1. Introduction

When the patients are lying on the stretcher of the ambulance, they are particularly sensitive to even tiny intensity of vibration. For ambulances, ride comfort, roll- and pitch-resistant performance requirements are more demanding than passenger cars. Since most of the ambulances are transformed from the commercial trucks, the comfort performance provided by the suspension of the sprung mass is usually not good. During the fast riding, the sprung mass of the ambulance may experience severe heave, rolling or pitching. All of those phenomenons will cause the patients and paramedics uncomfortable. So, simply introducing soft spring and proper damping on the stretcher suspension is not enough. The suspension of the ambulance is also needed to adjust to achieve the optimum comfort of the ambulance.

In this case, the Hydraulic Interconnected Suspension (HIS) is added to the conventional suspension of the ambulance to further improve the comfort performance of the ambulance. Particularly, there is a trade off among ride comfort, roll, and pitch dynamics. For example, the optimal roll-resistant performance of the vehicle is usually accompanied with excessive pitch-resistant moment, which would decrease the ride comfort of the vehicle. On the other hand, increasing the ride comfort would reduce the roll- and pitch-resistant performance.

In this study, the mathematical model of HIS suspension is built and coupled together with 8 DOF ambulance model forming a new dynamic model. Then based on this new model, the RMS values of acceleration of Zb, Zs, pitch motion and roll motion of the sprung mass are used as the indicators of the comfort performance of the ambulance. Then, the key parameters of the HIS suspension are varied in order to find their optimum value corresponding to the best trade off between each indicators and achieve an overall optimal performance of the ambulance. In the end, based on these optimum parameters, the comfort performance of ambulance with HIS suspension is compared with conventional suspension to verify our conclusion.

2. Working Principle of HIS Suspension

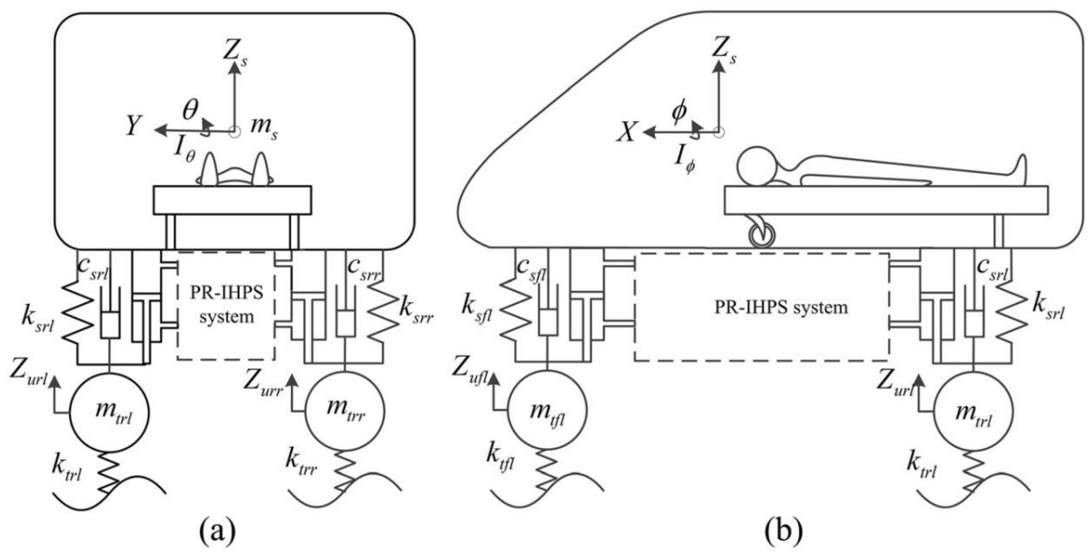

Figure 2.1 8 DOF ambulance with HIS suspension

The scheme of HIS subsystem is shown in Figure 2.2. The entire HIS system consists of four circuits connecting the different chambers. The components of each circuit include one nitrogen-filled diaphragm accumulator, one three-way junction, three damper valves and a few fluid pipelines.

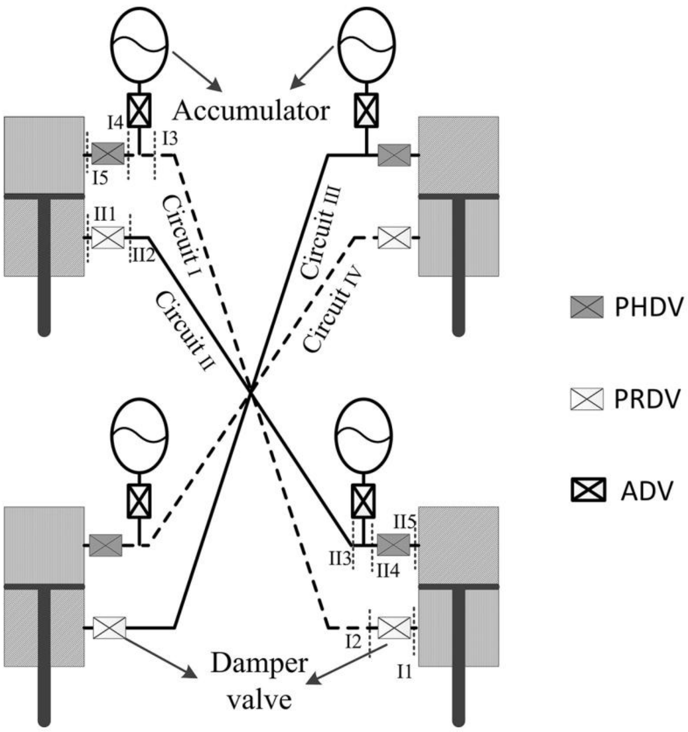

Figure 2.2 Scheme of HIS subsystem

When the ambulance turns left, positive roll motion between the sprung mass and unsprung masses occurs, and two left double-acting hydraulic cylinders are extended while right two double-acting hydraulic cylinders are compressed. At this point, hydraulic fluid in circuits I and III are lowly pressurized while ones in circuits II and IV are highly pressurized, which collectively provide a roll restoring moment to prevent the roll motion of sprung mass relative unsprung mass. There is a similar function when the ambulance turns right.

When the ambulance brakes, positive pitch motion will occur, which means the two front double-acting hydraulic cylinders are to be compressed while the rear ones extended. As a consequence, the HIS system provides a pitch restoring moment. With respect to bounce and warp motion modes, compression and extension of double-acting hydraulic cylinders lead to hydraulic fluid in circuits flows into extension chamber from compression chamber, which results in that the fluid pressure is almost unchanged. Therefore, the HIS system only provides additional damping forces but additional stiffness is not offered.

3. Mathematical Model of HIS Subsystem

To coupling the HIS subsystem with the 8 DOF ambulance model, the hydraulic forces are regarded as external force:

$$M \cdot \ddot{x} + C \cdot \dot{x} + K \cdot x = F_h + F_w$$

In this equation, $x=[z_b \quad z_s \quad \theta \quad \phi \quad z_{fr} \quad z_{fl} \quad z_{rl} \quad z_{rr}]^T$, matrices M, C, K are defined in ambulance model part. $F_w = \begin{bmatrix} 0 & 0 & 0 & 0 & k_u h_{fr} & k_u h_{fl} & k_u h_{rl} & k_u h_{rr} \end{bmatrix}^T$ is the road excitation. F_h is the hydraulic forces. It can be expressed as $F_h = D_{p(8\times8)} \cdot P_{(8\times1)}$. The pressure matrix $P=[P_{flT} \quad P_{flB} \quad P_{frT} \quad P_{frB} \quad P_{rlT} \quad P_{rlB} \quad P_{rrT} \quad P_{rrB}]^T$ and the area coefficient matrix D_P can be written as:

$$D_{p(8\times8)} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ S_{flT} & -S_{flB} & S_{frT} & -S_{frB} & S_{rlT} & -S_{rlB} & S_{rrT} & -S_{rrB} \\ -aS_{flT} & aS_{flB} & -aS_{frT} & aS_{frB} & bS_{rlT} & -bS_{rlB} & bS_{rrT} & -bS_{rrB} \\ lS_{flT} & -lS_{flB} & -lS_{frT} & lS_{frB} & lS_{rlT} & -lS_{rlB} & -lS_{rrT} & lS_{rrB} \\ -S_{flT} & S_{flB} & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & -S_{frT} & S_{frB} & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & -S_{frB} & S_{rlB} & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & -S_{rrT} & -S_{rrB} \end{bmatrix}$$

Since each fluid circuit is made up of one nitrogen-filled diaphragm accumulator, one three-way junction, three damper valves, and a few fluid pipelines components, as illustrated in Figure 2.2. Thus, using the fluid element lumped-parameter method, the mathematical relationship of flow rate and pressure in the circuit between upside and downside can be determined by a sequence of multiplications of the involved fluid component impedance matrices:

$$\begin{bmatrix} P_D^k \\ Q_D^k \end{bmatrix} = T^v \times T^t \times T^p \times T^v \begin{bmatrix} P_U^k \\ Q_U^k \end{bmatrix} = \begin{bmatrix} T_{11}^k & T_{12}^k \\ T_{21}^k & T_{22}^k \end{bmatrix} \begin{bmatrix} P_U^k \\ Q_U^k \end{bmatrix} \quad (*)$$

In this equation, “D” represent the downside of the flow, while “U” represent the upside of the flow. “v, t, p” represent each component of the system (“v” for damper valves and , “p” for pipelines and “t” for accumulator and ADV valve and three way conjunction). Matrices T is the fluid component impedance matrices. “k” represent the four circuits respectively (k=c1,c2,c3,c4 for each of the four circuits).

(1) Pipelines component impedance matrix T^p

The hydrodynamic equations of pipeline fluid element can be expressed as:

$$\begin{cases} P_U - P_D = R_P Q + I_P \dot{Q} \\ Q_U - Q_D = C_P \dot{P} \end{cases} \qquad \begin{cases} P = (P_U + P_D)/2 \\ Q = (Q_U + Q_D)/2 \end{cases}$$

Combining these two sets of equations, then do Laplace transform with zero initial condition. The relationship of flow and pressure between upside and downside in the pipelines components can be described by the impedance matrix T^p:

$$\begin{bmatrix} P_D \\ Q_D \end{bmatrix} = \begin{bmatrix} \dfrac{I_P s + R_p + 4s^{-1}/C_p}{-I_P s - R_p + 4s^{-1}/C_p} & -\dfrac{4(I_p s + R_P)s^{-1}/C_p}{-I_P s - R_p + 4s^{-1}/C_p} \\ -\dfrac{4}{-I_P s - R_p + 4s^{-1}/C_p} & \dfrac{I_P s + R_p + 4s^{-1}/C_p}{-I_P s - R_p + 4s^{-1}/C_p} \end{bmatrix} \begin{bmatrix} P_U \\ Q_U \end{bmatrix} = T^P \begin{bmatrix} P_U \\ Q_U \end{bmatrix}$$

(2) Damper valve component impedance matrix T^v

The hydrodynamic equation of this component can be written as (Z_H is the pressure loss coefficients of damper valve):

$$\begin{bmatrix} P_D \\ Q_D \end{bmatrix} = \begin{bmatrix} 1 & -Z_H \\ 0 & 1 \end{bmatrix} \begin{bmatrix} P_U \\ Q_U \end{bmatrix} = T^v \begin{bmatrix} P_U \\ Q_U \end{bmatrix}$$

(3) Accumulator, ADV valve and conjunction component impedance matrix T^v

The hydrodynamic equation of upside and downside of these combined component can be written as (Z_A is the pressure loss coefficients of ADV valve, C_a is the capacity of gas-filled diaphragm accumulator):

$$\begin{bmatrix} P_D \\ Q_D \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ \dfrac{1}{-1/(sC_a) - Z_A} & 1 \end{bmatrix} \begin{bmatrix} P_U \\ Q_U \end{bmatrix} = T^t \begin{bmatrix} P_U \\ Q_U \end{bmatrix}$$

Substituting all of those three sets of hydrodynamic equations into equation (*) and rearrange the equation to describe the relationship between P and Q instead of upside and downside, and expanding the expressions to all four circuits. The relationship between P and Q can be written as:

$$P = T(s) \cdot Q$$

In this equation, $Q = [Q_{flT} \quad Q_{flB} \quad Q_{frT} \quad Q_{frB} \quad Q_{rlT} \quad Q_{rlB} \quad Q_{rrT} \quad Q_{rrB}]^T$ is the flow rate in different chambers. T(s) is the total impedance matrix of the whole HIS subsystem. T(s) can be expressed as:

$$T(s) = \begin{bmatrix}
-\dfrac{T_{22}^{c1}}{T_{21}^{c1}} & 0 & 0 & 0 & 0 & 0 & 0 & \dfrac{1}{T_{21}^{c1}} \\
0 & \dfrac{T_{11}^{c2}}{T_{21}^{c2}} & 0 & 0 & 0 & 0 & \dfrac{T_{12}^{c2}T_{21}^{c2} - T_{11}^{c2}T_{22}^{c2}}{T_{21}^{c2}} & 0 \\
0 & 0 & -\dfrac{T_{22}^{c3}}{T_{21}^{c3}} & 0 & 0 & \dfrac{1}{T_{21}^{c3}} & 0 & 0 \\
0 & 0 & 0 & \dfrac{T_{11}^{c4}}{T_{21}^{c4}} & \dfrac{T_{12}^{c4}T_{21}^{c4} - T_{11}^{c4}T_{22}^{c4}}{T_{21}^{c4}} & 0 & 0 & 0 \\
0 & 0 & 0 & \dfrac{1}{T_{21}^{c4}} & -\dfrac{T_{22}^{c4}}{T_{21}^{c4}} & 0 & 0 & 0 \\
0 & 0 & \dfrac{T_{12}^{c3}T_{21}^{c3} - T_{11}^{c3}T_{22}^{c3}}{T_{21}^{c3}} & 0 & 0 & \dfrac{T_{11}^{c3}}{T_{21}^{c3}} & 0 & 0 \\
0 & \dfrac{1}{T_{21}^{c2}} & 0 & 0 & 0 & 0 & -\dfrac{T_{22}^{c2}}{T_{21}^{c2}} & 0 \\
\dfrac{T_{12}^{c1}T_{21}^{c1} - T_{11}^{c1}T_{22}^{c1}}{T_{21}^{c1}} & 0 & 0 & 0 & 0 & 0 & 0 & \dfrac{T_{11}^{c1}}{T_{21}^{c1}}
\end{bmatrix}$$

In addition, the flow rate Q(t) in different chamber can be described by cross-sectional areas of the chambers multiplies the speed of changing of the chamber volume. In this case, Q(t) can be expressed as:

$$Q(t) = D_m \cdot \dot{x}(t)$$

In this equation, D_m describe the cross-sectional areas responding to different speeds of all 8 degrees of freedoms.

$$D_m = \begin{bmatrix} 0 & -S_{frT} & aS_{frT} & -lS_{frT} & S_{frT} & 0 & 0 & 0 \\ 0 & -S_{frB} & aS_{frB} & -lS_{frB} & S_{frB} & 0 & 0 & 0 \\ 0 & -S_{flT} & aS_{flT} & lS_{flT} & 0 & S_{flT} & 0 & 0 \\ 0 & -S_{flB} & aS_{flB} & lS_{flB} & 0 & S_{flB} & 0 & 0 \\ 0 & -S_{rlT} & -bS_{rlT} & -lS_{rlT} & 0 & 0 & S_{rlT} & 0 \\ 0 & -S_{rlB} & -bS_{rlB} & -lS_{rlB} & 0 & 0 & S_{rlB} & 0 \\ 0 & -S_{rrT} & -bS_{rrT} & lS_{rrT} & 0 & 0 & 0 & S_{rrT} \\ 0 & -S_{rrB} & -bS_{rrB} & lS_{rrB} & 0 & 0 & 0 & S_{rrB} \end{bmatrix}$$

To sum up, the external forces F_h representing the HIS subsystem can be expressed by the following equations:

$$F_h = D_P \cdot T(s) \cdot D_m \cdot \dot{x}$$

4. Integration of Ambulance Model and HIS Suspension Model

After obtaining the HIS suspension mathematical model, the integrated model of HIS suspension and ambulance can be written as:

$$M \cdot \ddot{x} + C \cdot \dot{x} + K \cdot x = D_P \cdot T(s) \cdot D_m \cdot \dot{x} + F_w$$

To further integrate these two models, the external forces F_h can be further arranged to the differential equation forms like this:

$$D_P \cdot T(s) \cdot D_m \cdot \dot{x} = C_{HIS} \cdot \dot{x} + K_{HIS} \cdot x$$

In this case, the combined mathematical model can be written as:

$$M \cdot \ddot{x} + (C - C_{HIS}) \cdot \dot{x} + (K - K_{HIS}) \cdot x = F_w$$

4.1 Stiffness matrix K_{HIS}

The cross-sectional area of different cylinders can be expressed as the cross-sectional area ratio between the bottom and top of the front or rear cylinder η_i (i = f ,r) and the ratio between the rear and front top cylinders μ are introduced, which can be written as $\eta i = S_{iB}/S_{iT}$ and $\mu = S_{fT}/S_{rT}$.

The stiffness matrix of HIS suspension can be expressed as:

$$K_{HIS(8\times8)} = \frac{1}{C_P + C_a} \begin{bmatrix} 0_{(1\times1)} & 0_{(1\times3)} & 0_{(1\times4)} \\ 0_{(3\times1)} & K_{b(3\times3)} & K_{bw(3\times4)} \\ 0_{(4\times1)} & K_{bw(4\times3)}^T & K_{w(4\times4)} \end{bmatrix} S_{rT}^2$$

Where,

$$K_b = \begin{bmatrix} 2\left[(\mu-\eta_r)^2 + (\mu\eta_f)^2\right] & -2\left[(a\mu+b\eta_r)(\mu-\eta_r) + \mu\eta_f(a\mu\eta_f+b)\right] & 0 \\ -2\left[(a\mu+b\eta_r)(\mu-\eta_r) + \mu\eta_f(a\mu\eta_f+b)\right] & 2\left[(\mu-\eta_r)^2 + (\mu\eta_f)^2\right] & 0 \\ 0 & 0 & 2\left[(l\mu+l\eta_r)^2 + (l\mu\eta_f+l)^2\right] \end{bmatrix}$$

$$K_{bw} = \begin{bmatrix} -\mu(\mu-\eta_r)-(\mu\eta_f)^2 & -\mu(\mu-\eta_r)-(\mu\eta_f)^2 & \eta_r(\mu-\eta_r)+\mu\eta_f & \eta_r(\mu-\eta_r)+\mu\eta \\ \mu(a\mu+b\eta_r)+\mu\eta_f(a\mu+b\eta_r) & \mu(a\mu+b\eta_r)+\mu\eta_f(a\mu+b\eta_r) & -\eta_f(a\mu+b\eta_r)-(a\mu\eta_f+b) & -\eta_f(a\mu+b\eta_r)-(a\mu\eta_f+b) \\ -\mu(l\mu+l\eta_r)-\mu\eta_f(l\mu\eta_f+l) & \mu(l\mu+l\eta_r)+\mu\eta_f(l\mu\eta_f+l) & -\eta_r(l\mu+l\eta_r)-(l\mu\eta_f+l) & \eta_r(l\mu+l\eta_r)+(l\mu\eta_f+l) \end{bmatrix}$$

$$K_w = \begin{bmatrix} \mu^2(\eta_f^2+1) & 0 & 0 & -\mu(\eta_r+\eta_f) \\ 0 & \mu^2(\eta_f^2+1) & -\mu(\eta_r+\eta_f) & 0 \\ 0 & -\mu(\eta_r+\eta_f) & \eta_f^2+1 & 0 \\ -\mu(\eta_r+\eta_f) & 0 & 0 & \eta_f^2+1 \end{bmatrix}$$

4.2 Damping matrix C_{HIS}

The damping matrix of HIS suspension can be expressed as:

$$C_{HIS(8\times8)} = Z_A \begin{bmatrix} 0_{(1\times1)} & 0_{(1\times3)} & 0_{(1\times4)} \\ 0_{(3\times1)} & K_{b(3\times3)} & K_{bw(3\times4)} \\ 0_{(4\times1)} & K_{bw(4\times3)}^T & K_{w(4\times4)} \end{bmatrix} S_{rT}^2 + Z_H \begin{bmatrix} 0_{(1\times1)} & 0_{(1\times3)} & 0_{(1\times4)} \\ 0_{(3\times1)} & C_{b0(3\times3)} & C_{bw0(3\times4)} \\ 0_{(4\times1)} & C_{bw0(4\times3)}^T & C_{w0(4\times4)} \end{bmatrix} S_{rT}^2 + Z_R \begin{bmatrix} 0_{(1\times1)} & 0_{(1\times3)} & 0_{(1\times4)} \\ 0_{(3\times1)} & C_{b2(3\times3)} & C_{bw2(3\times4)} \\ 0_{(4\times1)} & C_{bw2(4\times3)}^T & C_{w2(4\times4)} \end{bmatrix} S_{rT}^2$$

$$C_{bi} = \begin{bmatrix} 2(\mu^2\eta_f^i + \eta_r^i) & -2(a\mu^2\eta_f^i - b\eta_r^i) & 0 \\ -2(a\mu^2\eta_f^i - b\eta_r^i) & 2(a^2\mu^2\eta_f^i + b\eta_r^i) & 0 \\ 0 & 0 & 2(l^2\mu^2\eta_f^i + l^2\eta_r^i) \end{bmatrix}$$

$$C_{bwi} = \begin{bmatrix} -\eta_f^i\mu^2 & -\eta_f^i\mu^2 & -\eta_r^i & -\eta_r^i \\ -a\eta_f^i\mu^2 & -a\eta_f^i\mu^2 & -b\eta_r^i & -b\eta_f^i \\ -l\eta_f^i\mu^2 & l\eta_f^i\mu^2 & -l\eta_r^i & l\eta_r^i \end{bmatrix} \quad C_{bwi} = \begin{bmatrix} \eta_f^i\mu^2 & 0 & 0 & 0 \\ 0 & \eta_f^i\mu^2 & 0 & 0 \\ 0 & 0 & \eta_r^i & 0 \\ 0 & 0 & 0 & \eta_r^i \end{bmatrix}$$

In those equations, i = 0, 2.

5. Optimize the Parameters of HIS System for the Ambulance Model

To further improve the comfort performance of the ambulance, the cross sectional ratios μ and η_i of HIS subsystem needs to be properly chosen. To do that, we build the integrated model in Matlab/Simulink, and use grade C random road profile as our road excitation and run the simulation to have the responses of acceleration of z_b, z_s, pitch and roll motion in time domain.

During the simulations, the series of different μ and η_i values are tested and the RMS values of responses of acceleration of z_b, z_s, pitch and roll motion is used as the indicators of the comfort performance of the ambulance. From the results of the RMS values, and make a trade-off between each indicators and choose the proper values of μ and η_i to achieve an overall optimal performance of the ambulance. Then, based on the optimized μ and η_i, the optimized responses of the ambulance ride performance is simulated.

5.1 Indicators of comfort performance of the ambulance.

Patients lying inside the ambulance are particularly sensitive to even tiny intensity of vibration, acceleration of z_b is certainly one important indicator. When the ambulances are in operation, vibration in the lateral direction, due to the curves, would make the emergency care not easy to operate for the paramedic and even cause trauma to patient. So acceleration of z_s and roll motion are also two important indicators. Moreover, the subsequent pitch motion due to frequently brake and start will generate negative foot-to-head acceleration in the lying patient, which would result in side effect, such as rapid shifting the blood to the head, reduction of venous return, and the rise of the patient's blood pressure.

In this case, there are four important indicators for the comfort performance of the ambulance: RMS of acceleration of z_b, z_s, roll of sprung mass and pitch of sprung mass.

5.2 Simulink model of the integrated model

The Simulink diagram of the integrated ambulance and HIS suspension model can be built shown in Figure 5.1.

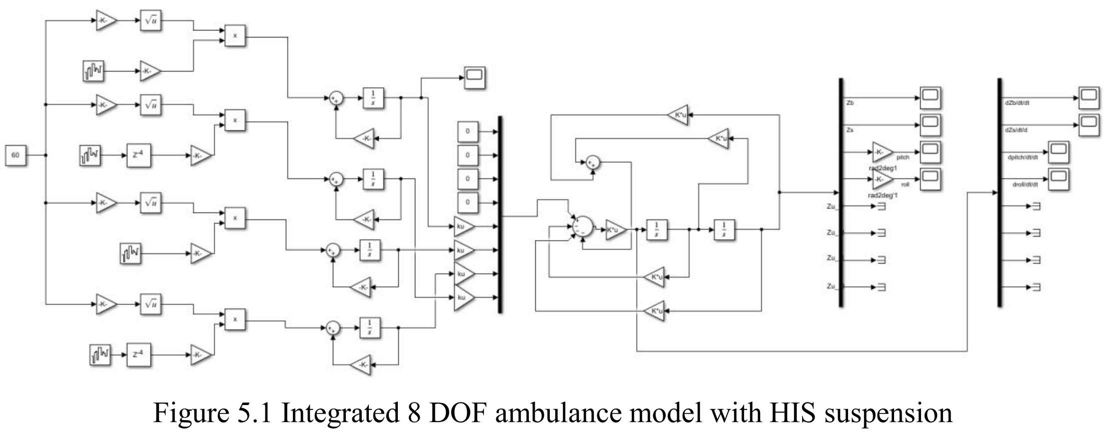

Figure 5.1 Integrated 8 DOF ambulance model with HIS suspension

5.2 Find the optimized value of μ

The ratio between the cross-sectional cylinder-areas of front and rear HIS μ is certainly going to influence the HIS comfort performance. To find the optimal value of μ, the results of RMS values of responses of acceleration of z_b, z_s, pitch and roll motion in time domain are shown in Figure 5.2. During this process, μ is varied from 0 to 2 at the distance of 0.1.

To find the best values of all of the three parameters μ and η_i (i = f, r), when varying μ, the values η_i are fixed as 1 (the right and rear cross-sectional areas of cylinders are equal).

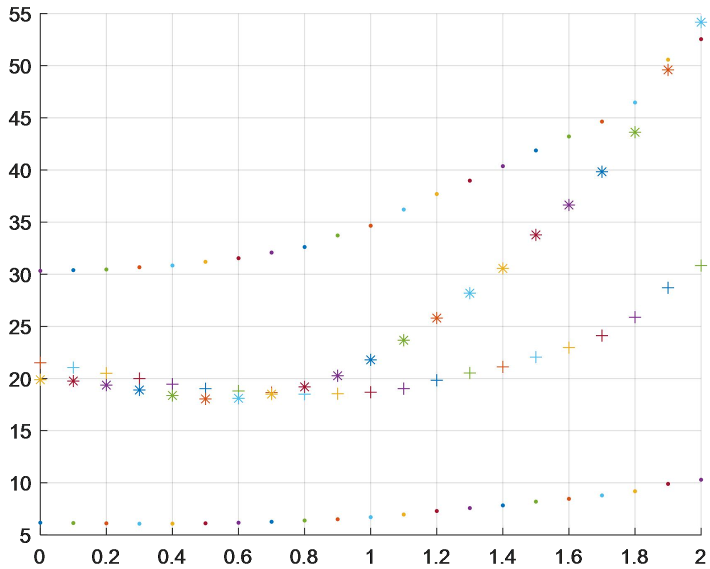

Figure 5.2 RMS values varying μ

In this figure, "+" and "*" represent the RMS values of acceleration of z_s and pitch respectively. The higher and lower "." represent the RMS values of the acceleration of roll motion and z_b respectively.

Since lower the RMS value better the results, but from the figure we can see that there is no single certain value of μ corresponding to all four indicator. After making a trade-off, μ = 0.6 can be regard as approximately the best value to achieve the overall comfort performance for the ambulance.

5.3 Find the optimized value of η_i

(1) The optimal value of η_f
In this process, μ is fixed at its optimal value 0.6. Then, η_f is varied from 0 to 3 at the distance of 0.1. The results of the RMS values is shown in Figure 5.3.

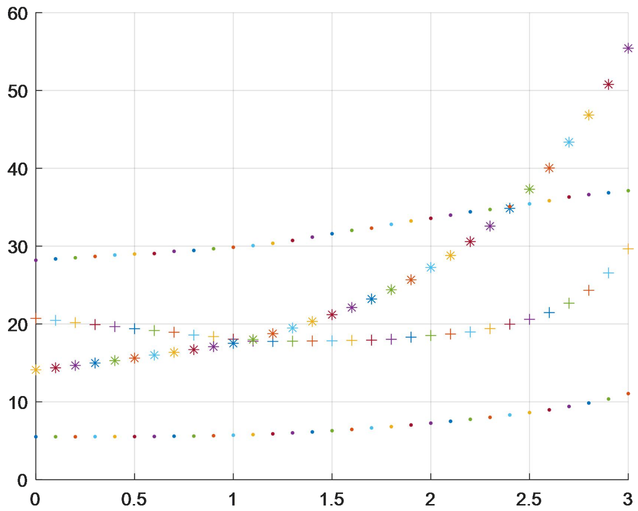

Figure 5.3 RMS values varying ηf

From the figure, the RMS of acceleration of z_s, z_b and roll is approximately the same from $\eta_f = 0$ to $\eta_f = 2$, while RMS of acceleration of pitch motion is decreasing as ηf is decreasing. So, to achieve the low RMS of pitch and at the same time not causing too high of RMS roll, the value of η_f is chosen at 0.5.

(2) The optimal value of η_r
In this process, μ and η_f are fixed at their optimal value 0.6 and 0.5. η_r is varied from 0 to 3 at the distance of 0.1. Then the results of RMS values are output in Figure 5.4.

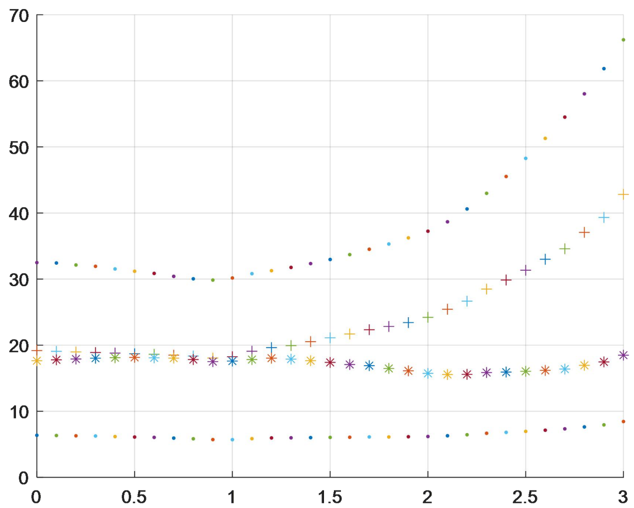

Figure 5.4 RMS values varying η_r

From the figure, the RMS of acceleration of z_s, z_b and roll is approximately constant low from $\eta_r = 0$ to $\eta_r = 1.5$, while RMS of acceleration of roll motion shows relatively obvious minimum at $\eta_r = 0.9$. So η_r is selected at value of 0.9 as its optimal one.

Summing up all the analysis, the ratio of cross-sectional areas of different cylinders are determined: $\mu = 0.6$, $\eta_f = 0.5$, $\eta_r = 0.9$.

6. Comparison Between HIS and Conventional Suspension

To further verify the improvement of the comfort performance of the ambulance with HIS, based on the optimal parameters of HIS ($\mu = 0.6$, $\eta_f = 0.5$, $\eta_r = 0.9$), the comfort responses of the ambulance with HIS and without HIS are compared. The input of this system is grade C random road profile. The results are shown from Figure 6.1 to 6.8.

The red line represent the responses without HIS, and the black line represent the responses with HIS.

(1) The responses of vertical motion of the stretcher

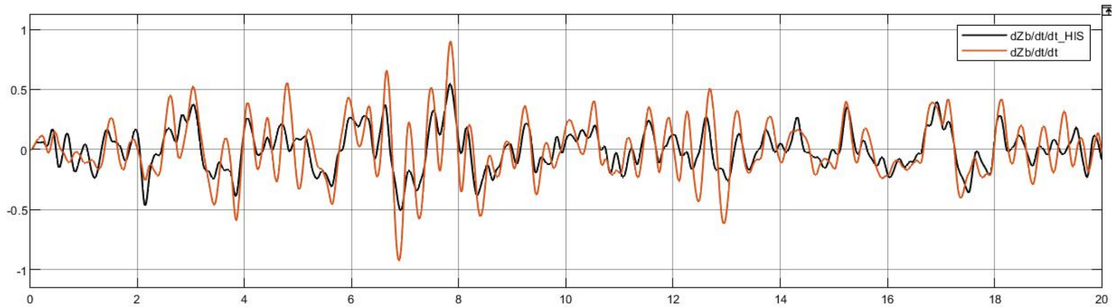

Figure 6.1 Comparison of acceleration of z_b

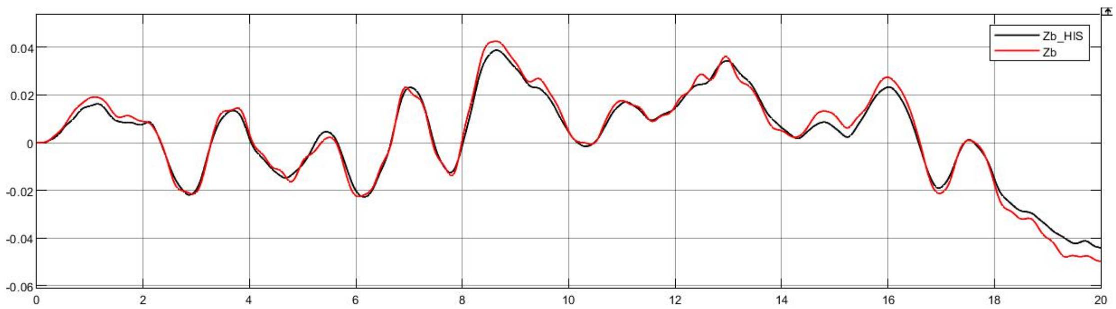

Figure 6.2 Comparison of z_b

(2) The responses of vertical motion of the sprung mass

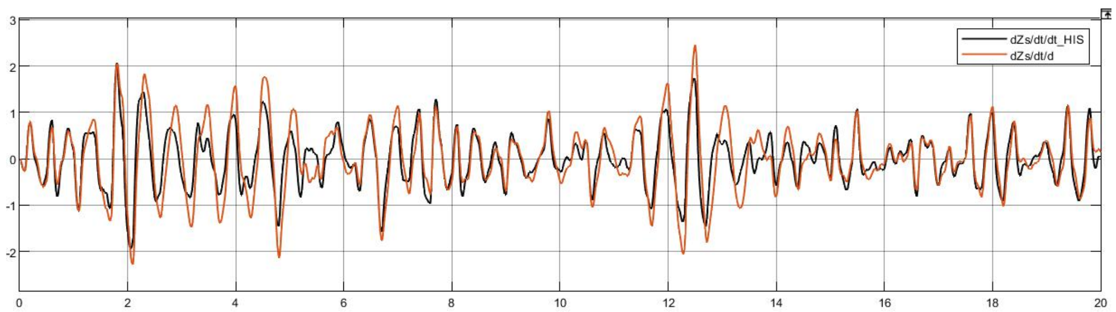

Figure 6.3 Comparison of acceleration of z_s

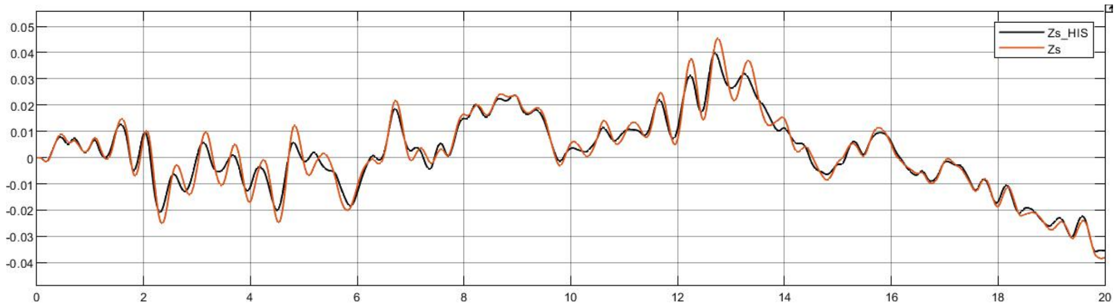

Figure 6.4 Comparison of z_s

(3) The responses of pitch motion of the sprung mass

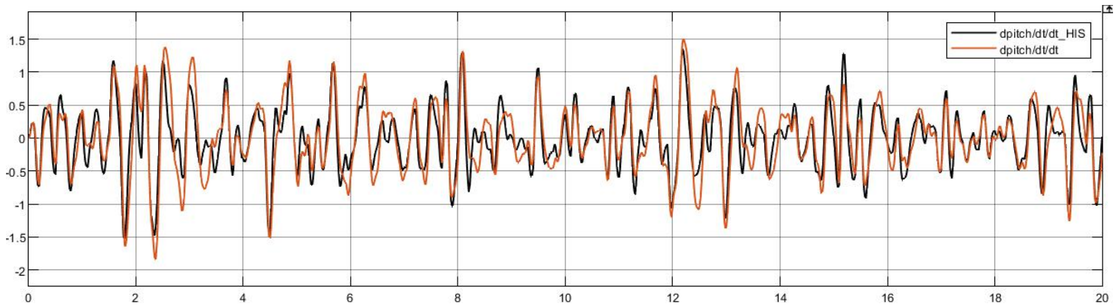

Figure 6.5 Comparison of acceleration of pitch of sprung mass

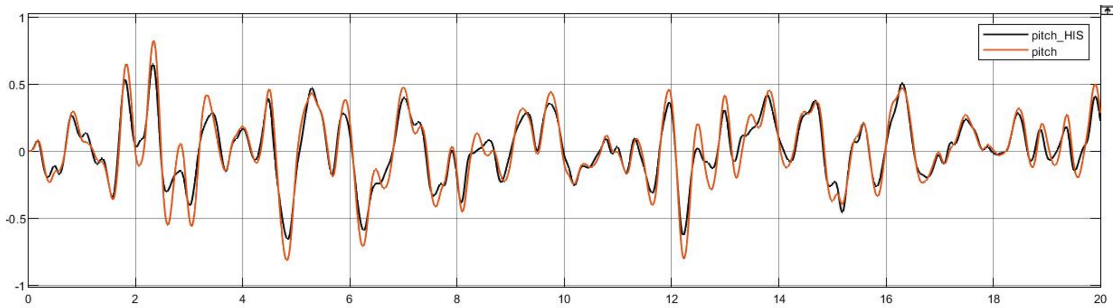

Figure 6.6 Comparison of pitch of sprung mass

(4) The responses of roll motion of the sprung mass

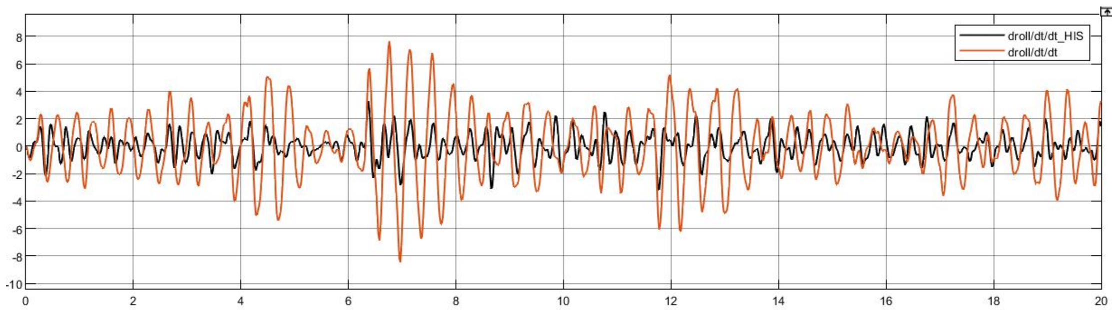

Figure 6.7 Comparison of acceleration of roll of sprung mass

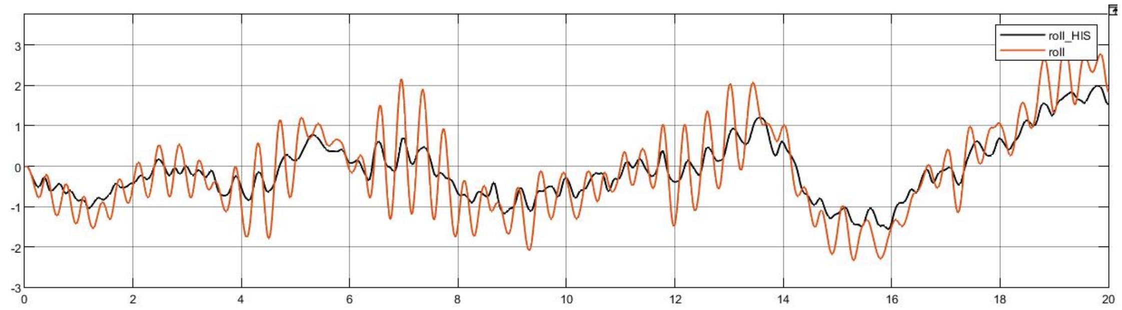

Figure 6.8 Comparison of roll of sprung mass

To show the results more clearly, the RMS values of each of the comfort responses is compared between the ambulance with and without HIS. The results are shown in the bar chart in Figure 6.9.

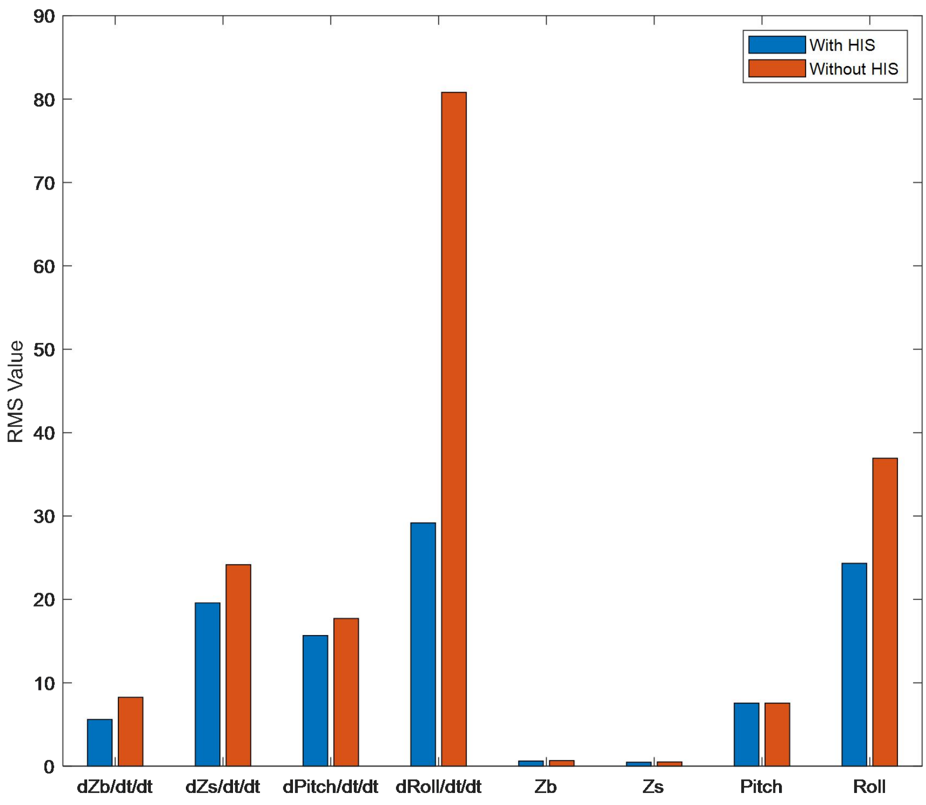

Figure 6.9 Comparison of RMS of the ambulance with and without HIS.

From this chart, we can find that the HIS can improve the comfort performance in all of these eight responses. In addition, the introduce of HIS can significantly improve the rolling performance of the ambulance. Overall, the HIS is a very good way to improve the riding performance of the ambulance.