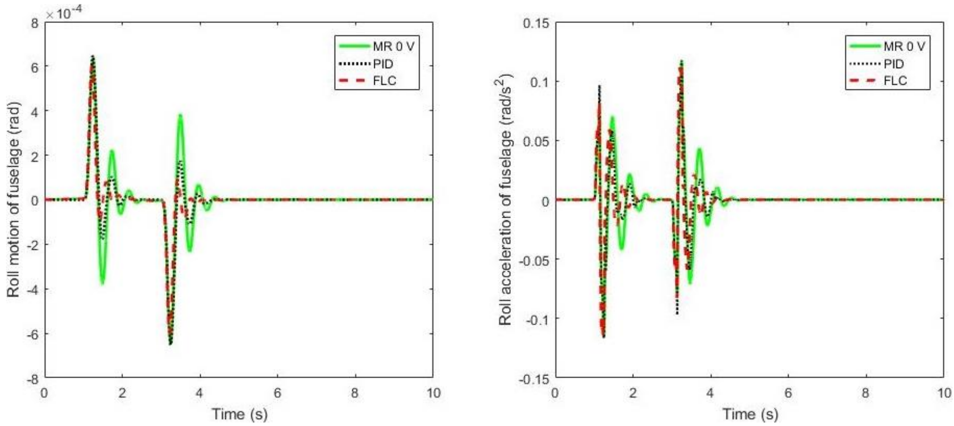


Figure 15. Roll motion and acceleration of the fuselage

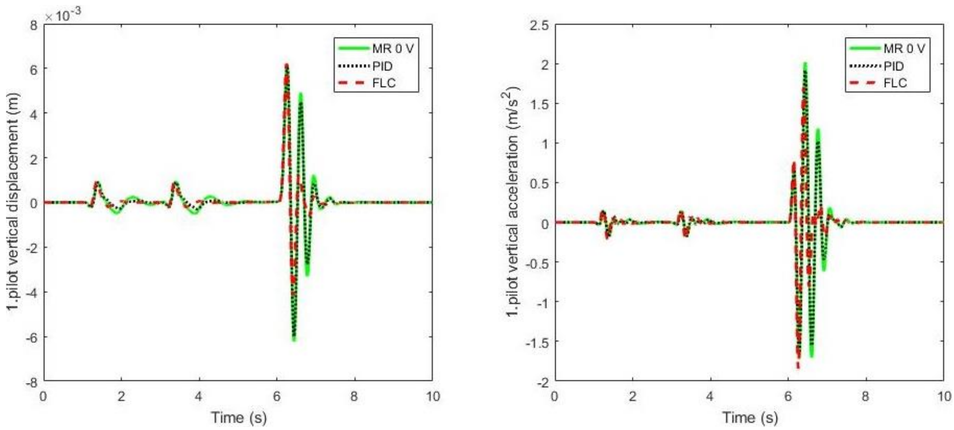


Figure 16. Vertical displacement and acceleration of the 1.pilot

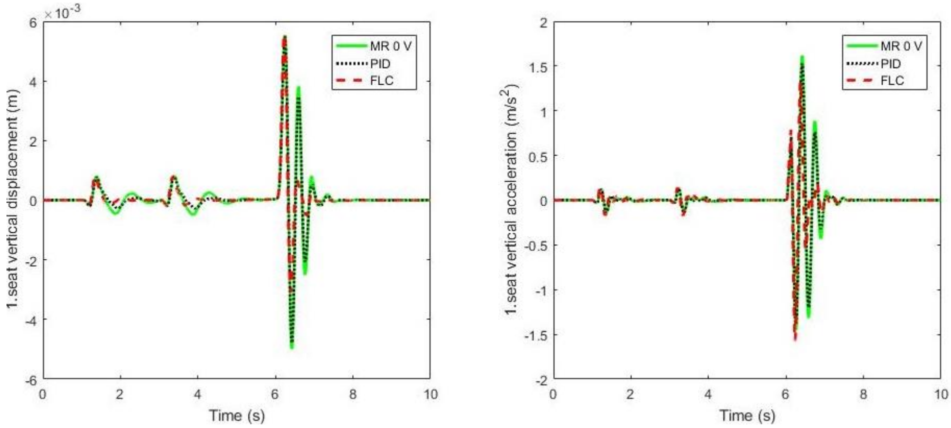


Figure 17. Vertical displacement and acceleration of the 1.seat

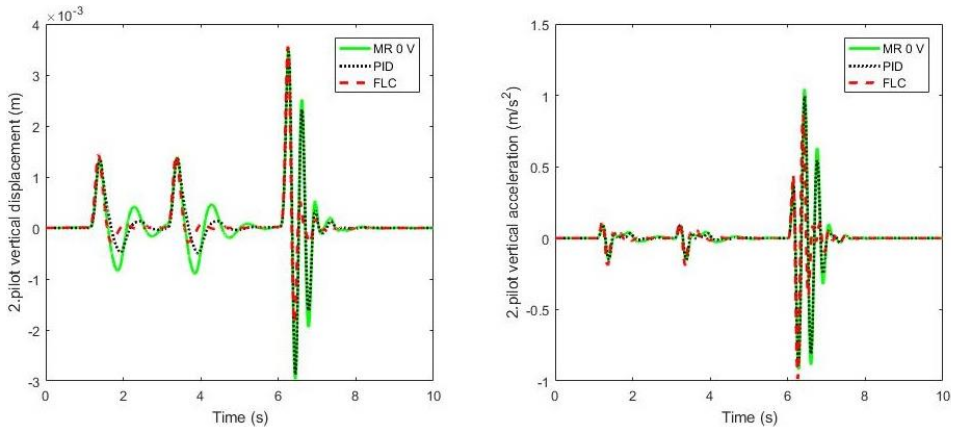


Figure 18. Vertical displacement and acceleration of the 2.pilot

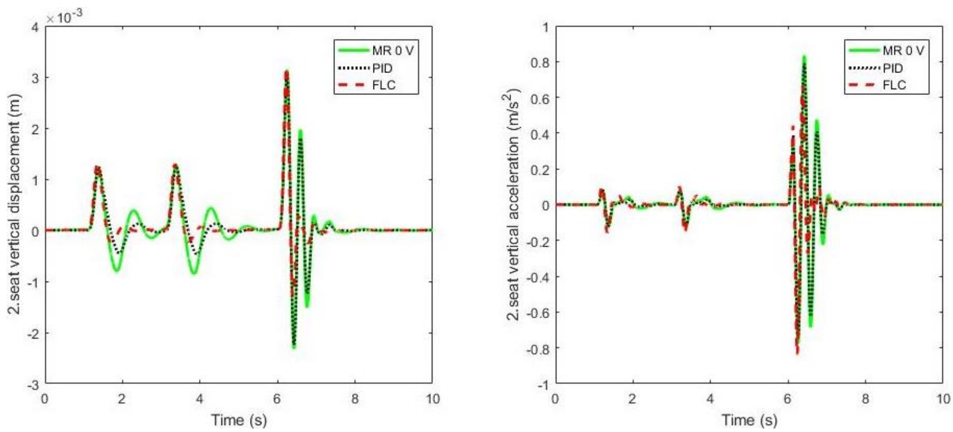
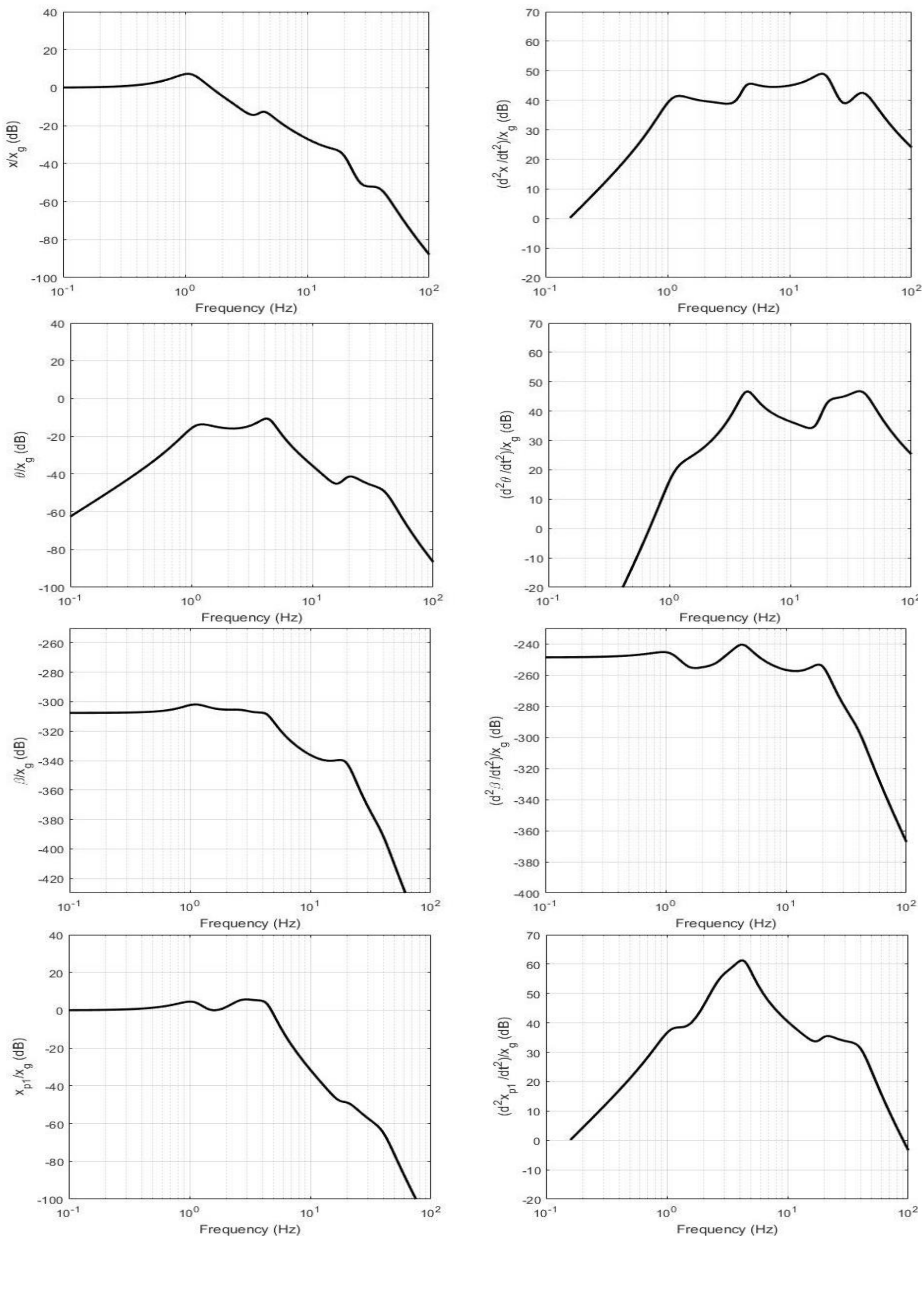


Figure 19. Vertical displacement and acceleration of the 2.seat


x/x_g (dB)
Frequency (Hz)
(d²x/dt²)/x_g (dB)
Frequency (Hz)
θ/x_g (dB)
Frequency (Hz)
(d²θ/dt²)/x_g (dB)
Frequency (Hz)
β/x_g (dB)
Frequency (Hz)
(d²β/dt²)/x_g (dB)
Frequency (Hz)
x_p1/x_g (dB)
Frequency (Hz)
(d²x_p1/dt²)/x_g (dB)
Frequency (Hz)

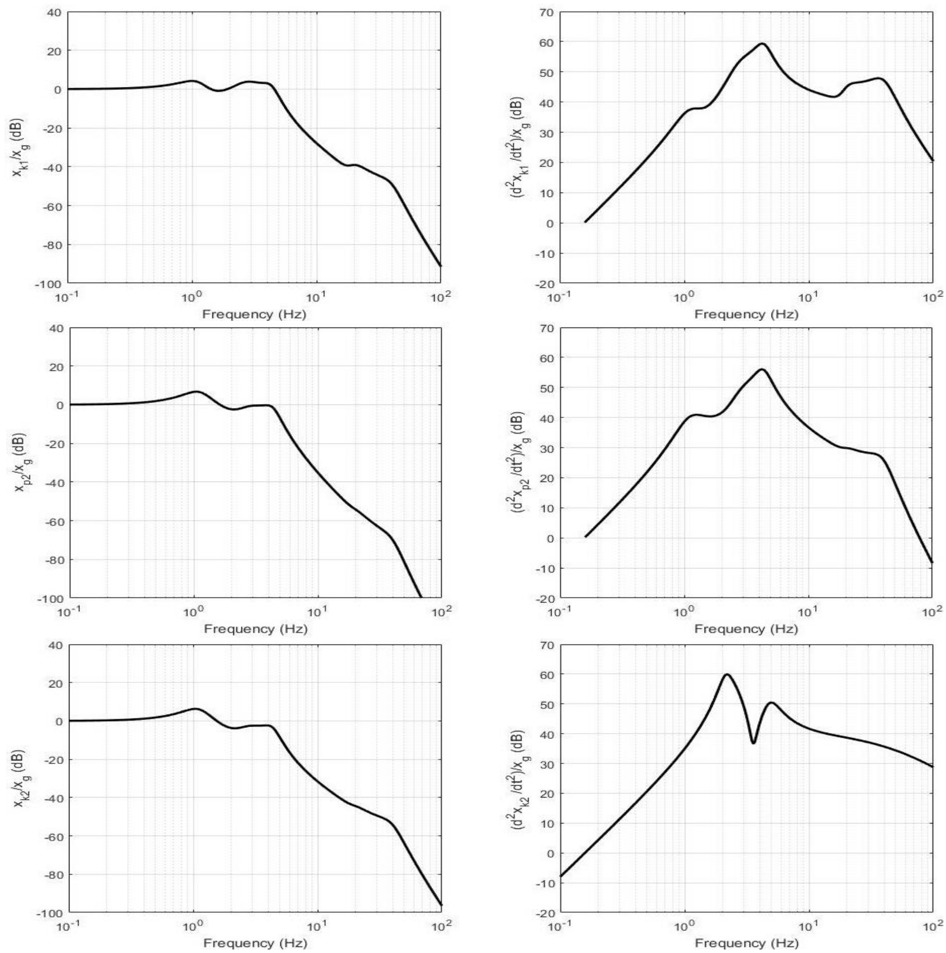


Figure 20. Frequency responses of MR 0 V case

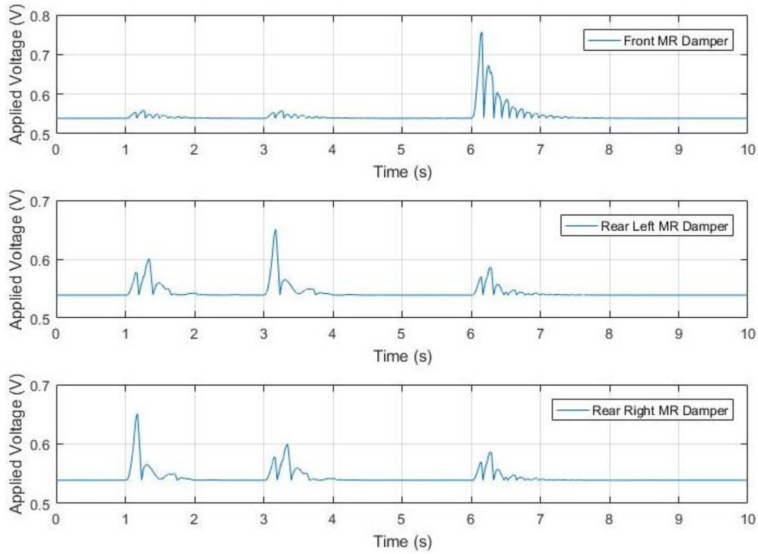


Figure 21. Applied voltage by fuzzy logic controller

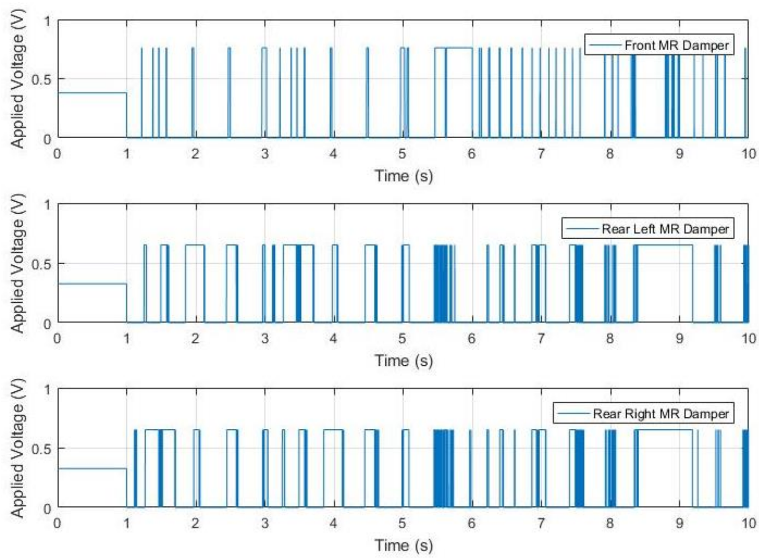


Figure 22. Applied voltage by PID controller

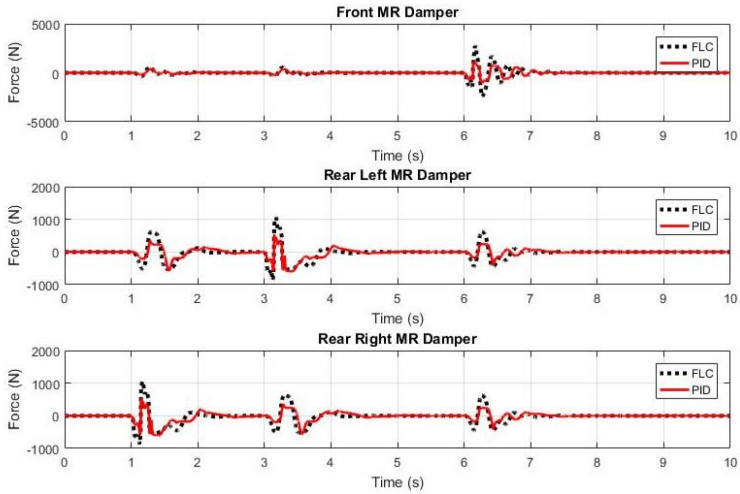


Figure 23. Produced forces by MR dampers using controllers

Table 2. PID Parameter using PSO algorithm

K_{P1}	K_{I1}	K_{D1}	K_{P2}	K_{I2}	K_{D2}	K_{P3}	K_{I3}	K_{D3}
75000	0	80	180500	300	20	180500	400	0

5. CONCLUSIONS

In this study, the fuzzy logic controller and PID controller for semi active landing gears with MR damper is designed to reduce the fuselage, seats and pilots vibrations during taxi position. MR damper voltages of semi active landing gears are determined using fuzzy logic controller and PID controller. The bounce, roll, pitch motions and accelerations, the seats and pilots vertical displacements and accelerations plots are compared with each other. The aircraft landing gears performance of designed controllers with MR damper is calculated via MATLAB-Simulink.

The main idea behind this study is the ability to use these type of controllers on aircrafts which becoming applicable. The simulation results prove that, two control methods have different taxiing performance. In fuzzy logic controlled case, the controller can guarantee efficient vibration attenuation for the fuselage, the seats and the pilots except the pitch acceleration. In PID controlled case, it can provide a good control for the fuselage except the pitch motion and acceleration. But for the seats and the pilots displacements, it has similar performance to passive case.

It is demonstrated that the controllers have better performance on passive system and fuzzy logic controller has a better performance than PID controller. It can be shown that controllers give low voltage to MR dampers. It proves that it has efficient energy consumption for the controllers methods. In conclusion, adding a semi active controller to landing gears improves the fuselage vibrations. But, PID controlled case does not give a good performance for pilots comforts.

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Appendix

Parameters of aircraft:

M=22000 kg, mt_1=130kg, mt_2= mt_3=260 kg, mk_1=mk_2=15 kg, mp_1=mp_2=61 kg, I_{yy}=65000 kgm^2, I_{zz}=100000 kgm^2, ks_1=673000 N/m, ks_2=ks_3=408000 N/m, kt_1=1590000 N/m, kt_2=kt_3=1590000 N/m, kp_1=kp_2=49340 N/m, ct_1=ct_2=ct_3=4066 Ns/m, cp_1=cp_2=4066 Ns/m, a=7.76 m, b=1.94 m, d=3.8425 m, e=3.8425 m, kk_1=kk_2=31000 N/m, ck_1=ck_2=830 Ns/m, k=3 m, l=6 m

Parameters of MR damper:

k_1=840N/m, k_0=3610 N/m, c_{0a}=784 Ns/m, c_{0b}=1803 Ns/Vm, c_{1a}=14649 Ns/m, c_{1b}=34622 Ns/Vm, A=58, α_α=12441 N/m, α_b=38430 Ns/Vm, γ=136320 $1/m^2$, β=2059020 $1/m^2$, η=190 1/s, n=2

Mass matrix and stiffness matrix:

$$M_s = \mathrm{diag}(mp_1, mp_2, mk_1, mk_2, M, I_{yy}, I_{xx}, mt_1, mt_2, mt_3)$$

$$K_s = \begin{bmatrix} Ks_{11} & Ks_{12} \\ Ks_{21} & Ks_{22} \end{bmatrix}$$

$$Ks_{11} = \begin{bmatrix} kp_1 & 0 & -kp_1 & 0 & 0 \\ 0 & kp_2 & 0 & -kp_2 & 0 \\ -kp_1 & 0 & kk_1 + kp_1 & 0 & -kk_1 \\ 0 & -kp_2 & 0 & kk_2 + kp_2 & -kk_2 \\ 0 & 0 & -kk_1 & -kk_2 & ks_1 + ks_2 + ks_3 + kk_1 + kk_2 \end{bmatrix}$$

$$Ks_{12} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ l\,kk_1 & 0 & 0 & 0 & 0 \\ k\,kk_2 & 0 & 0 & 0 & 0 \\ (b(ks_2 + ks_3) - a\,ks_1 - l\,kk_1 - k\,kk_2) & (e\,ks_3 - d\,ks_2) & -ks_1 & -ks_2 & -ks_3 \end{bmatrix}$$

$$Ks_{21} = \begin{bmatrix} 0 & 0 & -l\,kk_1 & -k\,kk_2 & (b(ks_2 + ks_3) - a\,ks_1 + l\,kk_1 + k\,kk_1) \\ 0 & 0 & 0 & 0 & (e\,ks_3 - d\,ks_2) \\ 0 & 0 & 0 & 0 & -ks_1 \\ 0 & 0 & 0 & 0 & -ks_2 \\ 0 & 0 & 0 & 0 & -ks_3 \end{bmatrix}$$

$$Ks_{22} = \begin{bmatrix} (a^2 ks_1 + b^2(ks_2 + ks_3) - l^2 kk_1 - k^2 kk_2) & (b\,e\,ks_3 - d\,b\,ks_2) & a\,ks_1 & -b\,ks_2 & -b\,ks_3 \\ (e\,b\,ks_3 - d\,b\,ks_2) & (d^2 ks_2 + e^2 ks_3) & 0 & d\,ks_2 & -e\,ks_3 \\ a\,ks_1 & 0 & kt_1 + ks_1 & 0 & 0 \\ -b\,ks_2 & d\,ks_2 & 0 & kt_2 + ks_2 & 0 \\ -b\,ks_3 & -e\,ks_3 & 0 & 0 & kt_3 + ks_3 \end{bmatrix}$$