

Efficient Computation of the Dynamic Model for Krang

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In our earlier report we derived the model of the robot, Golem Krang, using Kane's formulation. Since the purpose of deriving the model is either simulation or control, both of which require us to calculate the dynamics of the robot as fast as possible, we are stuck with a problem. Due to large number of degrees of freedom, the final expression for the dynamics of the system is extremely long. Also, it contains a repetition of same combination of terms. Thus the computation using the final form that will come out as a result of applying the results of the report mentioned earlier, are going to be inefficient. Even if the final expression is not directly used but the recursive formulation is used to calculate the terms still suffers with the same problem. For this reason, it will be nice if we can reduce the amount of computation time that is required to compute the dynamics of the system in run-time.

We use the ideas presented in [1]. The basic idea is simple. As we derive the kinematics of the system recursively, we keep substituting the resulting expressions, that are combinations of more than one variables, with one new variable. And we derive the kinematics of the succeeding links (in the serial structure) in terms of the substitute variables. And then we repeat this substitution process at each step. This allows us to express the final expression in simpler closed forms, and also if the substitutions are encoded, a potential recurring combination of variables will be evaluated/computed just once within an iteration thus resulting the overall computation time significantly.

$$\begin{aligned}
 \bar{\omega}_1 &= {}^1A_0\bar{\omega}_0 + \dot{q}_1\bar{e}_1 \\
 \bar{\omega}_1 &= [-\dot{q}_{imu} \quad \dot{\psi}c_{imu} \quad \dot{\psi}s_{imu} \quad] \\
 K_1 &= \dot{\psi}c_{imu} \\
 K_2 &= \dot{\psi}s_{imu} \\
 \bar{\omega}_1 &= [-\dot{q}_{imu} \quad K_1 \quad K_2 \quad] \\
 \bar{\omega}_1 &= [-\dot{q}_{imu} \quad \dot{\psi}c_{imu} \quad \dot{\psi}s_{imu} \quad] \\
 \bar{\omega}_1 &= [-\dot{q}_{imu} \quad \dot{\psi}c_{imu} \quad \dot{\psi}s_{imu} \quad] \\
 \bar{v}_1 &= {}^1A_0(\bar{v}_0 + \bar{\omega}_0 \times P_1) \\
 \bar{v}_1 &= [0 \quad \dot{x}s_{imu} \quad -\dot{x}c_{imu} \quad] \\
 K_3 &= \dot{x}s_{imu} \\
 K_4 &= -\dot{x}c_{imu} \\
 \bar{v}_1 &= [0 \quad K_3 \quad K_4 \quad] \\
 \bar{v}_1 &= [0 \quad \dot{x}s_{imu} \quad -\dot{x}c_{imu} \quad] \\
 \bar{v}_1 &= [0 \quad \dot{x}s_{imu} \quad -\dot{x}c_{imu} \quad] \\
 \bar{\alpha}_1 &= {}^1A_0\bar{\alpha}_0 + \ddot{q}_1\bar{e}_1 + \dot{q}_1(\bar{\omega}_1 \times \bar{e}_1) \\
 \bar{\alpha}_1 &= [-\ddot{q}_{imu} \quad \ddot{\psi}c_{imu} - K_2\dot{q}_{imu} \quad K_1\dot{q}_{imu} + \ddot{\psi}s_{imu} \quad] \\
 K_5 &= -K_2\dot{q}_{imu} \\
 K_6 &= K_1\dot{q}_{imu}
 \end{aligned}$$

$$\begin{aligned}
\bar{\alpha}_1 &= [-\dot{q}_{imu} \quad K_5 + \ddot{\psi}c_{imu} \quad K_6 + \ddot{\psi}s_{imu} \quad] \\
\bar{a}_1 &= {}^1A_0 (\bar{a}_0 + \bar{\alpha}_0 \times \bar{P}_1 + \bar{\omega}_0 \times (\bar{\omega}_0 \times \bar{P}_1)) \\
\bar{\alpha}_1 &= [-\dot{\psi} \quad \ddot{s}_{imu} \quad -\ddot{c}_{imu} \quad] \\
\bar{a}_1 &= [-\dot{\psi} \quad \ddot{s}_{imu} \quad -\ddot{c}_{imu} \quad] \\
\bar{g}_1 &= {}^1A_0 \bar{g}_0 \\
\bar{g}_1 &= [0 \quad -gc_{imu} \quad -gs_{imu} \quad] \\
\bar{g}_1 &= [0 \quad -gc_{imu} \quad -gs_{imu} \quad] \\
m_1 \bar{s}_1^\times \bar{g}_1 &= \mathbf{MS}_1 \times \bar{g}_1 \\
m_1 \bar{s}_1^\times \bar{g}_1 &= [\mathbf{MZ}_1 gc_{imu} - \mathbf{MY}_1 gs_{imu} \quad \mathbf{MX}_1 gs_{imu} \quad -\mathbf{MX}_1 gc_{imu} \quad] \\
D_1 &= \mathbf{MZ}_1 c_{imu} - \mathbf{MY}_1 s_{imu} \\
D_2 &= \mathbf{MX}_1 s_{imu} \\
D_3 &= -\mathbf{MX}_1 c_{imu} \\
m_1 \bar{s}_1^\times \bar{g}_1 &= [D_1 g \quad D_2 g \quad D_3 g \quad] \\
m_1 \bar{a}_{G(1)} &= m_1 \bar{a}_1 + \bar{\alpha}_1 \times \mathbf{MS}_1 + \bar{\omega}_1 \times (\bar{\omega}_1 \times \mathbf{MS}_1) \\
m_1 \bar{a}_{G(1)} &= [\mathbf{MZ}_1 (K_5 + \ddot{\psi}c_{imu}) - K_2 (\mathbf{MZ}_1 \dot{q}_{imu} + K_2 \mathbf{MX}_1) - \dot{\psi} m_1 - K_1 (\mathbf{MY}_1 \dot{q}_{imu} + K_1 \mathbf{MX}_1) - \mathbf{MY}_1 (K_6 + \ddot{\psi}s_{imu}) \quad \mathbf{MZ}_1 \dot{q}_{imu} - \dot{q}_{imu} (\mathbf{MZ}_1 \\
D_4 &= \mathbf{MZ}_1 c_{imu} - \mathbf{MY}_1 s_{imu} \\
D_5 &= K_5 \mathbf{MZ}_1 - K_1^2 \mathbf{MX}_1 - K_2^2 \mathbf{MX}_1 \\
&\quad - K_6 \mathbf{MY}_1 - \dot{\psi} m_1 - K_1 \mathbf{MY}_1 \dot{q}_{imu} \\
&\quad - K_2 \mathbf{MZ}_1 \dot{q}_{imu} \\
D_6 &= m_1 s_{imu} \\
D_7 &= \mathbf{MX}_1 s_{imu} \\
D_8 &= K_6 \mathbf{MX}_1 - \mathbf{MY}_1 \dot{q}_{imu}^2 - K_2^2 \mathbf{MY}_1 \\
&\quad + K_1 K_2 \mathbf{MZ}_1 - K_1 \mathbf{MX}_1 \dot{q}_{imu} \\
D_9 &= -m_1 c_{imu} \\
D_{10} &= -\mathbf{MX}_1 c_{imu} \\
D_{11} &= K_1 K_2 \mathbf{MY}_1 - \mathbf{MZ}_1 \dot{q}_{imu}^2 - K_5 \mathbf{MX}_1 \\
&\quad - K_1^2 \mathbf{MZ}_1 - K_2 \mathbf{MX}_1 \dot{q}_{imu} \\
m_1 \bar{a}_{G(1)} &= [D_5 + D_4 \ddot{\psi} \quad D_8 + D_7 \ddot{\psi} + D_6 \ddot{x} + \mathbf{MZ}_1 \dot{q}_{imu} \quad D_{11} + D_{10} \ddot{\psi} + D_9 \ddot{x} - \mathbf{MY}_1 \dot{q}_{imu} \quad] \\
\hat{H}_1 &= \mathbf{MS}_1 \times \bar{a}_1 + J_1 \bar{\alpha}_1 + \bar{\omega}_1 \times J_1 \bar{\omega}_1 \\
\hat{H}_1 &= [\mathbf{XZ}_1 (K_6 + \ddot{\psi}s_{imu}) - \mathbf{XX}_1 \dot{q}_{imu} - K_2 (K_1 \mathbf{YY}_1 + K_2 \mathbf{YZ}_1 - \mathbf{XY}_1 \dot{q}_{imu}) + K_1 (K_1 \mathbf{YZ}_1 + K_2 \mathbf{ZZ}_1 - \mathbf{XZ}_1 \dot{q}_{imu}) + \mathbf{XY}_1 (K_5 + \ddot{\psi}c_{imu}) - \\
D_{12} &= -\mathbf{MY}_1 c_{imu} - \mathbf{MZ}_1 s_{imu} \\
D_{13} &= \mathbf{XY}_1 c_{imu} + \mathbf{XZ}_1 s_{imu} \\
D_{14} &= K_5 \mathbf{XY}_1 + K_6 \mathbf{XZ}_1 + K_1^2 \mathbf{YZ}_1 \\
&\quad - K_2^2 \mathbf{YZ}_1 - K_1 K_2 \mathbf{YY}_1 + K_1 K_2 \mathbf{ZZ}_1 \\
&\quad + K_2 \mathbf{XY}_1 \dot{q}_{imu} - K_1 \mathbf{XZ}_1 \dot{q}_{imu} \\
D_{15} &= \mathbf{MX}_1 c_{imu} \\
D_{16} &= \mathbf{YY}_1 c_{imu} + \mathbf{YZ}_1 s_{imu} \\
D_{17} &= K_5 \mathbf{YY}_1 + K_6 \mathbf{YZ}_1 - \mathbf{MZ}_1 \dot{\psi} \\
&\quad + K_2^2 \mathbf{XZ}_1 - \mathbf{XZ}_1 \dot{q}_{imu}^2 + K_1 K_2 \mathbf{XY}_1 \\
&\quad - K_2 \mathbf{XX}_1 \dot{q}_{imu} + K_1 \mathbf{YZ}_1 \dot{q}_{imu} \\
&\quad + K_2 \mathbf{ZZ}_1 \dot{q}_{imu} \\
D_{18} &= \mathbf{MX}_1 s_{imu} \\
D_{19} &= \mathbf{YZ}_1 c_{imu} + \mathbf{ZZ}_1 s_{imu} \\
D_{20} &= K_5 \mathbf{YZ}_1 + K_6 \mathbf{ZZ}_1 + \mathbf{MY}_1 \dot{\psi} \\
&\quad - K_1^2 \mathbf{XY}_1 + \mathbf{XY}_1 \dot{q}_{imu}^2 - K_1 K_2 \mathbf{XZ}_1 \\
&\quad + K_1 \mathbf{XX}_1 \dot{q}_{imu} - K_1 \mathbf{YY}_1 \dot{q}_{imu} \\
&\quad - K_2 \mathbf{YZ}_1 \dot{q}_{imu} \\
\hat{H}_1 &= [D_5 + D_4 \ddot{\psi} \quad D_8 + D_7 \ddot{\psi} + D_6 \ddot{x} + \mathbf{MZ}_1 \dot{q}_{imu} \quad D_{11} + D_{10} \ddot{\psi} + D_9 \ddot{x} - \mathbf{MY}_1 \dot{q}_{imu} \quad] \\
\bar{\omega}_2 &= {}^2A_1 \bar{\omega}_1 + \dot{q}_2 \bar{e}_2 \\
\bar{\omega}_2 &= [-\dot{q}_w - \dot{q}_{imu} \quad K_1 c_w - K_2 s_w \quad K_2 c_w + K_1 s_w \quad] \\
K_7 &= -\dot{q}_w - \dot{q}_{imu} \\
K_8 &= K_1 c_w - K_2 s_w \\
K_9 &= K_2 c_w + K_1 s_w \\
\bar{\omega}_2 &= [K_7 \quad K_8 \quad K_9 \quad] \\
\bar{\omega}_2 &= [-\dot{q}_w - \dot{q}_{imu} \quad \dot{\psi}c_{imu}c_w - \dot{\psi}s_{imu}s_w \quad \dot{\psi}c_{imu}s_w + \dot{\psi}c_ws_{imu} \quad] \\
K_{10} &= c_{imu}c_w - s_{imu}s_w \\
K_{11} &= c_{imu}s_w + c_ws_{imu}
\end{aligned}$$

$$\begin{aligned}
\bar{\omega}_2 &= [-\dot{q}_w - \dot{q}_{imu} \quad K_{10}\dot{\psi} \quad K_{11}\dot{\psi} \quad] \\
\bar{v}_2 &= {}^2A_1(\bar{v}_1 + \bar{\omega}_1 \times \bar{P}_2) \\
\bar{v}_2 &= [-K_1 L_2 - K_2 L_1 \quad c_w(K_3 - L_2 \dot{q}_{imu}) - s_w(K_4 - L_1 \dot{q}_{imu}) \quad c_w(K_4 - L_1 \dot{q}_{imu}) + s_w(K_3 - L_2 \dot{q}_{imu}) \quad] \\
K_{12} &= -K_1 L_2 - K_2 L_1 \\
K_{13} &= c_w(K_3 - L_2 \dot{q}_{imu}) - s_w(K_4 \\
&\quad - L_1 \dot{q}_{imu}) \\
K_{14} &= c_w(K_4 - L_1 \dot{q}_{imu}) + s_w(K_3 \\
&\quad - L_2 \dot{q}_{imu}) \\
\bar{v}_2 &= [K_{12} \quad K_{13} \quad K_{14} \quad] \\
\bar{v}_2 &= [-L_2 \dot{\psi} c_{imu} - L_1 \dot{\psi} s_{imu} \quad s_w(L_1 \dot{q}_{imu} + \dot{x} c_{imu}) - c_w(L_2 \dot{q}_{imu} - \dot{x} s_{imu}) \quad -c_w(L_1 \dot{q}_{imu} + \dot{x} c_{imu}) - s_w(L_2 \dot{q}_{imu} - \dot{x} s_{imu}) \quad] \\
K_{15} &= -L_2 c_{imu} - L_1 s_{imu} \\
K_{16} &= L_1 s_w - L_2 c_w \\
K_{17} &= s_{imu} s_w - c_{imu} c_w \\
K_{18} &= -L_1 c_w - L_2 s_w \\
\bar{v}_2 &= [K_{15} \dot{\psi} \quad K_{16} \dot{q}_{imu} + K_{11} \ddot{x} \quad K_{18} \dot{q}_{imu} + K_{17} \ddot{x} \quad] \\
\bar{\alpha}_2 &= {}^2A_1 \bar{\alpha}_1 + \bar{q}_2 \bar{e}_2 + \bar{q}_2 (\bar{\omega}_2 \times \bar{e}_2) \\
\bar{\alpha}_2 &= [-\dot{q}_w - \dot{q}_{imu} \quad c_w(K_5 + \ddot{\psi} c_{imu}) - K_9 \dot{q}_w - s_w(K_6 + \ddot{\psi} s_{imu}) \quad K_8 \dot{q}_w + s_w(K_5 + \ddot{\psi} c_{imu}) + c_w(K_6 + \ddot{\psi} s_{imu}) \quad] \\
K_{19} &= K_5 c_w - K_9 \dot{q}_w - K_6 s_w \\
K_{20} &= K_8 \dot{q}_w + K_6 c_w + K_5 s_w \\
\bar{\alpha}_2 &= [-\dot{q}_w - \dot{q}_{imu} \quad K_{19} + K_{10} \ddot{\psi} \quad K_{20} + K_{11} \ddot{\psi} \quad] \\
\bar{a}_2 &= {}^2A_1(\bar{a}_1 + \bar{\alpha}_1 \times \bar{P}_2 + \bar{\omega}_1 \times (\bar{\omega}_1 \times \bar{P}_2)) \\
\bar{\alpha}_2 &= [K_2 L_2 \dot{q}_{imu} - L_2(K_5 + \ddot{\psi} c_{imu}) - L_1(K_6 + \ddot{\psi} s_{imu}) - K_1 L_1 \dot{q}_{imu} - \dot{\psi} \quad s_w(L_1 \dot{q}_{imu} - L_2 \dot{q}_{imu}^2 + \dot{x} c_{imu} - K_1(K_1 L_2 + K_2 L_1)) - c_w \\
K_{21} &= K_2 L_2 \dot{q}_{imu} - K_5 L_2 - K_6 L_1 \\
&\quad - K_1 L_1 \dot{q}_{imu} - \dot{\psi} \\
K_{22} &= -K_2^2 L_1 c_w - K_1^2 L_2 s_w \\
&\quad - L_1 \dot{q}_{imu}^2 c_w - L_2 \dot{q}_{imu}^2 s_w \\
&\quad - K_1 K_2 L_2 c_w - K_1 K_2 L_1 s_w \\
K_{23} &= K_1^2 L_2 c_w - K_2^2 L_1 s_w \\
&\quad + L_2 \dot{q}_{imu}^2 c_w - L_1 \dot{q}_{imu}^2 s_w \\
&\quad + K_1 K_2 L_1 c_w - K_1 K_2 L_2 s_w \\
\bar{a}_2 &= [K_{21} + K_{15} \dot{\psi} \quad K_{22} + K_{16} \dot{q}_{imu} + K_{11} \ddot{x} \quad K_{23} + K_{18} \dot{q}_{imu} + K_{17} \ddot{x} \quad] \\
\bar{g}_2 &= {}^2A_1 \bar{g}_1 \\
\bar{g}_2 &= [0 \quad g s_{imu} s_w - g c_{imu} c_w \quad -g c_{imu} s_w - g c_w s_{imu} \quad] \\
K_{24} &= -c_{imu} s_w - c_w s_{imu} \\
\bar{g}_2 &= [0 \quad K_{17} g \quad K_{24} g \quad] \\
m_2 \bar{S}_2^\times \bar{g}_2 &= \mathbf{MS}_2 \times \bar{g}_2 \\
m_2 \bar{S}_2^\times \bar{g}_2 &= [K_{24} \mathbf{MY}_{2g} - K_{17} \mathbf{MZ}_{2g} \quad -K_{24} \mathbf{MX}_{2g} \quad K_{17} \mathbf{MX}_{2g} \quad] \\
D_{21} &= K_{24} \mathbf{MY}_2 - K_{17} \mathbf{MZ}_2 \\
D_{22} &= -K_{24} \mathbf{MX}_2 \\
D_{23} &= K_{17} \mathbf{MX}_2 \\
m_2 \bar{S}_2^\times \bar{g}_2 &= [D_{21} g \quad D_{22} g \quad D_{23} g \quad] \\
m_2 \bar{a}_{G(2)} &= m_2 \bar{a}_2 + \bar{a}_2 \times \mathbf{MS}_2 + \bar{\omega}_2 \times (\bar{\omega}_2 \times \mathbf{MS}_2) \\
m_2 \bar{a}_{G(2)} &= [\mathbf{MZ}_2(K_{19} + K_{10} \ddot{\psi}) - \mathbf{MY}_2(K_{20} + K_{11} \ddot{\psi}) + m_2(K_{21} + K_{15} \ddot{\psi}) - K_8(K_8 \mathbf{MX}_2 - K_7 \mathbf{MY}_2) - K_9(K_9 \mathbf{MX}_2 - K_7 \mathbf{MZ}_2) \quad \mathbf{MX}_2(K_{20} + K_{11} \ddot{\psi}) \\
D_{24} &= K_{15} m_2 - K_{11} \mathbf{MY}_2 + K_{10} \mathbf{MZ}_2 \\
D_{25} &= K_{21} m_2 - K_8^2 \mathbf{MX}_2 - K_9^2 \mathbf{MX}_2 \\
&\quad - K_{20} \mathbf{MY}_2 + K_{19} \mathbf{MZ}_2 + K_7 K_8 \mathbf{MY}_2 \\
&\quad + K_7 K_9 \mathbf{MZ}_2 \\
D_{26} &= K_{11} m_2 \\
D_{27} &= K_{11} \mathbf{MX}_2 \\
D_{28} &= \mathbf{MZ}_2 + K_{16} m_2 \\
D_{29} &= K_{22} m_2 - K_7^2 \mathbf{MY}_2 - K_9^2 \mathbf{MY}_2 \\
&\quad + K_{20} \mathbf{MX}_2 + K_7 K_8 \mathbf{MX}_2 + K_8 K_9 \mathbf{MZ}_2 \\
D_{30} &= K_{17} m_2 \\
D_{31} &= -K_{10} \mathbf{MX}_2 \\
D_{32} &= K_{18} m_2 - \mathbf{MY}_2 \\
D_{33} &= K_{23} m_2 - K_7^2 \mathbf{MZ}_2 - K_8^2 \mathbf{MZ}_2 \\
&\quad - K_{19} \mathbf{MX}_2 + K_7 K_9 \mathbf{MX}_2 + K_8 K_9 \mathbf{MY}_2 \\
m_2 \bar{a}_{G(2)} &= [D_{25} + D_{24} \dot{\psi} \quad D_{29} + D_{27} \dot{\psi} + D_{28} \dot{q}_{imu} + D_{26} \ddot{x} + \mathbf{MZ}_2 \dot{q}_w \quad D_{33} + D_{31} \ddot{\psi} + D_{32} \dot{q}_{imu} + D_{30} \ddot{x} - \mathbf{MY}_2 \dot{q}_w \quad]
\end{aligned}$$

$$\begin{aligned}
\dot{\hat{H}}_2 &= \mathbf{M}\mathbf{S}_2 \times \bar{a}_2 + J_2 \bar{\alpha}_2 + \bar{\omega}_2 \times J_2 \bar{\omega}_2 \\
\dot{\hat{H}}_2 &= [K_8(K_7\mathbf{XZ}_2 + K_8\mathbf{YZ}_2 + K_9\mathbf{ZZ}_2) - K_9(K_7\mathbf{XY}_2 + K_8\mathbf{YY}_2 + K_9\mathbf{YZ}_2) + \mathbf{XY}_2(K_{19} + K_{10}\ddot{\psi}) + \mathbf{XZ}_2(K_{20} + K_{11}\ddot{\psi}) + \mathbf{MY}_2(K_{23} + K_{18}\ddot{\psi}) \\
D_{34} &= K_{17}\mathbf{MY}_2 - K_{11}\mathbf{MZ}_2 \\
D_{35} &= K_{10}\mathbf{XY}_2 + K_{11}\mathbf{XZ}_2 \\
D_{36} &= K_{18}\mathbf{MY}_2 - \mathbf{XX}_2 - K_{16}\mathbf{MZ}_2 \\
D_{37} &= K_{19}\mathbf{XY}_2 + K_{20}\mathbf{XZ}_2 + K_8^2\mathbf{YZ}_2 \\
&\quad - K_9^2\mathbf{YZ}_2 + K_{23}\mathbf{MY}_2 - K_{22}\mathbf{MZ}_2 \\
&\quad - K_7K_9\mathbf{XY}_2 + K_7K_8\mathbf{XZ}_2 \\
&\quad - K_8K_9\mathbf{YY}_2 + K_8K_9\mathbf{ZZ}_2 \\
D_{38} &= -K_{17}\mathbf{MX}_2 \\
D_{39} &= K_{10}\mathbf{YY}_2 + K_{11}\mathbf{YZ}_2 + K_{15}\mathbf{MZ}_2 \\
D_{40} &= -\mathbf{XY}_2 - K_{18}\mathbf{MX}_2 \\
D_{41} &= K_{19}\mathbf{YY}_2 + K_{20}\mathbf{YZ}_2 - K_7^2\mathbf{XZ}_2 \\
&\quad + K_9^2\mathbf{XZ}_2 - K_{23}\mathbf{MX}_2 + K_{21}\mathbf{MZ}_2 \\
&\quad + K_7K_9\mathbf{XX}_2 + K_8K_9\mathbf{XY}_2 \\
&\quad - K_7K_8\mathbf{YZ}_2 - K_7K_9\mathbf{ZZ}_2 \\
D_{42} &= K_{11}\mathbf{MX}_2 \\
D_{43} &= K_{10}\mathbf{YZ}_2 + K_{11}\mathbf{ZZ}_2 - K_{15}\mathbf{MY}_2 \\
D_{44} &= K_{16}\mathbf{MX}_2 - \mathbf{XZ}_2 \\
D_{45} &= K_{19}\mathbf{YZ}_2 + K_{20}\mathbf{ZZ}_2 + K_7^2\mathbf{XY}_2 \\
&\quad - K_8^2\mathbf{XY}_2 + K_{22}\mathbf{MX}_2 - K_{21}\mathbf{MY}_2 \\
&\quad - K_7K_8\mathbf{XX}_2 - K_8K_9\mathbf{XZ}_2 \\
&\quad + K_7K_8\mathbf{YY}_2 + K_7K_9\mathbf{YZ}_2 \\
\dot{\hat{H}}_2 &= [D_{25} + D_{24}\ddot{\psi} \quad D_{29} + D_{27}\ddot{\psi} + D_{28}\ddot{q}_{imu} + D_{26}\ddot{x} + \mathbf{MZ}_2\ddot{q}_w \quad D_{33} + D_{31}\ddot{\psi} + D_{32}\ddot{q}_{imu} + D_{30}\ddot{x} - \mathbf{MY}_2\ddot{q}_w \quad] \\
\bar{\omega}_3 &= {}^3A_2\bar{\omega}_2 + \dot{q}_3\bar{e}_3 \\
\bar{\omega}_3 &= [-K_7c_{torso} - K_9s_{torso} \quad K_8 - \dot{q}_{torso} \quad K_7s_{torso} - K_9c_{torso} \quad] \\
K_{25} &= -K_7c_{torso} - K_9s_{torso} \\
K_{26} &= K_8 - \dot{q}_{torso} \\
K_{27} &= K_7s_{torso} - K_9c_{torso} \\
\bar{\omega}_3 &= [K_{25} \quad K_{26} \quad K_{27} \quad] \\
\bar{\omega}_3 &= [c_{torso}(\dot{q}_w + \dot{q}_{imu}) - K_{11}\dot{\psi}s_{torso} \quad K_{10}\dot{\psi} - \dot{q}_{torso} \quad -s_{torso}(\dot{q}_w + \dot{q}_{imu}) - K_{11}\dot{\psi}c_{torso} \quad] \\
K_{28} &= -K_{11}s_{torso} \\
K_{29} &= -K_{11}c_{torso} \\
\bar{\omega}_3 &= [K_{28}\dot{\psi} + \dot{q}_wc_{torso} + \dot{q}_{imu}c_{torso} \quad K_{10}\dot{\psi} - \dot{q}_{torso} \quad K_{29}\dot{\psi} - \dot{q}_ws_{torso} - \dot{q}_{imu}s_{torso} \quad] \\
\bar{v}_3 &= {}^3A_2(\bar{v}_2 + \bar{\omega}_2 \times \bar{P}_3) \\
\bar{v}_3 &= [-c_{torso}(K_{12} + K_8L_4 - K_9L_3) - s_{torso}(K_{14} + K_7L_3) \quad K_{13} - K_7L_4 \quad s_{torso}(K_{12} + K_8L_4 - K_9L_3) - c_{torso}(K_{14} + K_7L_3) \quad] \\
K_{30} &= -c_{torso}(K_{12} + K_8L_4 - K_9L_3) \\
&\quad - s_{torso}(K_{14} + K_7L_3) \\
K_{31} &= K_{13} - K_7L_4 \\
K_{32} &= s_{torso}(K_{12} + K_8L_4 - K_9L_3) \\
&\quad - c_{torso}(K_{14} + K_7L_3) \\
\bar{v}_3 &= [K_{30} \quad K_{31} \quad K_{32} \quad] \\
\bar{v}_3 &= [-c_{torso}(K_{15}\dot{\psi} + K_{10}L_4\dot{\psi} - K_{11}L_3\dot{\psi}) - s_{torso}(K_{18}\dot{q}_{imu} + K_{17}\dot{x} - L_3(\dot{q}_w + \dot{q}_{imu})) \quad K_{16}\dot{q}_{imu} + K_{11}\dot{x} + L_4(\dot{q}_w + \dot{q}_{imu}) \quad s_{tors} \\
K_{33} &= -K_{17}s_{torso} \\
K_{34} &= -c_{torso}(K_{15} + K_{10}L_4 - K_{11}L_3) \\
K_{35} &= -s_{torso}(K_{18} - L_3) \\
K_{36} &= L_3s_{torso} \\
K_{37} &= K_{16} + L_4 \\
K_{38} &= -K_{17}c_{torso} \\
K_{39} &= s_{torso}(K_{15} + K_{10}L_4 - K_{11}L_3) \\
K_{40} &= -c_{torso}(K_{18} - L_3) \\
K_{41} &= L_3c_{torso} \\
\bar{v}_3 &= [K_{34}\dot{\psi} + K_{36}\dot{q}_w + K_{35}\dot{q}_{imu} + K_{33}\dot{x} \quad K_{37}\dot{q}_{imu} + K_{11}\dot{x} + L_4\dot{q}_w \quad K_{39}\dot{\psi} + K_{41}\dot{q}_w + K_{40}\dot{q}_{imu} + K_{38}\dot{x} \quad] \\
\bar{\alpha}_3 &= {}^3A_2\bar{\alpha}_2 + \dot{q}_3\bar{e}_3 + \dot{q}_3(\bar{\omega}_3 \times \bar{e}_3) \\
\bar{\alpha}_3 &= [K_{27}\dot{q}_{torso} + c_{torso}(\dot{q}_w + \dot{q}_{imu}) - s_{torso}(K_{20} + K_{11}\ddot{\psi}) \quad K_{19} - \dot{q}_{torso} + K_{10}\ddot{\psi} \quad -K_{25}\dot{q}_{torso} - s_{torso}(\dot{q}_w + \dot{q}_{imu}) - c_{torso}(K_{2} \\
K_{42} &= K_{27}\dot{q}_{torso} - K_{20}s_{torso} \\
K_{43} &= -K_{25}\dot{q}_{torso} - K_{20}c_{torso} \\
\bar{\alpha}_3 &= [K_{42} + K_{28}\ddot{\psi} + \dot{q}_wc_{torso} + \dot{q}_{imu}c_{torso} \quad K_{19} - \dot{q}_{torso} + K_{10}\ddot{\psi} \quad K_{43} + K_{29}\ddot{\psi} - \dot{q}_ws_{torso} - \dot{q}_{imu}s_{torso} \quad] \\
\bar{a}_3 &= {}^3A_2(\bar{a}_2 + \bar{\alpha}_2 \times \bar{P}_3 + \bar{\omega}_2 \times (\bar{\omega}_2 \times \bar{P}_3)) \\
\bar{\alpha}_3 &= [-s_{torso}(K_{23} + K_{18}\dot{q}_{imu} + K_{17}\dot{x} - K_7^2L_4 - L_3(\dot{q}_w + \dot{q}_{imu}) - K_8(K_8L_4 - K_9L_3)) - c_{torso}(K_{21} + K_{15}\ddot{\psi} + L_4(K_{19} + K_{10}\ddot{\psi}) - L_3
\end{aligned}$$

$$\begin{aligned}
K_{44} &= K_7^2 L_4^{storsso} - K_{23}^{storsso} - K_{21}^{ctorsso} \\
&\quad + K_8^2 L_4^{storsso} - K_{19} L_4^{ctorsso} \\
&\quad + K_{20} L_3^{ctorsso} - K_7 K_8 L_3^{ctorsso} \\
&\quad - K_7 K_9 L_4^{ctorsso} - K_8 K_9 L_3^{storsso} \\
K_{45} &= K_{22} - K_7^2 L_3 - K_9^2 L_3 + K_8 K_9 L_4 \\
K_{46} &= K_{21}^{storsso} - K_{23}^{ctorsso} + K_7^2 L_4^{ctorsso} \\
&\quad + K_8^2 L_4^{ctorsso} + K_{19} L_4^{storsso} \\
&\quad - K_{20} L_3^{storsso} - K_8 K_9 L_3^{ctorsso} \\
&\quad + K_7 K_8 L_3^{storsso} + K_7 K_9 L_4^{storsso} \\
\bar{a}_3 &= [K_{44} + K_{34}\ddot{\psi} + K_{36}\ddot{q}_w + K_{35}\ddot{q}_{imu} + K_{33}\ddot{x} \quad K_{45} + K_{37}\ddot{q}_{imu} + K_{11}\ddot{x} + L_4\ddot{q}_w \quad K_{46} + K_{39}\ddot{\psi} + K_{41}\ddot{q}_w + K_{40}\ddot{q}_{imu} + K_{38}\ddot{x} \quad] \\
\bar{g}_3 &= {}^3A_2\bar{g}_2 \\
\bar{g}_3 &= [-K_{24}g^{storsso} \quad K_{17}g \quad -K_{24}g^{ctorsso} \quad] \\
K_{47} &= -K_{24}^{storsso} \\
K_{48} &= -K_{24}^{ctorsso} \\
\bar{g}_3 &= [K_{47}g \quad K_{17}g \quad K_{48}g \quad] \\
m_3 \bar{S}_3^\times \bar{g}_3 &= \mathbf{MS}_3 \times \bar{g}_3 \\
m_3 \bar{S}_3^\times \bar{g}_3 &= [K_{48}\mathbf{MY}_{3g} - K_{17}\mathbf{MZ}_{3g} \quad K_{47}\mathbf{MZ}_{3g} - K_{48}\mathbf{MX}_{3g} \quad K_{17}\mathbf{MX}_{3g} - K_{47}\mathbf{MY}_{3g} \quad] \\
D_{46} &= K_{48}\mathbf{MY}_3 - K_{17}\mathbf{MZ}_3 \\
D_{47} &= K_{47}\mathbf{MZ}_3 - K_{48}\mathbf{MX}_3 \\
D_{48} &= K_{17}\mathbf{MX}_3 - K_{47}\mathbf{MY}_3 \\
m_3 \bar{S}_3^\times \bar{g}_3 &= [D_{46}g \quad D_{47}g \quad D_{48}g \quad] \\
m_3 \bar{a}_{G(3)} &= m_3 \bar{a}_3 + \bar{a}_3 \times \mathbf{MS}_3 + \bar{\omega}_3 \times (\bar{\omega}_3 \times \mathbf{MS}_3) \\
m_3 \bar{a}_{G(3)} &= [\mathbf{MZ}_3(K_{19} - \ddot{q}_{torsso} + K_{10}\ddot{\psi}) + m_3(K_{44} + K_{34}\ddot{\psi} + K_{36}\ddot{q}_w + K_{35}\ddot{q}_{imu} + K_{33}\ddot{x}) - \mathbf{MY}_3(K_{43} + K_{29}\ddot{\psi} - \ddot{q}_w^{storsso} - \ddot{q}_{imu}^{storsso}) - K_{20}\ddot{\psi} \\
D_{49} &= K_{33}m_3 \\
D_{50} &= K_{34}m_3 - K_{29}\mathbf{MY}_3 + K_{10}\mathbf{MZ}_3 \\
D_{51} &= K_{35}m_3 + \mathbf{MY}_3^{storsso} \\
D_{52} &= K_{36}m_3 + \mathbf{MY}_3^{storsso} \\
D_{53} &= K_{44}m_3 - K_{26}^2\mathbf{MX}_3 - K_{27}^2\mathbf{MX}_3 \\
&\quad - K_{43}\mathbf{MY}_3 + K_{19}\mathbf{MZ}_3 + K_{25}K_{26}\mathbf{MY}_3 \\
&\quad + K_{25}K_{27}\mathbf{MZ}_3 \\
D_{54} &= K_{11}m_3 \\
D_{55} &= K_{29}\mathbf{MX}_3 - K_{28}\mathbf{MZ}_3 \\
D_{56} &= K_{37}m_3 - \mathbf{MZ}_3^{ctorsso} - \mathbf{MX}_3^{storsso} \\
D_{57} &= L_4m_3 - \mathbf{MZ}_3^{ctorsso} - \mathbf{MX}_3^{storsso} \\
D_{58} &= K_{45}m_3 - K_{25}^2\mathbf{MY}_3 - K_{27}^2\mathbf{MY}_3 \\
&\quad + K_{43}\mathbf{MX}_3 - K_{42}\mathbf{MZ}_3 + K_{25}K_{26}\mathbf{MX}_3 \\
&\quad + K_{26}K_{27}\mathbf{MZ}_3 \\
D_{59} &= K_{38}m_3 \\
D_{60} &= K_{39}m_3 - K_{10}\mathbf{MX}_3 + K_{28}\mathbf{MY}_3 \\
D_{61} &= K_{40}m_3 + \mathbf{MY}_3^{ctorsso} \\
D_{62} &= K_{41}m_3 + \mathbf{MY}_3^{ctorsso} \\
D_{63} &= K_{46}m_3 - K_{25}^2\mathbf{MZ}_3 - K_{26}^2\mathbf{MZ}_3 \\
&\quad - K_{19}\mathbf{MX}_3 + K_{42}\mathbf{MY}_3 + K_{25}K_{27}\mathbf{MX}_3 \\
&\quad + K_{26}K_{27}\mathbf{MY}_3 \\
m_3 \bar{a}_{G(3)} &= [D_{53} + D_{50}\ddot{\psi} + D_{52}\ddot{q}_w + D_{51}\ddot{q}_{imu} + D_{49}\ddot{x} - \mathbf{MZ}_3\ddot{q}_{torsso} \quad D_{58} + D_{55}\ddot{\psi} + D_{57}\ddot{q}_w + D_{56}\ddot{q}_{imu} + D_{54}\ddot{x} \quad D_{63} + D_{60}\ddot{\psi} + D_{62}\ddot{q}_w + D_{61}\ddot{q}_{imu} + D_{59}\ddot{x} \quad] \\
\dot{H}_3 &= \mathbf{MS}_3 \times \bar{a}_3 + J_3\bar{a}_3 + \bar{\omega}_3 \times J_3\bar{\omega}_3 \\
\dot{H}_3 &= [K_{26}(K_{25}\mathbf{XZ}_3 + K_{26}\mathbf{YZ}_3 + K_{27}\mathbf{ZZ}_3) - K_{27}(K_{25}\mathbf{XY}_3 + K_{26}\mathbf{YY}_3 + K_{27}\mathbf{YZ}_3) + \mathbf{XY}_3(K_{19} - \ddot{q}_{torsso} + K_{10}\ddot{\psi}) - \mathbf{MZ}_3(K_{45} + K_{37}\ddot{q}_{imu} \\
D_{64} &= K_{38}\mathbf{MY}_3 - K_{11}\mathbf{MZ}_3 \\
D_{65} &= K_{28}\mathbf{XX}_3 + K_{10}\mathbf{XY}_3 + K_{29}\mathbf{XZ}_3 \\
&\quad + K_{39}\mathbf{MY}_3 \\
D_{66} &= \mathbf{XX}_3^{ctorsso} - \mathbf{XZ}_3^{storsso} + K_{40}\mathbf{MY}_3 \\
&\quad - K_{37}\mathbf{MZ}_3 \\
D_{67} &= \mathbf{XX}_3^{ctorsso} - \mathbf{XZ}_3^{storsso} + K_{41}\mathbf{MY}_3 \\
&\quad - L_4\mathbf{MZ}_3 \\
D_{68} &= K_{42}\mathbf{XX}_3 + K_{19}\mathbf{XY}_3 + K_{43}\mathbf{XZ}_3 \\
&\quad + K_{26}^2\mathbf{YZ}_3 - K_{27}^2\mathbf{YZ}_3 + K_{46}\mathbf{MY}_3 \\
&\quad - K_{45}\mathbf{MZ}_3 - K_{25}K_{27}\mathbf{XY}_3 + K_{25}K_{26}\mathbf{XZ}_3 \\
&\quad - K_{26}K_{27}\mathbf{YY}_3 + K_{26}K_{27}\mathbf{ZZ}_3 \\
D_{69} &= K_{33}\mathbf{MZ}_3 - K_{38}\mathbf{MX}_3
\end{aligned}$$

$$\begin{aligned}
D_{70} &= K_{28}\mathbf{XY}_3 + K_{10}\mathbf{YY}_3 + K_{29}\mathbf{YZ}_3 \\
&\quad - K_{39}\mathbf{MX}_3 + K_{34}\mathbf{MZ}_3 \\
D_{71} &= \mathbf{XY}_3^{c_{torso}} - \mathbf{YZ}_3^{s_{torso}} - K_{40}\mathbf{MX}_3 \\
&\quad + K_{35}\mathbf{MZ}_3 \\
D_{72} &= \mathbf{XY}_3^{c_{torso}} - \mathbf{YZ}_3^{s_{torso}} - K_{41}\mathbf{MX}_3 \\
&\quad + K_{36}\mathbf{MZ}_3 \\
D_{73} &= K_{42}\mathbf{XY}_3 + K_{19}\mathbf{YY}_3 + K_{43}\mathbf{YZ}_3 \\
&\quad - K_{25}^2\mathbf{XZ}_3 + K_{27}^2\mathbf{XZ}_3 - K_{46}\mathbf{MX}_3 \\
&\quad + K_{44}\mathbf{MZ}_3 + K_{25}K_{27}\mathbf{XX}_3 + K_{26}K_{27}\mathbf{XY}_3 \\
&\quad - K_{25}K_{26}\mathbf{YZ}_3 - K_{25}K_{27}\mathbf{ZZ}_3 \\
D_{74} &= K_{11}\mathbf{MX}_3 - K_{33}\mathbf{MY}_3 \\
D_{75} &= K_{28}\mathbf{XZ}_3 + K_{10}\mathbf{YZ}_3 + K_{29}\mathbf{ZZ}_3 \\
&\quad - K_{34}\mathbf{MY}_3 \\
D_{76} &= \mathbf{XZ}_3^{c_{torso}} - \mathbf{ZZ}_3^{s_{torso}} + K_{37}\mathbf{MX}_3 \\
&\quad - K_{35}\mathbf{MY}_3 \\
D_{77} &= \mathbf{XZ}_3^{c_{torso}} - \mathbf{ZZ}_3^{s_{torso}} - K_{36}\mathbf{MY}_3 \\
&\quad + L_4\mathbf{MX}_3 \\
D_{78} &= K_{42}\mathbf{XZ}_3 + K_{19}\mathbf{YZ}_3 + K_{43}\mathbf{ZZ}_3 \\
&\quad + K_{25}^2\mathbf{XY}_3 - K_{26}^2\mathbf{XY}_3 + K_{45}\mathbf{MX}_3 \\
&\quad - K_{44}\mathbf{MY}_3 - K_{25}K_{26}\mathbf{XX}_3 - K_{26}K_{27}\mathbf{XZ}_3 \\
&\quad + K_{25}K_{26}\mathbf{YY}_3 + K_{25}K_{27}\mathbf{YZ}_3 \\
\dot{H}_3 &= [D_{53} + D_{50}\ddot{\psi} + D_{52}\ddot{q}w + D_{51}\ddot{q}_{imu} + D_{49}\ddot{x} - \mathbf{MZ}_3\ddot{q}_{torso} \quad D_{58} + D_{55}\ddot{\psi} + D_{57}\ddot{q}w + D_{56}\ddot{q}_{imu} + D_{54}\ddot{x} \quad D_{63} + D_{60}\ddot{\psi} + D_{62}\ddot{q}w + D_{61}\ddot{q}_{imu} + D_{59}\ddot{x} - \mathbf{XZ}_3\ddot{q}_{torso}] \\
\bar{\omega}_{4l} &= {}^{4l}A_3\bar{\omega}_3 + \dot{q}_{4l}\bar{e}_{4l} \\
\bar{\omega}_{4l} &= [K_{26}c_{1l} - K_{27}s_{1l} \quad K_{25} - \dot{q}_{1l} \quad -K_{27}c_{1l} - K_{26}s_{1l} \quad] \\
K_{1l} &= K_{26}c_{1l} - K_{27}s_{1l} \\
K_{2l} &= K_{25} - \dot{q}_{1l} \\
K_{3l} &= -K_{27}c_{1l} - K_{26}s_{1l} \\
\bar{\omega}_{4l} &= [K_{1l} \quad K_{2l} \quad K_{3l} \quad] \\
\bar{\omega}_{4l} &= [s_{1l}(\dot{q}w^{s_{torso}} - K_{29}\dot{\psi} + \dot{q}_{imu}^{s_{torso}}) - c_{1l}(\dot{q}_{torso} - K_{10}\dot{\psi}) \quad K_{28}\dot{\psi} - \dot{q}_{1l} + \dot{q}w^{c_{torso}} + \dot{q}_{imu}^{c_{torso}} \quad s_{1l}(\dot{q}_{torso} - K_{10}\dot{\psi}) + c_{1l}(\dot{q}_{torso} - K_{10}\dot{\psi})] \\
K_{4l} &= K_{10}c_{1l} - K_{29}s_{1l} \\
K_{5l} &= s_{1l}^{s_{torso}} \\
K_{6l} &= -K_{29}c_{1l} - K_{10}s_{1l} \\
K_{7l} &= c_{1l}^{s_{torso}} \\
\bar{\omega}_{4l} &= [K_{4l}\dot{\psi} + K_{5l}\dot{q}w + K_{5l}\dot{q}_{imu} - \dot{q}_{torso}c_{1l} \quad K_{28}\dot{\psi} - \dot{q}_{1l} + \dot{q}w^{c_{torso}} + \dot{q}_{imu}^{c_{torso}} \quad K_{6l}\dot{\psi} + K_{7l}\dot{q}w + K_{7l}\dot{q}_{imu} + \dot{q}_{torso}s_{1l} \quad] \\
\bar{v}_{4l} &= {}^{4l}A_3(\bar{v}_3 + \bar{\omega}_3 \times \bar{P}_{4l}) \\
\bar{v}_{4l} &= [c_{1l}(K_{31} + K_{27}L_6) - s_{1l}(K_{32} + K_{25}L_5 - K_{26}L_6) \quad K_{30} - K_{27}L_5 \quad -c_{1l}(K_{32} + K_{25}L_5 - K_{26}L_6) - s_{1l}(K_{31} + K_{27}L_6) \quad] \\
K_{8l} &= c_{1l}(K_{31} + K_{27}L_6) - s_{1l}(K_{32} \\
&\quad + K_{25}L_5 - K_{26}L_6) \\
K_{9l} &= K_{30} - K_{27}L_5 \\
K_{10l} &= -c_{1l}(K_{32} + K_{25}L_5 - K_{26}L_6) \\
&\quad - s_{1l}(K_{31} + K_{27}L_6) \\
\bar{v}_{4l} &= [K_{8l} \quad K_{9l} \quad K_{10l} \quad] \\
\bar{v}_{4l} &= [c_{1l}(K_{37}\dot{q}_{imu} + K_{11}\dot{x} + L_4\dot{q}w - L_6(\dot{q}w^{s_{torso}} - K_{29}\dot{\psi} + \dot{q}_{imu}^{s_{torso}})) - s_{1l}(K_{39}\dot{\psi} + K_{41}\dot{q}w + K_{40}\dot{q}_{imu} + K_{38}\dot{x} + L_5(K_{28}\dot{\psi} + \dot{q}w^{c_{torso}} + \dot{q}_{imu}^{c_{torso}})) \\
K_{11l} &= K_{11}c_{1l} - K_{38}s_{1l} \\
K_{12l} &= K_{29}L_6c_{1l} - s_{1l}(K_{39} - K_{10}L_6 \\
&\quad + K_{28}L_5) \\
K_{13l} &= c_{1l}(K_{37} - L_6^{s_{torso}}) - s_{1l}(K_{40} \\
&\quad + L_5^{c_{torso}}) \\
K_{14l} &= c_{1l}(L_4 - L_6^{s_{torso}}) - s_{1l}(K_{41} \\
&\quad + L_5^{c_{torso}}) \\
K_{15l} &= -L_6s_{1l} \\
K_{16l} &= K_{34} - K_{29}L_5 \\
K_{17l} &= K_{35} + L_5^{s_{torso}} \\
K_{18l} &= K_{36} + L_5^{s_{torso}} \\
K_{19l} &= -K_{38}c_{1l} - K_{11}s_{1l} \\
K_{20l} &= -c_{1l}(K_{39} - K_{10}L_6 + K_{28}L_5) \\
&\quad - K_{29}L_6s_{1l} \\
K_{21l} &= -c_{1l}(K_{40} + L_5^{c_{torso}}) - s_{1l}(K_{37} \\
&\quad - L_6^{s_{torso}}) \\
K_{22l} &= -c_{1l}(K_{41} + L_5^{c_{torso}}) - s_{1l}(L_4 \\
&\quad - L_6^{s_{torso}}) \\
K_{23l} &= -L_6c_{1l} \\
\bar{v}_{4l} &= [K_{12l}\dot{\psi} + K_{14l}\dot{q}w + K_{13l}\dot{q}_{imu} + K_{15l}\dot{q}_{torso} + K_{11l}\dot{x} \quad K_{16l}\dot{\psi} + K_{18l}\dot{q}w + K_{17l}\dot{q}_{imu} + K_{33}\dot{x} \quad K_{20l}\dot{\psi} + K_{22l}\dot{q}w + K_{21l}\dot{q}_{imu} + K_{23l}\dot{x}]
\end{aligned}$$

$$\begin{aligned}
\bar{\alpha}_{4l} &= {}^4l A_3 \bar{\alpha}_3 + \bar{q}_{4l} \bar{e}_{4l} + \bar{q}_{4l} (\bar{\omega}_{4l} \times \bar{e}_{4l}) \\
\bar{\alpha}_{4l} &= [K_{3l} \bar{q}_{1l} - s_{1l} (K_{43} + K_{29} \bar{\psi} - \bar{q}_w s_{torso} - \bar{q}_{imu} s_{torso}) + c_{1l} (K_{19} - \bar{q}_{torso} + K_{10} \bar{\psi}) \quad K_{42} - \bar{q}_{1l} + K_{28} \bar{\psi} + \bar{q}_w c_{torso} + \bar{q}_{imu} c_{torso} \\
K_{24l} &= K_{3l} \bar{q}_{1l} + K_{19} c_{1l} - K_{43} s_{1l} \\
K_{25l} &= -K_{1l} \bar{q}_{1l} - K_{43} c_{1l} - K_{19} s_{1l} \\
\bar{\alpha}_{4l} &= [K_{24l} + K_{4l} \bar{\psi} + K_{5l} \bar{q}_w + K_{5l} \bar{q}_{imu} - \bar{q}_{torso} c_{1l} \quad K_{42} - \bar{q}_{1l} + K_{28} \bar{\psi} + \bar{q}_w c_{torso} + \bar{q}_{imu} c_{torso} \quad K_{25l} + K_{6l} \bar{\psi} + K_{7l} \bar{q}_w + K_{7l} \bar{q}_{imu} \\
\bar{a}_{4l} &= {}^4l A_3 (\bar{a}_3 + \bar{\alpha}_3 \times \bar{P}_{4l} + \bar{\omega}_3 \times (\bar{\omega}_3 \times \bar{P}_{4l})) \\
\bar{\alpha}_{4l} &= [c_{1l} (K_{45} + K_{37} \bar{q}_{imu} + K_{11} \bar{x} + L_4 \bar{q}_w - K_{27}^2 L_5 + L_6 (K_{43} + K_{29} \bar{\psi} - \bar{q}_w s_{torso} - \bar{q}_{imu} s_{torso}) - K_{25} (K_{25} L_5 - K_{26} L_6)) - s_{1l} (K_{46} + \\
K_{26l} &= K_{45} c_{1l} - K_{46} s_{1l} - K_{25}^2 L_5 c_{1l} \\
&\quad - K_{27}^2 L_5 c_{1l} + K_{43} L_6 c_{1l} \\
&\quad + K_{19} L_6 s_{1l} - K_{42} L_5 s_{1l} \\
&\quad + K_{25} K_{26} L_6 c_{1l} - K_{25} K_{27} L_6 s_{1l} \\
&\quad - K_{26} K_{27} L_5 s_{1l} \\
K_{27l} &= K_{44} - K_{26}^2 L_6 - K_{27}^2 L_6 - K_{43} L_5 \\
&\quad + K_{25} K_{26} L_5 \\
K_{28l} &= K_{25}^2 L_5 s_{1l} - K_{45} s_{1l} - K_{46} c_{1l} \\
&\quad + K_{27}^2 L_5 s_{1l} + K_{19} L_6 c_{1l} \\
&\quad - K_{42} L_5 c_{1l} - K_{43} L_6 s_{1l} \\
&\quad - K_{25} K_{27} L_6 c_{1l} - K_{26} K_{27} L_5 c_{1l} \\
&\quad - K_{25} K_{26} L_6 s_{1l} \\
\bar{a}_{4l} &= [K_{26l} + K_{12l} \bar{\psi} + K_{14l} \bar{q}_w + K_{13l} \bar{q}_{imu} + K_{15l} \bar{q}_{torso} + K_{11l} \bar{x} \quad K_{27l} + K_{16l} \bar{\psi} + K_{18l} \bar{q}_w + K_{17l} \bar{q}_{imu} + K_{33} \bar{x} \quad K_{28l} + K_{20l} \bar{\psi} + K_{22l} \bar{q}_w \\
\bar{g}_{4l} &= {}^4l A_3 \bar{g}_3 \\
\bar{g}_{4l} &= [K_{17} g c_{1l} - K_{48} g s_{1l} \quad K_{47} g \quad -K_{48} g c_{1l} - K_{17} g s_{1l} \quad] \\
K_{29l} &= K_{17} c_{1l} - K_{48} s_{1l} \\
K_{30l} &= -K_{48} c_{1l} - K_{17} s_{1l} \\
\bar{g}_{4l} &= [K_{29l} g \quad K_{47} g \quad K_{30l} g \quad] \\
m_{4l} \bar{S}_{4l}^\times \bar{g}_{4l} &= \mathbf{M} \mathbf{S}_{4l} \times \bar{g}_{4l} \\
m_{4l} \bar{S}_{4l}^\times \bar{g}_{4l} &= [K_{30l} \mathbf{M} \mathbf{Y}_{4l} g - K_{47} \mathbf{M} \mathbf{Z}_{4l} g \quad K_{29l} \mathbf{M} \mathbf{Z}_{4l} g - K_{30l} \mathbf{M} \mathbf{X}_{4l} g \quad K_{47} \mathbf{M} \mathbf{X}_{4l} g - K_{29l} \mathbf{M} \mathbf{Y}_{4l} g \quad] \\
D_{1l} &= K_{30l} \mathbf{M} \mathbf{Y}_{4l} - K_{47} \mathbf{M} \mathbf{Z}_{4l} \\
D_{2l} &= K_{29l} \mathbf{M} \mathbf{Z}_{4l} - K_{30l} \mathbf{M} \mathbf{X}_{4l} \\
D_{3l} &= K_{47} \mathbf{M} \mathbf{X}_{4l} - K_{29l} \mathbf{M} \mathbf{Y}_{4l} \\
m_{4l} \bar{S}_{4l}^\times \bar{g}_{4l} &= [D_{1l} g \quad D_{2l} g \quad D_{3l} g \quad] \\
m_{4l} \bar{a}_{G(4l)} &= m_{4l} \bar{a}_{4l} + \bar{\alpha}_{4l} \times \mathbf{M} \mathbf{S}_{4l} + \bar{\omega}_{4l} \times (\bar{\omega}_{4l} \times \mathbf{M} \mathbf{S}_{4l}) \\
m_{4l} \bar{a}_{G(4l)} &= [\mathbf{M} \mathbf{Z}_{4l} (K_{42} - \bar{q}_{1l} + K_{28} \bar{\psi} + \bar{q}_w c_{torso} + \bar{q}_{imu} c_{torso}) - \mathbf{M} \mathbf{Y}_{4l} (K_{25l} + K_{6l} \bar{\psi} + K_{7l} \bar{q}_w + K_{7l} \bar{q}_{imu} + \bar{q}_{torso} s_{1l}) + m_{4l} (K_{26l} + K_{12l} \bar{\psi} \\
D_{4l} &= K_{11l} m_{4l} \\
D_{5l} &= K_{12l} m_{4l} - K_{6l} \mathbf{M} \mathbf{Y}_{4l} + K_{28} \mathbf{M} \mathbf{Z}_{4l} \\
D_{6l} &= K_{13l} m_{4l} + \mathbf{M} \mathbf{Z}_{4l} c_{torso} - K_{7l} \mathbf{M} \mathbf{Y}_{4l} \\
D_{7l} &= K_{14l} m_{4l} + \mathbf{M} \mathbf{Z}_{4l} c_{torso} - K_{7l} \mathbf{M} \mathbf{Y}_{4l} \\
D_{8l} &= K_{15l} m_{4l} - \mathbf{M} \mathbf{Y}_{4l} s_{1l} \\
D_{9l} &= K_{26l} m_{4l} - K_{2l}^2 \mathbf{M} \mathbf{X}_{4l} - K_{3l}^2 \mathbf{M} \mathbf{X}_{4l} \\
&\quad - K_{25l} \mathbf{M} \mathbf{Y}_{4l} + K_{42} \mathbf{M} \mathbf{Z}_{4l} + K_{1l} K_{2l} \mathbf{M} \mathbf{Y}_{4l} \\
&\quad + K_{1l} K_{3l} \mathbf{M} \mathbf{Z}_{4l} \\
D_{10l} &= K_{33} m_{4l} \\
D_{11l} &= K_{16l} m_{4l} + K_{6l} \mathbf{M} \mathbf{X}_{4l} - K_{4l} \mathbf{M} \mathbf{Z}_{4l} \\
D_{12l} &= K_{17l} m_{4l} + K_{7l} \mathbf{M} \mathbf{X}_{4l} - K_{5l} \mathbf{M} \mathbf{Z}_{4l} \\
D_{13l} &= K_{18l} m_{4l} + K_{7l} \mathbf{M} \mathbf{X}_{4l} - K_{5l} \mathbf{M} \mathbf{Z}_{4l} \\
D_{14l} &= \mathbf{M} \mathbf{Z}_{4l} c_{1l} + \mathbf{M} \mathbf{X}_{4l} s_{1l} \\
D_{15l} &= K_{27l} m_{4l} - K_{1l}^2 \mathbf{M} \mathbf{Y}_{4l} - K_{3l}^2 \mathbf{M} \mathbf{Y}_{4l} \\
&\quad + K_{25l} \mathbf{M} \mathbf{X}_{4l} - K_{24l} \mathbf{M} \mathbf{Z}_{4l} + K_{1l} K_{2l} \mathbf{M} \mathbf{X}_{4l} \\
&\quad + K_{2l} K_{3l} \mathbf{M} \mathbf{Z}_{4l} \\
D_{16l} &= K_{19l} m_{4l} \\
D_{17l} &= K_{20l} m_{4l} - K_{28} \mathbf{M} \mathbf{X}_{4l} + K_{4l} \mathbf{M} \mathbf{Y}_{4l} \\
D_{18l} &= K_{21l} m_{4l} - \mathbf{M} \mathbf{X}_{4l} c_{torso} + K_{5l} \mathbf{M} \mathbf{Y}_{4l} \\
D_{19l} &= K_{22l} m_{4l} - \mathbf{M} \mathbf{X}_{4l} c_{torso} + K_{5l} \mathbf{M} \mathbf{Y}_{4l} \\
D_{20l} &= K_{23l} m_{4l} - \mathbf{M} \mathbf{Y}_{4l} c_{1l} \\
D_{21l} &= K_{28l} m_{4l} - K_{1l}^2 \mathbf{M} \mathbf{Z}_{4l} - K_{2l}^2 \mathbf{M} \mathbf{Z}_{4l} \\
&\quad - K_{42} \mathbf{M} \mathbf{X}_{4l} + K_{24l} \mathbf{M} \mathbf{Y}_{4l} + K_{1l} K_{3l} \mathbf{M} \mathbf{X}_{4l} \\
&\quad + K_{2l} K_{3l} \mathbf{M} \mathbf{Y}_{4l} \\
m_{4l} \bar{a}_{G(4l)} &= [D_{9l} + D_{5l} \bar{\psi} + D_{7l} \bar{q}_w + D_{6l} \bar{q}_{imu} + D_{8l} \bar{q}_{torso} + D_{4l} \bar{x} - \mathbf{M} \mathbf{Z}_{4l} \bar{q}_{1l} \quad D_{15l} + D_{11l} \bar{\psi} + D_{13l} \bar{q}_w + D_{12l} \bar{q}_{imu} + D_{14l} \bar{q}_{torso} + D_{10l} \bar{x} \quad]
\end{aligned}$$

$$\begin{aligned}
\dot{H}_{4l} &= \mathbf{M}\mathbf{S}_{4l} \times \bar{a}_{4l} + J_{4l}\bar{\alpha}_{4l} + \bar{\omega}_{4l} \times J_{4l}\bar{\omega}_{4l} \\
\dot{H}_{4l} &= [K_{2l}(K_{1l}\mathbf{XZ}_{4l} + K_{2l}\mathbf{YZ}_{4l} + K_{3l}\mathbf{ZZ}_{4l}) - K_{3l}(K_{1l}\mathbf{XY}_{4l} + K_{2l}\mathbf{YY}_{4l} + K_{3l}\mathbf{YZ}_{4l}) + \mathbf{XX}_{4l}(K_{24l} + K_{4l}\ddot{\psi} + K_{5l}\ddot{q}_w + K_{5l}\ddot{q}_{imu} - \ddot{q}_{torso}) \\
D_{22l} &= K_{19l}\mathbf{MY}_{4l} - K_{33}\mathbf{MZ}_{4l} \\
D_{23l} &= K_{4l}\mathbf{XX}_{4l} + K_{28}\mathbf{XY}_{4l} + K_{6l}\mathbf{XZ}_{4l} \\
&\quad + K_{20l}\mathbf{MY}_{4l} - K_{16l}\mathbf{MZ}_{4l} \\
D_{24l} &= K_{5l}\mathbf{XX}_{4l} + K_{7l}\mathbf{XZ}_{4l} + \mathbf{XY}_{4l}c_{torso} \\
&\quad + K_{21l}\mathbf{MY}_{4l} - K_{17l}\mathbf{MZ}_{4l} \\
D_{25l} &= K_{5l}\mathbf{XX}_{4l} + K_{7l}\mathbf{XZ}_{4l} + \mathbf{XY}_{4l}c_{torso} \\
&\quad + K_{22l}\mathbf{MY}_{4l} - K_{18l}\mathbf{MZ}_{4l} \\
D_{26l} &= \mathbf{XZ}_{4l}s_{1l} - \mathbf{XX}_{4l}c_{1l} + K_{23l}\mathbf{MY}_{4l} \\
D_{27l} &= K_{24l}\mathbf{XX}_{4l} + K_{42}\mathbf{XY}_{4l} + K_{25l}\mathbf{XZ}_{4l} \\
&\quad + K_{2l}^2\mathbf{YZ}_{4l} - K_{3l}^2\mathbf{YZ}_{4l} + K_{28l}\mathbf{MY}_{4l} \\
&\quad - K_{27l}\mathbf{MZ}_{4l} - K_{1l}K_{3l}\mathbf{XY}_{4l} + K_{1l}K_{2l}\mathbf{XZ}_{4l} \\
&\quad - K_{2l}K_{3l}\mathbf{YY}_{4l} + K_{2l}K_{3l}\mathbf{ZZ}_{4l} \\
D_{28l} &= K_{11l}\mathbf{MZ}_{4l} - K_{19l}\mathbf{MX}_{4l} \\
D_{29l} &= K_{4l}\mathbf{XY}_{4l} + K_{28}\mathbf{YY}_{4l} + K_{6l}\mathbf{YZ}_{4l} \\
&\quad - K_{20l}\mathbf{MX}_{4l} + K_{12l}\mathbf{MZ}_{4l} \\
D_{30l} &= K_{5l}\mathbf{XY}_{4l} + K_{7l}\mathbf{YZ}_{4l} + \mathbf{YY}_{4l}c_{torso} \\
&\quad - K_{21l}\mathbf{MX}_{4l} + K_{13l}\mathbf{MZ}_{4l} \\
D_{31l} &= K_{5l}\mathbf{XY}_{4l} + K_{7l}\mathbf{YZ}_{4l} + \mathbf{YY}_{4l}c_{torso} \\
&\quad - K_{22l}\mathbf{MX}_{4l} + K_{14l}\mathbf{MZ}_{4l} \\
D_{32l} &= \mathbf{YZ}_{4l}s_{1l} - \mathbf{XY}_{4l}c_{1l} - K_{23l}\mathbf{MX}_{4l} \\
&\quad + K_{15l}\mathbf{MZ}_{4l} \\
D_{33l} &= K_{24l}\mathbf{XY}_{4l} + K_{42}\mathbf{YY}_{4l} + K_{25l}\mathbf{YZ}_{4l} \\
&\quad - K_{1l}^2\mathbf{XZ}_{4l} + K_{3l}^2\mathbf{XZ}_{4l} - K_{28l}\mathbf{MX}_{4l} \\
&\quad + K_{26l}\mathbf{MZ}_{4l} + K_{1l}K_{3l}\mathbf{XX}_{4l} + K_{2l}K_{3l}\mathbf{XY}_{4l} \\
&\quad - K_{1l}K_{2l}\mathbf{YZ}_{4l} - K_{1l}K_{3l}\mathbf{ZZ}_{4l} \\
D_{34l} &= K_{33}\mathbf{MX}_{4l} - K_{11l}\mathbf{MY}_{4l} \\
D_{35l} &= K_{4l}\mathbf{XZ}_{4l} + K_{28}\mathbf{YZ}_{4l} + K_{6l}\mathbf{ZZ}_{4l} \\
&\quad + K_{16l}\mathbf{MX}_{4l} - K_{12l}\mathbf{MY}_{4l} \\
D_{36l} &= K_{5l}\mathbf{XZ}_{4l} + K_{7l}\mathbf{ZZ}_{4l} + \mathbf{YZ}_{4l}c_{torso} \\
&\quad + K_{17l}\mathbf{MX}_{4l} - K_{13l}\mathbf{MY}_{4l} \\
D_{37l} &= K_{5l}\mathbf{XZ}_{4l} + K_{7l}\mathbf{ZZ}_{4l} + \mathbf{YZ}_{4l}c_{torso} \\
&\quad + K_{18l}\mathbf{MX}_{4l} - K_{14l}\mathbf{MY}_{4l} \\
D_{38l} &= \mathbf{ZZ}_{4l}s_{1l} - \mathbf{XZ}_{4l}c_{1l} - K_{15l}\mathbf{MY}_{4l} \\
D_{39l} &= K_{24l}\mathbf{XZ}_{4l} + K_{42}\mathbf{YZ}_{4l} + K_{25l}\mathbf{ZZ}_{4l} \\
&\quad + K_{1l}^2\mathbf{XY}_{4l} - K_{2l}^2\mathbf{XY}_{4l} + K_{27l}\mathbf{MX}_{4l} \\
&\quad - K_{26l}\mathbf{MY}_{4l} - K_{1l}K_{2l}\mathbf{XX}_{4l} - K_{2l}K_{3l}\mathbf{XZ}_{4l} \\
&\quad + K_{1l}K_{2l}\mathbf{YY}_{4l} + K_{1l}K_{3l}\mathbf{YZ}_{4l} \\
\dot{H}_{4l} &= [D_{9l} + D_{5l}\ddot{\psi} + D_{7l}\ddot{q}_w + D_{6l}\ddot{q}_{imu} + D_{8l}\ddot{q}_{torso} + D_{4l}\ddot{x} - \mathbf{MZ}_{4l}\ddot{q}_{1l} \quad D_{15l} + D_{11l}\ddot{\psi} + D_{13l}\ddot{q}_w + D_{12l}\ddot{q}_{imu} + D_{14l}\ddot{q}_{torso} + D_{10l}\ddot{x} \quad] \\
\bar{\omega}_{5l} &= {}^{5l}A_{4l}\bar{\omega}_{4l} + \dot{q}_{5l}\bar{e}_{5l} \\
\bar{\omega}_{5l} &= [-K_{1l} - \dot{q}_{2l} \quad -K_{2l}c_{2l} - K_{3l}s_{2l} \quad K_{3l}c_{2l} - K_{2l}s_{2l} \quad] \\
K_{31l} &= -K_{1l} - \dot{q}_{2l} \\
K_{32l} &= -K_{2l}c_{2l} - K_{3l}s_{2l} \\
K_{33l} &= K_{3l}c_{2l} - K_{2l}s_{2l} \\
\bar{\omega}_{5l} &= [K_{31l} \quad K_{32l} \quad K_{33l} \quad] \\
\bar{\omega}_{5l} &= [\dot{q}_{torso}c_{1l} - K_{4l}\dot{\psi} - K_{5l}\dot{q}_w - K_{5l}\dot{q}_{imu} - \dot{q}_{2l} \quad -s_{2l}(K_{6l}\dot{\psi} + K_{7l}\dot{q}_w + K_{7l}\dot{q}_{imu} + \dot{q}_{torso}s_{1l}) - c_{2l}(K_{28}\dot{\psi} - \dot{q}_{1l} + \dot{q}_wc_{torso} + \dot{q}_{imu}) \\
K_{34l} &= -K_{28}c_{2l} - K_{6l}s_{2l} \\
K_{35l} &= -c_{2l}c_{torso} - K_{7l}s_{2l} \\
K_{36l} &= -s_{1l}s_{2l} \\
K_{37l} &= K_{6l}c_{2l} - K_{28}s_{2l} \\
K_{38l} &= K_{7l}c_{2l} - c_{torso}s_{2l} \\
K_{39l} &= c_{2l}s_{1l} \\
\bar{\omega}_{5l} &= [\dot{q}_{torso}c_{1l} - K_{4l}\dot{\psi} - K_{5l}\dot{q}_w - K_{5l}\dot{q}_{imu} - \dot{q}_{2l} \quad K_{34l}\dot{\psi} + K_{35l}\dot{q}_w + K_{35l}\dot{q}_{imu} + K_{36l}\dot{q}_{torso} + \dot{q}_{1l}c_{2l} \quad K_{37l}\dot{\psi} + K_{38l}\dot{q}_w + K_{38l}\dot{q}_{imu} \\
\bar{v}_{5l} &= {}^{5l}A_{4l}(\bar{v}_{4l} + \bar{\omega}_{4l} \times \bar{P}_{5l}) \\
\bar{v}_{5l} &= [-K_{8l} \quad -K_{9l}c_{2l} - K_{10l}s_{2l} \quad K_{10l}c_{2l} - K_{9l}s_{2l} \quad] \\
K_{40l} &= -K_{9l}c_{2l} - K_{10l}s_{2l} \\
K_{41l} &= K_{10l}c_{2l} - K_{9l}s_{2l} \\
\bar{v}_{5l} &= [-K_{8l} \quad K_{40l} \quad K_{41l} \quad] \\
\bar{v}_{5l} &= [-K_{12l}\dot{\psi} - K_{14l}\dot{q}_w - K_{13l}\dot{q}_{imu} - K_{15l}\dot{q}_{torso} - K_{11l}\ddot{x} \quad -c_{2l}(K_{16l}\dot{\psi} + K_{18l}\dot{q}_w + K_{17l}\dot{q}_{imu} + K_{33}\ddot{x}) - s_{2l}(K_{20l}\dot{\psi} + K_{22l}\dot{q}_w + K_{22l}\dot{q}_{imu} \\
K_{42l} &= -K_{33}c_{2l} - K_{19l}s_{2l} \\
K_{43l} &= -K_{16l}c_{2l} - K_{20l}s_{2l}
\end{aligned}$$

$$\begin{aligned}
K_{44l} &= -K_{17l}c_{2l} - K_{21l}s_{2l} \\
K_{45l} &= -K_{18l}c_{2l} - K_{22l}s_{2l} \\
K_{46l} &= -K_{23l}s_{2l} \\
K_{47l} &= K_{19l}c_{2l} - K_{33}s_{2l} \\
K_{48l} &= K_{20l}c_{2l} - K_{16l}s_{2l} \\
K_{49l} &= K_{21l}c_{2l} - K_{17l}s_{2l} \\
K_{50l} &= K_{22l}c_{2l} - K_{18l}s_{2l} \\
K_{51l} &= K_{23l}c_{2l} \\
\bar{v}_{5l} &= [-K_{12l}\dot{\psi} - K_{14l}\dot{q}_w - K_{13l}\dot{q}_{imu} - K_{15l}\dot{q}_{torso} - K_{11l}\ddot{x} \quad K_{43l}\dot{\psi} + K_{45l}\dot{q}_w + K_{44l}\dot{q}_{imu} + K_{46l}\dot{q}_{torso} + K_{42l}\ddot{x} \quad K_{48l}\dot{\psi} + K_{50l}\dot{q}_w \\
\bar{\alpha}_{5l} &= {}^5l A_{4l}\bar{\alpha}_{4l} + \bar{q}_{5l}\bar{e}_{5l} + \dot{q}_{5l}(\bar{\omega}_{5l} \times \bar{e}_{5l}) \\
\bar{\alpha}_{5l} &= [\bar{q}_{torso}c_{1l} - \bar{q}_{2l} - K_{4l}\ddot{\psi} - K_{5l}\ddot{q}_w - K_{5l}\ddot{q}_{imu} - K_{24l} \quad -K_{33l}\ddot{q}_{2l} - s_{2l}(K_{25l} + K_{6l}\ddot{\psi} + K_{7l}\ddot{q}_w + K_{7l}\ddot{q}_{imu} + \ddot{q}_{torso}s_{1l}) - c_{2l}(K_{42} - \\
K_{52l} &= -K_{33l}\ddot{q}_{2l} - K_{42}c_{2l} - K_{25l}s_{2l} \\
K_{53l} &= K_{32l}\ddot{q}_{2l} + K_{25l}c_{2l} - K_{42}s_{2l} \\
\bar{\alpha}_{5l} &= [\bar{q}_{torso}c_{1l} - \bar{q}_{2l} - K_{4l}\ddot{\psi} - K_{5l}\ddot{q}_w - K_{5l}\ddot{q}_{imu} - K_{24l} \quad K_{52l} + K_{34l}\ddot{\psi} + K_{35l}\ddot{q}_w + K_{35l}\ddot{q}_{imu} + K_{36l}\ddot{q}_{torso} + \ddot{q}_{1l}c_{2l} \quad K_{53l} + K_{37l} \\
\bar{a}_{5l} &= {}^5l A_{4l}(\bar{a}_{4l} + \bar{\alpha}_{4l} \times \bar{P}_{5l} + \bar{\omega}_{4l} \times (\bar{\omega}_{4l} \times \bar{P}_{5l})) \\
\bar{\alpha}_{5l} &= [-K_{26l} - K_{12l}\ddot{\psi} - K_{14l}\ddot{q}_w - K_{13l}\ddot{q}_{imu} - K_{15l}\ddot{q}_{torso} - K_{11l}\ddot{x} \quad -c_{2l}(K_{27l} + K_{16l}\ddot{\psi} + K_{18l}\ddot{q}_w + K_{17l}\ddot{q}_{imu} + K_{33}\ddot{x}) - s_{2l}(K_{28l} + \\
K_{54l} &= -K_{27l}c_{2l} - K_{28l}s_{2l} \\
K_{55l} &= K_{28l}c_{2l} - K_{27l}s_{2l} \\
\bar{a}_{5l} &= [-K_{26l} - K_{12l}\ddot{\psi} - K_{14l}\ddot{q}_w - K_{13l}\ddot{q}_{imu} - K_{15l}\ddot{q}_{torso} - K_{11l}\ddot{x} \quad K_{54l} + K_{43l}\ddot{\psi} + K_{45l}\ddot{q}_w + K_{44l}\ddot{q}_{imu} + K_{46l}\ddot{q}_{torso} + K_{42l}\ddot{x} \quad K_{55l} \\
\bar{g}_{5l} &= {}^5l A_{4l}\bar{g}_{4l} \\
\bar{g}_{5l} &= [-K_{29l}g \quad -K_{47}gc_{2l} - K_{30l}gs_{2l} \quad K_{30l}gc_{2l} - K_{47}gs_{2l} \quad] \\
K_{56l} &= -K_{47}c_{2l} - K_{30l}s_{2l} \\
K_{57l} &= K_{30l}c_{2l} - K_{47}s_{2l} \\
\bar{g}_{5l} &= [-K_{29l}g \quad K_{56l}g \quad K_{57l}g \quad] \\
m_{5l}\bar{S}_{5l}^\times \bar{g}_{5l} &= \mathbf{M}\mathbf{S}_{5l} \times \bar{g}_{5l} \\
m_{5l}\bar{S}_{5l}^\times \bar{g}_{5l} &= [K_{57l}\mathbf{M}\mathbf{Y}_{5l}g - K_{56l}\mathbf{M}\mathbf{Z}_{5l}g \quad -K_{57l}\mathbf{M}\mathbf{X}_{5l}g - K_{29l}\mathbf{M}\mathbf{Z}_{5l}g \quad K_{56l}\mathbf{M}\mathbf{X}_{5l}g + K_{29l}\mathbf{M}\mathbf{Y}_{5l}g \quad] \\
D_{40l} &= K_{57l}\mathbf{M}\mathbf{Y}_{5l} - K_{56l}\mathbf{M}\mathbf{Z}_{5l} \\
D_{41l} &= -K_{57l}\mathbf{M}\mathbf{X}_{5l} - K_{29l}\mathbf{M}\mathbf{Z}_{5l} \\
D_{42l} &= K_{56l}\mathbf{M}\mathbf{X}_{5l} + K_{29l}\mathbf{M}\mathbf{Y}_{5l} \\
m_{5l}\bar{S}_{5l}^\times \bar{g}_{5l} &= [D_{40l}g \quad D_{41l}g \quad D_{42l}g \quad] \\
m_{5l}\bar{a}_{G(5l)} &= m_{5l}\bar{a}_{5l} + \bar{\alpha}_{5l} \times \mathbf{M}\mathbf{S}_{5l} + \bar{\omega}_{5l} \times (\bar{\omega}_{5l} \times \mathbf{M}\mathbf{S}_{5l}) \\
m_{5l}\bar{a}_{G(5l)} &= [\mathbf{M}\mathbf{Z}_{5l}(K_{52l} + K_{34l}\ddot{\psi} + K_{35l}\ddot{q}_w + K_{35l}\ddot{q}_{imu} + K_{36l}\ddot{q}_{torso} + \ddot{q}_{1l}c_{2l}) - \mathbf{M}\mathbf{Y}_{5l}(K_{53l} + K_{37l}\ddot{\psi} + K_{38l}\ddot{q}_w + K_{38l}\ddot{q}_{imu} + K_{39l}\ddot{q}_{torso} + \\
D_{43l} &= -K_{11l}m_{5l} \\
D_{44l} &= K_{34l}\mathbf{M}\mathbf{Z}_{5l} - K_{37l}\mathbf{M}\mathbf{Y}_{5l} - K_{12l}m_{5l} \\
D_{45l} &= K_{35l}\mathbf{M}\mathbf{Z}_{5l} - K_{38l}\mathbf{M}\mathbf{Y}_{5l} - K_{13l}m_{5l} \\
D_{46l} &= K_{35l}\mathbf{M}\mathbf{Z}_{5l} - K_{38l}\mathbf{M}\mathbf{Y}_{5l} - K_{14l}m_{5l} \\
D_{47l} &= K_{36l}\mathbf{M}\mathbf{Z}_{5l} - K_{39l}\mathbf{M}\mathbf{Y}_{5l} - K_{15l}m_{5l} \\
D_{48l} &= \mathbf{M}\mathbf{Z}_{5l}c_{2l} - \mathbf{M}\mathbf{Y}_{5l}s_{2l} \\
D_{49l} &= K_{52l}\mathbf{M}\mathbf{Z}_{5l} - K_{32l}^2\mathbf{M}\mathbf{X}_{5l} - K_{33l}^2\mathbf{M}\mathbf{X}_{5l} \\
&\quad - K_{53l}\mathbf{M}\mathbf{Y}_{5l} - K_{26l}m_{5l} + K_{31l}K_{32l}\mathbf{M}\mathbf{Y}_{5l} \\
&\quad + K_{31l}K_{33l}\mathbf{M}\mathbf{Z}_{5l} \\
D_{50l} &= K_{42l}m_{5l} \\
D_{51l} &= K_{43l}m_{5l} + K_{37l}\mathbf{M}\mathbf{X}_{5l} + K_{4l}\mathbf{M}\mathbf{Z}_{5l} \\
D_{52l} &= K_{44l}m_{5l} + K_{38l}\mathbf{M}\mathbf{X}_{5l} + K_{5l}\mathbf{M}\mathbf{Z}_{5l} \\
D_{53l} &= K_{45l}m_{5l} + K_{38l}\mathbf{M}\mathbf{X}_{5l} + K_{5l}\mathbf{M}\mathbf{Z}_{5l} \\
D_{54l} &= K_{46l}m_{5l} - \mathbf{M}\mathbf{Z}_{5l}c_{1l} + K_{39l}\mathbf{M}\mathbf{X}_{5l} \\
D_{55l} &= \mathbf{M}\mathbf{X}_{5l}s_{2l} \\
D_{56l} &= K_{54l}m_{5l} - K_{31l}^2\mathbf{M}\mathbf{Y}_{5l} - K_{33l}^2\mathbf{M}\mathbf{Y}_{5l} \\
&\quad + K_{53l}\mathbf{M}\mathbf{X}_{5l} + K_{24l}\mathbf{M}\mathbf{Z}_{5l} + K_{31l}K_{32l}\mathbf{M}\mathbf{X}_{5l} \\
&\quad + K_{32l}K_{33l}\mathbf{M}\mathbf{Z}_{5l} \\
D_{57l} &= K_{47l}m_{5l} \\
D_{58l} &= K_{48l}m_{5l} - K_{34l}\mathbf{M}\mathbf{X}_{5l} - K_{4l}\mathbf{M}\mathbf{Y}_{5l} \\
D_{59l} &= K_{49l}m_{5l} - K_{35l}\mathbf{M}\mathbf{X}_{5l} - K_{5l}\mathbf{M}\mathbf{Y}_{5l} \\
D_{60l} &= K_{50l}m_{5l} - K_{35l}\mathbf{M}\mathbf{X}_{5l} - K_{5l}\mathbf{M}\mathbf{Y}_{5l} \\
D_{61l} &= K_{51l}m_{5l} + \mathbf{M}\mathbf{Y}_{5l}c_{1l} - K_{36l}\mathbf{M}\mathbf{X}_{5l} \\
D_{62l} &= -\mathbf{M}\mathbf{X}_{5l}c_{2l} \\
D_{63l} &= K_{55l}m_{5l} - K_{31l}^2\mathbf{M}\mathbf{Z}_{5l} - K_{32l}^2\mathbf{M}\mathbf{Z}_{5l} \\
&\quad - K_{52l}\mathbf{M}\mathbf{X}_{5l} - K_{24l}\mathbf{M}\mathbf{Y}_{5l} + K_{31l}K_{33l}\mathbf{M}\mathbf{X}_{5l} \\
&\quad + K_{32l}K_{33l}\mathbf{M}\mathbf{Y}_{5l} \\
m_{5l}\bar{a}_{G(5l)} &= [D_{49l} + D_{44l}\ddot{\psi} + D_{48l}\ddot{q}_{1l} + D_{46l}\ddot{q}_w + D_{45l}\ddot{q}_{imu} + D_{47l}\ddot{q}_{torso} + D_{43l}\ddot{x} \quad D_{56l} + D_{51l}\ddot{\psi} + D_{55l}\ddot{q}_{1l} + D_{53l}\ddot{q}_w + D_{52l}\ddot{q}_{imu} + D_{54l}\ddot{q}_{torso} +
\end{aligned}$$

$$\begin{aligned}
\dot{H}_{5l} &= \mathbf{M}\mathbf{S}_{5l} \times \bar{a}_{5l} + J_{5l}\bar{\alpha}_{5l} + \bar{\omega}_{5l} \times J_{5l}\bar{\omega}_{5l} \\
\dot{H}_{5l} &= [K_{32l}(K_{31l}\mathbf{X}\mathbf{Z}_{5l} + K_{32l}\mathbf{Y}\mathbf{Z}_{5l} + K_{33l}\mathbf{Z}\mathbf{Z}_{5l}) - K_{33l}(K_{31l}\mathbf{X}\mathbf{Y}_{5l} + K_{32l}\mathbf{Y}\mathbf{Y}_{5l} + K_{33l}\mathbf{Y}\mathbf{Z}_{5l}) + \mathbf{X}\mathbf{Y}_{5l}(K_{52l} + K_{34l}\ddot{\psi} + K_{35l}\ddot{q}_w + K_{35l}\ddot{q}_{imu} \\
D_{64l} &= K_{47l}\mathbf{M}\mathbf{Y}_{5l} - K_{42l}\mathbf{M}\mathbf{Z}_{5l} \\
D_{65l} &= K_{34l}\mathbf{X}\mathbf{Y}_{5l} - K_{4l}\mathbf{X}\mathbf{X}_{5l} + K_{37l}\mathbf{X}\mathbf{Z}_{5l} \\
&\quad + K_{48l}\mathbf{M}\mathbf{Y}_{5l} - K_{43l}\mathbf{M}\mathbf{Z}_{5l} \\
D_{66l} &= K_{35l}\mathbf{X}\mathbf{Y}_{5l} - K_{5l}\mathbf{X}\mathbf{X}_{5l} + K_{38l}\mathbf{X}\mathbf{Z}_{5l} \\
&\quad + K_{49l}\mathbf{M}\mathbf{Y}_{5l} - K_{44l}\mathbf{M}\mathbf{Z}_{5l} \\
D_{67l} &= K_{35l}\mathbf{X}\mathbf{Y}_{5l} - K_{5l}\mathbf{X}\mathbf{X}_{5l} + K_{38l}\mathbf{X}\mathbf{Z}_{5l} \\
&\quad + K_{50l}\mathbf{M}\mathbf{Y}_{5l} - K_{45l}\mathbf{M}\mathbf{Z}_{5l} \\
D_{68l} &= K_{36l}\mathbf{X}\mathbf{Y}_{5l} + K_{39l}\mathbf{X}\mathbf{Z}_{5l} + \mathbf{X}\mathbf{X}_{5l}c_{1l} \\
&\quad + K_{51l}\mathbf{M}\mathbf{Y}_{5l} - K_{46l}\mathbf{M}\mathbf{Z}_{5l} \\
D_{69l} &= \mathbf{X}\mathbf{Y}_{5l}c_{2l} + \mathbf{X}\mathbf{Z}_{5l}s_{2l} \\
D_{70l} &= K_{52l}\mathbf{X}\mathbf{Y}_{5l} - K_{24l}\mathbf{X}\mathbf{X}_{5l} + K_{53l}\mathbf{X}\mathbf{Z}_{5l} \\
&\quad + K_{32l}^2\mathbf{Y}\mathbf{Z}_{5l} - K_{33l}^2\mathbf{Y}\mathbf{Z}_{5l} + K_{55l}\mathbf{M}\mathbf{Y}_{5l} \\
&\quad - K_{54l}\mathbf{M}\mathbf{Z}_{5l} - K_{31l}K_{33l}\mathbf{X}\mathbf{Y}_{5l} + K_{31l}K_{32l}\mathbf{X}\mathbf{Z}_{5l} \\
&\quad - K_{32l}K_{33l}\mathbf{Y}\mathbf{Y}_{5l} + K_{32l}K_{33l}\mathbf{Z}\mathbf{Z}_{5l} \\
D_{71l} &= -K_{47l}\mathbf{M}\mathbf{X}_{5l} - K_{11l}\mathbf{M}\mathbf{Z}_{5l} \\
D_{72l} &= K_{34l}\mathbf{Y}\mathbf{Y}_{5l} - K_{4l}\mathbf{X}\mathbf{Y}_{5l} + K_{37l}\mathbf{Y}\mathbf{Z}_{5l} \\
&\quad - K_{48l}\mathbf{M}\mathbf{X}_{5l} - K_{12l}\mathbf{M}\mathbf{Z}_{5l} \\
D_{73l} &= K_{35l}\mathbf{Y}\mathbf{Y}_{5l} - K_{5l}\mathbf{X}\mathbf{Y}_{5l} + K_{38l}\mathbf{Y}\mathbf{Z}_{5l} \\
&\quad - K_{49l}\mathbf{M}\mathbf{X}_{5l} - K_{13l}\mathbf{M}\mathbf{Z}_{5l} \\
D_{74l} &= K_{35l}\mathbf{Y}\mathbf{Y}_{5l} - K_{5l}\mathbf{X}\mathbf{Y}_{5l} + K_{38l}\mathbf{Y}\mathbf{Z}_{5l} \\
&\quad - K_{50l}\mathbf{M}\mathbf{X}_{5l} - K_{14l}\mathbf{M}\mathbf{Z}_{5l} \\
D_{75l} &= K_{36l}\mathbf{Y}\mathbf{Y}_{5l} + K_{39l}\mathbf{Y}\mathbf{Z}_{5l} + \mathbf{X}\mathbf{Y}_{5l}c_{1l} \\
&\quad - K_{51l}\mathbf{M}\mathbf{X}_{5l} - K_{15l}\mathbf{M}\mathbf{Z}_{5l} \\
D_{76l} &= \mathbf{Y}\mathbf{Y}_{5l}c_{2l} + \mathbf{Y}\mathbf{Z}_{5l}s_{2l} \\
D_{77l} &= K_{52l}\mathbf{Y}\mathbf{Y}_{5l} - K_{24l}\mathbf{X}\mathbf{Y}_{5l} + K_{53l}\mathbf{Y}\mathbf{Z}_{5l} \\
&\quad - K_{31l}^2\mathbf{X}\mathbf{Z}_{5l} + K_{33l}^2\mathbf{X}\mathbf{Z}_{5l} - K_{55l}\mathbf{M}\mathbf{X}_{5l} \\
&\quad - K_{26l}\mathbf{M}\mathbf{Z}_{5l} + K_{31l}K_{33l}\mathbf{X}\mathbf{X}_{5l} + K_{32l}K_{33l}\mathbf{X}\mathbf{Y}_{5l} \\
&\quad - K_{31l}K_{32l}\mathbf{Y}\mathbf{Z}_{5l} - K_{31l}K_{33l}\mathbf{Z}\mathbf{Z}_{5l} \\
D_{78l} &= K_{42l}\mathbf{M}\mathbf{X}_{5l} + K_{11l}\mathbf{M}\mathbf{Y}_{5l} \\
D_{79l} &= K_{34l}\mathbf{Y}\mathbf{Z}_{5l} - K_{4l}\mathbf{X}\mathbf{Z}_{5l} + K_{37l}\mathbf{Z}\mathbf{Z}_{5l} \\
&\quad + K_{43l}\mathbf{M}\mathbf{X}_{5l} + K_{12l}\mathbf{M}\mathbf{Y}_{5l} \\
D_{80l} &= K_{35l}\mathbf{Y}\mathbf{Z}_{5l} - K_{5l}\mathbf{X}\mathbf{Z}_{5l} + K_{38l}\mathbf{Z}\mathbf{Z}_{5l} \\
&\quad + K_{44l}\mathbf{M}\mathbf{X}_{5l} + K_{13l}\mathbf{M}\mathbf{Y}_{5l} \\
D_{81l} &= K_{35l}\mathbf{Y}\mathbf{Z}_{5l} - K_{5l}\mathbf{X}\mathbf{Z}_{5l} + K_{38l}\mathbf{Z}\mathbf{Z}_{5l} \\
&\quad + K_{45l}\mathbf{M}\mathbf{X}_{5l} + K_{14l}\mathbf{M}\mathbf{Y}_{5l} \\
D_{82l} &= K_{36l}\mathbf{Y}\mathbf{Z}_{5l} + K_{39l}\mathbf{Z}\mathbf{Z}_{5l} + \mathbf{X}\mathbf{Z}_{5l}c_{1l} \\
&\quad + K_{46l}\mathbf{M}\mathbf{X}_{5l} + K_{15l}\mathbf{M}\mathbf{Y}_{5l} \\
D_{83l} &= \mathbf{Y}\mathbf{Z}_{5l}c_{2l} + \mathbf{Z}\mathbf{Z}_{5l}s_{2l} \\
D_{84l} &= K_{52l}\mathbf{Y}\mathbf{Z}_{5l} - K_{24l}\mathbf{X}\mathbf{Z}_{5l} + K_{53l}\mathbf{Z}\mathbf{Z}_{5l} \\
&\quad + K_{31l}^2\mathbf{X}\mathbf{Y}_{5l} - K_{32l}^2\mathbf{X}\mathbf{Y}_{5l} + K_{54l}\mathbf{M}\mathbf{X}_{5l} \\
&\quad + K_{26l}\mathbf{M}\mathbf{Y}_{5l} - K_{31l}K_{32l}\mathbf{X}\mathbf{X}_{5l} - K_{32l}K_{33l}\mathbf{X}\mathbf{Z}_{5l} \\
&\quad + K_{31l}K_{32l}\mathbf{Y}\mathbf{Y}_{5l} + K_{31l}K_{33l}\mathbf{Y}\mathbf{Z}_{5l} \\
\dot{H}_{5l} &= [D_{49l} + D_{44l}\ddot{\psi} + D_{48l}\ddot{q}_{1l} + D_{46l}\ddot{q}_w + D_{45l}\ddot{q}_{imu} + D_{47l}\ddot{q}_{torso} + D_{43l}\ddot{x} \quad D_{56l} + D_{51l}\ddot{\psi} + D_{55l}\ddot{q}_{1l} + D_{53l}\ddot{q}_w + D_{52l}\ddot{q}_{imu} + D_{54l}\ddot{q}_{torso} \\
\bar{\omega}_{6l} &= {}^{6l}A_{5l}\bar{\omega}_{5l} + \dot{q}_{6l}\bar{e}_{6l} \\
\bar{\omega}_{6l} &= [K_{33l}s_{3l} - K_{31l}c_{3l} \quad -K_{32l} - \dot{q}_{3l} \quad K_{33l}c_{3l} + K_{31l}s_{3l} \quad] \\
K_{58l} &= K_{33l}s_{3l} - K_{31l}c_{3l} \\
K_{59l} &= -K_{32l} - \dot{q}_{3l} \\
K_{60l} &= K_{33l}c_{3l} + K_{31l}s_{3l} \\
\bar{\omega}_{6l} &= [K_{58l} \quad K_{59l} \quad K_{60l} \quad] \\
\bar{\omega}_{6l} &= [s_{3l}(K_{37l}\dot{\psi} + K_{38l}\dot{q}_w + K_{38l}\dot{q}_{imu} + K_{39l}\dot{q}_{torso} + \dot{q}_{1l}s_{2l}) + c_{3l}(\dot{q}_{2l} + K_{4l}\dot{\psi} + K_{5l}\dot{q}_w + K_{5l}\dot{q}_{imu} - \dot{q}_{torso}c_{1l}) \quad -\dot{q}_{3l} - K_{34l}\dot{\psi} - K_{35l}\dot{q}_w - K_{35l}\dot{q}_{imu} - K_{36l}\dot{q}_{torso} - \dot{q}_{1l}c_{2l} \quad K_{36l}\dot{q}_{torso} - \dot{q}_{1l}c_{2l} \quad K_{36l}\dot{q}_{torso} - \dot{q}_{1l}c_{2l} \\
K_{61l} &= K_{4l}c_{3l} + K_{37l}s_{3l} \\
K_{62l} &= K_{5l}c_{3l} + K_{38l}s_{3l} \\
K_{63l} &= K_{39l}s_{3l} - c_{1l}c_{3l} \\
K_{64l} &= s_{2l}s_{3l} \\
K_{65l} &= K_{37l}c_{3l} - K_{4l}s_{3l} \\
K_{66l} &= K_{38l}c_{3l} - K_{5l}s_{3l} \\
K_{67l} &= c_{1l}s_{3l} + K_{39l}c_{3l} \\
K_{68l} &= c_{3l}s_{2l} \\
\bar{\omega}_{6l} &= [K_{61l}\dot{\psi} + K_{64l}\dot{q}_{1l} + K_{62l}\dot{q}_w + K_{62l}\dot{q}_{imu} + K_{63l}\dot{q}_{torso} + \dot{q}_{2l}c_{3l} \quad -\dot{q}_{3l} - K_{34l}\dot{\psi} - K_{35l}\dot{q}_w - K_{35l}\dot{q}_{imu} - K_{36l}\dot{q}_{torso} - \dot{q}_{1l}c_{2l} \quad K_{36l}\dot{q}_{torso} - \dot{q}_{1l}c_{2l} \\
\bar{v}_{6l} &= {}^{6l}A_{5l}(\bar{v}_{5l} + \bar{\omega}_{5l} \times \bar{P}_{6l}) \\
\bar{v}_{6l} &= [c_{3l}(K_{8l} - K_{33l}L_7) + s_{3l}(K_{41l} - K_{31l}L_7) \quad -K_{40l} \quad c_{3l}(K_{41l} - K_{31l}L_7) - s_{3l}(K_{8l} - K_{33l}L_7) \quad]
\end{aligned}$$

$$\begin{aligned}
K_{69l} &= c_{3l}(K_{8l} - K_{33l}L_7) + s_{3l}(K_{41l} - K_{31l}L_7) \\
K_{70l} &= c_{3l}(K_{41l} - K_{31l}L_7) - s_{3l}(K_{8l} - K_{33l}L_7) \\
\bar{v}_{6l} &= [K_{69l} \quad -K_{40l} \quad K_{70l} \quad] \\
\bar{v}_{6l} &= [s_{3l}(K_{48l}\dot{\psi} + K_{50l}\dot{q}w + K_{49l}\dot{q}_{imu} + K_{51l}\dot{q}_{torso} + K_{47l}\ddot{x} + L_7(\dot{q}_{2l} + K_{4l}\dot{\psi} + K_{5l}\dot{q}w + K_{5l}\dot{q}_{imu} - \dot{q}_{torso}c_{1l})) + c_{3l}(K_{12l}\dot{\psi} + K_{14l}\dot{q}w \\
K_{71l} &= K_{11l}c_{3l} + K_{47l}s_{3l} \\
K_{72l} &= c_{3l}(K_{12l} - K_{37l}L_7) + s_{3l}(K_{48l} + K_{4l}L_7) \\
K_{73l} &= c_{3l}(K_{13l} - K_{38l}L_7) + s_{3l}(K_{49l} + K_{5l}L_7) \\
K_{74l} &= c_{3l}(K_{14l} - K_{38l}L_7) + s_{3l}(K_{50l} + K_{5l}L_7) \\
K_{75l} &= s_{3l}(K_{51l} - L_7c_{1l}) + c_{3l}(K_{15l} - K_{39l}L_7) \\
K_{76l} &= -L_7c_{3l}s_{2l} \\
K_{77l} &= L_7s_{3l} \\
K_{78l} &= K_{47l}c_{3l} - K_{11l}s_{3l} \\
K_{79l} &= c_{3l}(K_{48l} + K_{4l}L_7) - s_{3l}(K_{12l} - K_{37l}L_7) \\
K_{80l} &= c_{3l}(K_{49l} + K_{5l}L_7) - s_{3l}(K_{13l} - K_{38l}L_7) \\
K_{81l} &= c_{3l}(K_{50l} + K_{5l}L_7) - s_{3l}(K_{14l} - K_{38l}L_7) \\
K_{82l} &= c_{3l}(K_{51l} - L_7c_{1l}) - s_{3l}(K_{15l} - K_{39l}L_7) \\
K_{83l} &= L_7s_{2l}s_{3l} \\
K_{84l} &= L_7c_{3l} \\
\bar{v}_{6l} &= [K_{72l}\dot{\psi} + K_{76l}\dot{q}_{1l} + K_{77l}\dot{q}_{2l} + K_{74l}\dot{q}w + K_{73l}\dot{q}_{imu} + K_{75l}\dot{q}_{torso} + K_{71l}\ddot{x} \quad -K_{43l}\dot{\psi} - K_{45l}\dot{q}w - K_{44l}\dot{q}_{imu} - K_{46l}\dot{q}_{torso} - K_{42l}\dot{q}_{torso} \\
\bar{\alpha}_{6l} &= {}^6l A_{5l}\bar{\alpha}_{5l} + \bar{q}_{6l}\bar{e}_{6l} + \bar{q}_{6l}(\bar{\omega}_{6l} \times \bar{e}_{6l}) \\
\bar{\alpha}_{6l} &= [c_{3l}(K_{24l} + \bar{q}_{2l} + K_{4l}\dot{\psi} + K_{5l}\dot{q}w + K_{5l}\dot{q}_{imu} - \dot{q}_{torso}c_{1l}) + K_{60l}\dot{q}_{3l} + s_{3l}(K_{53l} + K_{37l}\dot{\psi} + K_{38l}\dot{q}w + K_{38l}\dot{q}_{imu} + K_{39l}\dot{q}_{torso} + \bar{q}_{1l}s_{2l}) \\
K_{85l} &= K_{60l}\dot{q}_{3l} + K_{24l}c_{3l} + K_{53l}s_{3l} \\
K_{86l} &= K_{53l}c_{3l} - K_{58l}\dot{q}_{3l} - K_{24l}s_{3l} \\
\bar{\alpha}_{6l} &= [K_{85l} + K_{61l}\dot{\psi} + K_{64l}\bar{q}_{1l} + K_{62l}\dot{q}w + K_{62l}\dot{q}_{imu} + K_{63l}\dot{q}_{torso} + \bar{q}_{2l}c_{3l} \quad -K_{52l} - \dot{q}_{3l} - K_{34l}\dot{\psi} - K_{35l}\dot{q}w - K_{35l}\dot{q}_{imu} - K_{36l}\dot{q}_{torso} \\
\bar{a}_{6l} &= {}^6l A_{5l}(\bar{a}_{5l} + \bar{\alpha}_{5l} \times \bar{F}_{6l} + \bar{\omega}_{5l} \times (\bar{\omega}_{5l} \times \bar{F}_{6l})) \\
\bar{\alpha}_{6l} &= [c_{3l}(K_{26l} + K_{12l}\dot{\psi} + K_{14l}\dot{q}w + K_{13l}\dot{q}_{imu} + K_{15l}\dot{q}_{torso} + K_{11l}\ddot{x} - L_7(K_{53l} + K_{37l}\dot{\psi} + K_{38l}\dot{q}w + K_{38l}\dot{q}_{imu} + K_{39l}\dot{q}_{torso} + \bar{q}_{1l}s_{2l}) \\
K_{87l} &= K_{26l}c_{3l} + K_{55l}s_{3l} - K_{53l}L_7c_{3l} \\
&\quad + K_{24l}L_7s_{3l} + K_{31l}K_{32l}L_7c_{3l} \\
&\quad - K_{32l}K_{33l}L_7s_{3l} \\
K_{88l} &= -K_{54l} - K_{31l}^2L_7 - K_{33l}^2L_7 \\
K_{89l} &= K_{55l}c_{3l} - K_{26l}s_{3l} + K_{24l}L_7c_{3l} \\
&\quad + K_{53l}L_7s_{3l} - K_{32l}K_{33l}L_7c_{3l} \\
&\quad - K_{31l}K_{32l}L_7s_{3l} \\
\bar{a}_{6l} &= [K_{87l} + K_{72l}\dot{\psi} + K_{76l}\bar{q}_{1l} + K_{77l}\dot{q}_{2l} + K_{74l}\dot{q}w + K_{73l}\dot{q}_{imu} + K_{75l}\dot{q}_{torso} + K_{71l}\ddot{x} \quad K_{88l} - K_{43l}\dot{\psi} - K_{45l}\dot{q}w - K_{44l}\dot{q}_{imu} - K_{46l}\dot{q}_{torso} \\
\bar{g}_{6l} &= {}^6l A_{5l}\bar{g}_{5l} \\
\bar{g}_{6l} &= [K_{29l}g^{c_{3l}} + K_{57l}g^{s_{3l}} \quad -K_{56l}g \quad K_{57l}g^{c_{3l}} - K_{29l}g^{s_{3l}} \quad] \\
K_{90l} &= K_{29l}c_{3l} + K_{57l}s_{3l} \\
K_{91l} &= K_{57l}c_{3l} - K_{29l}s_{3l} \\
\bar{g}_{6l} &= [K_{90l}g \quad -K_{56l}g \quad K_{91l}g \quad] \\
m_{6l}\bar{S}_{6l}^\times\bar{g}_{6l} &= \mathbf{MS}_{6l} \times \bar{g}_{6l} \\
m_{6l}\bar{S}_{6l}^\times\bar{g}_{6l} &= [K_{91l}\mathbf{MY}_{6l}g + K_{56l}\mathbf{MZ}_{6l}g \quad K_{90l}\mathbf{MZ}_{6l}g - K_{91l}\mathbf{MX}_{6l}g \quad -K_{56l}\mathbf{MX}_{6l}g - K_{90l}\mathbf{MY}_{6l}g \quad] \\
D_{85l} &= K_{91l}\mathbf{MY}_{6l} + K_{56l}\mathbf{MZ}_{6l} \\
D_{86l} &= K_{90l}\mathbf{MZ}_{6l} - K_{91l}\mathbf{MX}_{6l} \\
D_{87l} &= -K_{56l}\mathbf{MX}_{6l} - K_{90l}\mathbf{MY}_{6l} \\
m_{6l}\bar{S}_{6l}^\times\bar{g}_{6l} &= [D_{85l}g \quad D_{86l}g \quad D_{87l}g \quad] \\
m_{6l}\bar{a}_{G(6l)} &= m_{6l}\bar{a}_{6l} + \bar{\alpha}_{6l} \times \mathbf{MS}_{6l} + \bar{\omega}_{6l} \times (\bar{\omega}_{6l} \times \mathbf{MS}_{6l}) \\
m_{6l}\bar{a}_{G(6l)} &= [m_{6l}(K_{87l} + K_{72l}\dot{\psi} + K_{76l}\bar{q}_{1l} + K_{77l}\dot{q}_{2l} + K_{74l}\dot{q}w + K_{73l}\dot{q}_{imu} + K_{75l}\dot{q}_{torso} + K_{71l}\ddot{x}) - \mathbf{MZ}_{6l}(K_{52l} + \dot{q}_{3l} + K_{34l}\dot{\psi} + K_{35l}\dot{q}w + K_{35l}\dot{q}_{imu} + K_{36l}\dot{q}_{torso} \\
D_{88l} &= K_{71l}m_{6l} \\
D_{89l} &= K_{72l}m_{6l} - K_{65l}\mathbf{MY}_{6l} - K_{34l}\mathbf{MZ}_{6l} \\
D_{90l} &= K_{73l}m_{6l} - K_{66l}\mathbf{MY}_{6l} - K_{35l}\mathbf{MZ}_{6l} \\
D_{91l} &= K_{74l}m_{6l} - K_{66l}\mathbf{MY}_{6l} - K_{35l}\mathbf{MZ}_{6l}
\end{aligned}$$

$$\begin{aligned}
D_{92l} &= K_{75l}m_{6l} - K_{67l}\mathbf{M}\mathbf{Y}_{6l} - K_{36l}\mathbf{M}\mathbf{Z}_{6l} \\
D_{93l} &= K_{76l}m_{6l} - \mathbf{M}\mathbf{Z}_{6l}c_{2l} - K_{68l}\mathbf{M}\mathbf{Y}_{6l} \\
D_{94l} &= K_{77l}m_{6l} + \mathbf{M}\mathbf{Y}_{6l}s_{3l} \\
D_{95l} &= K_{87l}m_{6l} - K_{59l}^2\mathbf{M}\mathbf{X}_{6l} - K_{60l}^2\mathbf{M}\mathbf{X}_{6l} \\
&\quad - K_{86l}\mathbf{M}\mathbf{Y}_{6l} - K_{52l}\mathbf{M}\mathbf{Z}_{6l} + K_{58l}K_{59l}\mathbf{M}\mathbf{Y}_{6l} \\
&\quad + K_{58l}K_{60l}\mathbf{M}\mathbf{Z}_{6l} \\
D_{96l} &= -K_{42l}m_{6l} \\
D_{97l} &= K_{65l}\mathbf{M}\mathbf{X}_{6l} - K_{43l}m_{6l} - K_{61l}\mathbf{M}\mathbf{Z}_{6l} \\
D_{98l} &= K_{66l}\mathbf{M}\mathbf{X}_{6l} - K_{44l}m_{6l} - K_{62l}\mathbf{M}\mathbf{Z}_{6l} \\
D_{99l} &= K_{66l}\mathbf{M}\mathbf{X}_{6l} - K_{45l}m_{6l} - K_{62l}\mathbf{M}\mathbf{Z}_{6l} \\
D_{100l} &= K_{67l}\mathbf{M}\mathbf{X}_{6l} - K_{46l}m_{6l} - K_{63l}\mathbf{M}\mathbf{Z}_{6l} \\
D_{101l} &= K_{68l}\mathbf{M}\mathbf{X}_{6l} - K_{64l}\mathbf{M}\mathbf{Z}_{6l} \\
D_{102l} &= -\mathbf{M}\mathbf{Z}_{6l}c_{3l} - \mathbf{M}\mathbf{X}_{6l}s_{3l} \\
D_{103l} &= K_{88l}m_{6l} - K_{58l}^2\mathbf{M}\mathbf{Y}_{6l} - K_{60l}^2\mathbf{M}\mathbf{Y}_{6l} \\
&\quad + K_{86l}\mathbf{M}\mathbf{X}_{6l} - K_{85l}\mathbf{M}\mathbf{Z}_{6l} + K_{58l}K_{59l}\mathbf{M}\mathbf{X}_{6l} \\
&\quad + K_{59l}K_{60l}\mathbf{M}\mathbf{Z}_{6l} \\
D_{104l} &= K_{78l}m_{6l} \\
D_{105l} &= K_{79l}m_{6l} + K_{34l}\mathbf{M}\mathbf{X}_{6l} + K_{61l}\mathbf{M}\mathbf{Y}_{6l} \\
D_{106l} &= K_{80l}m_{6l} + K_{35l}\mathbf{M}\mathbf{X}_{6l} + K_{62l}\mathbf{M}\mathbf{Y}_{6l} \\
D_{107l} &= K_{81l}m_{6l} + K_{35l}\mathbf{M}\mathbf{X}_{6l} + K_{62l}\mathbf{M}\mathbf{Y}_{6l} \\
D_{108l} &= K_{82l}m_{6l} + K_{36l}\mathbf{M}\mathbf{X}_{6l} + K_{63l}\mathbf{M}\mathbf{Y}_{6l} \\
D_{109l} &= K_{83l}m_{6l} + \mathbf{M}\mathbf{X}_{6l}c_{2l} + K_{64l}\mathbf{M}\mathbf{Y}_{6l} \\
D_{110l} &= K_{84l}m_{6l} + \mathbf{M}\mathbf{Y}_{6l}c_{3l} \\
D_{111l} &= K_{89l}m_{6l} - K_{58l}^2\mathbf{M}\mathbf{Z}_{6l} - K_{59l}^2\mathbf{M}\mathbf{Z}_{6l} \\
&\quad + K_{52l}\mathbf{M}\mathbf{X}_{6l} + K_{85l}\mathbf{M}\mathbf{Y}_{6l} + K_{58l}K_{60l}\mathbf{M}\mathbf{X}_{6l} \\
&\quad + K_{59l}K_{60l}\mathbf{M}\mathbf{Y}_{6l} \\
m_{6l}\bar{a}_{G(6l)} &= [D_{95l} + D_{89l}\ddot{\psi} + D_{93l}\ddot{q}_{1l} + D_{94l}\ddot{q}_{2l} + D_{91l}\ddot{q}_w + D_{90l}\ddot{q}_{imu} + D_{92l}\ddot{q}_{torso} + D_{88l}\ddot{x} - \mathbf{M}\mathbf{Z}_{6l}\ddot{q}_{3l} \quad D_{103l} + D_{97l}\ddot{\psi} + D_{101l}\ddot{q}_{1l} + D_{102l}\ddot{q}_{2l} \\
\dot{H}_{6l} &= \mathbf{M}\mathbf{S}_{6l} \times \bar{a}_{6l} + J_{6l}\bar{\alpha}_{6l} + \bar{\omega}_{6l} \times J_{6l}\bar{\omega}_{6l} \\
\ddot{H}_{6l} &= [\mathbf{M}\mathbf{Z}_{6l}(K_{43l}\ddot{\psi} - K_{88l} + K_{45l}\ddot{q}_w + K_{44l}\ddot{q}_{imu} + K_{46l}\ddot{q}_{torso} + K_{42l}\ddot{x}) - K_{60l}(K_{58l}\mathbf{X}\mathbf{Y}_{6l} + K_{59l}\mathbf{Y}\mathbf{Y}_{6l} + K_{60l}\mathbf{Y}\mathbf{Z}_{6l}) + K_{59l}(K_{58l}\mathbf{X}\mathbf{Z}_{6l} \\
D_{112l} &= K_{78l}\mathbf{M}\mathbf{Y}_{6l} + K_{42l}\mathbf{M}\mathbf{Z}_{6l} \\
D_{113l} &= K_{61l}\mathbf{X}\mathbf{X}_{6l} - K_{34l}\mathbf{X}\mathbf{Y}_{6l} + K_{65l}\mathbf{X}\mathbf{Z}_{6l} \\
&\quad + K_{79l}\mathbf{M}\mathbf{Y}_{6l} + K_{43l}\mathbf{M}\mathbf{Z}_{6l} \\
D_{114l} &= K_{62l}\mathbf{X}\mathbf{X}_{6l} - K_{35l}\mathbf{X}\mathbf{Y}_{6l} + K_{66l}\mathbf{X}\mathbf{Z}_{6l} \\
&\quad + K_{80l}\mathbf{M}\mathbf{Y}_{6l} + K_{44l}\mathbf{M}\mathbf{Z}_{6l} \\
D_{115l} &= K_{62l}\mathbf{X}\mathbf{X}_{6l} - K_{35l}\mathbf{X}\mathbf{Y}_{6l} + K_{66l}\mathbf{X}\mathbf{Z}_{6l} \\
&\quad + K_{81l}\mathbf{M}\mathbf{Y}_{6l} + K_{45l}\mathbf{M}\mathbf{Z}_{6l} \\
D_{116l} &= K_{63l}\mathbf{X}\mathbf{X}_{6l} - K_{36l}\mathbf{X}\mathbf{Y}_{6l} + K_{67l}\mathbf{X}\mathbf{Z}_{6l} \\
&\quad + K_{82l}\mathbf{M}\mathbf{Y}_{6l} + K_{46l}\mathbf{M}\mathbf{Z}_{6l} \\
D_{117l} &= K_{64l}\mathbf{X}\mathbf{X}_{6l} + K_{68l}\mathbf{X}\mathbf{Z}_{6l} - \mathbf{X}\mathbf{Y}_{6l}c_{2l} \\
&\quad + K_{83l}\mathbf{M}\mathbf{Y}_{6l} \\
D_{118l} &= \mathbf{X}\mathbf{X}_{6l}c_{3l} - \mathbf{X}\mathbf{Z}_{6l}s_{3l} + K_{84l}\mathbf{M}\mathbf{Y}_{6l} \\
D_{119l} &= K_{85l}\mathbf{X}\mathbf{X}_{6l} - K_{52l}\mathbf{X}\mathbf{Y}_{6l} + K_{86l}\mathbf{X}\mathbf{Z}_{6l} \\
&\quad + K_{59l}^2\mathbf{Y}\mathbf{Z}_{6l} - K_{60l}^2\mathbf{Y}\mathbf{Z}_{6l} + K_{89l}\mathbf{M}\mathbf{Y}_{6l} \\
&\quad - K_{88l}\mathbf{M}\mathbf{Z}_{6l} - K_{58l}K_{60l}\mathbf{X}\mathbf{Y}_{6l} + K_{58l}K_{59l}\mathbf{X}\mathbf{Z}_{6l} \\
&\quad - K_{59l}K_{60l}\mathbf{Y}\mathbf{Y}_{6l} + K_{59l}K_{60l}\mathbf{Z}\mathbf{Z}_{6l} \\
D_{120l} &= K_{71l}\mathbf{M}\mathbf{Z}_{6l} - K_{78l}\mathbf{M}\mathbf{X}_{6l} \\
D_{121l} &= K_{61l}\mathbf{X}\mathbf{Y}_{6l} - K_{34l}\mathbf{Y}\mathbf{Y}_{6l} + K_{65l}\mathbf{Y}\mathbf{Z}_{6l} \\
&\quad - K_{79l}\mathbf{M}\mathbf{X}_{6l} + K_{72l}\mathbf{M}\mathbf{Z}_{6l} \\
D_{122l} &= K_{62l}\mathbf{X}\mathbf{Y}_{6l} - K_{35l}\mathbf{Y}\mathbf{Y}_{6l} + K_{66l}\mathbf{Y}\mathbf{Z}_{6l} \\
&\quad - K_{80l}\mathbf{M}\mathbf{X}_{6l} + K_{73l}\mathbf{M}\mathbf{Z}_{6l} \\
D_{123l} &= K_{62l}\mathbf{X}\mathbf{Y}_{6l} - K_{35l}\mathbf{Y}\mathbf{Y}_{6l} + K_{66l}\mathbf{Y}\mathbf{Z}_{6l} \\
&\quad - K_{81l}\mathbf{M}\mathbf{X}_{6l} + K_{74l}\mathbf{M}\mathbf{Z}_{6l} \\
D_{124l} &= K_{63l}\mathbf{X}\mathbf{Y}_{6l} - K_{36l}\mathbf{Y}\mathbf{Y}_{6l} + K_{67l}\mathbf{Y}\mathbf{Z}_{6l} \\
&\quad - K_{82l}\mathbf{M}\mathbf{X}_{6l} + K_{75l}\mathbf{M}\mathbf{Z}_{6l} \\
D_{125l} &= K_{64l}\mathbf{X}\mathbf{Y}_{6l} + K_{68l}\mathbf{Y}\mathbf{Z}_{6l} - \mathbf{Y}\mathbf{Y}_{6l}c_{2l} \\
&\quad - K_{83l}\mathbf{M}\mathbf{X}_{6l} + K_{76l}\mathbf{M}\mathbf{Z}_{6l} \\
D_{126l} &= \mathbf{X}\mathbf{Y}_{6l}c_{3l} - \mathbf{Y}\mathbf{Z}_{6l}s_{3l} - K_{84l}\mathbf{M}\mathbf{X}_{6l} \\
&\quad + K_{77l}\mathbf{M}\mathbf{Z}_{6l} \\
D_{127l} &= K_{85l}\mathbf{X}\mathbf{Y}_{6l} - K_{52l}\mathbf{Y}\mathbf{Y}_{6l} + K_{86l}\mathbf{Y}\mathbf{Z}_{6l} \\
&\quad - K_{58l}^2\mathbf{X}\mathbf{Z}_{6l} + K_{60l}^2\mathbf{X}\mathbf{Z}_{6l} - K_{89l}\mathbf{M}\mathbf{X}_{6l} \\
&\quad + K_{87l}\mathbf{M}\mathbf{Z}_{6l} + K_{58l}K_{60l}\mathbf{X}\mathbf{X}_{6l} + K_{59l}K_{60l}\mathbf{X}\mathbf{Y}_{6l} \\
&\quad - K_{58l}K_{59l}\mathbf{Y}\mathbf{Z}_{6l} - K_{58l}K_{60l}\mathbf{Z}\mathbf{Z}_{6l} \\
D_{128l} &= -K_{42l}\mathbf{M}\mathbf{X}_{6l} - K_{71l}\mathbf{M}\mathbf{Y}_{6l}
\end{aligned}$$

$$\begin{aligned}
D_{129l} &= K_{61l} \mathbf{XZ}_{6l} - K_{34l} \mathbf{YZ}_{6l} + K_{65l} \mathbf{ZZ}_{6l} \\
&\quad - K_{43l} \mathbf{MX}_{6l} - K_{72l} \mathbf{MY}_{6l} \\
D_{130l} &= K_{62l} \mathbf{XZ}_{6l} - K_{35l} \mathbf{YZ}_{6l} + K_{66l} \mathbf{ZZ}_{6l} \\
&\quad - K_{44l} \mathbf{MX}_{6l} - K_{73l} \mathbf{MY}_{6l} \\
D_{131l} &= K_{62l} \mathbf{XZ}_{6l} - K_{35l} \mathbf{YZ}_{6l} + K_{66l} \mathbf{ZZ}_{6l} \\
&\quad - K_{45l} \mathbf{MX}_{6l} - K_{74l} \mathbf{MY}_{6l} \\
D_{132l} &= K_{63l} \mathbf{XZ}_{6l} - K_{36l} \mathbf{YZ}_{6l} + K_{67l} \mathbf{ZZ}_{6l} \\
&\quad - K_{46l} \mathbf{MX}_{6l} - K_{75l} \mathbf{MY}_{6l} \\
D_{133l} &= K_{64l} \mathbf{XZ}_{6l} + K_{68l} \mathbf{ZZ}_{6l} - \mathbf{YZ}_{6l} c_{2l} \\
&\quad - K_{76l} \mathbf{MY}_{6l} \\
D_{134l} &= \mathbf{XZ}_{6l} c_{3l} - \mathbf{ZZ}_{6l} s_{3l} - K_{77l} \mathbf{MY}_{6l} \\
D_{135l} &= K_{85l} \mathbf{XZ}_{6l} - K_{52l} \mathbf{YZ}_{6l} + K_{86l} \mathbf{ZZ}_{6l} \\
&\quad + K_{58l}^2 \mathbf{XY}_{6l} - K_{59l}^2 \mathbf{XY}_{6l} + K_{88l} \mathbf{MX}_{6l} \\
&\quad - K_{87l} \mathbf{MY}_{6l} - K_{58l} K_{59l} \mathbf{XX}_{6l} - K_{59l} K_{60l} \mathbf{XZ}_{6l} \\
&\quad + K_{58l} K_{59l} \mathbf{YY}_{6l} + K_{58l} K_{60l} \mathbf{YZ}_{6l} \\
\tilde{H}_{6l} &= [D_{95l} + D_{89l} \tilde{\psi} + D_{93l} \tilde{q}_{1l} + D_{94l} \tilde{q}_{2l} + D_{91l} \tilde{q}_w + D_{90l} \tilde{q}_{imu} + D_{92l} \tilde{q}_{torso} + D_{88l} \tilde{x} - \mathbf{MZ}_{6l} \tilde{q}_{3l} \quad D_{103l} + D_{97l} \tilde{\psi} + D_{101l} \tilde{q}_{1l} + D_{102l} \tilde{q}_{2l} \\
&\quad \tilde{\omega}_{7l} = {}^{7l}A_{6l} \tilde{\omega}_{6l} + \tilde{q}_{7l} \tilde{e}_{7l} \\
&\quad \tilde{\omega}_{7l} = [-K_{58l} - \tilde{q}_{4l} \quad -K_{59l} c_{4l} - K_{60l} s_{4l} \quad K_{60l} c_{4l} - K_{59l} s_{4l} \quad] \\
K_{92l} &= -K_{58l} - \tilde{q}_{4l} \\
K_{93l} &= -K_{59l} c_{4l} - K_{60l} s_{4l} \\
K_{94l} &= K_{60l} c_{4l} - K_{59l} s_{4l} \\
&\quad \tilde{\omega}_{7l} = [K_{92l} \quad K_{93l} \quad K_{94l} \quad] \\
&\quad \tilde{\omega}_{7l} = [-\tilde{q}_{4l} - K_{61l} \tilde{\psi} - K_{64l} \tilde{q}_{1l} - K_{62l} \tilde{q}_w - K_{62l} \tilde{q}_{imu} - K_{63l} \tilde{q}_{torso} - \tilde{q}_{2l} c_{3l} \quad c_{4l} (\tilde{q}_{3l} + K_{34l} \tilde{\psi} + K_{35l} \tilde{q}_w + K_{35l} \tilde{q}_{imu} + K_{36l} \tilde{q}_{torso} + K_{37l} \tilde{x} \\
K_{95l} &= K_{34l} c_{4l} - K_{65l} s_{4l} \\
K_{96l} &= K_{35l} c_{4l} - K_{66l} s_{4l} \\
K_{97l} &= K_{36l} c_{4l} - K_{67l} s_{4l} \\
K_{98l} &= c_{2l} c_{4l} - K_{68l} s_{4l} \\
K_{99l} &= s_{3l} s_{4l} \\
K_{100l} &= K_{65l} c_{4l} + K_{34l} s_{4l} \\
K_{101l} &= K_{66l} c_{4l} + K_{35l} s_{4l} \\
K_{102l} &= K_{67l} c_{4l} + K_{36l} s_{4l} \\
K_{103l} &= c_{2l} s_{4l} + K_{68l} c_{4l} \\
K_{104l} &= -c_{4l} s_{3l} \\
&\quad \tilde{\omega}_{7l} = [-\tilde{q}_{4l} - K_{61l} \tilde{\psi} - K_{64l} \tilde{q}_{1l} - K_{62l} \tilde{q}_w - K_{62l} \tilde{q}_{imu} - K_{63l} \tilde{q}_{torso} - \tilde{q}_{2l} c_{3l} \quad K_{95l} \tilde{\psi} + K_{98l} \tilde{q}_{1l} + K_{99l} \tilde{q}_{2l} + K_{96l} \tilde{q}_w + K_{96l} \tilde{q}_{imu} + K_{97l} \tilde{x} \\
&\quad \tilde{v}_{7l} = {}^{7l}A_{6l} (\tilde{v}_{6l} + \tilde{\omega}_{6l} \times \tilde{P}_{7l}) \\
&\quad \tilde{v}_{7l} = [-K_{69l} \quad K_{40l} c_{4l} - K_{70l} s_{4l} \quad K_{70l} c_{4l} + K_{40l} s_{4l} \quad] \\
K_{105l} &= K_{40l} c_{4l} - K_{70l} s_{4l} \\
K_{106l} &= K_{70l} c_{4l} + K_{40l} s_{4l} \\
&\quad \tilde{v}_{7l} = [-K_{69l} \quad K_{105l} \quad K_{106l} \quad] \\
&\quad \tilde{v}_{7l} = [-K_{72l} \tilde{\psi} - K_{76l} \tilde{q}_{1l} - K_{77l} \tilde{q}_{2l} - K_{74l} \tilde{q}_w - K_{73l} \tilde{q}_{imu} - K_{75l} \tilde{q}_{torso} - K_{71l} \tilde{x} \quad c_{4l} (K_{43l} \tilde{\psi} + K_{45l} \tilde{q}_w + K_{44l} \tilde{q}_{imu} + K_{46l} \tilde{q}_{torso} + K_{47l} \tilde{x} \\
K_{107l} &= K_{42l} c_{4l} - K_{78l} s_{4l} \\
K_{108l} &= K_{43l} c_{4l} - K_{79l} s_{4l} \\
K_{109l} &= K_{44l} c_{4l} - K_{80l} s_{4l} \\
K_{110l} &= K_{45l} c_{4l} - K_{81l} s_{4l} \\
K_{111l} &= K_{46l} c_{4l} - K_{82l} s_{4l} \\
K_{112l} &= -K_{83l} s_{4l} \\
K_{113l} &= -K_{84l} s_{4l} \\
K_{114l} &= K_{78l} c_{4l} + K_{42l} s_{4l} \\
K_{115l} &= K_{79l} c_{4l} + K_{43l} s_{4l} \\
K_{116l} &= K_{80l} c_{4l} + K_{44l} s_{4l} \\
K_{117l} &= K_{81l} c_{4l} + K_{45l} s_{4l} \\
K_{118l} &= K_{82l} c_{4l} + K_{46l} s_{4l} \\
K_{119l} &= K_{83l} c_{4l} \\
K_{120l} &= K_{84l} c_{4l} \\
&\quad \tilde{v}_{7l} = [-K_{72l} \tilde{\psi} - K_{76l} \tilde{q}_{1l} - K_{77l} \tilde{q}_{2l} - K_{74l} \tilde{q}_w - K_{73l} \tilde{q}_{imu} - K_{75l} \tilde{q}_{torso} - K_{71l} \tilde{x} \quad K_{108l} \tilde{\psi} + K_{112l} \tilde{q}_{1l} + K_{113l} \tilde{q}_{2l} + K_{110l} \tilde{q}_w + K_{109l} \tilde{q}_{torso} + K_{111l} \tilde{x} \\
&\quad \tilde{\alpha}_{7l} = {}^{7l}A_{6l} \tilde{\alpha}_{6l} + \tilde{q}_{7l} \tilde{e}_{7l} + \tilde{q}_{7l} (\tilde{\omega}_{7l} \times \tilde{e}_{7l}) \\
&\quad \tilde{\alpha}_{7l} = [-K_{85l} - \tilde{q}_{4l} - K_{61l} \tilde{\psi} - K_{64l} \tilde{q}_{1l} - K_{62l} \tilde{q}_w - K_{62l} \tilde{q}_{imu} - K_{63l} \tilde{q}_{torso} - \tilde{q}_{2l} c_{3l} \quad c_{4l} (K_{52l} + \tilde{q}_{3l} + K_{34l} \tilde{\psi} + K_{35l} \tilde{q}_w + K_{35l} \tilde{q}_{imu} + K_{36l} \tilde{q}_{torso} + K_{37l} \tilde{x} \\
K_{121l} &= K_{52l} c_{4l} - K_{94l} \tilde{q}_{4l} - K_{86l} s_{4l} \\
K_{122l} &= K_{93l} \tilde{q}_{4l} + K_{86l} c_{4l} + K_{52l} s_{4l} \\
&\quad \tilde{\alpha}_{7l} = [-K_{85l} - \tilde{q}_{4l} - K_{61l} \tilde{\psi} - K_{64l} \tilde{q}_{1l} - K_{62l} \tilde{q}_w - K_{62l} \tilde{q}_{imu} - K_{63l} \tilde{q}_{torso} - \tilde{q}_{2l} c_{3l} \quad K_{121l} + K_{95l} \tilde{\psi} + K_{98l} \tilde{q}_{1l} + K_{99l} \tilde{q}_{2l} + K_{96l} \tilde{q}_w + K_{96l} \tilde{q}_{imu} + K_{97l} \tilde{x} \\
&\quad \tilde{a}_{7l} = {}^{7l}A_{6l} (\tilde{a}_{6l} + \tilde{\alpha}_{6l} \times \tilde{P}_{7l} + \tilde{\omega}_{6l} \times (\tilde{\omega}_{6l} \times \tilde{P}_{7l})) \\
&\quad \tilde{\alpha}_{7l} = [-K_{87l} - K_{72l} \tilde{\psi} - K_{76l} \tilde{q}_{1l} - K_{77l} \tilde{q}_{2l} - K_{74l} \tilde{q}_w - K_{73l} \tilde{q}_{imu} - K_{75l} \tilde{q}_{torso} - K_{71l} \tilde{x} \quad c_{4l} (K_{43l} \tilde{\psi} - K_{88l} + K_{45l} \tilde{q}_w + K_{44l} \tilde{q}_{imu} + K_{46l} \tilde{q}_{torso} + K_{47l} \tilde{x}
\end{aligned}$$

$$\begin{aligned}
K_{123l} &= -K_{88l}c_{4l} - K_{89l}s_{4l} \\
K_{124l} &= K_{89l}c_{4l} - K_{88l}s_{4l} \\
\bar{a}_{7l} &= [-K_{87l} - K_{72l}\tilde{\psi} - K_{76l}\tilde{q}_{1l} - K_{77l}\tilde{q}_{2l} - K_{74l}\tilde{q}_w - K_{73l}\tilde{q}_{imu} - K_{75l}\tilde{q}_{tors} - K_{71l}\tilde{x} \quad K_{123l} + K_{108l}\tilde{\psi} + K_{112l}\tilde{q}_{1l} + K_{113l}\tilde{q}_{2l} + K_{114l}\tilde{q}_w + K_{115l}\tilde{q}_{imu} + K_{116l}\tilde{q}_{tors} + K_{117l}\tilde{x}] \\
\bar{g}_{7l} &= {}^{7l}A_{6l}\bar{g}_{6l} \\
\bar{g}_{7l} &= [-K_{90l}g \quad K_{56l}gc_{4l} - K_{91l}gs_{4l} \quad K_{91l}gc_{4l} + K_{56l}gs_{4l} \quad] \\
K_{125l} &= K_{56l}c_{4l} - K_{91l}s_{4l} \\
K_{126l} &= K_{91l}c_{4l} + K_{56l}s_{4l} \\
\bar{g}_{7l} &= [-K_{90l}g \quad K_{125l}g \quad K_{126l}g \quad] \\
m_{7l}\tilde{S}_{7l}^\times \bar{g}_{7l} &= \mathbf{MS}_{7l} \times \bar{g}_{7l} \\
m_{7l}\tilde{S}_{7l}^\times \bar{g}_{7l} &= [K_{126l}\mathbf{MY}_{7l}g - K_{125l}\mathbf{MZ}_{7l}g \quad -K_{126l}\mathbf{MX}_{7l}g - K_{90l}\mathbf{MZ}_{7l}g \quad K_{125l}\mathbf{MX}_{7l}g + K_{90l}\mathbf{MY}_{7l}g \quad] \\
D_{136l} &= K_{126l}\mathbf{MY}_{7l} - K_{125l}\mathbf{MZ}_{7l} \\
D_{137l} &= -K_{126l}\mathbf{MX}_{7l} - K_{90l}\mathbf{MZ}_{7l} \\
D_{138l} &= K_{125l}\mathbf{MX}_{7l} + K_{90l}\mathbf{MY}_{7l} \\
m_{7l}\tilde{S}_{7l}^\times \bar{g}_{7l} &= [D_{136l}g \quad D_{137l}g \quad D_{138l}g \quad] \\
m_{7l}\bar{a}_G(7l) &= m_{7l}\bar{a}_{7l} + \bar{\alpha}_{7l} \times \mathbf{MS}_{7l} + \bar{\omega}_{7l} \times (\bar{\omega}_{7l} \times \mathbf{MS}_{7l}) \\
m_{7l}\bar{a}_G(7l) &= [\mathbf{MZ}_{7l}(K_{121l} + K_{95l}\tilde{\psi} + K_{98l}\tilde{q}_{1l} + K_{99l}\tilde{q}_{2l} + K_{96l}\tilde{q}_w + K_{96l}\tilde{q}_{imu} + K_{97l}\tilde{q}_{tors} + \tilde{q}_{3l}c_{4l}) - \mathbf{MY}_{7l}(K_{122l} + K_{100l}\tilde{\psi} + K_{103l}\tilde{q}_{1l} + K_{104l}\tilde{q}_{2l} + K_{101l}\tilde{q}_w + K_{101l}\tilde{q}_{imu} + K_{102l}\tilde{q}_{tors} + \tilde{q}_{4l}c_{4l}) \\
D_{139l} &= -K_{71l}m_{7l} \\
D_{140l} &= K_{95l}\mathbf{MZ}_{7l} - K_{100l}\mathbf{MY}_{7l} - K_{72l}m_{7l} \\
D_{141l} &= K_{96l}\mathbf{MZ}_{7l} - K_{101l}\mathbf{MY}_{7l} - K_{73l}m_{7l} \\
D_{142l} &= K_{96l}\mathbf{MZ}_{7l} - K_{101l}\mathbf{MY}_{7l} - K_{74l}m_{7l} \\
D_{143l} &= K_{97l}\mathbf{MZ}_{7l} - K_{102l}\mathbf{MY}_{7l} - K_{75l}m_{7l} \\
D_{144l} &= K_{98l}\mathbf{MZ}_{7l} - K_{103l}\mathbf{MY}_{7l} - K_{76l}m_{7l} \\
D_{145l} &= K_{99l}\mathbf{MZ}_{7l} - K_{104l}\mathbf{MY}_{7l} - K_{77l}m_{7l} \\
D_{146l} &= \mathbf{MZ}_{7l}c_{4l} - \mathbf{MY}_{7l}s_{4l} \\
D_{147l} &= K_{121l}\mathbf{MZ}_{7l} - K_{93l}^2\mathbf{MX}_{7l} - K_{94l}^2\mathbf{MX}_{7l} \\
&\quad - K_{122l}\mathbf{MY}_{7l} - K_{87l}m_{7l} + K_{92l}K_{93l}\mathbf{MY}_{7l} \\
&\quad + K_{92l}K_{94l}\mathbf{MZ}_{7l} \\
D_{148l} &= K_{107l}m_{7l} \\
D_{149l} &= K_{108l}m_{7l} + K_{100l}\mathbf{MX}_{7l} + K_{61l}\mathbf{MZ}_{7l} \\
D_{150l} &= K_{109l}m_{7l} + K_{101l}\mathbf{MX}_{7l} + K_{62l}\mathbf{MZ}_{7l} \\
D_{151l} &= K_{110l}m_{7l} + K_{101l}\mathbf{MX}_{7l} + K_{62l}\mathbf{MZ}_{7l} \\
D_{152l} &= K_{111l}m_{7l} + K_{102l}\mathbf{MX}_{7l} + K_{63l}\mathbf{MZ}_{7l} \\
D_{153l} &= K_{112l}m_{7l} + K_{103l}\mathbf{MX}_{7l} + K_{64l}\mathbf{MZ}_{7l} \\
D_{154l} &= K_{113l}m_{7l} + \mathbf{MZ}_{7l}c_{3l} + K_{104l}\mathbf{MX}_{7l} \\
D_{155l} &= \mathbf{MX}_{7l}s_{4l} \\
D_{156l} &= K_{123l}m_{7l} - K_{92l}^2\mathbf{MY}_{7l} - K_{94l}^2\mathbf{MY}_{7l} \\
&\quad + K_{122l}\mathbf{MX}_{7l} + K_{85l}\mathbf{MZ}_{7l} + K_{92l}K_{93l}\mathbf{MX}_{7l} \\
&\quad + K_{93l}K_{94l}\mathbf{MZ}_{7l} \\
D_{157l} &= K_{114l}m_{7l} \\
D_{158l} &= K_{115l}m_{7l} - K_{95l}\mathbf{MX}_{7l} - K_{61l}\mathbf{MY}_{7l} \\
D_{159l} &= K_{116l}m_{7l} - K_{96l}\mathbf{MX}_{7l} - K_{62l}\mathbf{MY}_{7l} \\
D_{160l} &= K_{117l}m_{7l} - K_{96l}\mathbf{MX}_{7l} - K_{62l}\mathbf{MY}_{7l} \\
D_{161l} &= K_{118l}m_{7l} - K_{97l}\mathbf{MX}_{7l} - K_{63l}\mathbf{MY}_{7l} \\
D_{162l} &= K_{119l}m_{7l} - K_{98l}\mathbf{MX}_{7l} - K_{64l}\mathbf{MY}_{7l} \\
D_{163l} &= K_{120l}m_{7l} - \mathbf{MY}_{7l}c_{3l} - K_{99l}\mathbf{MX}_{7l} \\
D_{164l} &= -\mathbf{MX}_{7l}c_{4l} \\
D_{165l} &= K_{124l}m_{7l} - K_{92l}^2\mathbf{MZ}_{7l} - K_{93l}^2\mathbf{MZ}_{7l} \\
&\quad - K_{121l}\mathbf{MX}_{7l} - K_{85l}\mathbf{MY}_{7l} + K_{92l}K_{94l}\mathbf{MX}_{7l} \\
&\quad + K_{93l}K_{94l}\mathbf{MY}_{7l} \\
m_{7l}\bar{a}_G(7l) &= [D_{147l} + D_{140l}\tilde{\psi} + D_{144l}\tilde{q}_{1l} + D_{145l}\tilde{q}_{2l} + D_{146l}\tilde{q}_{3l} + D_{142l}\tilde{q}_w + D_{141l}\tilde{q}_{imu} + D_{143l}\tilde{q}_{tors} + D_{139l}\tilde{x} \quad D_{156l} + D_{149l}\tilde{\psi} + D_{153l}\tilde{q}_{1l} + D_{154l}\tilde{q}_{2l} + D_{155l}\tilde{q}_{3l} + D_{157l}\tilde{x} + D_{158l}\tilde{\psi} + D_{159l}\tilde{q}_{1l} + D_{160l}\tilde{q}_{2l} + D_{161l}\tilde{q}_{3l} + D_{162l}\tilde{q}_w + D_{163l}\tilde{q}_{imu} + D_{164l}\tilde{q}_{tors} + D_{165l}\tilde{x}] \\
\dot{\bar{a}}_{7l} &= \mathbf{MS}_{7l} \times \bar{a}_{7l} + J_{7l}\bar{\alpha}_{7l} + \bar{\omega}_{7l} \times J_{7l}\bar{\omega}_{7l} \\
\dot{\bar{g}}_{7l} &= [K_{93l}(K_{92l}\mathbf{XZ}_{7l} + K_{93l}\mathbf{YZ}_{7l} + K_{94l}\mathbf{ZZ}_{7l}) - K_{94l}(K_{92l}\mathbf{XY}_{7l} + K_{93l}\mathbf{YY}_{7l} + K_{94l}\mathbf{YZ}_{7l}) + \mathbf{XY}_{7l}(K_{121l} + K_{95l}\tilde{\psi} + K_{98l}\tilde{q}_{1l} + K_{99l}\tilde{q}_{2l} + K_{96l}\tilde{q}_w + K_{96l}\tilde{q}_{imu} + K_{97l}\tilde{q}_{tors} + \tilde{q}_{3l}c_{4l}) \\
D_{166l} &= K_{114l}\mathbf{MY}_{7l} - K_{107l}\mathbf{MZ}_{7l} \\
D_{167l} &= K_{95l}\mathbf{XY}_{7l} - K_{61l}\mathbf{XX}_{7l} + K_{100l}\mathbf{XZ}_{7l} \\
&\quad + K_{115l}\mathbf{MY}_{7l} - K_{108l}\mathbf{MZ}_{7l} \\
D_{168l} &= K_{96l}\mathbf{XY}_{7l} - K_{62l}\mathbf{XX}_{7l} + K_{101l}\mathbf{XZ}_{7l} \\
&\quad + K_{116l}\mathbf{MY}_{7l} - K_{109l}\mathbf{MZ}_{7l} \\
D_{169l} &= K_{96l}\mathbf{XY}_{7l} - K_{62l}\mathbf{XX}_{7l} + K_{101l}\mathbf{XZ}_{7l} \\
&\quad + K_{117l}\mathbf{MY}_{7l} - K_{110l}\mathbf{MZ}_{7l} \\
D_{170l} &= K_{97l}\mathbf{XY}_{7l} - K_{63l}\mathbf{XX}_{7l} + K_{102l}\mathbf{XZ}_{7l} \\
&\quad + K_{118l}\mathbf{MY}_{7l} - K_{111l}\mathbf{MZ}_{7l}
\end{aligned}$$

$$\begin{aligned}
D_{171l} &= K_{98l} \mathbf{XY}_{7l} - K_{64l} \mathbf{XX}_{7l} + K_{103l} \mathbf{XZ}_{7l} \\
&\quad + K_{119l} \mathbf{MY}_{7l} - K_{112l} \mathbf{MZ}_{7l} \\
D_{172l} &= K_{99l} \mathbf{XY}_{7l} + K_{104l} \mathbf{XZ}_{7l} - \mathbf{XX}_{7l} c_{3l} \\
&\quad + K_{120l} \mathbf{MY}_{7l} - K_{113l} \mathbf{MZ}_{7l} \\
D_{173l} &= \mathbf{XY}_{7l} c_{4l} + \mathbf{XZ}_{7l} s_{4l} \\
D_{174l} &= K_{121l} \mathbf{XY}_{7l} - K_{85l} \mathbf{XX}_{7l} + K_{122l} \mathbf{XZ}_{7l} \\
&\quad + K_{93l}^2 \mathbf{YZ}_{7l} - K_{94l}^2 \mathbf{YZ}_{7l} + K_{124l} \mathbf{MY}_{7l} \\
&\quad - K_{123l} \mathbf{MZ}_{7l} - K_{92l} K_{94l} \mathbf{XY}_{7l} + K_{92l} K_{93l} \mathbf{XZ}_{7l} \\
&\quad - K_{93l} K_{94l} \mathbf{YY}_{7l} + K_{93l} K_{94l} \mathbf{ZZ}_{7l} \\
D_{175l} &= -K_{114l} \mathbf{MX}_{7l} - K_{71l} \mathbf{MZ}_{7l} \\
D_{176l} &= K_{95l} \mathbf{YY}_{7l} - K_{61l} \mathbf{XY}_{7l} + K_{100l} \mathbf{YZ}_{7l} \\
&\quad - K_{115l} \mathbf{MX}_{7l} - K_{72l} \mathbf{MZ}_{7l} \\
D_{177l} &= K_{96l} \mathbf{YY}_{7l} - K_{62l} \mathbf{XY}_{7l} + K_{101l} \mathbf{YZ}_{7l} \\
&\quad - K_{116l} \mathbf{MX}_{7l} - K_{73l} \mathbf{MZ}_{7l} \\
D_{178l} &= K_{96l} \mathbf{YY}_{7l} - K_{62l} \mathbf{XY}_{7l} + K_{101l} \mathbf{YZ}_{7l} \\
&\quad - K_{117l} \mathbf{MX}_{7l} - K_{74l} \mathbf{MZ}_{7l} \\
D_{179l} &= K_{97l} \mathbf{YY}_{7l} - K_{63l} \mathbf{XY}_{7l} + K_{102l} \mathbf{YZ}_{7l} \\
&\quad - K_{118l} \mathbf{MX}_{7l} - K_{75l} \mathbf{MZ}_{7l} \\
D_{180l} &= K_{98l} \mathbf{YY}_{7l} - K_{64l} \mathbf{XY}_{7l} + K_{103l} \mathbf{YZ}_{7l} \\
&\quad - K_{119l} \mathbf{MX}_{7l} - K_{76l} \mathbf{MZ}_{7l} \\
D_{181l} &= K_{99l} \mathbf{YY}_{7l} + K_{104l} \mathbf{YZ}_{7l} - \mathbf{XY}_{7l} c_{3l} \\
&\quad - K_{120l} \mathbf{MX}_{7l} - K_{77l} \mathbf{MZ}_{7l} \\
D_{182l} &= \mathbf{YY}_{7l} c_{4l} + \mathbf{YZ}_{7l} s_{4l} \\
D_{183l} &= K_{121l} \mathbf{YY}_{7l} - K_{85l} \mathbf{XY}_{7l} + K_{122l} \mathbf{YZ}_{7l} \\
&\quad - K_{92l}^2 \mathbf{XZ}_{7l} + K_{94l}^2 \mathbf{XZ}_{7l} - K_{124l} \mathbf{MX}_{7l} \\
&\quad - K_{87l} \mathbf{MZ}_{7l} + K_{92l} K_{94l} \mathbf{XX}_{7l} + K_{93l} K_{94l} \mathbf{XY}_{7l} \\
&\quad - K_{92l} K_{93l} \mathbf{YZ}_{7l} - K_{92l} K_{94l} \mathbf{ZZ}_{7l} \\
D_{184l} &= K_{107l} \mathbf{MX}_{7l} + K_{71l} \mathbf{MY}_{7l} \\
D_{185l} &= K_{95l} \mathbf{YZ}_{7l} - K_{61l} \mathbf{XZ}_{7l} + K_{100l} \mathbf{ZZ}_{7l} \\
&\quad + K_{108l} \mathbf{MX}_{7l} + K_{72l} \mathbf{MY}_{7l} \\
D_{186l} &= K_{96l} \mathbf{YZ}_{7l} - K_{62l} \mathbf{XZ}_{7l} + K_{101l} \mathbf{ZZ}_{7l} \\
&\quad + K_{109l} \mathbf{MX}_{7l} + K_{73l} \mathbf{MY}_{7l} \\
D_{187l} &= K_{96l} \mathbf{YZ}_{7l} - K_{62l} \mathbf{XZ}_{7l} + K_{101l} \mathbf{ZZ}_{7l} \\
&\quad + K_{110l} \mathbf{MX}_{7l} + K_{74l} \mathbf{MY}_{7l} \\
D_{188l} &= K_{97l} \mathbf{YZ}_{7l} - K_{63l} \mathbf{XZ}_{7l} + K_{102l} \mathbf{ZZ}_{7l} \\
&\quad + K_{111l} \mathbf{MX}_{7l} + K_{75l} \mathbf{MY}_{7l} \\
D_{189l} &= K_{98l} \mathbf{YZ}_{7l} - K_{64l} \mathbf{XZ}_{7l} + K_{103l} \mathbf{ZZ}_{7l} \\
&\quad + K_{112l} \mathbf{MX}_{7l} + K_{76l} \mathbf{MY}_{7l} \\
D_{190l} &= K_{99l} \mathbf{YZ}_{7l} + K_{104l} \mathbf{ZZ}_{7l} - \mathbf{XZ}_{7l} c_{3l} \\
&\quad + K_{113l} \mathbf{MX}_{7l} + K_{77l} \mathbf{MY}_{7l} \\
D_{191l} &= \mathbf{YZ}_{7l} c_{4l} + \mathbf{ZZ}_{7l} s_{4l} \\
D_{192l} &= K_{121l} \mathbf{YZ}_{7l} - K_{85l} \mathbf{XZ}_{7l} + K_{122l} \mathbf{ZZ}_{7l} \\
&\quad + K_{92l}^2 \mathbf{XY}_{7l} - K_{93l}^2 \mathbf{XY}_{7l} + K_{123l} \mathbf{MX}_{7l} \\
&\quad + K_{87l} \mathbf{MY}_{7l} - K_{92l} K_{93l} \mathbf{XX}_{7l} - K_{93l} K_{94l} \mathbf{XZ}_{7l} \\
&\quad + K_{92l} K_{93l} \mathbf{YY}_{7l} + K_{92l} K_{94l} \mathbf{YZ}_{7l} \\
\dot{H}_{7l} &= [D_{147l} + D_{140l} \dot{\psi} + D_{144l} \dot{q}_{1l} + D_{145l} \dot{q}_{2l} + D_{146l} \dot{q}_{3l} + D_{142l} \dot{q}_w + D_{141l} \dot{q}_{imu} + D_{143l} \dot{q}_{torso} + D_{139l} \ddot{x} \quad D_{156l} + D_{149l} \dot{\psi} + D_{153l} \dot{q}_{1l} \\
\bar{\omega}_{8l} &= {}^8l A_{7l} \bar{\omega}_{7l} + \dot{q}_{8l} \bar{e}_{8l} \\
\bar{\omega}_{8l} &= [K_{94l} s_{5l} - K_{92l} c_{5l} \quad -K_{93l} - \dot{q}_{5l} \quad -K_{94l} c_{5l} + K_{92l} s_{5l} \quad] \\
K_{127l} &= K_{94l} s_{5l} - K_{92l} c_{5l} \\
K_{128l} &= -K_{93l} - \dot{q}_{5l} \\
K_{129l} &= K_{94l} c_{5l} + K_{92l} s_{5l} \\
\bar{\omega}_{8l} &= [K_{127l} \quad K_{128l} \quad K_{129l} \quad] \\
\bar{\omega}_{8l} &= [s_{5l} (K_{100l} \dot{\psi} + K_{103l} \dot{q}_{1l} + K_{104l} \dot{q}_{2l} + K_{101l} \dot{q}_w + K_{101l} \dot{q}_{imu} + K_{102l} \dot{q}_{torso} + \dot{q}_{3l} s_{4l}) + c_{5l} (\dot{q}_{4l} + K_{61l} \dot{\psi} + K_{64l} \dot{q}_{1l} + K_{62l} \dot{q}_w + K_{62l} \dot{q}_{1l} \\
K_{130l} &= K_{61l} c_{5l} + K_{100l} s_{5l} \\
K_{131l} &= K_{62l} c_{5l} + K_{101l} s_{5l} \\
K_{132l} &= K_{63l} c_{5l} + K_{102l} s_{5l} \\
K_{133l} &= K_{64l} c_{5l} + K_{103l} s_{5l} \\
K_{134l} &= c_{3l} c_{5l} + K_{104l} s_{5l} \\
K_{135l} &= s_{4l} s_{5l} \\
K_{136l} &= K_{100l} c_{5l} - K_{61l} s_{5l} \\
K_{137l} &= K_{101l} c_{5l} - K_{62l} s_{5l} \\
K_{138l} &= K_{102l} c_{5l} - K_{63l} s_{5l} \\
K_{139l} &= K_{103l} c_{5l} - K_{64l} s_{5l}
\end{aligned}$$

$$\begin{aligned}
K_{140l} &= K_{104l}c_{5l} - c_{3l}s_{5l} \\
K_{141l} &= c_{5l}s_{4l} \\
\bar{\omega}_{8l} &= [K_{130l}\bar{\psi} + K_{133l}\bar{q}_{1l} + K_{134l}\bar{q}_{2l} + K_{135l}\bar{q}_{3l} + K_{131l}\bar{q}_w + K_{131l}\bar{q}_{imu} + K_{132l}\bar{q}_{torso} + \bar{q}_{4l}c_{5l} - \bar{q}_{5l} - K_{95l}\bar{\psi} - K_{98l}\bar{q}_{1l} - K_{99l}\bar{q}_{2l} \\
\bar{s}_{8l} &= s_{lA_{7l}}(\bar{v}_{7l} + \bar{\omega}_{7l} \times \bar{P}_{8l}) \\
\bar{v}_{8l} &= [c_{5l}(K_{69l} - K_{94l}L_8) + s_{5l}(K_{106l} - K_{92l}L_8) - K_{105l}c_{5l}(K_{106l} - K_{92l}L_8) - s_{5l}(K_{69l} - K_{94l}L_8)] \\
K_{142l} &= c_{5l}(K_{69l} - K_{94l}L_8) + s_{5l}(K_{106l} - K_{92l}L_8) \\
K_{143l} &= c_{5l}(K_{106l} - K_{92l}L_8) - s_{5l}(K_{69l} - K_{94l}L_8) \\
\bar{v}_{8l} &= [K_{142l} - K_{105l}K_{143l}] \\
\bar{v}_{8l} &= [c_{5l}(K_{72l}\bar{\psi} - L_8(K_{100l}\bar{\psi} + K_{103l}\bar{q}_{1l} + K_{104l}\bar{q}_{2l} + K_{101l}\bar{q}_w + K_{101l}\bar{q}_{imu} + K_{102l}\bar{q}_{torso} + \bar{q}_{3l}s_{4l}) + K_{76l}\bar{q}_{1l} + K_{77l}\bar{q}_{2l} + K_{74l}\bar{q}_w + \\
K_{144l} &= K_{71l}c_{5l} + K_{114l}s_{5l} \\
K_{145l} &= c_{5l}(K_{72l} - K_{100l}L_8) + s_{5l}(K_{115l} + K_{61l}L_8) \\
K_{146l} &= c_{5l}(K_{73l} - K_{101l}L_8) + s_{5l}(K_{116l} + K_{62l}L_8) \\
K_{147l} &= c_{5l}(K_{74l} - K_{101l}L_8) + s_{5l}(K_{117l} + K_{62l}L_8) \\
K_{148l} &= c_{5l}(K_{75l} - K_{102l}L_8) + s_{5l}(K_{118l} + K_{63l}L_8) \\
K_{149l} &= c_{5l}(K_{76l} - K_{103l}L_8) + s_{5l}(K_{119l} + K_{64l}L_8) \\
K_{150l} &= s_{5l}(K_{120l} + L_8c_{3l}) + c_{5l}(K_{77l} - K_{104l}L_8) \\
K_{151l} &= -L_8c_{5l}s_{4l} \\
K_{152l} &= L_8s_{5l} \\
K_{153l} &= K_{114l}c_{5l} - K_{71l}s_{5l} \\
K_{154l} &= c_{5l}(K_{115l} + K_{61l}L_8) - s_{5l}(K_{72l} - K_{100l}L_8) \\
K_{155l} &= c_{5l}(K_{116l} + K_{62l}L_8) - s_{5l}(K_{73l} - K_{101l}L_8) \\
K_{156l} &= c_{5l}(K_{117l} + K_{62l}L_8) - s_{5l}(K_{74l} - K_{101l}L_8) \\
K_{157l} &= c_{5l}(K_{118l} + K_{63l}L_8) - s_{5l}(K_{75l} - K_{102l}L_8) \\
K_{158l} &= c_{5l}(K_{119l} + K_{64l}L_8) - s_{5l}(K_{76l} - K_{103l}L_8) \\
K_{159l} &= c_{5l}(K_{120l} + L_8c_{3l}) - s_{5l}(K_{77l} - K_{104l}L_8) \\
K_{160l} &= L_8s_{4l}s_{5l} \\
K_{161l} &= L_8c_{5l} \\
\bar{v}_{8l} &= [K_{145l}\bar{\psi} + K_{149l}\bar{q}_{1l} + K_{150l}\bar{q}_{2l} + K_{151l}\bar{q}_{3l} + K_{152l}\bar{q}_{4l} + K_{147l}\bar{q}_w + K_{146l}\bar{q}_{imu} + K_{148l}\bar{q}_{torso} + K_{144l}\bar{x} - K_{108l}\bar{\psi} - K_{112l}\bar{q}_{1l} - \\
\bar{\alpha}_{8l} &= s_{lA_{7l}}\bar{\alpha}_{7l} + \bar{q}_{8l}\bar{e}_{8l} + \bar{q}_{8l}(\bar{\omega}_{8l} \times \bar{e}_{8l}) \\
\bar{\alpha}_{8l} &= [K_{129l}\bar{q}_{5l} + c_{5l}(K_{85l} + \bar{q}_{4l} + K_{61l}\bar{\psi} + K_{64l}\bar{q}_{1l} + K_{62l}\bar{q}_w + K_{62l}\bar{q}_{imu} + K_{63l}\bar{q}_{torso} + \bar{q}_{2l}c_{3l}) + s_{5l}(K_{122l} + K_{100l}\bar{\psi} + K_{103l}\bar{q}_{1l} + K_{104l}\bar{q}_{2l} \\
K_{162l} &= K_{129l}\bar{q}_{5l} + K_{85l}c_{5l} + K_{122l}s_{5l} \\
K_{163l} &= K_{122l}c_{5l} - K_{127l}\bar{q}_{5l} - K_{85l}s_{5l} \\
\bar{\alpha}_{8l} &= [K_{162l} + K_{130l}\bar{\psi} + K_{133l}\bar{q}_{1l} + K_{134l}\bar{q}_{2l} + K_{135l}\bar{q}_{3l} + K_{131l}\bar{q}_w + K_{131l}\bar{q}_{imu} + K_{132l}\bar{q}_{torso} + \bar{q}_{4l}c_{5l} - K_{121l} - \bar{q}_{5l} - K_{95l}\bar{\psi} - K_{98l}\bar{q}_{1l} - K_{99l}\bar{q}_{2l} \\
\bar{\alpha}_{8l} &= s_{lA_{7l}}(\bar{a}_{7l} + \bar{\alpha}_{7l} \times \bar{P}_{8l} + \bar{\omega}_{7l} \times (\bar{\omega}_{7l} \times \bar{P}_{8l})) \\
\bar{\alpha}_{8l} &= [s_{5l}(K_{124l} + K_{115l}\bar{\psi} + K_{119l}\bar{q}_{1l} + K_{120l}\bar{q}_{2l} + K_{117l}\bar{q}_w + K_{116l}\bar{q}_{imu} + K_{118l}\bar{q}_{torso} + K_{114l}\bar{x} + L_8(K_{85l} + \bar{q}_{4l} + K_{61l}\bar{\psi} + K_{64l}\bar{q}_{1l} + K_{62l}\bar{q}_w + K_{62l}\bar{q}_{imu} + K_{63l}\bar{q}_{torso} + \bar{q}_{2l}c_{3l}) \\
K_{164l} &= K_{87l}c_{5l} + K_{124l}s_{5l} - K_{122l}L_8c_{5l} \\
&+ K_{85l}L_8s_{5l} + K_{92l}K_{93l}L_8c_{5l} - K_{93l}K_{94l}L_8s_{5l} \\
K_{165l} &= -K_{123l} - K_{92l}^2L_8 - K_{94l}^2L_8 \\
K_{166l} &= K_{124l}c_{5l} - K_{87l}s_{5l} + K_{85l}L_8c_{5l} + K_{122l}L_8s_{5l} - K_{93l}K_{94l}L_8c_{5l} - K_{92l}K_{93l}L_8s_{5l} \\
\bar{a}_{8l} &= [K_{164l} + K_{145l}\bar{\psi} + K_{149l}\bar{q}_{1l} + K_{150l}\bar{q}_{2l} + K_{151l}\bar{q}_{3l} + K_{152l}\bar{q}_{4l} + K_{147l}\bar{q}_w + K_{146l}\bar{q}_{imu} + K_{148l}\bar{q}_{torso} + K_{144l}\bar{x} - K_{165l} - K_{108l}\bar{\psi} - K_{112l}\bar{q}_{1l} - \\
\bar{g}_{8l} &= s_{lA_{7l}}\bar{g}_{7l} \\
\bar{g}_{8l} &= [K_{90l}g_{c5l} + K_{126l}g_{s5l} - K_{125l}g - K_{126l}g_{c5l} - K_{90l}g_{s5l}] \\
K_{167l} &= K_{90l}c_{5l} + K_{126l}s_{5l} \\
K_{168l} &= K_{126l}c_{5l} - K_{90l}s_{5l} \\
\bar{g}_{8l} &= [K_{167l}g - K_{125l}g - K_{168l}g]
\end{aligned}$$

$$\begin{aligned}
m_{8l} \bar{S}_{8l}^{\times} \bar{g}_{8l} &= \mathbf{M} \mathbf{S}_{8l} \times \bar{g}_{8l} \\
m_{8l} \bar{S}_{8l}^{\times} \bar{g}_{8l} &= [K_{168l} \mathbf{M} \mathbf{Y}_{8r,g} + K_{125l} \mathbf{M} \mathbf{Z}_{8r,g} \quad K_{167l} \mathbf{M} \mathbf{Z}_{8r,g} - K_{168l} \mathbf{M} \mathbf{X}_{8r,g} \quad -K_{125l} \mathbf{M} \mathbf{X}_{8r,g} - K_{167l} \mathbf{M} \mathbf{Y}_{8r,g} \quad] \\
D_{193l} &= K_{168l} \mathbf{M} \mathbf{Y}_{8r} + K_{125l} \mathbf{M} \mathbf{Z}_{8r} \\
D_{194l} &= K_{167l} \mathbf{M} \mathbf{Z}_{8r} - K_{168l} \mathbf{M} \mathbf{X}_{8r} \\
D_{195l} &= -K_{125l} \mathbf{M} \mathbf{X}_{8r} - K_{167l} \mathbf{M} \mathbf{Y}_{8r} \\
m_{8l} \bar{S}_{8l}^{\times} \bar{g}_{8l} &= [D_{193l,g} \quad D_{194l,g} \quad D_{195l,g} \quad] \\
m_{8l} \bar{a}_G(8l) &= m_{8l} \bar{a}_{8l} + \bar{a}_{8l} \times \mathbf{M} \mathbf{S}_{8l} + \bar{\omega}_{8l} \times (\bar{\omega}_{8l} \times \mathbf{M} \mathbf{S}_{8l}) \\
m_{8l} \bar{a}_G(8l) &= [m_{8r}(K_{164l} + K_{145l} \ddot{\psi} + K_{149l} \ddot{q}_{1l} + K_{150l} \ddot{q}_{2l} + K_{151l} \ddot{q}_{3l} + K_{152l} \ddot{q}_{4l} + K_{147l} \ddot{q}_w + K_{146l} \ddot{q}_{imu} + K_{148l} \ddot{q}_{torso} + K_{144l} \ddot{x}) - \mathbf{M} \mathbf{Z}_{8r}(K_{144l} \ddot{x} \\
D_{196l} &= K_{144l} m_{8r} \\
D_{197l} &= K_{145l} m_{8r} - K_{136l} \mathbf{M} \mathbf{Y}_{8r} - K_{95l} \mathbf{M} \mathbf{Z}_{8r} \\
D_{198l} &= K_{146l} m_{8r} - K_{137l} \mathbf{M} \mathbf{Y}_{8r} - K_{96l} \mathbf{M} \mathbf{Z}_{8r} \\
D_{199l} &= K_{147l} m_{8r} - K_{137l} \mathbf{M} \mathbf{Y}_{8r} - K_{96l} \mathbf{M} \mathbf{Z}_{8r} \\
D_{200l} &= K_{148l} m_{8r} - K_{138l} \mathbf{M} \mathbf{Y}_{8r} - K_{97l} \mathbf{M} \mathbf{Z}_{8r} \\
D_{201l} &= K_{149l} m_{8r} - K_{139l} \mathbf{M} \mathbf{Y}_{8r} - K_{98l} \mathbf{M} \mathbf{Z}_{8r} \\
D_{202l} &= K_{150l} m_{8r} - K_{140l} \mathbf{M} \mathbf{Y}_{8r} - K_{99l} \mathbf{M} \mathbf{Z}_{8r} \\
D_{203l} &= K_{151l} m_{8r} - \mathbf{M} \mathbf{Z}_{8r} c_{4l} - K_{141l} \mathbf{M} \mathbf{Y}_{8r} \\
D_{204l} &= K_{152l} m_{8r} + \mathbf{M} \mathbf{Y}_{8r} s_{5l} \\
D_{205l} &= K_{164l} m_{8r} - K_{128l}^2 \mathbf{M} \mathbf{X}_{8r} - K_{129l}^2 \mathbf{M} \mathbf{X}_{8r} \\
&\quad - K_{163l} \mathbf{M} \mathbf{Y}_{8r} - K_{121l} \mathbf{M} \mathbf{Z}_{8r} + K_{127l} K_{128l} \mathbf{M} \mathbf{Y}_{8r} \\
&\quad + K_{127l} K_{129l} \mathbf{M} \mathbf{Z}_{8r} \\
D_{206l} &= -K_{107l} m_{8r} \\
D_{207l} &= K_{136l} \mathbf{M} \mathbf{X}_{8r} - K_{108l} m_{8r} - K_{130l} \mathbf{M} \mathbf{Z}_{8r} \\
D_{208l} &= K_{137l} \mathbf{M} \mathbf{X}_{8r} - K_{109l} m_{8r} - K_{131l} \mathbf{M} \mathbf{Z}_{8r} \\
D_{209l} &= K_{137l} \mathbf{M} \mathbf{X}_{8r} - K_{110l} m_{8r} - K_{131l} \mathbf{M} \mathbf{Z}_{8r} \\
D_{210l} &= K_{138l} \mathbf{M} \mathbf{X}_{8r} - K_{111l} m_{8r} - K_{132l} \mathbf{M} \mathbf{Z}_{8r} \\
D_{211l} &= K_{139l} \mathbf{M} \mathbf{X}_{8r} - K_{112l} m_{8r} - K_{133l} \mathbf{M} \mathbf{Z}_{8r} \\
D_{212l} &= K_{140l} \mathbf{M} \mathbf{X}_{8r} - K_{113l} m_{8r} - K_{134l} \mathbf{M} \mathbf{Z}_{8r} \\
D_{213l} &= K_{141l} \mathbf{M} \mathbf{X}_{8r} - K_{135l} \mathbf{M} \mathbf{Z}_{8r} \\
D_{214l} &= -\mathbf{M} \mathbf{Z}_{8r} c_{5l} - \mathbf{M} \mathbf{X}_{8r} s_{5l} \\
D_{215l} &= K_{165l} m_{8r} - K_{127l}^2 \mathbf{M} \mathbf{Y}_{8r} - K_{129l}^2 \mathbf{M} \mathbf{Y}_{8r} \\
&\quad + K_{163l} \mathbf{M} \mathbf{X}_{8r} - K_{162l} \mathbf{M} \mathbf{Z}_{8r} + K_{127l} K_{128l} \mathbf{M} \mathbf{X}_{8r} \\
&\quad + K_{128l} K_{129l} \mathbf{M} \mathbf{Z}_{8r} \\
D_{216l} &= K_{153l} m_{8r} \\
D_{217l} &= K_{154l} m_{8r} + K_{95l} \mathbf{M} \mathbf{X}_{8r} + K_{130l} \mathbf{M} \mathbf{Y}_{8r} \\
D_{218l} &= K_{155l} m_{8r} + K_{96l} \mathbf{M} \mathbf{X}_{8r} + K_{131l} \mathbf{M} \mathbf{Y}_{8r} \\
D_{219l} &= K_{156l} m_{8r} + K_{96l} \mathbf{M} \mathbf{X}_{8r} + K_{131l} \mathbf{M} \mathbf{Y}_{8r} \\
D_{220l} &= K_{157l} m_{8r} + K_{97l} \mathbf{M} \mathbf{X}_{8r} + K_{132l} \mathbf{M} \mathbf{Y}_{8r} \\
D_{221l} &= K_{158l} m_{8r} + K_{98l} \mathbf{M} \mathbf{X}_{8r} + K_{133l} \mathbf{M} \mathbf{Y}_{8r} \\
D_{222l} &= K_{159l} m_{8r} + K_{99l} \mathbf{M} \mathbf{X}_{8r} + K_{134l} \mathbf{M} \mathbf{Y}_{8r} \\
D_{223l} &= K_{160l} m_{8r} + \mathbf{M} \mathbf{X}_{8r} c_{4l} + K_{135l} \mathbf{M} \mathbf{Y}_{8r} \\
D_{224l} &= K_{161l} m_{8r} + \mathbf{M} \mathbf{Y}_{8r} c_{5l} \\
D_{225l} &= K_{166l} m_{8r} - K_{127l}^2 \mathbf{M} \mathbf{Z}_{8r} - K_{128l}^2 \mathbf{M} \mathbf{Z}_{8r} \\
&\quad + K_{121l} \mathbf{M} \mathbf{X}_{8r} + K_{162l} \mathbf{M} \mathbf{Y}_{8r} + K_{127l} K_{129l} \mathbf{M} \mathbf{X}_{8r} \\
&\quad + K_{128l} K_{129l} \mathbf{M} \mathbf{Y}_{8r} \\
m_{8l} \bar{a}_G(8l) &= [D_{205l} + D_{197l} \ddot{\psi} + D_{201l} \ddot{q}_{1l} + D_{202l} \ddot{q}_{2l} + D_{203l} \ddot{q}_{3l} + D_{204l} \ddot{q}_{4l} + D_{199l} \ddot{q}_w + D_{198l} \ddot{q}_{imu} + D_{200l} \ddot{q}_{torso} + D_{196l} \ddot{x} - \mathbf{M} \mathbf{Z}_{8r} \ddot{q}_{5l} \quad D_{214l} \ddot{q}_w \\
\ddot{H}_{8l} &= \mathbf{M} \mathbf{S}_{8l} \times \bar{a}_{8l} + J_{8l} \bar{a}_{8l} + \bar{\omega}_{8l} \times J_{8l} \bar{\omega}_{8l} \\
\ddot{H}_{8l} &= [K_{128l}(K_{127l} \mathbf{X} \mathbf{Z}_{8r} + K_{128l} \mathbf{Y} \mathbf{Z}_{8r} + K_{129l} \mathbf{Z} \mathbf{Z}_{8r}) - K_{129l}(K_{127l} \mathbf{X} \mathbf{Y}_{8r} + K_{128l} \mathbf{Y} \mathbf{Y}_{8r} + K_{129l} \mathbf{Y} \mathbf{Z}_{8r}) + \mathbf{M} \mathbf{Z}_{8r}(K_{108l} \ddot{\psi} - K_{165l} + K_{112l} \ddot{x} \\
D_{226l} &= K_{153l} \mathbf{M} \mathbf{Y}_{8r} + K_{107l} \mathbf{M} \mathbf{Z}_{8r} \\
D_{227l} &= K_{130l} \mathbf{X} \mathbf{X}_{8r} - K_{95l} \mathbf{X} \mathbf{Y}_{8r} + K_{136l} \mathbf{X} \mathbf{Z}_{8r} \\
&\quad + K_{154l} \mathbf{M} \mathbf{Y}_{8r} + K_{108l} \mathbf{M} \mathbf{Z}_{8r} \\
D_{228l} &= K_{131l} \mathbf{X} \mathbf{X}_{8r} - K_{96l} \mathbf{X} \mathbf{Y}_{8r} + K_{137l} \mathbf{X} \mathbf{Z}_{8r} \\
&\quad + K_{155l} \mathbf{M} \mathbf{Y}_{8r} + K_{109l} \mathbf{M} \mathbf{Z}_{8r} \\
D_{229l} &= K_{131l} \mathbf{X} \mathbf{X}_{8r} - K_{96l} \mathbf{X} \mathbf{Y}_{8r} + K_{137l} \mathbf{X} \mathbf{Z}_{8r} \\
&\quad + K_{156l} \mathbf{M} \mathbf{Y}_{8r} + K_{110l} \mathbf{M} \mathbf{Z}_{8r} \\
D_{230l} &= K_{132l} \mathbf{X} \mathbf{X}_{8r} - K_{97l} \mathbf{X} \mathbf{Y}_{8r} + K_{138l} \mathbf{X} \mathbf{Z}_{8r} \\
&\quad + K_{157l} \mathbf{M} \mathbf{Y}_{8r} + K_{111l} \mathbf{M} \mathbf{Z}_{8r} \\
D_{231l} &= K_{133l} \mathbf{X} \mathbf{X}_{8r} - K_{98l} \mathbf{X} \mathbf{Y}_{8r} + K_{139l} \mathbf{X} \mathbf{Z}_{8r} \\
&\quad + K_{158l} \mathbf{M} \mathbf{Y}_{8r} + K_{112l} \mathbf{M} \mathbf{Z}_{8r} \\
D_{232l} &= K_{134l} \mathbf{X} \mathbf{X}_{8r} - K_{99l} \mathbf{X} \mathbf{Y}_{8r} + K_{140l} \mathbf{X} \mathbf{Z}_{8r} \\
&\quad + K_{159l} \mathbf{M} \mathbf{Y}_{8r} + K_{113l} \mathbf{M} \mathbf{Z}_{8r} \\
D_{233l} &= K_{135l} \mathbf{X} \mathbf{X}_{8r} + K_{141l} \mathbf{X} \mathbf{Z}_{8r} - \mathbf{X} \mathbf{Y}_{8r} c_{4l} \\
&\quad + K_{160l} \mathbf{M} \mathbf{Y}_{8r}
\end{aligned}$$

$$\begin{aligned}
D_{234l} &= \mathbf{X}\mathbf{X}_{8r}c_{5l} - \mathbf{X}\mathbf{Z}_{8r}s_{5l} + K_{161l}\mathbf{M}\mathbf{Y}_{8r} \\
D_{235l} &= K_{162l}\mathbf{X}\mathbf{X}_{8r} - K_{121l}\mathbf{X}\mathbf{Y}_{8r} + K_{163l}\mathbf{X}\mathbf{Z}_{8r} \\
&\quad + K_{128l}^2\mathbf{Y}\mathbf{Z}_{8r} - K_{129l}^2\mathbf{Y}\mathbf{Z}_{8r} + K_{166l}\mathbf{M}\mathbf{Y}_{8r} \\
&\quad - K_{165l}\mathbf{M}\mathbf{Z}_{8r} - K_{127l}K_{129l}\mathbf{X}\mathbf{Y}_{8r} + K_{127l}K_{128l}\mathbf{X}\mathbf{Z}_{8r} \\
&\quad - K_{128l}K_{129l}\mathbf{Y}\mathbf{Y}_{8r} + K_{128l}K_{129l}\mathbf{Z}\mathbf{Z}_{8r} \\
D_{236l} &= K_{144l}\mathbf{M}\mathbf{Z}_{8r} - K_{153l}\mathbf{M}\mathbf{X}_{8r} \\
D_{237l} &= K_{130l}\mathbf{X}\mathbf{Y}_{8r} - K_{95l}\mathbf{Y}\mathbf{Y}_{8r} + K_{136l}\mathbf{Y}\mathbf{Z}_{8r} \\
&\quad - K_{154l}\mathbf{M}\mathbf{X}_{8r} + K_{145l}\mathbf{M}\mathbf{Z}_{8r} \\
D_{238l} &= K_{131l}\mathbf{X}\mathbf{Y}_{8r} - K_{96l}\mathbf{Y}\mathbf{Y}_{8r} + K_{137l}\mathbf{Y}\mathbf{Z}_{8r} \\
&\quad - K_{155l}\mathbf{M}\mathbf{X}_{8r} + K_{146l}\mathbf{M}\mathbf{Z}_{8r} \\
D_{239l} &= K_{131l}\mathbf{X}\mathbf{Y}_{8r} - K_{96l}\mathbf{Y}\mathbf{Y}_{8r} + K_{137l}\mathbf{Y}\mathbf{Z}_{8r} \\
&\quad - K_{156l}\mathbf{M}\mathbf{X}_{8r} + K_{147l}\mathbf{M}\mathbf{Z}_{8r} \\
D_{240l} &= K_{132l}\mathbf{X}\mathbf{Y}_{8r} - K_{97l}\mathbf{Y}\mathbf{Y}_{8r} + K_{138l}\mathbf{Y}\mathbf{Z}_{8r} \\
&\quad - K_{157l}\mathbf{M}\mathbf{X}_{8r} + K_{148l}\mathbf{M}\mathbf{Z}_{8r} \\
D_{241l} &= K_{133l}\mathbf{X}\mathbf{Y}_{8r} - K_{98l}\mathbf{Y}\mathbf{Y}_{8r} + K_{139l}\mathbf{Y}\mathbf{Z}_{8r} \\
&\quad - K_{158l}\mathbf{M}\mathbf{X}_{8r} + K_{149l}\mathbf{M}\mathbf{Z}_{8r} \\
D_{242l} &= K_{134l}\mathbf{X}\mathbf{Y}_{8r} - K_{99l}\mathbf{Y}\mathbf{Y}_{8r} + K_{140l}\mathbf{Y}\mathbf{Z}_{8r} \\
&\quad - K_{159l}\mathbf{M}\mathbf{X}_{8r} + K_{150l}\mathbf{M}\mathbf{Z}_{8r} \\
D_{243l} &= K_{135l}\mathbf{X}\mathbf{Y}_{8r} + K_{141l}\mathbf{Y}\mathbf{Z}_{8r} - \mathbf{Y}\mathbf{Y}_{8r}c_{4l} \\
&\quad - K_{160l}\mathbf{M}\mathbf{X}_{8r} + K_{151l}\mathbf{M}\mathbf{Z}_{8r} \\
D_{244l} &= \mathbf{X}\mathbf{Y}_{8r}c_{5l} - \mathbf{Y}\mathbf{Z}_{8r}s_{5l} - K_{161l}\mathbf{M}\mathbf{X}_{8r} \\
&\quad + K_{152l}\mathbf{M}\mathbf{Z}_{8r} \\
D_{245l} &= K_{162l}\mathbf{X}\mathbf{Y}_{8r} - K_{121l}\mathbf{Y}\mathbf{Y}_{8r} + K_{163l}\mathbf{Y}\mathbf{Z}_{8r} \\
&\quad - K_{127l}^2\mathbf{X}\mathbf{Z}_{8r} + K_{129l}^2\mathbf{X}\mathbf{Z}_{8r} - K_{166l}\mathbf{M}\mathbf{X}_{8r} \\
&\quad + K_{164l}\mathbf{M}\mathbf{Z}_{8r} + K_{127l}K_{129l}\mathbf{X}\mathbf{X}_{8r} + K_{128l}K_{129l}\mathbf{X}\mathbf{Y}_{8r} \\
&\quad - K_{127l}K_{128l}\mathbf{Y}\mathbf{Z}_{8r} - K_{127l}K_{129l}\mathbf{Z}\mathbf{Z}_{8r} \\
D_{246l} &= -K_{107l}\mathbf{M}\mathbf{X}_{8r} - K_{144l}\mathbf{M}\mathbf{Y}_{8r} \\
D_{247l} &= K_{130l}\mathbf{X}\mathbf{Z}_{8r} - K_{95l}\mathbf{Y}\mathbf{Z}_{8r} + K_{136l}\mathbf{Z}\mathbf{Z}_{8r} \\
&\quad - K_{108l}\mathbf{M}\mathbf{X}_{8r} - K_{145l}\mathbf{M}\mathbf{Y}_{8r} \\
D_{248l} &= K_{131l}\mathbf{X}\mathbf{Z}_{8r} - K_{96l}\mathbf{Y}\mathbf{Z}_{8r} + K_{137l}\mathbf{Z}\mathbf{Z}_{8r} \\
&\quad - K_{109l}\mathbf{M}\mathbf{X}_{8r} - K_{146l}\mathbf{M}\mathbf{Y}_{8r} \\
D_{249l} &= K_{131l}\mathbf{X}\mathbf{Z}_{8r} - K_{96l}\mathbf{Y}\mathbf{Z}_{8r} + K_{137l}\mathbf{Z}\mathbf{Z}_{8r} \\
&\quad - K_{110l}\mathbf{M}\mathbf{X}_{8r} - K_{147l}\mathbf{M}\mathbf{Y}_{8r} \\
D_{250l} &= K_{132l}\mathbf{X}\mathbf{Z}_{8r} - K_{97l}\mathbf{Y}\mathbf{Z}_{8r} + K_{138l}\mathbf{Z}\mathbf{Z}_{8r} \\
&\quad - K_{111l}\mathbf{M}\mathbf{X}_{8r} - K_{148l}\mathbf{M}\mathbf{Y}_{8r} \\
D_{251l} &= K_{133l}\mathbf{X}\mathbf{Z}_{8r} - K_{98l}\mathbf{Y}\mathbf{Z}_{8r} + K_{139l}\mathbf{Z}\mathbf{Z}_{8r} \\
&\quad - K_{112l}\mathbf{M}\mathbf{X}_{8r} - K_{149l}\mathbf{M}\mathbf{Y}_{8r} \\
D_{252l} &= K_{134l}\mathbf{X}\mathbf{Z}_{8r} - K_{99l}\mathbf{Y}\mathbf{Z}_{8r} + K_{140l}\mathbf{Z}\mathbf{Z}_{8r} \\
&\quad - K_{113l}\mathbf{M}\mathbf{X}_{8r} - K_{150l}\mathbf{M}\mathbf{Y}_{8r} \\
D_{253l} &= K_{135l}\mathbf{X}\mathbf{Z}_{8r} + K_{141l}\mathbf{Z}\mathbf{Z}_{8r} - \mathbf{Y}\mathbf{Z}_{8r}c_{4l} \\
&\quad - K_{151l}\mathbf{M}\mathbf{Y}_{8r} \\
D_{254l} &= \mathbf{X}\mathbf{Z}_{8r}c_{5l} - \mathbf{Z}\mathbf{Z}_{8r}s_{5l} - K_{152l}\mathbf{M}\mathbf{Y}_{8r} \\
D_{255l} &= K_{162l}\mathbf{X}\mathbf{Z}_{8r} - K_{121l}\mathbf{Y}\mathbf{Z}_{8r} + K_{163l}\mathbf{Z}\mathbf{Z}_{8r} \\
&\quad + K_{127l}^2\mathbf{X}\mathbf{Y}_{8r} - K_{128l}^2\mathbf{X}\mathbf{Y}_{8r} + K_{165l}\mathbf{M}\mathbf{X}_{8r} \\
&\quad - K_{164l}\mathbf{M}\mathbf{Y}_{8r} - K_{127l}K_{128l}\mathbf{X}\mathbf{X}_{8r} - K_{128l}K_{129l}\mathbf{X}\mathbf{Z}_{8r} \\
&\quad + K_{127l}K_{128l}\mathbf{Y}\mathbf{Y}_{8r} + K_{127l}K_{129l}\mathbf{Y}\mathbf{Z}_{8r} \\
\ddot{H}_{8l} &= [D_{205l} + D_{197l}\ddot{\psi} + D_{201l}\ddot{q}_{1l} + D_{202l}\ddot{q}_{2l} + D_{203l}\ddot{q}_{3l} + D_{204l}\ddot{q}_{4l} + D_{199l}\ddot{q}_w + D_{198l}\ddot{q}_{imu} + D_{200l}\ddot{q}_{torso} + D_{196l}\ddot{x} - \mathbf{M}\mathbf{Z}_{8r}\ddot{q}_{5l} \quad D_{206l}\ddot{y} \\
\ddot{\omega}_{9l} &= {}^{9l}A_{8l}\ddot{\omega}_{8l} + \ddot{q}_{9l}\ddot{e}_{9l} \\
\ddot{\omega}_{9l} &= [-K_{127l} - \ddot{q}_{6l} \quad -K_{128l}c_{6l} - K_{129l}s_{6l} \quad K_{129l}c_{6l} - K_{128l}s_{6l} \quad] \\
K_{169l} &= -K_{127l} - \ddot{q}_{6l} \\
K_{170l} &= -K_{128l}c_{6l} - K_{129l}s_{6l} \\
K_{171l} &= K_{129l}c_{6l} - K_{128l}s_{6l} \\
\ddot{\omega}_{9l} &= [K_{169l} \quad K_{170l} \quad K_{171l} \quad] \\
\ddot{\omega}_{9l} &= [-\ddot{q}_{6l} - K_{130l}\ddot{\psi} - K_{133l}\ddot{q}_{1l} - K_{134l}\ddot{q}_{2l} - K_{135l}\ddot{q}_{3l} - K_{131l}\ddot{q}_w - K_{131l}\ddot{q}_{imu} - K_{132l}\ddot{q}_{torso} - \ddot{q}_{4l}c_{5l} \quad c_{6l}(\ddot{q}_{5l} + K_{95l}\ddot{\psi} + K_{98l}\ddot{q}_{1l} + \\
K_{172l} &= K_{95l}c_{6l} - K_{136l}s_{6l} \\
K_{173l} &= K_{96l}c_{6l} - K_{137l}s_{6l} \\
K_{174l} &= K_{97l}c_{6l} - K_{138l}s_{6l} \\
K_{175l} &= K_{98l}c_{6l} - K_{139l}s_{6l} \\
K_{176l} &= K_{99l}c_{6l} - K_{140l}s_{6l} \\
K_{177l} &= c_{4l}c_{6l} - K_{141l}s_{6l} \\
K_{178l} &= s_{5l}s_{6l} \\
K_{179l} &= K_{136l}c_{6l} + K_{95l}s_{6l} \\
K_{180l} &= K_{137l}c_{6l} + K_{96l}s_{6l}
\end{aligned}$$

$$\begin{aligned}
K_{181l} &= K_{138l}c_{6l} + K_{97l}s_{6l} \\
K_{182l} &= K_{139l}c_{6l} + K_{98l}s_{6l} \\
K_{183l} &= K_{140l}c_{6l} + K_{99l}s_{6l} \\
K_{184l} &= c_{4l}s_{6l} + K_{141l}c_{6l} \\
K_{185l} &= -c_{6l}s_{5l} \\
\bar{\omega}_{9l} &= [-\dot{q}_{6l} - K_{130l}\dot{\psi} - K_{133l}\dot{q}_{1l} - K_{134l}\dot{q}_{2l} - K_{135l}\dot{q}_{3l} - K_{131l}\dot{q}_w - K_{131l}\dot{q}_{imu} - K_{132l}\dot{q}_{torso} - \dot{q}_{4l}c_{5l} \quad K_{172l}\dot{\psi} + K_{175l}\dot{q}_{1l} + K_{176l}\dot{q}_{2l} \\
\bar{v}_{9l} &= {}^9l A_{8l}(\bar{v}_{8l} + \bar{\omega}_{8l} \times \bar{P}_{9l}) \\
\bar{v}_{9l} &= [-K_{142l} \quad K_{105l}c_{6l} - K_{143l}s_{6l} \quad K_{143l}c_{6l} + K_{105l}s_{6l} \quad] \\
K_{186l} &= K_{105l}c_{6l} - K_{143l}s_{6l} \\
K_{187l} &= K_{143l}c_{6l} + K_{105l}s_{6l} \\
\bar{v}_{9l} &= [-K_{142l} \quad K_{186l} \quad K_{187l} \quad] \\
\bar{v}_{9l} &= [-K_{145l}\dot{\psi} - K_{149l}\dot{q}_{1l} - K_{150l}\dot{q}_{2l} - K_{151l}\dot{q}_{3l} - K_{152l}\dot{q}_{4l} - K_{147l}\dot{q}_w - K_{146l}\dot{q}_{imu} - K_{148l}\dot{q}_{torso} - K_{144l}\dot{x} \quad c_{6l}(K_{108l}\dot{\psi} + K_{112l}\dot{q}_{1l} \\
K_{188l} &= K_{107l}c_{6l} - K_{153l}s_{6l} \\
K_{189l} &= K_{108l}c_{6l} - K_{154l}s_{6l} \\
K_{190l} &= K_{109l}c_{6l} - K_{155l}s_{6l} \\
K_{191l} &= K_{110l}c_{6l} - K_{156l}s_{6l} \\
K_{192l} &= K_{111l}c_{6l} - K_{157l}s_{6l} \\
K_{193l} &= K_{112l}c_{6l} - K_{158l}s_{6l} \\
K_{194l} &= K_{113l}c_{6l} - K_{159l}s_{6l} \\
K_{195l} &= -K_{160l}s_{6l} \\
K_{196l} &= -K_{161l}s_{6l} \\
K_{197l} &= K_{153l}c_{6l} + K_{107l}s_{6l} \\
K_{198l} &= K_{154l}c_{6l} + K_{108l}s_{6l} \\
K_{199l} &= K_{155l}c_{6l} + K_{109l}s_{6l} \\
K_{200l} &= K_{156l}c_{6l} + K_{110l}s_{6l} \\
K_{201l} &= K_{157l}c_{6l} + K_{111l}s_{6l} \\
K_{202l} &= K_{158l}c_{6l} + K_{112l}s_{6l} \\
K_{203l} &= K_{159l}c_{6l} + K_{113l}s_{6l} \\
K_{204l} &= K_{160l}c_{6l} \\
K_{205l} &= K_{161l}c_{6l} \\
\bar{v}_{9l} &= [-K_{145l}\dot{\psi} - K_{149l}\dot{q}_{1l} - K_{150l}\dot{q}_{2l} - K_{151l}\dot{q}_{3l} - K_{152l}\dot{q}_{4l} - K_{147l}\dot{q}_w - K_{146l}\dot{q}_{imu} - K_{148l}\dot{q}_{torso} - K_{144l}\dot{x} \quad K_{189l}\dot{\psi} + K_{193l}\dot{q}_{1l} + \\
\bar{\alpha}_{9l} &= {}^9l A_{8l}\bar{\alpha}_{8l} + \dot{q}_{9l}\bar{e}_{9l} + \dot{q}_{9l}(\bar{\omega}_{9l} \times \bar{e}_{9l}) \\
\bar{\alpha}_{9l} &= [-K_{162l} - \dot{q}_{6l} - K_{130l}\dot{\psi} - K_{133l}\dot{q}_{1l} - K_{134l}\dot{q}_{2l} - K_{135l}\dot{q}_{3l} - K_{131l}\dot{q}_w - K_{131l}\dot{q}_{imu} - K_{132l}\dot{q}_{torso} - \dot{q}_{4l}c_{5l} \quad c_{6l}(K_{121l} + \dot{q}_{5l} + K_{122l}\dot{\psi} \\
K_{206l} &= K_{121l}c_{6l} - K_{171l}\dot{q}_{6l} - K_{163l}s_{6l} \\
K_{207l} &= K_{170l}\dot{q}_{6l} + K_{163l}c_{6l} + K_{121l}s_{6l} \\
\bar{\alpha}_{9l} &= [-K_{162l} - \dot{q}_{6l} - K_{130l}\dot{\psi} - K_{133l}\dot{q}_{1l} - K_{134l}\dot{q}_{2l} - K_{135l}\dot{q}_{3l} - K_{131l}\dot{q}_w - K_{131l}\dot{q}_{imu} - K_{132l}\dot{q}_{torso} - \dot{q}_{4l}c_{5l} \quad K_{206l} + K_{172l}\dot{\psi} + K_{175l}\dot{q}_{1l} + \\
\bar{a}_{9l} &= {}^9l A_{8l}(\bar{a}_{8l} + \bar{\alpha}_{8l} \times \bar{P}_{9l} + \bar{\omega}_{8l} \times (\bar{\omega}_{8l} \times \bar{P}_{9l})) \\
\bar{\alpha}_{9l} &= [-K_{164l} - K_{145l}\dot{\psi} - K_{149l}\dot{q}_{1l} - K_{150l}\dot{q}_{2l} - K_{151l}\dot{q}_{3l} - K_{152l}\dot{q}_{4l} - K_{147l}\dot{q}_w - K_{146l}\dot{q}_{imu} - K_{148l}\dot{q}_{torso} - K_{144l}\dot{x} \quad c_{6l}(K_{108l}\dot{\psi} + K_{112l}\dot{q}_{1l} \\
K_{208l} &= -K_{165l}c_{6l} - K_{166l}s_{6l} \\
K_{209l} &= K_{166l}c_{6l} - K_{165l}s_{6l} \\
\bar{a}_{9l} &= [-K_{164l} - K_{145l}\dot{\psi} - K_{149l}\dot{q}_{1l} - K_{150l}\dot{q}_{2l} - K_{151l}\dot{q}_{3l} - K_{152l}\dot{q}_{4l} - K_{147l}\dot{q}_w - K_{146l}\dot{q}_{imu} - K_{148l}\dot{q}_{torso} - K_{144l}\dot{x} \quad K_{208l} + K_{189l}\dot{\psi} + K_{193l}\dot{q}_{1l} + \\
\bar{g}_{9l} &= {}^9l A_{8l}\bar{g}_{8l} \\
\bar{g}_{9l} &= [-K_{167l}g \quad K_{125l}g^c_{6l} - K_{168l}g^s_{6l} \quad K_{168l}g^c_{6l} + K_{125l}g^s_{6l} \quad] \\
K_{210l} &= K_{125l}c_{6l} - K_{168l}s_{6l} \\
K_{211l} &= K_{168l}c_{6l} + K_{125l}s_{6l} \\
\bar{g}_{9l} &= [-K_{167l}g \quad K_{210l}g \quad K_{211l}g \quad] \\
m_{9l}\bar{S}_{9l}^\times \bar{g}_{9l} &= \mathbf{MS}_{9l} \times \bar{g}_{9l} \\
m_{9l}\bar{S}_{9l}^\times \bar{g}_{9l} &= [K_{211l}\mathbf{MY}_{9r}g - K_{210l}\mathbf{MZ}_{9r}g \quad -K_{211l}\mathbf{MX}_{9r}g - K_{167l}\mathbf{MZ}_{9r}g \quad K_{210l}\mathbf{MX}_{9r}g + K_{167l}\mathbf{MY}_{9r}g \quad] \\
D_{256l} &= K_{211l}\mathbf{MY}_{9r} - K_{210l}\mathbf{MZ}_{9r} \\
D_{257l} &= -K_{211l}\mathbf{MX}_{9r} - K_{167l}\mathbf{MZ}_{9r} \\
D_{258l} &= K_{210l}\mathbf{MX}_{9r} + K_{167l}\mathbf{MY}_{9r} \\
m_{9l}\bar{S}_{9l}^\times \bar{g}_{9l} &= [D_{256l}g \quad D_{257l}g \quad D_{258l}g \quad] \\
m_{9l}\bar{a}_G(9l) &= m_{9l}\bar{a}_{9l} + \bar{\alpha}_{9l} \times \mathbf{MS}_{9l} + \bar{\omega}_{9l} \times (\bar{\omega}_{9l} \times \mathbf{MS}_{9l}) \\
m_{9l}\bar{a}_G(9l) &= [\mathbf{MZ}_{9r}(K_{206l} + K_{172l}\dot{\psi} + K_{175l}\dot{q}_{1l} + K_{176l}\dot{q}_{2l} + K_{177l}\dot{q}_{3l} + K_{178l}\dot{q}_{4l} + K_{173l}\dot{q}_w + K_{173l}\dot{q}_{imu} + K_{174l}\dot{q}_{torso} + \dot{q}_{5l}c_{6l}) - \mathbf{MY}_{9r}(K_{172l}\dot{\psi} + K_{175l}\dot{q}_{1l} + K_{176l}\dot{q}_{2l} + K_{177l}\dot{q}_{3l} + K_{178l}\dot{q}_{4l} + K_{173l}\dot{q}_w + K_{173l}\dot{q}_{imu} + K_{174l}\dot{q}_{torso} + \dot{q}_{5l}c_{6l}) \\
D_{259l} &= -K_{144l}m_{9r} \\
D_{260l} &= K_{172l}\mathbf{MZ}_{9r} - K_{179l}\mathbf{MY}_{9r} - K_{145l}m_{9r} \\
D_{261l} &= K_{173l}\mathbf{MZ}_{9r} - K_{180l}\mathbf{MY}_{9r} - K_{146l}m_{9r} \\
D_{262l} &= K_{173l}\mathbf{MZ}_{9r} - K_{180l}\mathbf{MY}_{9r} - K_{147l}m_{9r} \\
D_{263l} &= K_{174l}\mathbf{MZ}_{9r} - K_{181l}\mathbf{MY}_{9r} - K_{148l}m_{9r} \\
D_{264l} &= K_{175l}\mathbf{MZ}_{9r} - K_{182l}\mathbf{MY}_{9r} - K_{149l}m_{9r} \\
D_{265l} &= K_{176l}\mathbf{MZ}_{9r} - K_{183l}\mathbf{MY}_{9r} - K_{150l}m_{9r}
\end{aligned}$$

$$\begin{aligned}
D_{266l} &= K_{177l} \mathbf{MZ}_{9r} - K_{184l} \mathbf{MY}_{9r} - K_{151l} m_{9r} \\
D_{267l} &= K_{178l} \mathbf{MZ}_{9r} - K_{185l} \mathbf{MY}_{9r} - K_{152l} m_{9r} \\
D_{268l} &= \mathbf{MZ}_{9r} c_{6l} - \mathbf{MY}_{9r} s_{6l} \\
D_{269l} &= K_{206l} \mathbf{MZ}_{9r} - K_{170l}^2 \mathbf{MX}_{9r} - K_{171l}^2 \mathbf{MX}_{9r} \\
&\quad - K_{207l} \mathbf{MY}_{9r} - K_{164l} m_{9r} + K_{169l} K_{170l} \mathbf{MY}_{9r} \\
&\quad + K_{169l} K_{171l} \mathbf{MZ}_{9r} \\
D_{270l} &= K_{188l} m_{9r} \\
D_{271l} &= K_{189l} m_{9r} + K_{179l} \mathbf{MX}_{9r} + K_{130l} \mathbf{MZ}_{9r} \\
D_{272l} &= K_{190l} m_{9r} + K_{180l} \mathbf{MX}_{9r} + K_{131l} \mathbf{MZ}_{9r} \\
D_{273l} &= K_{191l} m_{9r} + K_{180l} \mathbf{MX}_{9r} + K_{131l} \mathbf{MZ}_{9r} \\
D_{274l} &= K_{192l} m_{9r} + K_{181l} \mathbf{MX}_{9r} + K_{132l} \mathbf{MZ}_{9r} \\
D_{275l} &= K_{193l} m_{9r} + K_{182l} \mathbf{MX}_{9r} + K_{133l} \mathbf{MZ}_{9r} \\
D_{276l} &= K_{194l} m_{9r} + K_{183l} \mathbf{MX}_{9r} + K_{134l} \mathbf{MZ}_{9r} \\
D_{277l} &= K_{195l} m_{9r} + K_{184l} \mathbf{MX}_{9r} + K_{135l} \mathbf{MZ}_{9r} \\
D_{278l} &= K_{196l} m_{9r} + \mathbf{MZ}_{9r} c_{5l} + K_{185l} \mathbf{MX}_{9r} \\
D_{279l} &= \mathbf{MX}_{9r} s_{6l} \\
D_{280l} &= K_{208l} m_{9r} - K_{169l}^2 \mathbf{MY}_{9r} - K_{171l}^2 \mathbf{MY}_{9r} \\
&\quad + K_{207l} \mathbf{MX}_{9r} + K_{162l} \mathbf{MZ}_{9r} + K_{169l} K_{170l} \mathbf{MX}_{9r} \\
&\quad + K_{170l} K_{171l} \mathbf{MZ}_{9r} \\
D_{281l} &= K_{197l} m_{9r} \\
D_{282l} &= K_{198l} m_{9r} - K_{172l} \mathbf{MX}_{9r} - K_{130l} \mathbf{MY}_{9r} \\
D_{283l} &= K_{199l} m_{9r} - K_{173l} \mathbf{MX}_{9r} - K_{131l} \mathbf{MY}_{9r} \\
D_{284l} &= K_{200l} m_{9r} - K_{173l} \mathbf{MX}_{9r} - K_{131l} \mathbf{MY}_{9r} \\
D_{285l} &= K_{201l} m_{9r} - K_{174l} \mathbf{MX}_{9r} - K_{132l} \mathbf{MY}_{9r} \\
D_{286l} &= K_{202l} m_{9r} - K_{175l} \mathbf{MX}_{9r} - K_{133l} \mathbf{MY}_{9r} \\
D_{287l} &= K_{203l} m_{9r} - K_{176l} \mathbf{MX}_{9r} - K_{134l} \mathbf{MY}_{9r} \\
D_{288l} &= K_{204l} m_{9r} - K_{177l} \mathbf{MX}_{9r} - K_{135l} \mathbf{MY}_{9r} \\
D_{289l} &= K_{205l} m_{9r} - \mathbf{MY}_{9r} c_{5l} - K_{178l} \mathbf{MX}_{9r} \\
D_{290l} &= -\mathbf{MX}_{9r} c_{6l} \\
D_{291l} &= K_{209l} m_{9r} - K_{169l}^2 \mathbf{MZ}_{9r} - K_{170l}^2 \mathbf{MZ}_{9r} \\
&\quad - K_{206l} \mathbf{MX}_{9r} - K_{162l} \mathbf{MY}_{9r} + K_{169l} K_{171l} \mathbf{MX}_{9r} \\
&\quad + K_{170l} K_{171l} \mathbf{MY}_{9r} \\
m_{9l} \bar{a}_G(9l) &= [D_{269l} + D_{260l} \bar{\psi} + D_{264l} \bar{q}_{1l} + D_{265l} \bar{q}_{2l} + D_{266l} \bar{q}_{3l} + D_{267l} \bar{q}_{4l} + D_{262l} \bar{q}_w + D_{268l} \bar{q}_{5l} + D_{261l} \bar{q}_{imu} + D_{263l} \bar{q}_{torso} + D_{259l} \bar{x} \quad D_{289l} \\
\bar{H}_{9l} &= \mathbf{MS}_{9l} \times \bar{a}_{9l} + J_{9l} \bar{a}_{9l} + \bar{\omega}_{9l} \times J_{9l} \bar{\omega}_{9l} \\
\bar{H}_{9l} &= [K_{170l} (K_{169l} \mathbf{XZ}_{9r} + K_{170l} \mathbf{YZ}_{9r} + K_{171l} \mathbf{ZZ}_{9r}) - K_{171l} (K_{169l} \mathbf{XY}_{9r} + K_{170l} \mathbf{YY}_{9r} + K_{171l} \mathbf{YZ}_{9r}) + \mathbf{XY}_{9r} (K_{206l} + K_{172l} \bar{\psi} + K_{173l} \bar{q}_{1l}) \\
D_{292l} &= K_{197l} \mathbf{MY}_{9r} - K_{188l} \mathbf{MZ}_{9r} \\
D_{293l} &= K_{172l} \mathbf{XY}_{9r} - K_{130l} \mathbf{XX}_{9r} + K_{179l} \mathbf{XZ}_{9r} \\
&\quad + K_{198l} \mathbf{MY}_{9r} - K_{189l} \mathbf{MZ}_{9r} \\
D_{294l} &= K_{173l} \mathbf{XY}_{9r} - K_{131l} \mathbf{XX}_{9r} + K_{180l} \mathbf{XZ}_{9r} \\
&\quad + K_{199l} \mathbf{MY}_{9r} - K_{190l} \mathbf{MZ}_{9r} \\
D_{295l} &= K_{173l} \mathbf{XY}_{9r} - K_{131l} \mathbf{XX}_{9r} + K_{180l} \mathbf{XZ}_{9r} \\
&\quad + K_{200l} \mathbf{MY}_{9r} - K_{191l} \mathbf{MZ}_{9r} \\
D_{296l} &= K_{174l} \mathbf{XY}_{9r} - K_{132l} \mathbf{XX}_{9r} + K_{181l} \mathbf{XZ}_{9r} \\
&\quad + K_{201l} \mathbf{MY}_{9r} - K_{192l} \mathbf{MZ}_{9r} \\
D_{297l} &= K_{175l} \mathbf{XY}_{9r} - K_{133l} \mathbf{XX}_{9r} + K_{182l} \mathbf{XZ}_{9r} \\
&\quad + K_{202l} \mathbf{MY}_{9r} - K_{193l} \mathbf{MZ}_{9r} \\
D_{298l} &= K_{176l} \mathbf{XY}_{9r} - K_{134l} \mathbf{XX}_{9r} + K_{183l} \mathbf{XZ}_{9r} \\
&\quad + K_{203l} \mathbf{MY}_{9r} - K_{194l} \mathbf{MZ}_{9r} \\
D_{299l} &= K_{177l} \mathbf{XY}_{9r} - K_{135l} \mathbf{XX}_{9r} + K_{184l} \mathbf{XZ}_{9r} \\
&\quad + K_{204l} \mathbf{MY}_{9r} - K_{195l} \mathbf{MZ}_{9r} \\
D_{300l} &= K_{178l} \mathbf{XY}_{9r} + K_{185l} \mathbf{XZ}_{9r} - \mathbf{XX}_{9r} c_{5l} \\
&\quad + K_{205l} \mathbf{MY}_{9r} - K_{196l} \mathbf{MZ}_{9r} \\
D_{301l} &= \mathbf{XY}_{9r} c_{6l} + \mathbf{XZ}_{9r} s_{6l} \\
D_{302l} &= K_{206l} \mathbf{XY}_{9r} - K_{162l} \mathbf{XX}_{9r} + K_{207l} \mathbf{XZ}_{9r} \\
&\quad + K_{170l}^2 \mathbf{YZ}_{9r} - K_{171l}^2 \mathbf{YZ}_{9r} + K_{209l} \mathbf{MY}_{9r} \\
&\quad - K_{208l} \mathbf{MZ}_{9r} - K_{169l} K_{171l} \mathbf{XY}_{9r} + K_{169l} K_{170l} \mathbf{XZ}_{9r} \\
&\quad - K_{170l} K_{171l} \mathbf{YY}_{9r} + K_{170l} K_{171l} \mathbf{ZZ}_{9r} \\
D_{303l} &= -K_{197l} \mathbf{MX}_{9r} - K_{144l} \mathbf{MZ}_{9r} \\
D_{304l} &= K_{172l} \mathbf{YY}_{9r} - K_{130l} \mathbf{XY}_{9r} + K_{179l} \mathbf{YZ}_{9r} \\
&\quad - K_{198l} \mathbf{MX}_{9r} - K_{145l} \mathbf{MZ}_{9r} \\
D_{305l} &= K_{173l} \mathbf{YY}_{9r} - K_{131l} \mathbf{XY}_{9r} + K_{180l} \mathbf{YZ}_{9r} \\
&\quad - K_{199l} \mathbf{MX}_{9r} - K_{146l} \mathbf{MZ}_{9r} \\
D_{306l} &= K_{173l} \mathbf{YY}_{9r} - K_{131l} \mathbf{XY}_{9r} + K_{180l} \mathbf{YZ}_{9r}
\end{aligned}$$

$$\begin{aligned}
& -K_{200l}\mathbf{MX}_{9r}-K_{147l}\mathbf{MZ}_{9r}\\
D_{307l}&=K_{174l}\mathbf{YY}_{9r}-K_{132l}\mathbf{XY}_{9r}+K_{181l}\mathbf{YZ}_{9r}\\
& -K_{201l}\mathbf{MX}_{9r}-K_{148l}\mathbf{MZ}_{9r}\\
D_{308l}&=K_{175l}\mathbf{YY}_{9r}-K_{133l}\mathbf{XY}_{9r}+K_{182l}\mathbf{YZ}_{9r}\\
& -K_{202l}\mathbf{MX}_{9r}-K_{149l}\mathbf{MZ}_{9r}\\
D_{309l}&=K_{176l}\mathbf{YY}_{9r}-K_{134l}\mathbf{XY}_{9r}+K_{183l}\mathbf{YZ}_{9r}\\
& -K_{203l}\mathbf{MX}_{9r}-K_{150l}\mathbf{MZ}_{9r}\\
D_{310l}&=K_{177l}\mathbf{YY}_{9r}-K_{135l}\mathbf{XY}_{9r}+K_{184l}\mathbf{YZ}_{9r}\\
& -K_{204l}\mathbf{MX}_{9r}-K_{151l}\mathbf{MZ}_{9r}\\
D_{311l}&=K_{178l}\mathbf{YY}_{9r}+K_{185l}\mathbf{YZ}_{9r}-\mathbf{XY}_{9r}c_{5l}\\
& -K_{205l}\mathbf{MX}_{9r}-K_{152l}\mathbf{MZ}_{9r}\\
D_{312l}&=\mathbf{YY}_{9r}c_{6l}+\mathbf{YZ}_{9r}s_{6l}\\
D_{313l}&=K_{206l}\mathbf{YY}_{9r}-K_{162l}\mathbf{XY}_{9r}+K_{207l}\mathbf{YZ}_{9r}\\
& -K_{169l}^2\mathbf{XZ}_{9r}+K_{171l}^2\mathbf{XZ}_{9r}-K_{209l}\mathbf{MX}_{9r}\\
& -K_{164l}\mathbf{MZ}_{9r}+K_{169l}K_{171l}\mathbf{XX}_{9r}+K_{170l}K_{171l}\mathbf{XY}_{9r}\\
& -K_{169l}K_{170l}\mathbf{YZ}_{9r}-K_{169l}K_{171l}\mathbf{ZZ}_{9r}\\
D_{314l}&=K_{188l}\mathbf{MX}_{9r}+K_{144l}\mathbf{MY}_{9r}\\
D_{315l}&=K_{172l}\mathbf{YZ}_{9r}-K_{130l}\mathbf{XZ}_{9r}+K_{179l}\mathbf{ZZ}_{9r}\\
& +K_{189l}\mathbf{MX}_{9r}+K_{145l}\mathbf{MY}_{9r}\\
D_{316l}&=K_{173l}\mathbf{YZ}_{9r}-K_{131l}\mathbf{XZ}_{9r}+K_{180l}\mathbf{ZZ}_{9r}\\
& +K_{190l}\mathbf{MX}_{9r}+K_{146l}\mathbf{MY}_{9r}\\
D_{317l}&=K_{173l}\mathbf{YZ}_{9r}-K_{131l}\mathbf{XZ}_{9r}+K_{180l}\mathbf{ZZ}_{9r}\\
& +K_{191l}\mathbf{MX}_{9r}+K_{147l}\mathbf{MY}_{9r}\\
D_{318l}&=K_{174l}\mathbf{YZ}_{9r}-K_{132l}\mathbf{XZ}_{9r}+K_{181l}\mathbf{ZZ}_{9r}\\
& +K_{192l}\mathbf{MX}_{9r}+K_{148l}\mathbf{MY}_{9r}\\
D_{319l}&=K_{175l}\mathbf{YZ}_{9r}-K_{133l}\mathbf{XZ}_{9r}+K_{182l}\mathbf{ZZ}_{9r}\\
& +K_{193l}\mathbf{MX}_{9r}+K_{149l}\mathbf{MY}_{9r}\\
D_{320l}&=K_{176l}\mathbf{YZ}_{9r}-K_{134l}\mathbf{XZ}_{9r}+K_{183l}\mathbf{ZZ}_{9r}\\
& +K_{194l}\mathbf{MX}_{9r}+K_{150l}\mathbf{MY}_{9r}\\
D_{321l}&=K_{177l}\mathbf{YZ}_{9r}-K_{135l}\mathbf{XZ}_{9r}+K_{184l}\mathbf{ZZ}_{9r}\\
& +K_{195l}\mathbf{MX}_{9r}+K_{151l}\mathbf{MY}_{9r}\\
D_{322l}&=K_{178l}\mathbf{YZ}_{9r}+K_{185l}\mathbf{ZZ}_{9r}-\mathbf{XZ}_{9r}c_{5l}\\
& +K_{196l}\mathbf{MX}_{9r}+K_{152l}\mathbf{MY}_{9r}\\
D_{323l}&=\mathbf{YZ}_{9r}c_{6l}+\mathbf{ZZ}_{9r}s_{6l}\\
D_{324l}&=K_{206l}\mathbf{YZ}_{9r}-K_{162l}\mathbf{XZ}_{9r}+K_{207l}\mathbf{ZZ}_{9r}\\
& +K_{169l}^2\mathbf{XY}_{9r}-K_{170l}^2\mathbf{XY}_{9r}+K_{208l}\mathbf{MX}_{9r}\\
& +K_{164l}\mathbf{MY}_{9r}-K_{169l}K_{170l}\mathbf{XX}_{9r}-K_{170l}K_{171l}\mathbf{XZ}_{9r}\\
& +K_{169l}K_{170l}\mathbf{YY}_{9r}+K_{169l}K_{171l}\mathbf{YZ}_{9r}\\
\dot{H}_{9l}&=[D_{269l}+D_{260l}\psi+D_{264l}\dot{q}_{1l}+D_{265l}\dot{q}_2+D_{266l}\dot{q}_3+D_{267l}\dot{q}_4+D_{262l}\dot{q}_w+D_{268l}\dot{q}_5+D_{261l}\dot{q}_{imu}+D_{263l}\dot{q}_{torso}+D_{259l}\ddot{x}-D_{289l}\dot{\psi}]\\
\bar{\omega}_{10l}&=^{10l}A_{9l}\bar{\omega}_{9l}+\dot{q}_{10l}\bar{e}_{10l}\\
\bar{\omega}_{10l}&=[K_{171l}s_{7l}-K_{169l}c_{7l}-K_{171l}c_{7l}-K_{169l}s_{7l}-K_{170l}-\dot{q}_{7l}]\\
K_{212l}&=K_{171l}s_{7l}-K_{169l}c_{7l}\\
K_{213l}&=-K_{171l}c_{7l}-K_{169l}s_{7l}\\
K_{214l}&=-K_{170l}-\dot{q}_{7l}\\
\bar{\omega}_{10l}&=[K_{212l} \quad K_{213l} \quad K_{214l}]\\
\bar{\omega}_{10l}&=[s_{7l}(K_{179l}\psi+K_{182l}\dot{q}_{1l}+K_{183l}\dot{q}_2+K_{184l}\dot{q}_3+K_{185l}\dot{q}_4+K_{180l}\dot{q}_w+K_{180l}\dot{q}_{imu}+K_{181l}\dot{q}_{torso}+\dot{q}_5s_{6l})+c_{7l}(\dot{q}_6+K_{130l}\psi+K_{131l}\dot{q}_1)\\
K_{215l}&=K_{130l}c_{7l}+K_{179l}s_{7l}\\
K_{216l}&=K_{131l}c_{7l}+K_{180l}s_{7l}\\
K_{217l}&=K_{132l}c_{7l}+K_{181l}s_{7l}\\
K_{218l}&=K_{133l}c_{7l}+K_{182l}s_{7l}\\
K_{219l}&=K_{134l}c_{7l}+K_{183l}s_{7l}\\
K_{220l}&=K_{135l}c_{7l}+K_{184l}s_{7l}\\
K_{221l}&=c_{5l}c_{7l}+K_{185l}s_{7l}\\
K_{222l}&=s_{6l}s_{7l}\\
K_{223l}&=K_{130l}s_{7l}-K_{179l}c_{7l}\\
K_{224l}&=K_{131l}s_{7l}-K_{180l}c_{7l}\\
K_{225l}&=K_{132l}s_{7l}-K_{181l}c_{7l}\\
K_{226l}&=K_{133l}s_{7l}-K_{182l}c_{7l}\\
K_{227l}&=K_{134l}s_{7l}-K_{183l}c_{7l}\\
K_{228l}&=K_{135l}s_{7l}-K_{184l}c_{7l}\\
K_{229l}&=c_{5l}s_{7l}-K_{185l}c_{7l}\\
K_{230l}&=-c_{7l}s_{6l}\\
\bar{\omega}_{10l}&=[K_{215l}\psi+K_{218l}\dot{q}_1+K_{219l}\dot{q}_2+K_{220l}\dot{q}_3+K_{221l}\dot{q}_4+K_{216l}\dot{q}_w+K_{222l}\dot{q}_5+K_{216l}\dot{q}_{imu}+K_{217l}\dot{q}_{torso}+\dot{q}_6l c_{7l}-K_{223l}\dot{\psi}+K_{224l}\dot{q}_7]
\end{aligned}$$

$$\begin{aligned}
\bar{v}_{10l} &= {}^{10l}A_{9l} (\bar{v}_{9l} + \bar{\omega}_{9l} \times \bar{P}_{10l}) \\
\bar{v}_{10l} &= [c_{7l}(K_{142l} - K_{171l}L_9) + s_{7l}(K_{187l} - K_{169l}L_9) \quad s_{7l}(K_{142l} - K_{171l}L_9) - c_{7l}(K_{187l} - K_{169l}L_9) \quad -K_{186l} \quad] \\
K_{231l} &= c_{7l}(K_{142l} - K_{171l}L_9) + s_{7l}(K_{187l} \\
&\quad - K_{169l}L_9) \\
K_{232l} &= s_{7l}(K_{142l} - K_{171l}L_9) - c_{7l}(K_{187l} \\
&\quad - K_{169l}L_9) \\
\bar{v}_{10l} &= [K_{231l} \quad K_{232l} \quad -K_{186l} \quad] \\
\bar{v}_{10l} &= [c_{7l}(K_{145l}\bar{\psi} + K_{149l}\bar{q}_{1l} + K_{150l}\bar{q}_{2l} + K_{151l}\bar{q}_{3l} + K_{152l}\bar{q}_{4l} + K_{147l}\bar{q}_w + K_{146l}\bar{q}_{imu} + K_{148l}\bar{q}_{torso} + K_{144l}\bar{x} - L_9(K_{179l}\bar{\psi} + K_{182l} \\
K_{233l} &= K_{144l}c_{7l} + K_{197l}s_{7l} \\
K_{234l} &= c_{7l}(K_{145l} - K_{179l}L_9) + s_{7l}(K_{198l} \\
&\quad + K_{130l}L_9) \\
K_{235l} &= c_{7l}(K_{146l} - K_{180l}L_9) + s_{7l}(K_{199l} \\
&\quad + K_{131l}L_9) \\
K_{236l} &= c_{7l}(K_{147l} - K_{180l}L_9) + s_{7l}(K_{200l} \\
&\quad + K_{131l}L_9) \\
K_{237l} &= c_{7l}(K_{148l} - K_{181l}L_9) + s_{7l}(K_{201l} \\
&\quad + K_{132l}L_9) \\
K_{238l} &= c_{7l}(K_{149l} - K_{182l}L_9) + s_{7l}(K_{202l} \\
&\quad + K_{133l}L_9) \\
K_{239l} &= c_{7l}(K_{150l} - K_{183l}L_9) + s_{7l}(K_{203l} \\
&\quad + K_{134l}L_9) \\
K_{240l} &= c_{7l}(K_{151l} - K_{184l}L_9) + s_{7l}(K_{204l} \\
&\quad + K_{135l}L_9) \\
K_{241l} &= s_{7l}(K_{205l} + L_9c_{5l}) + c_{7l}(K_{152l} \\
&\quad - K_{185l}L_9) \\
K_{242l} &= -L_9c_{7l}s_{6l} \\
K_{243l} &= L_9s_{7l} \\
K_{244l} &= K_{144l}s_{7l} - K_{197l}c_{7l} \\
K_{245l} &= s_{7l}(K_{145l} - K_{179l}L_9) - c_{7l}(K_{198l} \\
&\quad + K_{130l}L_9) \\
K_{246l} &= s_{7l}(K_{146l} - K_{180l}L_9) - c_{7l}(K_{199l} \\
&\quad + K_{131l}L_9) \\
K_{247l} &= s_{7l}(K_{147l} - K_{180l}L_9) - c_{7l}(K_{200l} \\
&\quad + K_{131l}L_9) \\
K_{248l} &= s_{7l}(K_{148l} - K_{181l}L_9) - c_{7l}(K_{201l} \\
&\quad + K_{132l}L_9) \\
K_{249l} &= s_{7l}(K_{149l} - K_{182l}L_9) - c_{7l}(K_{202l} \\
&\quad + K_{133l}L_9) \\
K_{250l} &= s_{7l}(K_{150l} - K_{183l}L_9) - c_{7l}(K_{203l} \\
&\quad + K_{134l}L_9) \\
K_{251l} &= s_{7l}(K_{151l} - K_{184l}L_9) - c_{7l}(K_{204l} \\
&\quad + K_{135l}L_9) \\
K_{252l} &= s_{7l}(K_{152l} - K_{185l}L_9) - c_{7l}(K_{205l} \\
&\quad + L_9c_{5l}) \\
K_{253l} &= -L_9s_{6l}s_{7l} \\
K_{254l} &= -L_9c_{7l} \\
\bar{v}_{10l} &= [K_{234l}\bar{\psi} + K_{238l}\bar{q}_{1l} + K_{239l}\bar{q}_{2l} + K_{240l}\bar{q}_{3l} + K_{241l}\bar{q}_{4l} + K_{236l}\bar{q}_w + K_{242l}\bar{q}_{5l} + K_{243l}\bar{q}_{6l} + K_{235l}\bar{q}_{imu} + K_{237l}\bar{q}_{torso} + K_{233l}\bar{x} \\
\bar{\alpha}_{10l} &= {}^{10l}A_{9l}\bar{\alpha}_{9l} + \bar{q}_{10l}\bar{e}_{10l} + \bar{q}_{10l}(\bar{\omega}_{10l} \times \bar{e}_{10l}) \\
\bar{\alpha}_{10l} &= [s_{7l}(K_{207l} + K_{179l}\bar{\psi} + K_{182l}\bar{q}_{1l} + K_{183l}\bar{q}_{2l} + K_{184l}\bar{q}_{3l} + K_{185l}\bar{q}_{4l} + K_{180l}\bar{q}_w + K_{180l}\bar{q}_{imu} + K_{181l}\bar{q}_{torso} + \bar{q}_{5l}s_{6l}) - K_{213l}\bar{q}_{7l} + \\
K_{255l} &= K_{162l}c_{7l} - K_{213l}\bar{q}_{7l} + K_{207l}s_{7l} \\
K_{256l} &= K_{212l}\bar{q}_{7l} - K_{207l}c_{7l} + K_{162l}s_{7l} \\
\bar{\alpha}_{10l} &= [K_{255l} + K_{215l}\bar{\psi} + K_{218l}\bar{q}_{1l} + K_{219l}\bar{q}_{2l} + K_{220l}\bar{q}_{3l} + K_{221l}\bar{q}_{4l} + K_{216l}\bar{q}_w + K_{222l}\bar{q}_{5l} + K_{216l}\bar{q}_{imu} + K_{217l}\bar{q}_{torso} + \bar{q}_{6l}c_{7l} \quad K_{256l} \\
\bar{a}_{10l} &= {}^{10l}A_{9l}(\bar{a}_{9l} + \bar{\alpha}_{9l} \times \bar{P}_{10l} + \bar{\omega}_{9l} \times (\bar{\omega}_{9l} \times \bar{P}_{10l})) \\
\bar{\alpha}_{10l} &= [c_{7l}(K_{164l} + K_{145l}\bar{\psi} + K_{149l}\bar{q}_{1l} + K_{150l}\bar{q}_{2l} + K_{151l}\bar{q}_{3l} + K_{152l}\bar{q}_{4l} + K_{147l}\bar{q}_w + K_{146l}\bar{q}_{imu} + K_{148l}\bar{q}_{torso} + K_{144l}\bar{x} - L_9(K_{207l} + \\
K_{257l} &= K_{164l}c_{7l} + K_{209l}s_{7l} - K_{207l}L_9c_{7l} \\
&\quad + K_{162l}L_9s_{7l} + K_{169l}K_{170l}L_9c_{7l} \\
&\quad - K_{170l}K_{171l}L_9s_{7l} \\
K_{258l} &= K_{164l}s_{7l} - K_{209l}c_{7l} - K_{162l}L_9c_{7l} \\
&\quad - K_{207l}L_9s_{7l} + K_{170l}K_{171l}L_9c_{7l} \\
&\quad + K_{169l}K_{170l}L_9s_{7l} \\
K_{259l} &= -K_{208l} - K_{169l}^2L_9 - K_{171l}^2L_9 \\
\bar{a}_{10l} &= [K_{257l} + K_{234l}\bar{\psi} + K_{238l}\bar{q}_{1l} + K_{239l}\bar{q}_{2l} + K_{240l}\bar{q}_{3l} + K_{241l}\bar{q}_{4l} + K_{236l}\bar{q}_w + K_{242l}\bar{q}_{5l} + K_{243l}\bar{q}_{6l} + K_{235l}\bar{q}_{imu} + K_{237l}\bar{q}_{torso} + K_{233l}\bar{x} \\
\bar{g}_{10l} &= {}^{10l}A_{9l}\bar{g}_{9l}
\end{aligned}$$

$$\begin{aligned}
\bar{g}_{10l} &= [K_{167l}g^c7l + K_{211l}g^s7l & K_{167l}g^s7l - K_{211l}g^c7l & -K_{210l}g &] \\
K_{260l} &= K_{167l}c7l + K_{211l}s7l \\
K_{261l} &= K_{167l}s7l - K_{211l}c7l \\
\bar{g}_{10l} &= [K_{260l}g & K_{261l}g & -K_{210l}g &] \\
m_{10l}\bar{S}_{10l}^\times \bar{g}_{10l} &= \mathbf{MS}_{10l} \times \bar{g}_{10l} \\
m_{10l}\bar{S}_{10l}^\times \bar{g}_{10l} &= [-K_{210l}\mathbf{MY}_{10r}g - K_{261l}\mathbf{MZ}_{10r}g & K_{210l}\mathbf{MX}_{10r}g + K_{260l}\mathbf{MZ}_{10r}g & K_{261l}\mathbf{MX}_{10r}g - K_{260l}\mathbf{MY}_{10r}g &] \\
D_{325l} &= -K_{210l}\mathbf{MY}_{10r} - K_{261l}\mathbf{MZ}_{10r} \\
D_{326l} &= K_{210l}\mathbf{MX}_{10r} + K_{260l}\mathbf{MZ}_{10r} \\
D_{327l} &= K_{261l}\mathbf{MX}_{10r} - K_{260l}\mathbf{MY}_{10r} \\
m_{10l}\bar{S}_{10l}^\times \bar{g}_{10l} &= [D_{325l}g & D_{326l}g & D_{327l}g &] \\
m_{10l}\bar{a}_G(10l) &= m_{10l}\bar{a}_{10l} + \bar{\alpha}_{10l} \times \mathbf{MS}_{10l} + \bar{\omega}_{10l} \times (\bar{\omega}_{10l} \times \mathbf{MS}_{10l}) \\
m_{10l}\bar{a}_G(10l) &= [m_{10r}(K_{257l} + K_{234l}\bar{\psi} + K_{238l}\bar{q}_{1l} + K_{239l}\bar{q}_{2l} + K_{240l}\bar{q}_{3l} + K_{241l}\bar{q}_{4l} + K_{236l}\bar{q}_w + K_{242l}\bar{q}_{5l} + K_{243l}\bar{q}_{6l} + K_{235l}\bar{q}_{imu} + K_{237l}\bar{q}_{torso} \\
&D_{328l} = K_{233l}m_{10r} \\
&D_{329l} = K_{234l}m_{10r} + K_{172l}\mathbf{MY}_{10r} + K_{223l}\mathbf{MZ}_{10r} \\
&D_{330l} = K_{235l}m_{10r} + K_{173l}\mathbf{MY}_{10r} + K_{224l}\mathbf{MZ}_{10r} \\
&D_{331l} = K_{236l}m_{10r} + K_{173l}\mathbf{MY}_{10r} + K_{224l}\mathbf{MZ}_{10r} \\
&D_{332l} = K_{237l}m_{10r} + K_{174l}\mathbf{MY}_{10r} + K_{225l}\mathbf{MZ}_{10r} \\
&D_{333l} = K_{238l}m_{10r} + K_{175l}\mathbf{MY}_{10r} + K_{226l}\mathbf{MZ}_{10r} \\
&D_{334l} = K_{239l}m_{10r} + K_{176l}\mathbf{MY}_{10r} + K_{227l}\mathbf{MZ}_{10r} \\
&D_{335l} = K_{240l}m_{10r} + K_{177l}\mathbf{MY}_{10r} + K_{228l}\mathbf{MZ}_{10r} \\
&D_{336l} = K_{241l}m_{10r} + K_{178l}\mathbf{MY}_{10r} + K_{229l}\mathbf{MZ}_{10r} \\
&D_{337l} = K_{242l}m_{10r} + \mathbf{MY}_{10r}c_{6l} + K_{230l}\mathbf{MZ}_{10r} \\
&D_{338l} = K_{243l}m_{10r} + \mathbf{MZ}_{10r}s_{7l} \\
&D_{339l} = K_{257l}m_{10r} - K_{213l}^2\mathbf{MX}_{10r} - K_{214l}^2\mathbf{MX}_{10r} \\
&\quad + K_{206l}\mathbf{MY}_{10r} + K_{256l}\mathbf{MZ}_{10r} + K_{212l}K_{213l}\mathbf{MY}_{10r} \\
&\quad + K_{212l}K_{214l}\mathbf{MZ}_{10r} \\
&D_{340l} = K_{244l}m_{10r} \\
&D_{341l} = K_{245l}m_{10r} - K_{172l}\mathbf{MX}_{10r} - K_{215l}\mathbf{MZ}_{10r} \\
&D_{342l} = K_{246l}m_{10r} - K_{173l}\mathbf{MX}_{10r} - K_{216l}\mathbf{MZ}_{10r} \\
&D_{343l} = K_{247l}m_{10r} - K_{173l}\mathbf{MX}_{10r} - K_{216l}\mathbf{MZ}_{10r} \\
&D_{344l} = K_{248l}m_{10r} - K_{174l}\mathbf{MX}_{10r} - K_{217l}\mathbf{MZ}_{10r} \\
&D_{345l} = K_{249l}m_{10r} - K_{175l}\mathbf{MX}_{10r} - K_{218l}\mathbf{MZ}_{10r} \\
&D_{346l} = K_{250l}m_{10r} - K_{176l}\mathbf{MX}_{10r} - K_{219l}\mathbf{MZ}_{10r} \\
&D_{347l} = K_{251l}m_{10r} - K_{177l}\mathbf{MX}_{10r} - K_{220l}\mathbf{MZ}_{10r} \\
&D_{348l} = K_{252l}m_{10r} - K_{178l}\mathbf{MX}_{10r} - K_{221l}\mathbf{MZ}_{10r} \\
&D_{349l} = K_{253l}m_{10r} - \mathbf{MX}_{10r}c_{6l} - K_{222l}\mathbf{MZ}_{10r} \\
&D_{350l} = K_{254l}m_{10r} - \mathbf{MZ}_{10r}c_{7l} \\
&D_{351l} = K_{258l}m_{10r} - K_{212l}^2\mathbf{MY}_{10r} - K_{214l}^2\mathbf{MY}_{10r} \\
&\quad - K_{206l}\mathbf{MX}_{10r} - K_{255l}\mathbf{MZ}_{10r} + K_{212l}K_{213l}\mathbf{MX}_{10r} \\
&\quad + K_{213l}K_{214l}\mathbf{MZ}_{10r} \\
&D_{352l} = -K_{188l}m_{10r} \\
&D_{353l} = K_{215l}\mathbf{MY}_{10r} - K_{223l}\mathbf{MX}_{10r} - K_{189l}m_{10r} \\
&D_{354l} = K_{216l}\mathbf{MY}_{10r} - K_{224l}\mathbf{MX}_{10r} - K_{190l}m_{10r} \\
&D_{355l} = K_{216l}\mathbf{MY}_{10r} - K_{224l}\mathbf{MX}_{10r} - K_{191l}m_{10r} \\
&D_{356l} = K_{217l}\mathbf{MY}_{10r} - K_{225l}\mathbf{MX}_{10r} - K_{192l}m_{10r} \\
&D_{357l} = K_{218l}\mathbf{MY}_{10r} - K_{226l}\mathbf{MX}_{10r} - K_{193l}m_{10r} \\
&D_{358l} = K_{219l}\mathbf{MY}_{10r} - K_{227l}\mathbf{MX}_{10r} - K_{194l}m_{10r} \\
&D_{359l} = K_{220l}\mathbf{MY}_{10r} - K_{228l}\mathbf{MX}_{10r} - K_{195l}m_{10r} \\
&D_{360l} = K_{221l}\mathbf{MY}_{10r} - K_{229l}\mathbf{MX}_{10r} - K_{196l}m_{10r} \\
&D_{361l} = K_{222l}\mathbf{MY}_{10r} - K_{230l}\mathbf{MX}_{10r} \\
&D_{362l} = \mathbf{MY}_{10r}c_{7l} - \mathbf{MX}_{10r}s_{7l} \\
&D_{363l} = K_{259l}m_{10r} - K_{212l}^2\mathbf{MZ}_{10r} - K_{213l}^2\mathbf{MZ}_{10r} \\
&\quad - K_{256l}\mathbf{MX}_{10r} + K_{255l}\mathbf{MY}_{10r} + K_{212l}K_{214l}\mathbf{MX}_{10r} \\
&\quad + K_{213l}K_{214l}\mathbf{MY}_{10r} \\
m_{10l}\bar{a}_G(10l) &= [D_{339l} + D_{329l}\bar{\psi} + D_{333l}\bar{q}_{1l} + D_{334l}\bar{q}_{2l} + D_{335l}\bar{q}_{3l} + D_{336l}\bar{q}_{4l} + D_{331l}\bar{q}_w + D_{337l}\bar{q}_{5l} + D_{338l}\bar{q}_{6l} + D_{330l}\bar{q}_{imu} + D_{332l}\bar{q}_{torso} + D_{334l}\bar{q}_{torso} \\
&\quad \dot{\bar{H}}_{10l} = \mathbf{MS}_{10l} \times \bar{a}_{10l} + J_{10l}\bar{\alpha}_{10l} + \bar{\omega}_{10l} \times J_{10l}\bar{\omega}_{10l} \\
&\quad \dot{\bar{H}}_{10l} = [K_{213l}(K_{212l}\mathbf{XZ}_{10r} + K_{213l}\mathbf{YZ}_{10r} + K_{214l}\mathbf{ZZ}_{10r}) - K_{214l}(K_{212l}\mathbf{XY}_{10r} + K_{213l}\mathbf{YY}_{10r} + K_{214l}\mathbf{YZ}_{10r}) - \mathbf{MY}_{10r}(K_{189l}\bar{\psi} - K_{259l} \\
&D_{364l} = -K_{188l}\mathbf{MY}_{10r} - K_{244l}\mathbf{MZ}_{10r} \\
&D_{365l} = K_{215l}\mathbf{XX}_{10r} + K_{223l}\mathbf{XY}_{10r} - K_{172l}\mathbf{XZ}_{10r} \\
&\quad - K_{189l}\mathbf{MY}_{10r} - K_{245l}\mathbf{MZ}_{10r} \\
&D_{366l} = K_{216l}\mathbf{XX}_{10r} + K_{224l}\mathbf{XY}_{10r} - K_{173l}\mathbf{XZ}_{10r} \\
&\quad - K_{190l}\mathbf{MY}_{10r} - K_{246l}\mathbf{MZ}_{10r}
\end{aligned}$$

$$\begin{aligned}
D_{367l} &= K_{216l}\mathbf{XX}_{10r} + K_{224l}\mathbf{XY}_{10r} - K_{173l}\mathbf{XZ}_{10r} \\
&\quad - K_{191l}\mathbf{MY}_{10r} - K_{247l}\mathbf{MZ}_{10r} \\
D_{368l} &= K_{217l}\mathbf{XX}_{10r} + K_{225l}\mathbf{XY}_{10r} - K_{174l}\mathbf{XZ}_{10r} \\
&\quad - K_{192l}\mathbf{MY}_{10r} - K_{248l}\mathbf{MZ}_{10r} \\
D_{369l} &= K_{218l}\mathbf{XX}_{10r} + K_{226l}\mathbf{XY}_{10r} - K_{175l}\mathbf{XZ}_{10r} \\
&\quad - K_{193l}\mathbf{MY}_{10r} - K_{249l}\mathbf{MZ}_{10r} \\
D_{370l} &= K_{219l}\mathbf{XX}_{10r} + K_{227l}\mathbf{XY}_{10r} - K_{176l}\mathbf{XZ}_{10r} \\
&\quad - K_{194l}\mathbf{MY}_{10r} - K_{250l}\mathbf{MZ}_{10r} \\
D_{371l} &= K_{220l}\mathbf{XX}_{10r} + K_{228l}\mathbf{XY}_{10r} - K_{177l}\mathbf{XZ}_{10r} \\
&\quad - K_{195l}\mathbf{MY}_{10r} - K_{251l}\mathbf{MZ}_{10r} \\
D_{372l} &= K_{221l}\mathbf{XX}_{10r} + K_{229l}\mathbf{XY}_{10r} - K_{178l}\mathbf{XZ}_{10r} \\
&\quad - K_{196l}\mathbf{MY}_{10r} - K_{252l}\mathbf{MZ}_{10r} \\
D_{373l} &= K_{222l}\mathbf{XX}_{10r} + K_{230l}\mathbf{XY}_{10r} - \mathbf{XZ}_{10r}c_{6l} \\
&\quad - K_{253l}\mathbf{MZ}_{10r} \\
D_{374l} &= \mathbf{XX}_{10r}c_{7l} + \mathbf{XY}_{10r}s_{7l} - K_{254l}\mathbf{MZ}_{10r} \\
D_{375l} &= K_{255l}\mathbf{XX}_{10r} + K_{256l}\mathbf{XY}_{10r} - K_{206l}\mathbf{XZ}_{10r} \\
&\quad + K_{213l}^2\mathbf{YZ}_{10r} - K_{214l}^2\mathbf{YZ}_{10r} + K_{259l}\mathbf{MY}_{10r} \\
&\quad - K_{258l}\mathbf{MZ}_{10r} - K_{212l}K_{214l}\mathbf{XY}_{10r} + K_{212l}K_{213l}\mathbf{XZ}_{10r} \\
&\quad - K_{213l}K_{214l}\mathbf{YY}_{10r} + K_{213l}K_{214l}\mathbf{ZZ}_{10r} \\
D_{376l} &= K_{188l}\mathbf{MX}_{10r} + K_{233l}\mathbf{MZ}_{10r} \\
D_{377l} &= K_{215l}\mathbf{XY}_{10r} + K_{223l}\mathbf{YY}_{10r} - K_{172l}\mathbf{YZ}_{10r} \\
&\quad + K_{189l}\mathbf{MX}_{10r} + K_{234l}\mathbf{MZ}_{10r} \\
D_{378l} &= K_{216l}\mathbf{XY}_{10r} + K_{224l}\mathbf{YY}_{10r} - K_{173l}\mathbf{YZ}_{10r} \\
&\quad + K_{190l}\mathbf{MX}_{10r} + K_{235l}\mathbf{MZ}_{10r} \\
D_{379l} &= K_{216l}\mathbf{XY}_{10r} + K_{224l}\mathbf{YY}_{10r} - K_{173l}\mathbf{YZ}_{10r} \\
&\quad + K_{191l}\mathbf{MX}_{10r} + K_{236l}\mathbf{MZ}_{10r} \\
D_{380l} &= K_{217l}\mathbf{XY}_{10r} + K_{225l}\mathbf{YY}_{10r} - K_{174l}\mathbf{YZ}_{10r} \\
&\quad + K_{192l}\mathbf{MX}_{10r} + K_{237l}\mathbf{MZ}_{10r} \\
D_{381l} &= K_{218l}\mathbf{XY}_{10r} + K_{226l}\mathbf{YY}_{10r} - K_{175l}\mathbf{YZ}_{10r} \\
&\quad + K_{193l}\mathbf{MX}_{10r} + K_{238l}\mathbf{MZ}_{10r} \\
D_{382l} &= K_{219l}\mathbf{XY}_{10r} + K_{227l}\mathbf{YY}_{10r} - K_{176l}\mathbf{YZ}_{10r} \\
&\quad + K_{194l}\mathbf{MX}_{10r} + K_{239l}\mathbf{MZ}_{10r} \\
D_{383l} &= K_{220l}\mathbf{XY}_{10r} + K_{228l}\mathbf{YY}_{10r} - K_{177l}\mathbf{YZ}_{10r} \\
&\quad + K_{195l}\mathbf{MX}_{10r} + K_{240l}\mathbf{MZ}_{10r} \\
D_{384l} &= K_{221l}\mathbf{XY}_{10r} + K_{229l}\mathbf{YY}_{10r} - K_{178l}\mathbf{YZ}_{10r} \\
&\quad + K_{196l}\mathbf{MX}_{10r} + K_{241l}\mathbf{MZ}_{10r} \\
D_{385l} &= K_{222l}\mathbf{XY}_{10r} + K_{230l}\mathbf{YY}_{10r} - \mathbf{YZ}_{10r}c_{6l} \\
&\quad + K_{242l}\mathbf{MZ}_{10r} \\
D_{386l} &= \mathbf{XY}_{10r}c_{7l} + \mathbf{YY}_{10r}s_{7l} + K_{243l}\mathbf{MZ}_{10r} \\
D_{387l} &= K_{255l}\mathbf{XY}_{10r} + K_{256l}\mathbf{YY}_{10r} - K_{206l}\mathbf{YZ}_{10r} \\
&\quad - K_{212l}^2\mathbf{XZ}_{10r} + K_{214l}^2\mathbf{XZ}_{10r} - K_{259l}\mathbf{MX}_{10r} \\
&\quad + K_{257l}\mathbf{MZ}_{10r} + K_{212l}K_{214l}\mathbf{XX}_{10r} + K_{213l}K_{214l}\mathbf{XY}_{10r} \\
&\quad - K_{212l}K_{213l}\mathbf{YZ}_{10r} - K_{212l}K_{214l}\mathbf{ZZ}_{10r} \\
D_{388l} &= K_{244l}\mathbf{MX}_{10r} - K_{233l}\mathbf{MY}_{10r} \\
D_{389l} &= K_{215l}\mathbf{XZ}_{10r} + K_{223l}\mathbf{YZ}_{10r} - K_{172l}\mathbf{ZZ}_{10r} \\
&\quad + K_{245l}\mathbf{MX}_{10r} - K_{234l}\mathbf{MY}_{10r} \\
D_{390l} &= K_{216l}\mathbf{XZ}_{10r} + K_{224l}\mathbf{YZ}_{10r} - K_{173l}\mathbf{ZZ}_{10r} \\
&\quad + K_{246l}\mathbf{MX}_{10r} - K_{235l}\mathbf{MY}_{10r} \\
D_{391l} &= K_{216l}\mathbf{XZ}_{10r} + K_{224l}\mathbf{YZ}_{10r} - K_{173l}\mathbf{ZZ}_{10r} \\
&\quad + K_{247l}\mathbf{MX}_{10r} - K_{236l}\mathbf{MY}_{10r} \\
D_{392l} &= K_{217l}\mathbf{XZ}_{10r} + K_{225l}\mathbf{YZ}_{10r} - K_{174l}\mathbf{ZZ}_{10r} \\
&\quad + K_{248l}\mathbf{MX}_{10r} - K_{237l}\mathbf{MY}_{10r} \\
D_{393l} &= K_{218l}\mathbf{XZ}_{10r} + K_{226l}\mathbf{YZ}_{10r} - K_{175l}\mathbf{ZZ}_{10r} \\
&\quad + K_{249l}\mathbf{MX}_{10r} - K_{238l}\mathbf{MY}_{10r} \\
D_{394l} &= K_{219l}\mathbf{XZ}_{10r} + K_{227l}\mathbf{YZ}_{10r} - K_{176l}\mathbf{ZZ}_{10r} \\
&\quad + K_{250l}\mathbf{MX}_{10r} - K_{239l}\mathbf{MY}_{10r} \\
D_{395l} &= K_{220l}\mathbf{XZ}_{10r} + K_{228l}\mathbf{YZ}_{10r} - K_{177l}\mathbf{ZZ}_{10r} \\
&\quad + K_{251l}\mathbf{MX}_{10r} - K_{240l}\mathbf{MY}_{10r} \\
D_{396l} &= K_{221l}\mathbf{XZ}_{10r} + K_{229l}\mathbf{YZ}_{10r} - K_{178l}\mathbf{ZZ}_{10r} \\
&\quad + K_{252l}\mathbf{MX}_{10r} - K_{241l}\mathbf{MY}_{10r} \\
D_{397l} &= K_{222l}\mathbf{XZ}_{10r} + K_{230l}\mathbf{YZ}_{10r} - \mathbf{ZZ}_{10r}c_{6l} \\
&\quad + K_{253l}\mathbf{MX}_{10r} - K_{242l}\mathbf{MY}_{10r} \\
D_{398l} &= \mathbf{XZ}_{10r}c_{7l} + \mathbf{YZ}_{10r}s_{7l} + K_{254l}\mathbf{MX}_{10r} \\
&\quad - K_{243l}\mathbf{MY}_{10r} \\
D_{399l} &= K_{255l}\mathbf{XZ}_{10r} + K_{256l}\mathbf{YZ}_{10r} - K_{206l}\mathbf{ZZ}_{10r}
\end{aligned}$$

$$\begin{aligned}
& + K_{212l}^2 \mathbf{X}\mathbf{Y}_{10r} - K_{213l}^2 \mathbf{X}\mathbf{Y}_{10r} + K_{258l} \mathbf{M}\mathbf{X}_{10r} \\
& - K_{257l} \mathbf{M}\mathbf{Y}_{10r} - K_{212l} K_{213l} \mathbf{X}\mathbf{X}_{10r} - K_{213l} K_{214l} \mathbf{X}\mathbf{Z}_{10r} \\
& + K_{212l} K_{213l} \mathbf{Y}\mathbf{Y}_{10r} + K_{212l} K_{214l} \mathbf{Y}\mathbf{Z}_{10r} \\
\dot{H}_{10l} = & [D_{339l} + D_{329l} \ddot{\psi} + D_{333l} \dot{q}_{1l} + D_{334l} \dot{q}_{2l} + D_{335l} \dot{q}_{3l} + D_{336l} \dot{q}_{4l} + D_{331l} \dot{q}_w + D_{337l} \dot{q}_{5l} + D_{338l} \dot{q}_{6l} + D_{330l} \dot{q}_{imu} + D_{332l} \dot{q}_{torso} + D_{334l} \dot{q}_{torso} \\
\bar{\omega}_{4r} = & {}^4r A_3 \bar{\omega}_3 + \dot{q}_{4r} \bar{e}_{4r} \\
\bar{\omega}_{4r} = & [K_{26} c_{1r} + K_{27} s_{1r} \quad -K_{25} - \dot{q}_{1r} \quad K_{27} c_{1r} - K_{26} s_{1r} \quad] \\
K_{1r} = & K_{26} c_{1r} + K_{27} s_{1r} \\
K_{2r} = & -K_{25} - \dot{q}_{1r} \\
K_{3r} = & K_{27} c_{1r} - K_{26} s_{1r} \\
\bar{\omega}_{4r} = & [K_{1r} \quad K_{2r} \quad K_{3r} \quad] \\
\bar{\omega}_{4r} = & [-s_{1r}(\dot{q}_w s_{torso} - K_{29} \dot{\psi} + \dot{q}_{imu} s_{torso}) - c_{1r}(\dot{q}_{torso} - K_{10} \dot{\psi}) \quad -\dot{q}_{1r} - K_{28} \dot{\psi} - \dot{q}_w c_{torso} - \dot{q}_{imu} c_{torso} \quad s_{1r}(\dot{q}_{torso} - K_{10} \dot{\psi}) - \\
K_{4r} = & K_{10} c_{1r} + K_{29} s_{1r} \\
K_{5r} = & -s_{1r} s_{torso} \\
K_{6r} = & K_{29} c_{1r} - K_{10} s_{1r} \\
K_{7r} = & -c_{1r} s_{torso} \\
\bar{\omega}_{4r} = & [K_{4r} \dot{\psi} + K_{5r} \dot{q}_w + K_{5r} \dot{q}_{imu} - \dot{q}_{torso} c_{1r} \quad -\dot{q}_{1r} - K_{28} \dot{\psi} - \dot{q}_w c_{torso} - \dot{q}_{imu} c_{torso} \quad K_{6r} \dot{\psi} + K_{7r} \dot{q}_w + K_{7r} \dot{q}_{imu} + \dot{q}_{torso} s_{1r} \quad] \\
\bar{v}_{4r} = & {}^4r A_3 (\bar{v}_3 + \bar{\omega}_3 \times \bar{P}_{4r}) \\
\bar{v}_{4r} = & [c_{1r}(K_{31} - K_{27} L_6) + s_{1r}(K_{32} + K_{25} L_5 + K_{26} L_6) \quad K_{27} L_5 - K_{30} \quad c_{1r}(K_{32} + K_{25} L_5 + K_{26} L_6) - s_{1r}(K_{31} - K_{27} L_6) \quad] \\
K_{8r} = & c_{1r}(K_{31} - K_{27} L_6) + s_{1r}(K_{32} \\
& + K_{25} L_5 + K_{26} L_6) \\
K_{9r} = & K_{27} L_5 - K_{30} \\
K_{10r} = & c_{1r}(K_{32} + K_{25} L_5 + K_{26} L_6) \\
& - s_{1r}(K_{31} - K_{27} L_6) \\
\bar{v}_{4r} = & [K_{8r} \quad K_{9r} \quad K_{10r} \quad] \\
\bar{v}_{4r} = & [c_{1r}(K_{37} \dot{q}_{imu} + K_{11} \dot{x} + L_4 \dot{q}_w + L_6(\dot{q}_w s_{torso} - K_{29} \dot{\psi} + \dot{q}_{imu} s_{torso})) + s_{1r}(K_{39} \dot{\psi} + K_{41} \dot{q}_w + K_{40} \dot{q}_{imu} + K_{38} \dot{x} + L_5(K_{28} \dot{\psi} + \dot{q}_w c_{torso} \\
K_{11r} = & K_{11} c_{1r} + K_{38} s_{1r} \\
K_{12r} = & s_{1r}(K_{39} + K_{10} L_6 + K_{28} L_5) \\
& - K_{29} L_6 c_{1r} \\
K_{13r} = & c_{1r}(K_{37} + L_6 s_{torso}) + s_{1r}(K_{40} \\
& + L_5 c_{torso}) \\
K_{14r} = & s_{1r}(K_{41} + L_5 c_{torso}) + c_{1r}(L_4 \\
& + L_6 s_{torso}) \\
K_{15r} = & -L_6 s_{1r} \\
K_{16r} = & K_{29} L_5 - K_{34} \\
K_{17r} = & -K_{35} - L_5 s_{torso} \\
K_{18r} = & -K_{36} - L_5 s_{torso} \\
K_{19r} = & K_{38} c_{1r} - K_{11} s_{1r} \\
K_{20r} = & c_{1r}(K_{39} + K_{10} L_6 + K_{28} L_5) \\
& + K_{29} L_6 s_{1r} \\
K_{21r} = & c_{1r}(K_{40} + L_5 c_{torso}) - s_{1r}(K_{37} \\
& + L_6 s_{torso}) \\
K_{22r} = & c_{1r}(K_{41} + L_5 c_{torso}) - s_{1r}(L_4 \\
& + L_6 s_{torso}) \\
K_{23r} = & -L_6 c_{1r} \\
\bar{v}_{4r} = & [K_{12r} \dot{\psi} + K_{14r} \dot{q}_w + K_{13r} \dot{q}_{imu} + K_{15r} \dot{q}_{torso} + K_{11r} \dot{x} \quad K_{16r} \dot{\psi} + K_{18r} \dot{q}_w + K_{17r} \dot{q}_{imu} - K_{33} \dot{x} \quad K_{20r} \dot{\psi} + K_{22r} \dot{q}_w + K_{21r} \dot{q}_{imu} \\
\bar{\alpha}_{4r} = & {}^4r A_3 \bar{\alpha}_3 + \dot{q}_{4r} \bar{e}_{4r} + \dot{q}_{4r} (\bar{\omega}_{4r} \times \bar{e}_{4r}) \\
\bar{\alpha}_{4r} = & [K_{3r} \dot{q}_{1r} + s_{1r}(K_{43} + K_{29} \ddot{\psi} - \dot{q}_w s_{torso} - \dot{q}_{imu} s_{torso}) + c_{1r}(K_{19} - \dot{q}_{torso} + K_{10} \ddot{\psi}) \quad -K_{42} - \dot{q}_{1r} - K_{28} \ddot{\psi} - \dot{q}_w c_{torso} - \dot{q}_{imu} c_{torso} \\
K_{24r} = & K_{3r} \dot{q}_{1r} + K_{19} c_{1r} + K_{43} s_{1r} \\
K_{25r} = & K_{43} c_{1r} - K_{1r} \dot{q}_{1r} - K_{19} s_{1r} \\
\bar{\alpha}_{4r} = & [K_{24r} + K_{4r} \ddot{\psi} + K_{5r} \dot{q}_w + K_{5r} \dot{q}_{imu} - \dot{q}_{torso} c_{1r} \quad -K_{42} - \dot{q}_{1r} - K_{28} \ddot{\psi} - \dot{q}_w c_{torso} - \dot{q}_{imu} c_{torso} \quad K_{25r} + K_{6r} \ddot{\psi} + K_{7r} \dot{q}_w + K_{7r} \dot{q}_{imu} \\
\bar{a}_{4r} = & {}^4r A_3 (\bar{a}_3 + \bar{\alpha}_3 \times \bar{P}_{4r} + \bar{\omega}_3 \times (\bar{\omega}_3 \times \bar{P}_{4r})) \\
\bar{\alpha}_{4r} = & [c_{1r}(K_{45} + K_{37} \dot{q}_{imu} + K_{11} \dot{x} + L_4 \dot{q}_w - K_{27}^2 L_5 - L_6(K_{43} + K_{29} \ddot{\psi} - \dot{q}_w s_{torso} - \dot{q}_{imu} s_{torso}) - K_{25}(K_{25} L_5 + K_{26} L_6)) + s_{1r}(K_{46} + \\
K_{26r} = & K_{45} c_{1r} + K_{46} s_{1r} - K_{25}^2 L_5 c_{1r} \\
& - K_{27}^2 L_5 c_{1r} - K_{43} L_6 c_{1r} \\
& + K_{19} L_6 s_{1r} + K_{42} L_5 s_{1r} \\
& - K_{25} K_{26} L_6 c_{1r} - K_{25} K_{27} L_6 s_{1r} \\
& + K_{26} K_{27} L_5 s_{1r} \\
K_{27r} = & K_{43} L_5 - K_{26}^2 L_6 - K_{27}^2 L_6 \\
& - K_{44} - K_{25} K_{26} L_5 \\
K_{28r} = & K_{46} c_{1r} - K_{45} s_{1r} + K_{25}^2 L_5 s_{1r}
\end{aligned}$$

$$\begin{aligned}
& + K_{27}^2 L_5 s_{1r} + K_{19} L_6 c_{1r} \\
& + K_{42} L_5 c_{1r} + K_{43} L_6 s_{1r} \\
& - K_{25} K_{27} L_6 c_{1r} + K_{26} K_{27} L_5 c_{1r} \\
& + K_{25} K_{26} L_6 s_{1r} \\
\bar{a}_{4r} &= [K_{26r} + K_{12r} \ddot{\psi} + K_{14r} \ddot{q}_w + K_{13r} \ddot{q}_{imu} + K_{15r} \ddot{q}_{torso} + K_{11r} \ddot{x} \quad K_{27r} + K_{16r} \ddot{\psi} + K_{18r} \ddot{q}_w + K_{17r} \ddot{q}_{imu} - K_{33} \ddot{x} \quad K_{28r} + K_{20r} \ddot{\psi} - \\
\bar{\theta}_{4r} &= {}^4r A_3 \bar{\theta}_3 \\
\bar{\theta}_{4r} &= [K_{17g} c_{1r} + K_{48g} s_{1r} \quad -K_{47g} \quad K_{48g} c_{1r} - K_{17g} s_{1r} \quad] \\
K_{29r} &= K_{17c_{1r}} + K_{48s_{1r}} \\
K_{30r} &= K_{48c_{1r}} - K_{17s_{1r}} \\
\bar{\theta}_{4r} &= [K_{29rg} \quad -K_{47g} \quad K_{30rg} \quad] \\
m_{4r} \bar{S}_{4r}^\times \bar{\theta}_{4r} &= \mathbf{MS}_{4r} \times \bar{\theta}_{4r} \\
m_{4r} \bar{S}_{4r}^\times \bar{\theta}_{4r} &= [K_{30r} \mathbf{MY}_{4rg} + K_{47r} \mathbf{MZ}_{4rg} \quad K_{29r} \mathbf{MZ}_{4rg} - K_{30r} \mathbf{MX}_{4rg} \quad -K_{47r} \mathbf{MX}_{4rg} - K_{29r} \mathbf{MY}_{4rg} \quad] \\
D_{1r} &= K_{30r} \mathbf{MY}_{4r} + K_{47r} \mathbf{MZ}_{4r} \\
D_{2r} &= K_{29r} \mathbf{MZ}_{4r} - K_{30r} \mathbf{MX}_{4r} \\
D_{3r} &= -K_{47r} \mathbf{MX}_{4r} - K_{29r} \mathbf{MY}_{4r} \\
m_{4r} \bar{S}_{4r}^\times \bar{\theta}_{4r} &= [D_{1rg} \quad D_{2rg} \quad D_{3rg} \quad] \\
m_{4r} \bar{a}_G(4r) &= m_{4r} \bar{a}_{4r} + \bar{\alpha}_{4r} \times \mathbf{MS}_{4r} + \bar{\omega}_{4r} \times (\bar{\omega}_{4r} \times \mathbf{MS}_{4r}) \\
m_{4r} \bar{a}_G(4r) &= [m_{4r} (K_{26r} + K_{12r} \ddot{\psi} + K_{14r} \ddot{q}_w + K_{13r} \ddot{q}_{imu} + K_{15r} \ddot{q}_{torso} + K_{11r} \ddot{x}) - \mathbf{MY}_{4r} (K_{25r} + K_{6r} \ddot{\psi} + K_{7r} \ddot{q}_w + K_{7r} \ddot{q}_{imu} + \ddot{q}_{torso} s_{1r}) - K_{25r} \\
D_{4r} &= K_{11r} m_{4r} \\
D_{5r} &= K_{12r} m_{4r} - K_{6r} \mathbf{MY}_{4r} - K_{28} \mathbf{MZ}_{4r} \\
D_{6r} &= K_{13r} m_{4r} - \mathbf{MZ}_{4r} c_{torso} - K_{7r} \mathbf{MY}_{4r} \\
D_{7r} &= K_{14r} m_{4r} - \mathbf{MZ}_{4r} c_{torso} - K_{7r} \mathbf{MY}_{4r} \\
D_{8r} &= K_{15r} m_{4r} - \mathbf{MY}_{4r} s_{1r} \\
D_{9r} &= K_{26r} m_{4r} - K_{2r}^2 \mathbf{MX}_{4r} - K_{3r}^2 \mathbf{MX}_{4r} \\
& - K_{25r} \mathbf{MY}_{4r} - K_{42} \mathbf{MZ}_{4r} + K_{1r} K_{2r} \mathbf{MY}_{4r} \\
& + K_{1r} K_{3r} \mathbf{MZ}_{4r} \\
D_{10r} &= -K_{33} m_{4r} \\
D_{11r} &= K_{16r} m_{4r} + K_{6r} \mathbf{MX}_{4r} - K_{4r} \mathbf{MZ}_{4r} \\
D_{12r} &= K_{17r} m_{4r} + K_{7r} \mathbf{MX}_{4r} - K_{5r} \mathbf{MZ}_{4r} \\
D_{13r} &= K_{18r} m_{4r} + K_{7r} \mathbf{MX}_{4r} - K_{5r} \mathbf{MZ}_{4r} \\
D_{14r} &= \mathbf{MZ}_{4r} c_{1r} + \mathbf{MX}_{4r} s_{1r} \\
D_{15r} &= K_{27r} m_{4r} - K_{1r}^2 \mathbf{MY}_{4r} - K_{3r}^2 \mathbf{MY}_{4r} \\
& + K_{25r} \mathbf{MX}_{4r} - K_{24r} \mathbf{MZ}_{4r} + K_{1r} K_{2r} \mathbf{MX}_{4r} \\
& + K_{2r} K_{3r} \mathbf{MZ}_{4r} \\
D_{16r} &= K_{19r} m_{4r} \\
D_{17r} &= K_{20r} m_{4r} + K_{28} \mathbf{MX}_{4r} + K_{4r} \mathbf{MY}_{4r} \\
D_{18r} &= K_{21r} m_{4r} + \mathbf{MX}_{4r} c_{torso} + K_{5r} \mathbf{MY}_{4r} \\
D_{19r} &= K_{22r} m_{4r} + \mathbf{MX}_{4r} c_{torso} + K_{5r} \mathbf{MY}_{4r} \\
D_{20r} &= K_{23r} m_{4r} - \mathbf{MY}_{4r} c_{1r} \\
D_{21r} &= K_{28r} m_{4r} - K_{1r}^2 \mathbf{MZ}_{4r} - K_{2r}^2 \mathbf{MZ}_{4r} \\
& + K_{42} \mathbf{MX}_{4r} + K_{24r} \mathbf{MY}_{4r} + K_{1r} K_{3r} \mathbf{MX}_{4r} \\
& + K_{2r} K_{3r} \mathbf{MY}_{4r} \\
m_{4r} \bar{a}_G(4r) &= [D_{9r} + D_{5r} \ddot{\psi} + D_{7r} \ddot{q}_w + D_{6r} \ddot{q}_{imu} + D_{8r} \ddot{q}_{torso} + D_{4r} \ddot{x} - \mathbf{MZ}_{4r} \ddot{q}_{1r} \quad D_{15r} + D_{11r} \ddot{\psi} + D_{13r} \ddot{q}_w + D_{12r} \ddot{q}_{imu} + D_{14r} \ddot{q}_{torso} + D_{10r} \\
\dot{\bar{H}}_{4r} &= \mathbf{MS}_{4r} \times \bar{a}_{4r} + J_{4r} \bar{\alpha}_{4r} + \bar{\omega}_{4r} \times J_{4r} \bar{\omega}_{4r} \\
\dot{\bar{H}}_{4r} &= [K_{2r} (K_{1r} \mathbf{XZ}_{4r} + K_{2r} \mathbf{YZ}_{4r} + K_{3r} \mathbf{ZZ}_{4r}) - K_{3r} (K_{1r} \mathbf{XY}_{4r} + K_{2r} \mathbf{YY}_{4r} + K_{3r} \mathbf{YZ}_{4r}) - \mathbf{XY}_{4r} (K_{42} + \ddot{q}_{1r} + K_{28} \ddot{\psi} + \ddot{q}_w c_{torso} + \ddot{q}_{imu} s_{1r}) \\
D_{22r} &= K_{19r} \mathbf{MY}_{4r} + K_{33} \mathbf{MZ}_{4r} \\
D_{23r} &= K_{4r} \mathbf{XX}_{4r} - K_{28} \mathbf{XY}_{4r} + K_{6r} \mathbf{XZ}_{4r} \\
& + K_{20r} \mathbf{MY}_{4r} - K_{16r} \mathbf{MZ}_{4r} \\
D_{24r} &= K_{5r} \mathbf{XX}_{4r} + K_{7r} \mathbf{XZ}_{4r} - \mathbf{XY}_{4r} c_{torso} \\
& + K_{21r} \mathbf{MY}_{4r} - K_{17r} \mathbf{MZ}_{4r} \\
D_{25r} &= K_{5r} \mathbf{XX}_{4r} + K_{7r} \mathbf{XZ}_{4r} - \mathbf{XY}_{4r} c_{torso} \\
& + K_{22r} \mathbf{MY}_{4r} - K_{18r} \mathbf{MZ}_{4r} \\
D_{26r} &= \mathbf{XZ}_{4r} s_{1r} - \mathbf{XX}_{4r} c_{1r} + K_{23r} \mathbf{MY}_{4r} \\
D_{27r} &= K_{24r} \mathbf{XX}_{4r} - K_{42} \mathbf{XY}_{4r} + K_{25r} \mathbf{XZ}_{4r} \\
& + K_{2r}^2 \mathbf{YZ}_{4r} - K_{3r}^2 \mathbf{YZ}_{4r} + K_{28r} \mathbf{MY}_{4r} \\
& - K_{27r} \mathbf{MZ}_{4r} - K_{1r} K_{3r} \mathbf{XY}_{4r} + K_{1r} K_{2r} \mathbf{XZ}_{4r} \\
& - K_{2r} K_{3r} \mathbf{YY}_{4r} + K_{2r} K_{3r} \mathbf{ZZ}_{4r} \\
D_{28r} &= K_{11r} \mathbf{MZ}_{4r} - K_{19r} \mathbf{MX}_{4r} \\
D_{29r} &= K_{4r} \mathbf{XY}_{4r} - K_{28} \mathbf{YY}_{4r} + K_{6r} \mathbf{YZ}_{4r} \\
& - K_{20r} \mathbf{MX}_{4r} + K_{12r} \mathbf{MZ}_{4r}
\end{aligned}$$

$$\begin{aligned}
D_{30r} &= K_{5r}\mathbf{XY}_{4r} + K_{7r}\mathbf{YZ}_{4r} - \mathbf{YY}_{4r}c_{torso} \\
&\quad - K_{21r}\mathbf{MX}_{4r} + K_{13r}\mathbf{MZ}_{4r} \\
D_{31r} &= K_{5r}\mathbf{XY}_{4r} + K_{7r}\mathbf{YZ}_{4r} - \mathbf{YY}_{4r}c_{torso} \\
&\quad - K_{22r}\mathbf{MX}_{4r} + K_{14r}\mathbf{MZ}_{4r} \\
D_{32r} &= \mathbf{YZ}_{4r}s_{1r} - \mathbf{XY}_{4r}c_{1r} - K_{23r}\mathbf{MX}_{4r} \\
&\quad + K_{15r}\mathbf{MZ}_{4r} \\
D_{33r} &= K_{24r}\mathbf{XY}_{4r} - K_{42}\mathbf{YY}_{4r} + K_{25r}\mathbf{YZ}_{4r} \\
&\quad - K_{1r}^2\mathbf{XZ}_{4r} + K_{3r}^2\mathbf{XZ}_{4r} - K_{28r}\mathbf{MX}_{4r} \\
&\quad + K_{26r}\mathbf{MZ}_{4r} + K_{1r}K_{3r}\mathbf{XX}_{4r} + K_{2r}K_{3r}\mathbf{XY}_{4r} \\
&\quad - K_{1r}K_{2r}\mathbf{YZ}_{4r} - K_{1r}K_{3r}\mathbf{ZZ}_{4r} \\
D_{34r} &= -K_{33}\mathbf{MX}_{4r} - K_{11r}\mathbf{MY}_{4r} \\
D_{35r} &= K_{4r}\mathbf{XZ}_{4r} - K_{28}\mathbf{YZ}_{4r} + K_{6r}\mathbf{ZZ}_{4r} \\
&\quad + K_{16r}\mathbf{MX}_{4r} - K_{12r}\mathbf{MY}_{4r} \\
D_{36r} &= K_{5r}\mathbf{XZ}_{4r} + K_{7r}\mathbf{ZZ}_{4r} - \mathbf{YZ}_{4r}c_{torso} \\
&\quad + K_{17r}\mathbf{MX}_{4r} - K_{13r}\mathbf{MY}_{4r} \\
D_{37r} &= K_{5r}\mathbf{XZ}_{4r} + K_{7r}\mathbf{ZZ}_{4r} - \mathbf{YZ}_{4r}c_{torso} \\
&\quad + K_{18r}\mathbf{MX}_{4r} - K_{14r}\mathbf{MY}_{4r} \\
D_{38r} &= \mathbf{ZZ}_{4r}s_{1r} - \mathbf{XZ}_{4r}c_{1r} - K_{15r}\mathbf{MY}_{4r} \\
D_{39r} &= K_{24r}\mathbf{XZ}_{4r} - K_{42}\mathbf{YZ}_{4r} + K_{25r}\mathbf{ZZ}_{4r} \\
&\quad + K_{1r}^2\mathbf{XY}_{4r} - K_{2r}^2\mathbf{XY}_{4r} + K_{27r}\mathbf{MX}_{4r} \\
&\quad - K_{26r}\mathbf{MY}_{4r} - K_{1r}K_{2r}\mathbf{XX}_{4r} - K_{2r}K_{3r}\mathbf{XZ}_{4r} \\
&\quad + K_{1r}K_{2r}\mathbf{YY}_{4r} + K_{1r}K_{3r}\mathbf{YZ}_{4r} \\
\dot{H}_{4r} &= [D_{9r} + D_{5r}\dot{\psi} + D_{7r}\dot{q}w + D_{6r}\dot{q}_{imu} + D_{8r}\dot{q}_{torso} + D_{4r}\ddot{x} - \mathbf{MZ}_{4r}\dot{q}_{1r} \quad D_{15r} + D_{11r}\dot{\psi} + D_{13r}\dot{q}w + D_{12r}\dot{q}_{imu} + D_{14r}\dot{q}_{torso} + D_{10r}\dot{q}_{torso}] \\
\bar{\omega}_{5r} &= {}^{5r}A_{4r}\bar{\omega}_{4r} + \dot{q}_{5r}\bar{e}_{5r} \\
\bar{\omega}_{5r} &= [-K_{1r} - \dot{q}_{2r} \quad -K_{2r}c_{2r} - K_{3r}s_{2r} \quad K_{3r}c_{2r} - K_{2r}s_{2r} \quad] \\
K_{31r} &= -K_{1r} - \dot{q}_{2r} \\
K_{32r} &= -K_{2r}c_{2r} - K_{3r}s_{2r} \\
K_{33r} &= K_{3r}c_{2r} - K_{2r}s_{2r} \\
\bar{\omega}_{5r} &= [K_{31r} \quad K_{32r} \quad K_{33r} \quad] \\
\bar{\omega}_{5r} &= [\dot{q}_{torso}c_{1r} - K_{4r}\dot{\psi} - K_{5r}\dot{q}w - K_{5r}\dot{q}_{imu} - \dot{q}_{2r} \quad c_{2r}(\dot{q}_{1r} + K_{28}\dot{\psi} + \dot{q}w c_{torso} + \dot{q}_{imu} c_{torso}) - s_{2r}(K_{6r}\dot{\psi} + K_{7r}\dot{q}w + K_{7r}\dot{q}_{imu} + \dot{q}_{torso}) \\
K_{34r} &= K_{28}c_{2r} - K_{6r}s_{2r} \\
K_{35r} &= c_{2r}c_{torso} - K_{7r}s_{2r} \\
K_{36r} &= -s_{1r}s_{2r} \\
K_{37r} &= K_{6r}c_{2r} + K_{28}s_{2r} \\
K_{38r} &= c_{torso}s_{2r} + K_{7r}c_{2r} \\
K_{39r} &= c_{2r}s_{1r} \\
\bar{\omega}_{5r} &= [\dot{q}_{torso}c_{1r} - K_{4r}\dot{\psi} - K_{5r}\dot{q}w - K_{5r}\dot{q}_{imu} - \dot{q}_{2r} \quad K_{34r}\dot{\psi} + K_{35r}\dot{q}w + K_{35r}\dot{q}_{imu} + K_{36r}\dot{q}_{torso} + \dot{q}_{1r}c_{2r} \quad K_{37r}\dot{\psi} + K_{38r}\dot{q}w + K_{38r}\dot{q}_{torso} \\
\bar{v}_{5r} &= {}^{5r}A_{4r}(\bar{v}_{4r} + \bar{\omega}_{4r} \times \bar{P}_{5r}) \\
\bar{v}_{5r} &= [-K_{8r} \quad -K_{9r}c_{2r} - K_{10r}s_{2r} \quad K_{10r}c_{2r} - K_{9r}s_{2r} \quad] \\
K_{40r} &= -K_{9r}c_{2r} - K_{10r}s_{2r} \\
K_{41r} &= K_{10r}c_{2r} - K_{9r}s_{2r} \\
\bar{v}_{5r} &= [-K_{8r} \quad K_{40r} \quad K_{41r} \quad] \\
\bar{v}_{5r} &= [-K_{12r}\dot{\psi} - K_{14r}\dot{q}w - K_{13r}\dot{q}_{imu} - K_{15r}\dot{q}_{torso} - K_{11r}\ddot{x} \quad -c_{2r}(K_{16r}\dot{\psi} + K_{18r}\dot{q}w + K_{17r}\dot{q}_{imu} - K_{33}\ddot{x}) - s_{2r}(K_{20r}\dot{\psi} + K_{22r}\dot{q}w + K_{22r}\dot{q}_{torso}) \\
K_{42r} &= K_{33}c_{2r} - K_{19r}s_{2r} \\
K_{43r} &= -K_{16r}c_{2r} - K_{20r}s_{2r} \\
K_{44r} &= -K_{17r}c_{2r} - K_{21r}s_{2r} \\
K_{45r} &= -K_{18r}c_{2r} - K_{22r}s_{2r} \\
K_{46r} &= -K_{23r}s_{2r} \\
K_{47r} &= K_{19r}c_{2r} + K_{33}s_{2r} \\
K_{48r} &= K_{20r}c_{2r} - K_{16r}s_{2r} \\
K_{49r} &= K_{21r}c_{2r} - K_{17r}s_{2r} \\
K_{50r} &= K_{22r}c_{2r} - K_{18r}s_{2r} \\
K_{51r} &= K_{23r}c_{2r} \\
\bar{v}_{5r} &= [-K_{12r}\dot{\psi} - K_{14r}\dot{q}w - K_{13r}\dot{q}_{imu} - K_{15r}\dot{q}_{torso} - K_{11r}\ddot{x} \quad K_{43r}\dot{\psi} + K_{45r}\dot{q}w + K_{44r}\dot{q}_{imu} + K_{46r}\dot{q}_{torso} + K_{42r}\ddot{x} \quad K_{48r}\dot{\psi} + K_{50r}\dot{q}w + K_{50r}\dot{q}_{torso} \\
\bar{\alpha}_{5r} &= {}^{5r}A_{4r}\bar{\alpha}_{4r} + \dot{q}_{5r}\bar{e}_{5r} + \dot{q}_{5r}(\bar{\omega}_{5r} \times \bar{e}_{5r}) \\
\bar{\alpha}_{5r} &= [\dot{q}_{torso}c_{1r} - \dot{q}_{2r} - K_{4r}\dot{\psi} - K_{5r}\dot{q}w - K_{5r}\dot{q}_{imu} - K_{24r} \quad c_{2r}(K_{42} + \dot{q}_{1r} + K_{28}\dot{\psi} + \dot{q}w c_{torso} + \dot{q}_{imu} c_{torso}) - K_{33r}\dot{q}_{2r} - s_{2r}(K_{25r}\dot{\psi} + K_{27r}\dot{q}w + K_{27r}\dot{q}_{torso}) \\
K_{52r} &= K_{42}c_{2r} - K_{33r}\dot{q}_{2r} - K_{25r}s_{2r} \\
K_{53r} &= K_{32r}\dot{q}_{2r} + K_{25r}c_{2r} + K_{42}s_{2r} \\
\bar{\alpha}_{5r} &= [\dot{q}_{torso}c_{1r} - \dot{q}_{2r} - K_{4r}\dot{\psi} - K_{5r}\dot{q}w - K_{5r}\dot{q}_{imu} - K_{24r} \quad K_{52r} + K_{34r}\dot{\psi} + K_{35r}\dot{q}w + K_{35r}\dot{q}_{imu} + K_{36r}\dot{q}_{torso} + \dot{q}_{1r}c_{2r} \quad K_{53r} + K_{37r}\dot{\psi} + K_{38r}\dot{q}w + K_{38r}\dot{q}_{torso} \\
\bar{\alpha}_{5r} &= {}^{5r}A_{4r}(\bar{\alpha}_{4r} + \bar{\alpha}_{4r} \times \bar{P}_{5r} + \bar{\omega}_{4r} \times (\bar{\omega}_{4r} \times \bar{P}_{5r})) \\
\bar{\alpha}_{5r} &= [-K_{26r} - K_{12r}\dot{\psi} - K_{14r}\dot{q}w - K_{13r}\dot{q}_{imu} - K_{15r}\dot{q}_{torso} - K_{11r}\ddot{x} \quad -c_{2r}(K_{27r} + K_{16r}\dot{\psi} + K_{18r}\dot{q}w + K_{17r}\dot{q}_{imu} - K_{33}\ddot{x}) - s_{2r}(K_{20r}\dot{\psi} + K_{22r}\dot{q}w + K_{22r}\dot{q}_{torso}) \\
K_{54r} &= -K_{27r}c_{2r} - K_{28r}s_{2r}
\end{aligned}$$

$$\begin{aligned}
K_{55r} &= K_{28r}c_{2r} - K_{27r}s_{2r} \\
\bar{a}_{5r} &= [-K_{26r} - K_{12r}\ddot{\psi} - K_{14r}\ddot{q}_w - K_{13r}\ddot{q}_{imu} - K_{15r}\ddot{q}_{torso} - K_{11r}\ddot{x} \quad K_{54r} + K_{43r}\ddot{\psi} + K_{45r}\ddot{q}_w + K_{44r}\ddot{q}_{imu} + K_{46r}\ddot{q}_{torso} + K_{42r}\ddot{x} \\
\bar{g}_{5r} &= {}^{5r}A_{4r}\bar{g}_{4r} \\
\bar{g}_{5r} &= [-K_{29r}g \quad K_{47r}gc_{2r} - K_{30r}gs_{2r} \quad K_{30r}gc_{2r} + K_{47r}gs_{2r} \quad] \\
K_{56r} &= K_{47r}c_{2r} - K_{30r}s_{2r} \\
K_{57r} &= K_{30r}c_{2r} + K_{47r}s_{2r} \\
\bar{g}_{5r} &= [-K_{29r}g \quad K_{56r}g \quad K_{57r}g \quad] \\
m_{5r}\bar{S}_{5r}^\times \bar{g}_{5r} &= \mathbf{MS}_{5r} \times \bar{g}_{5r} \\
m_{5r}\bar{S}_{5r}^\times \bar{g}_{5r} &= [K_{57r}\mathbf{MY}_{5r}g - K_{56r}\mathbf{MZ}_{5r}g \quad -K_{57r}\mathbf{MX}_{5r}g - K_{29r}\mathbf{MZ}_{5r}g \quad K_{56r}\mathbf{MX}_{5r}g + K_{29r}\mathbf{MY}_{5r}g \quad] \\
D_{40r} &= K_{57r}\mathbf{MY}_{5r} - K_{56r}\mathbf{MZ}_{5r} \\
D_{41r} &= -K_{57r}\mathbf{MX}_{5r} - K_{29r}\mathbf{MZ}_{5r} \\
D_{42r} &= K_{56r}\mathbf{MX}_{5r} + K_{29r}\mathbf{MY}_{5r} \\
m_{5r}\bar{S}_{5r}^\times \bar{g}_{5r} &= [D_{40r}g \quad D_{41r}g \quad D_{42r}g \quad] \\
m_{5r}\bar{a}_G(5r) &= m_{5r}\bar{a}_{5r} + \bar{\alpha}_{5r} \times \mathbf{MS}_{5r} + \bar{\omega}_{5r} \times (\bar{\omega}_{5r} \times \mathbf{MS}_{5r}) \\
m_{5r}\bar{a}_G(5r) &= [\mathbf{MZ}_{5r}(K_{52r} + K_{34r}\ddot{\psi} + K_{35r}\ddot{q}_w + K_{35r}\ddot{q}_{imu} + K_{36r}\ddot{q}_{torso} + \ddot{q}_{1r}c_{2r}) - \mathbf{MY}_{5r}(K_{53r} + K_{37r}\ddot{\psi} + K_{38r}\ddot{q}_w + K_{38r}\ddot{q}_{imu} + K_{39r}\ddot{q}_{torso} \\
D_{43r} &= -K_{11r}m_{5r} \\
D_{44r} &= K_{34r}\mathbf{MZ}_{5r} - K_{37r}\mathbf{MY}_{5r} - K_{12r}m_{5r} \\
D_{45r} &= K_{35r}\mathbf{MZ}_{5r} - K_{38r}\mathbf{MY}_{5r} - K_{13r}m_{5r} \\
D_{46r} &= K_{35r}\mathbf{MZ}_{5r} - K_{38r}\mathbf{MY}_{5r} - K_{14r}m_{5r} \\
D_{47r} &= K_{36r}\mathbf{MZ}_{5r} - K_{39r}\mathbf{MY}_{5r} - K_{15r}m_{5r} \\
D_{48r} &= \mathbf{MZ}_{5r}c_{2r} - \mathbf{MY}_{5r}s_{2r} \\
D_{49r} &= K_{52r}\mathbf{MZ}_{5r} - K_{32r}^2\mathbf{MX}_{5r} - K_{33r}^2\mathbf{MX}_{5r} \\
&\quad - K_{53r}\mathbf{MY}_{5r} - K_{26r}m_{5r} + K_{31r}K_{32r}\mathbf{MY}_{5r} \\
&\quad + K_{31r}K_{33r}\mathbf{MZ}_{5r} \\
D_{50r} &= K_{42r}m_{5r} \\
D_{51r} &= K_{43r}m_{5r} + K_{37r}\mathbf{MX}_{5r} + K_{4r}\mathbf{MZ}_{5r} \\
D_{52r} &= K_{44r}m_{5r} + K_{38r}\mathbf{MX}_{5r} + K_{5r}\mathbf{MZ}_{5r} \\
D_{53r} &= K_{45r}m_{5r} + K_{38r}\mathbf{MX}_{5r} + K_{5r}\mathbf{MZ}_{5r} \\
D_{54r} &= K_{46r}m_{5r} - \mathbf{MZ}_{5r}c_{1r} + K_{39r}\mathbf{MX}_{5r} \\
D_{55r} &= \mathbf{MX}_{5r}s_{2r} \\
D_{56r} &= K_{54r}m_{5r} - K_{31r}^2\mathbf{MY}_{5r} - K_{33r}^2\mathbf{MY}_{5r} \\
&\quad + K_{53r}\mathbf{MX}_{5r} + K_{24r}\mathbf{MZ}_{5r} + K_{31r}K_{32r}\mathbf{MX}_{5r} \\
&\quad + K_{32r}K_{33r}\mathbf{MZ}_{5r} \\
D_{57r} &= K_{47r}m_{5r} \\
D_{58r} &= K_{48r}m_{5r} - K_{34r}\mathbf{MX}_{5r} - K_{4r}\mathbf{MY}_{5r} \\
D_{59r} &= K_{49r}m_{5r} - K_{35r}\mathbf{MX}_{5r} - K_{5r}\mathbf{MY}_{5r} \\
D_{60r} &= K_{50r}m_{5r} - K_{35r}\mathbf{MX}_{5r} - K_{5r}\mathbf{MY}_{5r} \\
D_{61r} &= K_{51r}m_{5r} + \mathbf{MY}_{5r}c_{1r} - K_{36r}\mathbf{MX}_{5r} \\
D_{62r} &= -\mathbf{MX}_{5r}c_{2r} \\
D_{63r} &= K_{55r}m_{5r} - K_{31r}^2\mathbf{MZ}_{5r} - K_{32r}^2\mathbf{MZ}_{5r} \\
&\quad - K_{52r}\mathbf{MX}_{5r} - K_{24r}\mathbf{MY}_{5r} + K_{31r}K_{33r}\mathbf{MX}_{5r} \\
&\quad + K_{32r}K_{33r}\mathbf{MY}_{5r} \\
m_{5r}\bar{a}_G(5r) &= [D_{49r} + D_{44r}\ddot{\psi} + D_{48r}\ddot{q}_{1r} + D_{46r}\ddot{q}_w + D_{45r}\ddot{q}_{imu} + D_{47r}\ddot{q}_{torso} + D_{43r}\ddot{x} \quad D_{56r} + D_{51r}\ddot{\psi} + D_{55r}\ddot{q}_{1r} + D_{53r}\ddot{q}_w + D_{52r}\ddot{q}_{imu} + D_{54r}\ddot{q}_{torso} \\
\dot{H}_{5r} &= \mathbf{MS}_{5r} \times \bar{a}_{5r} + J_{5r}\bar{\alpha}_{5r} + \bar{\omega}_{5r} \times J_{5r}\bar{\omega}_{5r} \\
\dot{H}_{5r} &= [K_{32r}(K_{31r}\mathbf{XZ}_{5r} + K_{32r}\mathbf{YZ}_{5r} + K_{33r}\mathbf{ZZ}_{5r}) - K_{33r}(K_{31r}\mathbf{XY}_{5r} + K_{32r}\mathbf{YY}_{5r} + K_{33r}\mathbf{YZ}_{5r}) + \mathbf{XY}_{5r}(K_{52r} + K_{34r}\ddot{\psi} + K_{35r}\ddot{q}_w + K_{35r}\ddot{q}_{imu} + K_{36r}\ddot{q}_{torso} \\
D_{64r} &= K_{47r}\mathbf{MY}_{5r} - K_{42r}\mathbf{MZ}_{5r} \\
D_{65r} &= K_{34r}\mathbf{XY}_{5r} - K_{4r}\mathbf{XX}_{5r} + K_{37r}\mathbf{XZ}_{5r} \\
&\quad + K_{48r}\mathbf{MY}_{5r} - K_{43r}\mathbf{MZ}_{5r} \\
D_{66r} &= K_{35r}\mathbf{XY}_{5r} - K_{5r}\mathbf{XX}_{5r} + K_{38r}\mathbf{XZ}_{5r} \\
&\quad + K_{49r}\mathbf{MY}_{5r} - K_{44r}\mathbf{MZ}_{5r} \\
D_{67r} &= K_{35r}\mathbf{XY}_{5r} - K_{5r}\mathbf{XX}_{5r} + K_{38r}\mathbf{XZ}_{5r} \\
&\quad + K_{50r}\mathbf{MY}_{5r} - K_{45r}\mathbf{MZ}_{5r} \\
D_{68r} &= K_{36r}\mathbf{XY}_{5r} + K_{39r}\mathbf{XZ}_{5r} + \mathbf{XX}_{5r}c_{1r} \\
&\quad + K_{51r}\mathbf{MY}_{5r} - K_{46r}\mathbf{MZ}_{5r} \\
D_{69r} &= \mathbf{XY}_{5r}c_{2r} + \mathbf{XZ}_{5r}s_{2r} \\
D_{70r} &= K_{52r}\mathbf{XY}_{5r} - K_{24r}\mathbf{XX}_{5r} + K_{53r}\mathbf{XZ}_{5r} \\
&\quad + K_{32r}^2\mathbf{YZ}_{5r} - K_{33r}^2\mathbf{YZ}_{5r} + K_{55r}\mathbf{MY}_{5r} \\
&\quad - K_{54r}\mathbf{MZ}_{5r} - K_{31r}K_{33r}\mathbf{XY}_{5r} + K_{31r}K_{32r}\mathbf{XZ}_{5r} \\
&\quad - K_{32r}K_{33r}\mathbf{YY}_{5r} + K_{32r}K_{33r}\mathbf{ZZ}_{5r} \\
D_{71r} &= -K_{47r}\mathbf{MX}_{5r} - K_{11r}\mathbf{MZ}_{5r} \\
D_{72r} &= K_{34r}\mathbf{YY}_{5r} - K_{4r}\mathbf{XY}_{5r} + K_{37r}\mathbf{YZ}_{5r}
\end{aligned}$$

$$\begin{aligned}
& -K_{48r}\mathbf{MX}_{5r} - K_{12r}\mathbf{MZ}_{5r} \\
D_{73r} &= K_{35r}\mathbf{YY}_{5r} - K_{5r}\mathbf{XY}_{5r} + K_{38r}\mathbf{YZ}_{5r} \\
& -K_{49r}\mathbf{MX}_{5r} - K_{13r}\mathbf{MZ}_{5r} \\
D_{74r} &= K_{35r}\mathbf{YY}_{5r} - K_{5r}\mathbf{XY}_{5r} + K_{38r}\mathbf{YZ}_{5r} \\
& -K_{50r}\mathbf{MX}_{5r} - K_{14r}\mathbf{MZ}_{5r} \\
D_{75r} &= K_{36r}\mathbf{YY}_{5r} + K_{39r}\mathbf{YZ}_{5r} + \mathbf{XY}_{5r}c_{1r} \\
& -K_{51r}\mathbf{MX}_{5r} - K_{15r}\mathbf{MZ}_{5r} \\
D_{76r} &= \mathbf{YY}_{5r}c_{2r} + \mathbf{YZ}_{5r}s_{2r} \\
D_{77r} &= K_{52r}\mathbf{YY}_{5r} - K_{24r}\mathbf{XY}_{5r} + K_{53r}\mathbf{YZ}_{5r} \\
& -K_{31r}^2\mathbf{XZ}_{5r} + K_{33r}^2\mathbf{XZ}_{5r} - K_{55r}\mathbf{MX}_{5r} \\
& -K_{26r}\mathbf{MZ}_{5r} + K_{31r}K_{33r}\mathbf{XX}_{5r} + K_{32r}K_{33r}\mathbf{XY}_{5r} \\
& -K_{31r}K_{32r}\mathbf{YZ}_{5r} - K_{31r}K_{33r}\mathbf{ZZ}_{5r} \\
D_{78r} &= K_{42r}\mathbf{MX}_{5r} + K_{11r}\mathbf{MY}_{5r} \\
D_{79r} &= K_{34r}\mathbf{YZ}_{5r} - K_{4r}\mathbf{XZ}_{5r} + K_{37r}\mathbf{ZZ}_{5r} \\
& + K_{43r}\mathbf{MX}_{5r} + K_{12r}\mathbf{MY}_{5r} \\
D_{80r} &= K_{35r}\mathbf{YZ}_{5r} - K_{5r}\mathbf{XZ}_{5r} + K_{38r}\mathbf{ZZ}_{5r} \\
& + K_{44r}\mathbf{MX}_{5r} + K_{13r}\mathbf{MY}_{5r} \\
D_{81r} &= K_{35r}\mathbf{YZ}_{5r} - K_{5r}\mathbf{XZ}_{5r} + K_{38r}\mathbf{ZZ}_{5r} \\
& + K_{45r}\mathbf{MX}_{5r} + K_{14r}\mathbf{MY}_{5r} \\
D_{82r} &= K_{36r}\mathbf{YZ}_{5r} + K_{39r}\mathbf{ZZ}_{5r} + \mathbf{XZ}_{5r}c_{1r} \\
& + K_{46r}\mathbf{MX}_{5r} + K_{15r}\mathbf{MY}_{5r} \\
D_{83r} &= \mathbf{YZ}_{5r}c_{2r} + \mathbf{ZZ}_{5r}s_{2r} \\
D_{84r} &= K_{52r}\mathbf{YZ}_{5r} - K_{24r}\mathbf{XZ}_{5r} + K_{53r}\mathbf{ZZ}_{5r} \\
& + K_{31r}^2\mathbf{XY}_{5r} - K_{32r}^2\mathbf{XY}_{5r} + K_{54r}\mathbf{MX}_{5r} \\
& + K_{26r}\mathbf{MY}_{5r} - K_{31r}K_{32r}\mathbf{XX}_{5r} - K_{32r}K_{33r}\mathbf{XZ}_{5r} \\
& + K_{31r}K_{32r}\mathbf{YY}_{5r} + K_{31r}K_{33r}\mathbf{YZ}_{5r} \\
\dot{H}_{5r} &= [D_{49r} + D_{44r}\dot{\psi} + D_{48r}\dot{q}_{1r} + D_{46r}\dot{q}_w + D_{45r}\dot{q}_{imu} + D_{47r}\dot{q}_{torso} + D_{43r}\ddot{x} \quad D_{56r} + D_{51r}\ddot{\psi} + D_{55r}\dot{q}_{1r} + D_{53r}\dot{q}_w + D_{52r}\dot{q}_{imu} + D_{57r}\dot{q}_{torso}] \\
\bar{\omega}_{6r} &= {}^{6r}A_{5r}\bar{\omega}_{5r} + \dot{q}_{6r}e_{6r} \\
\bar{\omega}_{6r} &= [K_{33r}s_{3r} - K_{31r}c_{3r} \quad -K_{32r} - \dot{q}_{3r} \quad K_{33r}c_{3r} + K_{31r}s_{3r} \quad] \\
K_{58r} &= K_{33r}s_{3r} - K_{31r}c_{3r} \\
K_{59r} &= -K_{32r} - \dot{q}_{3r} \\
K_{60r} &= K_{33r}c_{3r} + K_{31r}s_{3r} \\
\bar{\omega}_{6r} &= [K_{58r} \quad K_{59r} \quad K_{60r} \quad] \\
\bar{\omega}_{6r} &= [s_{3r}(K_{37r}\dot{\psi} + K_{38r}\dot{q}_w + K_{38r}\dot{q}_{imu} + K_{39r}\dot{q}_{torso} + \dot{q}_{1r}s_{2r}) + c_{3r}(\dot{q}_{2r} + K_{4r}\dot{\psi} + K_{5r}\dot{q}_w + K_{5r}\dot{q}_{imu} - \dot{q}_{torso}c_{1r}) \quad -\dot{q}_{3r} - K_{34r}\dot{\psi} + K_{35r}\dot{q}_w + K_{35r}\dot{q}_{imu} - \dot{q}_{torso}c_{1r}] \\
K_{61r} &= K_{4r}c_{3r} + K_{37r}s_{3r} \\
K_{62r} &= K_{5r}c_{3r} + K_{38r}s_{3r} \\
K_{63r} &= K_{39r}s_{3r} - c_{1r}c_{3r} \\
K_{64r} &= s_{2r}s_{3r} \\
K_{65r} &= K_{37r}c_{3r} - K_{4r}s_{3r} \\
K_{66r} &= K_{38r}c_{3r} - K_{5r}s_{3r} \\
K_{67r} &= c_{1r}s_{3r} + K_{39r}c_{3r} \\
K_{68r} &= c_{3r}s_{2r} \\
\bar{\omega}_{6r} &= [K_{61r}\dot{\psi} + K_{64r}\dot{q}_{1r} + K_{62r}\dot{q}_w + K_{62r}\dot{q}_{imu} + K_{63r}\dot{q}_{torso} + \dot{q}_{2r}c_{3r} \quad -\dot{q}_{3r} - K_{34r}\dot{\psi} - K_{35r}\dot{q}_w - K_{35r}\dot{q}_{imu} - K_{36r}\dot{q}_{torso} - \dot{q}_{1r}c_{2r}] \\
\bar{v}_{6r} &= {}^{6r}A_{5r}(\bar{v}_{5r} + \bar{\omega}_{5r} \times \bar{P}_{6r}) \\
\bar{v}_{6r} &= [c_{3r}(K_{8r} - K_{33r}L_7) + s_{3r}(K_{41r} - K_{31r}L_7) \quad -K_{40r} \quad c_{3r}(K_{41r} - K_{31r}L_7) - s_{3r}(K_{8r} - K_{33r}L_7) \quad] \\
K_{69r} &= c_{3r}(K_{8r} - K_{33r}L_7) + s_{3r}(K_{41r} - K_{31r}L_7) \\
& -K_{31r}L_7 \\
K_{70r} &= c_{3r}(K_{41r} - K_{31r}L_7) - s_{3r}(K_{8r} - K_{33r}L_7) \\
\bar{v}_{6r} &= [K_{69r} \quad -K_{40r} \quad K_{70r} \quad] \\
\bar{v}_{6r} &= [s_{3r}(K_{48r}\dot{\psi} + K_{50r}\dot{q}_w + K_{49r}\dot{q}_{imu} + K_{51r}\dot{q}_{torso} + K_{47r}\ddot{x} + L_7(\dot{q}_{2r} + K_{4r}\dot{\psi} + K_{5r}\dot{q}_w + K_{5r}\dot{q}_{imu} - \dot{q}_{torso}c_{1r})) + c_{3r}(K_{12r}\dot{\psi} + K_{13r}\dot{q}_w + K_{13r}\dot{q}_{imu} - \dot{q}_{torso}c_{1r})] \\
K_{71r} &= K_{11r}c_{3r} + K_{47r}s_{3r} \\
K_{72r} &= c_{3r}(K_{12r} - K_{37r}L_7) + s_{3r}(K_{48r} + K_{4r}L_7) \\
K_{73r} &= c_{3r}(K_{13r} - K_{38r}L_7) + s_{3r}(K_{49r} + K_{5r}L_7) \\
K_{74r} &= c_{3r}(K_{14r} - K_{38r}L_7) + s_{3r}(K_{50r} + K_{5r}L_7) \\
K_{75r} &= s_{3r}(K_{51r} - L_7c_{1r}) + c_{3r}(K_{15r} - K_{39r}L_7) \\
K_{76r} &= -L_7c_{3r}s_{2r} \\
K_{77r} &= L_7s_{3r} \\
K_{78r} &= K_{47r}c_{3r} - K_{11r}s_{3r}
\end{aligned}$$

$$\begin{aligned}
K_{79r} &= c_{3r}(K_{48r} + K_{4r}L_7) - s_{3r}(K_{12r} \\
&\quad - K_{37r}L_7) \\
K_{80r} &= c_{3r}(K_{49r} + K_{5r}L_7) - s_{3r}(K_{13r} \\
&\quad - K_{38r}L_7) \\
K_{81r} &= c_{3r}(K_{50r} + K_{5r}L_7) - s_{3r}(K_{14r} \\
&\quad - K_{38r}L_7) \\
K_{82r} &= c_{3r}(K_{51r} - L_7c_{1r}) - s_{3r}(K_{15r} \\
&\quad - K_{39r}L_7) \\
K_{83r} &= L_7s_{2r}s_{3r} \\
K_{84r} &= L_7c_{3r} \\
\bar{v}_{6r} &= [K_{72r}\bar{\psi} + K_{76r}\bar{q}_{1r} + K_{74r}\bar{q}_w + K_{77r}\bar{q}_{2r} + K_{73r}\bar{q}_{imu} + K_{75r}\bar{q}_{torso} + K_{71r}\bar{x} \quad -K_{43r}\bar{\psi} - K_{45r}\bar{q}_w - K_{44r}\bar{q}_{imu} - K_{46r}\bar{q}_{torso} - K_{47r}\bar{x} \\
\bar{\alpha}_{6r} &= {}^6rA_{5r}\bar{\alpha}_{5r} + \bar{q}_{6r}\bar{e}_{6r} + \bar{q}_{6r}(\bar{\omega}_{6r} \times \bar{e}_{6r}) \\
\bar{\alpha}_{6r} &= [c_{3r}(K_{24r} + \bar{q}_{2r} + K_{4r}\bar{\psi} + K_{5r}\bar{q}_w + K_{5r}\bar{q}_{imu} - \bar{q}_{torsoc_{1r}}) + K_{60r}\bar{q}_{3r} + s_{3r}(K_{53r} + K_{37r}\bar{\psi} + K_{38r}\bar{q}_w + K_{38r}\bar{q}_{imu} + K_{39r}\bar{q}_{torso} \\
K_{85r} &= K_{60r}\bar{q}_{3r} + K_{24r}c_{3r} + K_{53r}s_{3r} \\
K_{86r} &= K_{53r}c_{3r} - K_{58r}\bar{q}_{3r} - K_{24r}s_{3r} \\
\bar{\alpha}_{6r} &= [K_{85r} + K_{61r}\bar{\psi} + K_{64r}\bar{q}_{1r} + K_{62r}\bar{q}_w + K_{62r}\bar{q}_{imu} + K_{63r}\bar{q}_{torso} + \bar{q}_{2r}c_{3r} \quad -K_{52r} - \bar{q}_{3r} - K_{34r}\bar{\psi} - K_{35r}\bar{q}_w - K_{35r}\bar{q}_{imu} - K_{36r}\bar{x} \\
\bar{a}_{6r} &= {}^6rA_{5r}(\bar{a}_{5r} + \bar{\alpha}_{5r} \times \bar{P}_{6r} + \bar{\omega}_{5r} \times (\bar{\omega}_{5r} \times \bar{P}_{6r})) \\
\bar{\alpha}_{6r} &= [c_{3r}(K_{26r} + K_{12r}\bar{\psi} + K_{14r}\bar{q}_w + K_{13r}\bar{q}_{imu} + K_{15r}\bar{q}_{torso} + K_{11r}\bar{x} - L_7(K_{53r} + K_{37r}\bar{\psi} + K_{38r}\bar{q}_w + K_{38r}\bar{q}_{imu} + K_{39r}\bar{q}_{torso} + \bar{q}_{1r} \\
K_{87r} &= K_{26r}c_{3r} + K_{55r}s_{3r} - K_{53r}L_7c_{3r} \\
&\quad + K_{24r}L_7s_{3r} + K_{31r}K_{32r}L_7c_{3r} \\
&\quad - K_{32r}K_{33r}L_7s_{3r} \\
K_{88r} &= -K_{54r} - K_{31r}^2L_7 - K_{33r}^2L_7 \\
K_{89r} &= K_{55r}c_{3r} - K_{26r}s_{3r} + K_{24r}L_7c_{3r} \\
&\quad + K_{53r}L_7s_{3r} - K_{32r}K_{33r}L_7c_{3r} \\
&\quad - K_{31r}K_{32r}L_7s_{3r} \\
\bar{a}_{6r} &= [K_{87r} + K_{72r}\bar{\psi} + K_{76r}\bar{q}_{1r} + K_{74r}\bar{q}_w + K_{77r}\bar{q}_{2r} + K_{73r}\bar{q}_{imu} + K_{75r}\bar{q}_{torso} + K_{71r}\bar{x} \quad K_{88r} - K_{43r}\bar{\psi} - K_{45r}\bar{q}_w - K_{44r}\bar{q}_{imu} - K_{46r}\bar{q}_{torso} - K_{47r}\bar{x} \\
\bar{g}_{6r} &= {}^6rA_{5r}\bar{g}_{5r} \\
\bar{g}_{6r} &= [K_{29r}g_{c_{3r}} + K_{57r}g_{s_{3r}} \quad -K_{56r}g \quad K_{57r}g_{c_{3r}} - K_{29r}g_{s_{3r}} \quad] \\
K_{90r} &= K_{29r}c_{3r} + K_{57r}s_{3r} \\
K_{91r} &= K_{57r}c_{3r} - K_{29r}s_{3r} \\
\bar{g}_{6r} &= [K_{90r}g \quad -K_{56r}g \quad K_{91r}g \quad] \\
m_{6r}\bar{S}_{6r}^{\times}\bar{g}_{6r} &= \mathbf{MS}_{6r} \times \bar{g}_{6r} \\
m_{6r}\bar{S}_{6r}^{\times}\bar{g}_{6r} &= [K_{91r}\mathbf{MY}_{6r}g + K_{56r}\mathbf{MZ}_{6r}g \quad K_{90r}\mathbf{MZ}_{6r}g - K_{91r}\mathbf{MX}_{6r}g \quad -K_{56r}\mathbf{MX}_{6r}g - K_{90r}\mathbf{MY}_{6r}g \quad] \\
D_{85r} &= K_{91r}\mathbf{MY}_{6r} + K_{56r}\mathbf{MZ}_{6r} \\
D_{86r} &= K_{90r}\mathbf{MZ}_{6r} - K_{91r}\mathbf{MX}_{6r} \\
D_{87r} &= -K_{56r}\mathbf{MX}_{6r} - K_{90r}\mathbf{MY}_{6r} \\
m_{6r}\bar{S}_{6r}^{\times}\bar{g}_{6r} &= [D_{85r}g \quad D_{86r}g \quad D_{87r}g \quad] \\
m_{6r}\bar{a}_G(6r) &= m_{6r}\bar{a}_{6r} + \bar{\alpha}_{6r} \times \mathbf{MS}_{6r} + \bar{\omega}_{6r} \times (\bar{\omega}_{6r} \times \mathbf{MS}_{6r}) \\
m_{6r}\bar{a}_G(6r) &= [m_{6r}(K_{87r} + K_{72r}\bar{\psi} + K_{76r}\bar{q}_{1r} + K_{74r}\bar{q}_w + K_{77r}\bar{q}_{2r} + K_{73r}\bar{q}_{imu} + K_{75r}\bar{q}_{torso} + K_{71r}\bar{x}) - \mathbf{MZ}_{6r}(K_{52r} + \bar{q}_{3r} + K_{34r}\bar{\psi} + K_{35r}\bar{q}_w \\
D_{88r} &= K_{71r}m_{6r} \\
D_{89r} &= K_{72r}m_{6r} - K_{65r}\mathbf{MY}_{6r} - K_{34r}\mathbf{MZ}_{6r} \\
D_{90r} &= K_{73r}m_{6r} - K_{66r}\mathbf{MY}_{6r} - K_{35r}\mathbf{MZ}_{6r} \\
D_{91r} &= K_{74r}m_{6r} - K_{66r}\mathbf{MY}_{6r} - K_{35r}\mathbf{MZ}_{6r} \\
D_{92r} &= K_{75r}m_{6r} - K_{67r}\mathbf{MY}_{6r} - K_{36r}\mathbf{MZ}_{6r} \\
D_{93r} &= K_{76r}m_{6r} - \mathbf{MZ}_{6r}c_{2r} - K_{68r}\mathbf{MY}_{6r} \\
D_{94r} &= K_{77r}m_{6r} + \mathbf{MY}_{6r}s_{3r} \\
D_{95r} &= K_{87r}m_{6r} - K_{59r}^2\mathbf{MX}_{6r} - K_{60r}^2\mathbf{MX}_{6r} \\
&\quad - K_{86r}\mathbf{MY}_{6r} - K_{52r}\mathbf{MZ}_{6r} + K_{58r}K_{59r}\mathbf{MY}_{6r} \\
&\quad + K_{58r}K_{60r}\mathbf{MZ}_{6r} \\
D_{96r} &= -K_{42r}m_{6r} \\
D_{97r} &= K_{65r}\mathbf{MX}_{6r} - K_{43r}m_{6r} - K_{61r}\mathbf{MZ}_{6r} \\
D_{98r} &= K_{66r}\mathbf{MX}_{6r} - K_{44r}m_{6r} - K_{62r}\mathbf{MZ}_{6r} \\
D_{99r} &= K_{66r}\mathbf{MX}_{6r} - K_{45r}m_{6r} - K_{62r}\mathbf{MZ}_{6r} \\
D_{100r} &= K_{67r}\mathbf{MX}_{6r} - K_{46r}m_{6r} - K_{63r}\mathbf{MZ}_{6r} \\
D_{101r} &= K_{68r}\mathbf{MX}_{6r} - K_{64r}\mathbf{MZ}_{6r} \\
D_{102r} &= -\mathbf{MZ}_{6r}c_{3r} - \mathbf{MX}_{6r}s_{3r} \\
D_{103r} &= K_{88r}m_{6r} - K_{58r}^2\mathbf{MY}_{6r} - K_{60r}^2\mathbf{MY}_{6r} \\
&\quad + K_{86r}\mathbf{MX}_{6r} - K_{85r}\mathbf{MZ}_{6r} + K_{58r}K_{59r}\mathbf{MX}_{6r} \\
&\quad + K_{59r}K_{60r}\mathbf{MZ}_{6r} \\
D_{104r} &= K_{78r}m_{6r}
\end{aligned}$$

$$\begin{aligned}
D_{105r} &= K_{79r}m_{6r} + K_{34r}\mathbf{MX}_{6r} + K_{61r}\mathbf{MY}_{6r} \\
D_{106r} &= K_{80r}m_{6r} + K_{35r}\mathbf{MX}_{6r} + K_{62r}\mathbf{MY}_{6r} \\
D_{107r} &= K_{81r}m_{6r} + K_{35r}\mathbf{MX}_{6r} + K_{62r}\mathbf{MY}_{6r} \\
D_{108r} &= K_{82r}m_{6r} + K_{36r}\mathbf{MX}_{6r} + K_{63r}\mathbf{MY}_{6r} \\
D_{109r} &= K_{83r}m_{6r} + \mathbf{MX}_{6r}c_{2r} + K_{64r}\mathbf{MY}_{6r} \\
D_{110r} &= K_{84r}m_{6r} + \mathbf{MY}_{6r}c_{3r} \\
D_{111r} &= K_{89r}m_{6r} - K_{58r}^2\mathbf{MZ}_{6r} - K_{59r}^2\mathbf{MZ}_{6r} \\
&\quad + K_{52r}\mathbf{MX}_{6r} + K_{85r}\mathbf{MY}_{6r} + K_{58r}K_{60r}\mathbf{MX}_{6r} \\
&\quad + K_{59r}K_{60r}\mathbf{MY}_{6r} \\
m_{6r}\bar{a}_G(6r) &= [D_{95r} + D_{89r}\bar{\psi} + D_{93r}\bar{q}_{1r} + D_{91r}\bar{q}_w + D_{94r}\bar{q}_{2r} + D_{90r}\bar{q}_{imu} + D_{92r}\bar{q}_{torsor} + D_{88r}\bar{x} - \mathbf{MZ}_{6r}\bar{q}_{3r} \quad D_{103r} + D_{97r}\bar{\psi} + D_{101r}\bar{q}_{1r} + L \\
\bar{H}_{6r} &= \mathbf{MS}_{6r} \times \bar{a}_{6r} + J_{6r}\bar{\alpha}_{6r} + \bar{\omega}_{6r} \times J_{6r}\bar{\omega}_{6r} \\
\bar{H}_{6r} &= [\mathbf{MZ}_{6r}(K_{43r}\bar{\psi} - K_{88r} + K_{45r}\bar{q}_w + K_{44r}\bar{q}_{imu} + K_{46r}\bar{q}_{torsor} + K_{42r}\bar{x}) - K_{60r}(K_{58r}\mathbf{XY}_{6r} + K_{59r}\mathbf{YY}_{6r} + K_{60r}\mathbf{YZ}_{6r}) + K_{59r}(K_{58r} \\
D_{112r} &= K_{78r}\mathbf{MY}_{6r} + K_{42r}\mathbf{MZ}_{6r} \\
D_{113r} &= K_{61r}\mathbf{XX}_{6r} - K_{34r}\mathbf{XY}_{6r} + K_{65r}\mathbf{XZ}_{6r} \\
&\quad + K_{79r}\mathbf{MY}_{6r} + K_{43r}\mathbf{MZ}_{6r} \\
D_{114r} &= K_{62r}\mathbf{XX}_{6r} - K_{35r}\mathbf{XY}_{6r} + K_{66r}\mathbf{XZ}_{6r} \\
&\quad + K_{80r}\mathbf{MY}_{6r} + K_{44r}\mathbf{MZ}_{6r} \\
D_{115r} &= K_{62r}\mathbf{XX}_{6r} - K_{35r}\mathbf{XY}_{6r} + K_{66r}\mathbf{XZ}_{6r} \\
&\quad + K_{81r}\mathbf{MY}_{6r} + K_{45r}\mathbf{MZ}_{6r} \\
D_{116r} &= K_{63r}\mathbf{XX}_{6r} - K_{36r}\mathbf{XY}_{6r} + K_{67r}\mathbf{XZ}_{6r} \\
&\quad + K_{82r}\mathbf{MY}_{6r} + K_{46r}\mathbf{MZ}_{6r} \\
D_{117r} &= K_{64r}\mathbf{XX}_{6r} + K_{68r}\mathbf{XZ}_{6r} - \mathbf{XY}_{6r}c_{2r} \\
&\quad + K_{83r}\mathbf{MY}_{6r} \\
D_{118r} &= \mathbf{XX}_{6r}c_{3r} - \mathbf{XZ}_{6r}s_{3r} + K_{84r}\mathbf{MY}_{6r} \\
D_{119r} &= K_{85r}\mathbf{XX}_{6r} - K_{52r}\mathbf{XY}_{6r} + K_{86r}\mathbf{XZ}_{6r} \\
&\quad + K_{59r}^2\mathbf{YZ}_{6r} - K_{60r}^2\mathbf{YZ}_{6r} + K_{89r}\mathbf{MY}_{6r} \\
&\quad - K_{88r}\mathbf{MZ}_{6r} - K_{58r}K_{60r}\mathbf{XY}_{6r} + K_{58r}K_{59r}\mathbf{XZ}_{6r} \\
&\quad - K_{59r}K_{60r}\mathbf{YY}_{6r} + K_{59r}K_{60r}\mathbf{ZZ}_{6r} \\
D_{120r} &= K_{71r}\mathbf{MZ}_{6r} - K_{78r}\mathbf{MX}_{6r} \\
D_{121r} &= K_{61r}\mathbf{XY}_{6r} - K_{34r}\mathbf{YY}_{6r} + K_{65r}\mathbf{YZ}_{6r} \\
&\quad - K_{79r}\mathbf{MX}_{6r} + K_{72r}\mathbf{MZ}_{6r} \\
D_{122r} &= K_{62r}\mathbf{XY}_{6r} - K_{35r}\mathbf{YY}_{6r} + K_{66r}\mathbf{YZ}_{6r} \\
&\quad - K_{80r}\mathbf{MX}_{6r} + K_{73r}\mathbf{MZ}_{6r} \\
D_{123r} &= K_{62r}\mathbf{XY}_{6r} - K_{35r}\mathbf{YY}_{6r} + K_{66r}\mathbf{YZ}_{6r} \\
&\quad - K_{81r}\mathbf{MX}_{6r} + K_{74r}\mathbf{MZ}_{6r} \\
D_{124r} &= K_{63r}\mathbf{XY}_{6r} - K_{36r}\mathbf{YY}_{6r} + K_{67r}\mathbf{YZ}_{6r} \\
&\quad - K_{82r}\mathbf{MX}_{6r} + K_{75r}\mathbf{MZ}_{6r} \\
D_{125r} &= K_{64r}\mathbf{XY}_{6r} + K_{68r}\mathbf{YZ}_{6r} - \mathbf{YY}_{6r}c_{2r} \\
&\quad - K_{83r}\mathbf{MX}_{6r} + K_{76r}\mathbf{MZ}_{6r} \\
D_{126r} &= \mathbf{XY}_{6r}c_{3r} - \mathbf{YZ}_{6r}s_{3r} - K_{84r}\mathbf{MX}_{6r} \\
&\quad + K_{77r}\mathbf{MZ}_{6r} \\
D_{127r} &= K_{85r}\mathbf{XY}_{6r} - K_{52r}\mathbf{YY}_{6r} + K_{86r}\mathbf{YZ}_{6r} \\
&\quad - K_{58r}^2\mathbf{XZ}_{6r} + K_{60r}^2\mathbf{XZ}_{6r} - K_{89r}\mathbf{MX}_{6r} \\
&\quad + K_{87r}\mathbf{MZ}_{6r} + K_{58r}K_{60r}\mathbf{XX}_{6r} + K_{59r}K_{60r}\mathbf{XY}_{6r} \\
&\quad - K_{58r}K_{59r}\mathbf{YZ}_{6r} - K_{58r}K_{60r}\mathbf{ZZ}_{6r} \\
D_{128r} &= -K_{42r}\mathbf{MX}_{6r} - K_{71r}\mathbf{MY}_{6r} \\
D_{129r} &= K_{61r}\mathbf{XZ}_{6r} - K_{34r}\mathbf{YZ}_{6r} + K_{65r}\mathbf{ZZ}_{6r} \\
&\quad - K_{43r}\mathbf{MX}_{6r} - K_{72r}\mathbf{MY}_{6r} \\
D_{130r} &= K_{62r}\mathbf{XZ}_{6r} - K_{35r}\mathbf{YZ}_{6r} + K_{66r}\mathbf{ZZ}_{6r} \\
&\quad - K_{44r}\mathbf{MX}_{6r} - K_{73r}\mathbf{MY}_{6r} \\
D_{131r} &= K_{62r}\mathbf{XZ}_{6r} - K_{35r}\mathbf{YZ}_{6r} + K_{66r}\mathbf{ZZ}_{6r} \\
&\quad - K_{45r}\mathbf{MX}_{6r} - K_{74r}\mathbf{MY}_{6r} \\
D_{132r} &= K_{63r}\mathbf{XZ}_{6r} - K_{36r}\mathbf{YZ}_{6r} + K_{67r}\mathbf{ZZ}_{6r} \\
&\quad - K_{46r}\mathbf{MX}_{6r} - K_{75r}\mathbf{MY}_{6r} \\
D_{133r} &= K_{64r}\mathbf{XZ}_{6r} + K_{68r}\mathbf{ZZ}_{6r} - \mathbf{YZ}_{6r}c_{2r} \\
&\quad - K_{76r}\mathbf{MY}_{6r} \\
D_{134r} &= \mathbf{XZ}_{6r}c_{3r} - \mathbf{ZZ}_{6r}s_{3r} - K_{77r}\mathbf{MY}_{6r} \\
D_{135r} &= K_{85r}\mathbf{XZ}_{6r} - K_{52r}\mathbf{YZ}_{6r} + K_{86r}\mathbf{ZZ}_{6r} \\
&\quad + K_{58r}^2\mathbf{XY}_{6r} - K_{59r}^2\mathbf{XY}_{6r} + K_{88r}\mathbf{MX}_{6r} \\
&\quad - K_{87r}\mathbf{MY}_{6r} - K_{58r}K_{59r}\mathbf{XX}_{6r} - K_{59r}K_{60r}\mathbf{XZ}_{6r} \\
&\quad + K_{58r}K_{59r}\mathbf{YY}_{6r} + K_{58r}K_{60r}\mathbf{YZ}_{6r} \\
\bar{H}_{6r} &= [D_{95r} + D_{89r}\bar{\psi} + D_{93r}\bar{q}_{1r} + D_{91r}\bar{q}_w + D_{94r}\bar{q}_{2r} + D_{90r}\bar{q}_{imu} + D_{92r}\bar{q}_{torsor} + D_{88r}\bar{x} - \mathbf{MZ}_{6r}\bar{q}_{3r} \quad D_{103r} + D_{97r}\bar{\psi} + D_{101r}\bar{q}_{1r} + L \\
\bar{\omega}_{7r} &= {}^{7r}A_{6r}\bar{\omega}_{6r} + \bar{q}_{7r}e_{7r}
\end{aligned}$$

$$\begin{aligned}
\omega_{7r} &= [-K_{58r} - \dot{q}_{4r} & -K_{59r}c_{4r} - K_{60r}s_{4r} & K_{60r}c_{4r} - K_{59r}s_{4r} &] \\
K_{92r} &= -K_{58r} - \dot{q}_{4r} \\
K_{93r} &= -K_{59r}c_{4r} - K_{60r}s_{4r} \\
K_{94r} &= K_{60r}c_{4r} - K_{59r}s_{4r} \\
\bar{\omega}_{7r} &= [K_{92r} & K_{93r} & K_{94r} &] \\
\omega_{7r} &= [-\dot{q}_{4r} - K_{61r}\dot{\psi} - K_{64r}\dot{q}_{1r} - K_{62r}\dot{q}w - K_{62r}\dot{q}_{imu} - K_{63r}\dot{q}_{torso} - \dot{q}_{2r}c_{3r} & c_{4r}(\dot{q}_{3r} + K_{34r}\dot{\psi} + K_{35r}\dot{q}w + K_{35r}\dot{q}_{imu} + K_{36r}\dot{q}_{torso} &] \\
K_{95r} &= K_{34r}c_{4r} - K_{65r}s_{4r} \\
K_{96r} &= K_{35r}c_{4r} - K_{66r}s_{4r} \\
K_{97r} &= K_{36r}c_{4r} - K_{67r}s_{4r} \\
K_{98r} &= c_{2r}c_{4r} - K_{68r}s_{4r} \\
K_{99r} &= s_{3r}s_{4r} \\
K_{100r} &= K_{65r}c_{4r} + K_{34r}s_{4r} \\
K_{101r} &= K_{66r}c_{4r} + K_{35r}s_{4r} \\
K_{102r} &= K_{67r}c_{4r} + K_{36r}s_{4r} \\
K_{103r} &= c_{2r}s_{4r} + K_{68r}c_{4r} \\
K_{104r} &= -c_{4r}s_{3r} \\
\omega_{7r} &= [-\dot{q}_{4r} - K_{61r}\dot{\psi} - K_{64r}\dot{q}_{1r} - K_{62r}\dot{q}w - K_{62r}\dot{q}_{imu} - K_{63r}\dot{q}_{torso} - \dot{q}_{2r}c_{3r} & K_{95r}\dot{\psi} + K_{98r}\dot{q}_{1r} + K_{96r}\dot{q}w + K_{99r}\dot{q}_{2r} + K_{96r}\dot{q}_{imu} &] \\
\bar{v}_{7r} &= {}^{7r}A_{6r}(\bar{v}_{6r} + \bar{\omega}_{6r} \times \bar{P}_{7r}) \\
\bar{v}_{7r} &= [-K_{69r} & K_{40r}c_{4r} - K_{70r}s_{4r} & K_{70r}c_{4r} + K_{40r}s_{4r} &] \\
K_{105r} &= K_{40r}c_{4r} - K_{70r}s_{4r} \\
K_{106r} &= K_{70r}c_{4r} + K_{40r}s_{4r} \\
\bar{v}_{7r} &= [-K_{69r} & K_{105r} & K_{106r} &] \\
\bar{v}_{7r} &= [-K_{72r}\dot{\psi} - K_{76r}\dot{q}_{1r} - K_{74r}\dot{q}w - K_{77r}\dot{q}_{2r} - K_{73r}\dot{q}_{imu} - K_{75r}\dot{q}_{torso} - K_{71r}\ddot{x} & c_{4r}(K_{43r}\dot{\psi} + K_{45r}\dot{q}w + K_{44r}\dot{q}_{imu} + K_{46r}\dot{q}_{torso} &] \\
K_{107r} &= K_{42r}c_{4r} - K_{78r}s_{4r} \\
K_{108r} &= K_{43r}c_{4r} - K_{79r}s_{4r} \\
K_{109r} &= K_{44r}c_{4r} - K_{80r}s_{4r} \\
K_{110r} &= K_{45r}c_{4r} - K_{81r}s_{4r} \\
K_{111r} &= K_{46r}c_{4r} - K_{82r}s_{4r} \\
K_{112r} &= -K_{83r}s_{4r} \\
K_{113r} &= -K_{84r}s_{4r} \\
K_{114r} &= K_{78r}c_{4r} + K_{42r}s_{4r} \\
K_{115r} &= K_{79r}c_{4r} + K_{43r}s_{4r} \\
K_{116r} &= K_{80r}c_{4r} + K_{44r}s_{4r} \\
K_{117r} &= K_{81r}c_{4r} + K_{45r}s_{4r} \\
K_{118r} &= K_{82r}c_{4r} + K_{46r}s_{4r} \\
K_{119r} &= K_{83r}c_{4r} \\
K_{120r} &= K_{84r}c_{4r} \\
\bar{v}_{7r} &= [-K_{72r}\dot{\psi} - K_{76r}\dot{q}_{1r} - K_{74r}\dot{q}w - K_{77r}\dot{q}_{2r} - K_{73r}\dot{q}_{imu} - K_{75r}\dot{q}_{torso} - K_{71r}\ddot{x} & K_{108r}\dot{\psi} + K_{112r}\dot{q}_{1r} + K_{110r}\dot{q}w + K_{113r}\dot{q}_{2r} + K_{110r}\dot{q}_{imu} &] \\
\bar{\alpha}_{7r} &= {}^{7r}A_{6r}\bar{\alpha}_{6r} + \dot{q}_{7r}\bar{e}_{7r} + \dot{q}_{7r}(\bar{\omega}_{7r} \times \bar{e}_{7r}) \\
\bar{\alpha}_{7r} &= [-K_{85r} - \dot{q}_{4r} - K_{61r}\ddot{\psi} - K_{64r}\ddot{q}_{1r} - K_{62r}\ddot{q}w - K_{62r}\ddot{q}_{imu} - K_{63r}\ddot{q}_{torso} - \ddot{q}_{2r}c_{3r} & c_{4r}(K_{52r} + \ddot{q}_{3r} + K_{34r}\ddot{\psi} + K_{35r}\ddot{q}w + K_{35r}\ddot{q}_{imu} &] \\
K_{121r} &= K_{52r}c_{4r} - K_{94r}\dot{q}_{4r} - K_{86r}s_{4r} \\
K_{122r} &= K_{93r}\dot{q}_{4r} + K_{86r}c_{4r} + K_{52r}s_{4r} \\
\bar{\alpha}_{7r} &= [-K_{85r} - \dot{q}_{4r} - K_{61r}\ddot{\psi} - K_{64r}\ddot{q}_{1r} - K_{62r}\ddot{q}w - K_{62r}\ddot{q}_{imu} - K_{63r}\ddot{q}_{torso} - \ddot{q}_{2r}c_{3r} & K_{121r} + K_{95r}\ddot{\psi} + K_{98r}\ddot{q}_{1r} + K_{96r}\ddot{q}w + K_{99r}\ddot{q}_{2r} &] \\
\bar{a}_{7r} &= {}^{7r}A_{6r}(\bar{a}_{6r} + \bar{\alpha}_{6r} \times \bar{P}_{7r} + \bar{\omega}_{6r} \times (\bar{\omega}_{6r} \times \bar{P}_{7r})) \\
\bar{\alpha}_{7r} &= [-K_{87r} - K_{72r}\ddot{\psi} - K_{76r}\ddot{q}_{1r} - K_{74r}\ddot{q}w - K_{77r}\ddot{q}_{2r} - K_{73r}\ddot{q}_{imu} - K_{75r}\ddot{q}_{torso} - K_{71r}\ddot{x} & c_{4r}(K_{43r}\ddot{\psi} - K_{88r} + K_{45r}\ddot{q}w + K_{44r}\ddot{q}_{imu} &] \\
K_{123r} &= -K_{88r}c_{4r} - K_{89r}s_{4r} \\
K_{124r} &= K_{89r}c_{4r} - K_{88r}s_{4r} \\
\bar{a}_{7r} &= [-K_{87r} - K_{72r}\ddot{\psi} - K_{76r}\ddot{q}_{1r} - K_{74r}\ddot{q}w - K_{77r}\ddot{q}_{2r} - K_{73r}\ddot{q}_{imu} - K_{75r}\ddot{q}_{torso} - K_{71r}\ddot{x} & K_{123r} + K_{108r}\ddot{\psi} + K_{112r}\ddot{q}_{1r} + K_{110r}\ddot{q}w &] \\
\bar{g}_{7r} &= {}^{7r}A_{6r}\bar{g}_{6r} \\
\bar{g}_{7r} &= [-K_{90r}g & K_{56r}gc_{4r} - K_{91r}gs_{4r} & K_{91r}gc_{4r} + K_{56r}gs_{4r} &] \\
K_{125r} &= K_{56r}c_{4r} - K_{91r}s_{4r} \\
K_{126r} &= K_{91r}c_{4r} + K_{56r}s_{4r} \\
\bar{g}_{7r} &= [-K_{90r}g & K_{125r}g & K_{126r}g &] \\
m_{7r}\bar{S}_{7r}^\times\bar{g}_{7r} &= \mathbf{MS}_{7r} \times \bar{g}_{7r} \\
m_{7r}\bar{S}_{7r}^\times\bar{g}_{7r} &= [K_{126r}\mathbf{MY}_{7r}g - K_{125r}\mathbf{MZ}_{7r}g & -K_{126r}\mathbf{MX}_{7r}g - K_{90r}\mathbf{MZ}_{7r}g & K_{125r}\mathbf{MX}_{7r}g + K_{90r}\mathbf{MY}_{7r}g &] \\
D_{136r} &= K_{126r}\mathbf{MY}_{7r} - K_{125r}\mathbf{MZ}_{7r} \\
D_{137r} &= -K_{126r}\mathbf{MX}_{7r} - K_{90r}\mathbf{MZ}_{7r} \\
D_{138r} &= K_{125r}\mathbf{MX}_{7r} + K_{90r}\mathbf{MY}_{7r} \\
m_{7r}\bar{S}_{7r}^\times\bar{g}_{7r} &= [D_{136r}g & D_{137r}g & D_{138r}g &] \\
m_{7r}\bar{a}_G(7r) &= m_{7r}\bar{a}_{7r} + \bar{\alpha}_{7r} \times \mathbf{MS}_{7r} + \bar{\omega}_{7r} \times (\bar{\omega}_{7r} \times \mathbf{MS}_{7r}) \\
m_{7r}\bar{a}_G(7r) &= [\mathbf{MZ}_{7r}(K_{121r} + K_{95r}\ddot{\psi} + K_{98r}\ddot{q}_{1r} + K_{96r}\ddot{q}w + K_{99r}\ddot{q}_{2r} + K_{96r}\ddot{q}_{imu} + K_{97r}\ddot{q}_{torso} + \ddot{q}_{3r}c_{4r}) - \mathbf{MY}_{7r}(K_{122r} + K_{100r}\ddot{\psi} + K_{103r}\ddot{q}_{1r} &]
\end{aligned}$$

$$\begin{aligned}
D_{139r} &= -K_{71r}m_{7r} \\
D_{140r} &= K_{95r}\mathbf{MZ}_{7r} - K_{100r}\mathbf{MY}_{7r} - K_{72r}m_{7r} \\
D_{141r} &= K_{96r}\mathbf{MZ}_{7r} - K_{101r}\mathbf{MY}_{7r} - K_{73r}m_{7r} \\
D_{142r} &= K_{96r}\mathbf{MZ}_{7r} - K_{101r}\mathbf{MY}_{7r} - K_{74r}m_{7r} \\
D_{143r} &= K_{97r}\mathbf{MZ}_{7r} - K_{102r}\mathbf{MY}_{7r} - K_{75r}m_{7r} \\
D_{144r} &= K_{98r}\mathbf{MZ}_{7r} - K_{103r}\mathbf{MY}_{7r} - K_{76r}m_{7r} \\
D_{145r} &= K_{99r}\mathbf{MZ}_{7r} - K_{104r}\mathbf{MY}_{7r} - K_{77r}m_{7r} \\
D_{146r} &= \mathbf{MZ}_{7r}c_{4r} - \mathbf{MY}_{7r}s_{4r} \\
D_{147r} &= K_{121r}\mathbf{MZ}_{7r} - K_{93r}^2\mathbf{MX}_{7r} - K_{94r}^2\mathbf{MX}_{7r} \\
&\quad - K_{122r}\mathbf{MY}_{7r} - K_{87r}m_{7r} + K_{92r}K_{93r}\mathbf{MY}_{7r} \\
&\quad + K_{92r}K_{94r}\mathbf{MZ}_{7r} \\
D_{148r} &= K_{107r}m_{7r} \\
D_{149r} &= K_{108r}m_{7r} + K_{100r}\mathbf{MX}_{7r} + K_{61r}\mathbf{MZ}_{7r} \\
D_{150r} &= K_{109r}m_{7r} + K_{101r}\mathbf{MX}_{7r} + K_{62r}\mathbf{MZ}_{7r} \\
D_{151r} &= K_{110r}m_{7r} + K_{101r}\mathbf{MX}_{7r} + K_{62r}\mathbf{MZ}_{7r} \\
D_{152r} &= K_{111r}m_{7r} + K_{102r}\mathbf{MX}_{7r} + K_{63r}\mathbf{MZ}_{7r} \\
D_{153r} &= K_{112r}m_{7r} + K_{103r}\mathbf{MX}_{7r} + K_{64r}\mathbf{MZ}_{7r} \\
D_{154r} &= K_{113r}m_{7r} + \mathbf{MZ}_{7r}c_{3r} + K_{104r}\mathbf{MX}_{7r} \\
D_{155r} &= \mathbf{MX}_{7r}s_{4r} \\
D_{156r} &= K_{123r}m_{7r} - K_{92r}^2\mathbf{MY}_{7r} - K_{94r}^2\mathbf{MY}_{7r} \\
&\quad + K_{122r}\mathbf{MX}_{7r} + K_{85r}\mathbf{MZ}_{7r} + K_{92r}K_{93r}\mathbf{MX}_{7r} \\
&\quad + K_{93r}K_{94r}\mathbf{MZ}_{7r} \\
D_{157r} &= K_{114r}m_{7r} \\
D_{158r} &= K_{115r}m_{7r} - K_{95r}\mathbf{MX}_{7r} - K_{61r}\mathbf{MY}_{7r} \\
D_{159r} &= K_{116r}m_{7r} - K_{96r}\mathbf{MX}_{7r} - K_{62r}\mathbf{MY}_{7r} \\
D_{160r} &= K_{117r}m_{7r} - K_{96r}\mathbf{MX}_{7r} - K_{62r}\mathbf{MY}_{7r} \\
D_{161r} &= K_{118r}m_{7r} - K_{97r}\mathbf{MX}_{7r} - K_{63r}\mathbf{MY}_{7r} \\
D_{162r} &= K_{119r}m_{7r} - K_{98r}\mathbf{MX}_{7r} - K_{64r}\mathbf{MY}_{7r} \\
D_{163r} &= K_{120r}m_{7r} - \mathbf{MY}_{7r}c_{3r} - K_{99r}\mathbf{MX}_{7r} \\
D_{164r} &= -\mathbf{MX}_{7r}c_{4r} \\
D_{165r} &= K_{124r}m_{7r} - K_{92r}^2\mathbf{MZ}_{7r} - K_{93r}^2\mathbf{MZ}_{7r} \\
&\quad - K_{121r}\mathbf{MX}_{7r} - K_{85r}\mathbf{MY}_{7r} + K_{92r}K_{94r}\mathbf{MX}_{7r} \\
&\quad + K_{93r}K_{94r}\mathbf{MY}_{7r} \\
m_{7r}\bar{a}_G(7r) &= [D_{147r} + D_{140r}\bar{\psi} + D_{144r}\bar{q}_{1r} + D_{142r}\bar{q}_w + D_{145r}\bar{q}_2r + D_{146r}\bar{q}_3r + D_{141r}\bar{q}_{imu} + D_{143r}\bar{q}_{torso} + D_{139r}\bar{x} \quad D_{156r} + D_{149r}\bar{\psi} + D_{157r}\bar{\psi} \\
&\quad \bar{H}_{7r} = \mathbf{MS}_{7r} \times \bar{a}_{7r} + J_{7r}\bar{\alpha}_{7r} + \bar{\omega}_{7r} \times J_{7r}\bar{\omega}_{7r} \\
&\quad \bar{H}_{7r} = [K_{93r}(K_{92r}\mathbf{XZ}_{7r} + K_{93r}\mathbf{YZ}_{7r} + K_{94r}\mathbf{ZZ}_{7r}) - K_{94r}(K_{92r}\mathbf{XY}_{7r} + K_{93r}\mathbf{YY}_{7r} + K_{94r}\mathbf{YZ}_{7r}) + \mathbf{XY}_{7r}(K_{121r} + K_{95r}\bar{\psi} + K_{98r}\bar{q}_{1r} + \\
D_{166r} &= K_{114r}\mathbf{MY}_{7r} - K_{107r}\mathbf{MZ}_{7r} \\
D_{167r} &= K_{95r}\mathbf{XY}_{7r} - K_{61r}\mathbf{XX}_{7r} + K_{100r}\mathbf{XZ}_{7r} \\
&\quad + K_{115r}\mathbf{MY}_{7r} - K_{108r}\mathbf{MZ}_{7r} \\
D_{168r} &= K_{96r}\mathbf{XY}_{7r} - K_{62r}\mathbf{XX}_{7r} + K_{101r}\mathbf{XZ}_{7r} \\
&\quad + K_{116r}\mathbf{MY}_{7r} - K_{109r}\mathbf{MZ}_{7r} \\
D_{169r} &= K_{96r}\mathbf{XY}_{7r} - K_{62r}\mathbf{XX}_{7r} + K_{101r}\mathbf{XZ}_{7r} \\
&\quad + K_{117r}\mathbf{MY}_{7r} - K_{110r}\mathbf{MZ}_{7r} \\
D_{170r} &= K_{97r}\mathbf{XY}_{7r} - K_{63r}\mathbf{XX}_{7r} + K_{102r}\mathbf{XZ}_{7r} \\
&\quad + K_{118r}\mathbf{MY}_{7r} - K_{111r}\mathbf{MZ}_{7r} \\
D_{171r} &= K_{98r}\mathbf{XY}_{7r} - K_{64r}\mathbf{XX}_{7r} + K_{103r}\mathbf{XZ}_{7r} \\
&\quad + K_{119r}\mathbf{MY}_{7r} - K_{112r}\mathbf{MZ}_{7r} \\
D_{172r} &= K_{99r}\mathbf{XY}_{7r} + K_{104r}\mathbf{XZ}_{7r} - \mathbf{XX}_{7r}c_{3r} \\
&\quad + K_{120r}\mathbf{MY}_{7r} - K_{113r}\mathbf{MZ}_{7r} \\
D_{173r} &= \mathbf{XY}_{7r}c_{4r} + \mathbf{XZ}_{7r}s_{4r} \\
D_{174r} &= K_{121r}\mathbf{XY}_{7r} - K_{85r}\mathbf{XX}_{7r} + K_{122r}\mathbf{XZ}_{7r} \\
&\quad + K_{93r}^2\mathbf{YZ}_{7r} - K_{94r}^2\mathbf{YZ}_{7r} + K_{124r}\mathbf{MY}_{7r} \\
&\quad - K_{123r}\mathbf{MZ}_{7r} - K_{92r}K_{94r}\mathbf{XY}_{7r} + K_{92r}K_{93r}\mathbf{XZ}_{7r} \\
&\quad - K_{93r}K_{94r}\mathbf{YY}_{7r} + K_{93r}K_{94r}\mathbf{ZZ}_{7r} \\
D_{175r} &= -K_{114r}\mathbf{MX}_{7r} - K_{71r}\mathbf{MZ}_{7r} \\
D_{176r} &= K_{95r}\mathbf{YY}_{7r} - K_{61r}\mathbf{XY}_{7r} + K_{100r}\mathbf{YZ}_{7r} \\
&\quad - K_{115r}\mathbf{MX}_{7r} - K_{72r}\mathbf{MZ}_{7r} \\
D_{177r} &= K_{96r}\mathbf{YY}_{7r} - K_{62r}\mathbf{XY}_{7r} + K_{101r}\mathbf{YZ}_{7r} \\
&\quad - K_{116r}\mathbf{MX}_{7r} - K_{73r}\mathbf{MZ}_{7r} \\
D_{178r} &= K_{96r}\mathbf{YY}_{7r} - K_{62r}\mathbf{XY}_{7r} + K_{101r}\mathbf{YZ}_{7r} \\
&\quad - K_{117r}\mathbf{MX}_{7r} - K_{74r}\mathbf{MZ}_{7r} \\
D_{179r} &= K_{97r}\mathbf{YY}_{7r} - K_{63r}\mathbf{XY}_{7r} + K_{102r}\mathbf{YZ}_{7r} \\
&\quad - K_{118r}\mathbf{MX}_{7r} - K_{75r}\mathbf{MZ}_{7r}
\end{aligned}$$

$$\begin{aligned}
D_{180r} &= K_{98r} \mathbf{Y} \mathbf{Y}_{7r} - K_{64r} \mathbf{X} \mathbf{Y}_{7r} + K_{103r} \mathbf{Y} \mathbf{Z}_{7r} \\
&\quad - K_{119r} \mathbf{M} \mathbf{X}_{7r} - K_{76r} \mathbf{M} \mathbf{Z}_{7r} \\
D_{181r} &= K_{99r} \mathbf{Y} \mathbf{Y}_{7r} + K_{104r} \mathbf{Y} \mathbf{Z}_{7r} - \mathbf{X} \mathbf{Y}_{7r} c_{3r} \\
&\quad - K_{120r} \mathbf{M} \mathbf{X}_{7r} - K_{77r} \mathbf{M} \mathbf{Z}_{7r} \\
D_{182r} &= \mathbf{Y} \mathbf{Y}_{7r} c_{4r} + \mathbf{Y} \mathbf{Z}_{7r} s_{4r} \\
D_{183r} &= K_{121r} \mathbf{Y} \mathbf{Y}_{7r} - K_{85r} \mathbf{X} \mathbf{Y}_{7r} + K_{122r} \mathbf{Y} \mathbf{Z}_{7r} \\
&\quad - K_{92r}^2 \mathbf{X} \mathbf{Z}_{7r} + K_{94r}^2 \mathbf{X} \mathbf{Z}_{7r} - K_{124r} \mathbf{M} \mathbf{X}_{7r} \\
&\quad - K_{87r} \mathbf{M} \mathbf{Z}_{7r} + K_{92r} K_{94r} \mathbf{X} \mathbf{X}_{7r} + K_{93r} K_{94r} \mathbf{X} \mathbf{Y}_{7r} \\
&\quad - K_{92r} K_{93r} \mathbf{Y} \mathbf{Z}_{7r} - K_{92r} K_{94r} \mathbf{Z} \mathbf{Z}_{7r} \\
D_{184r} &= K_{107r} \mathbf{M} \mathbf{X}_{7r} + K_{71r} \mathbf{M} \mathbf{Y}_{7r} \\
D_{185r} &= K_{95r} \mathbf{Y} \mathbf{Z}_{7r} - K_{61r} \mathbf{X} \mathbf{Z}_{7r} + K_{100r} \mathbf{Z} \mathbf{Z}_{7r} \\
&\quad + K_{108r} \mathbf{M} \mathbf{X}_{7r} + K_{72r} \mathbf{M} \mathbf{Y}_{7r} \\
D_{186r} &= K_{96r} \mathbf{Y} \mathbf{Z}_{7r} - K_{62r} \mathbf{X} \mathbf{Z}_{7r} + K_{101r} \mathbf{Z} \mathbf{Z}_{7r} \\
&\quad + K_{109r} \mathbf{M} \mathbf{X}_{7r} + K_{73r} \mathbf{M} \mathbf{Y}_{7r} \\
D_{187r} &= K_{96r} \mathbf{Y} \mathbf{Z}_{7r} - K_{62r} \mathbf{X} \mathbf{Z}_{7r} + K_{101r} \mathbf{Z} \mathbf{Z}_{7r} \\
&\quad + K_{110r} \mathbf{M} \mathbf{X}_{7r} + K_{74r} \mathbf{M} \mathbf{Y}_{7r} \\
D_{188r} &= K_{97r} \mathbf{Y} \mathbf{Z}_{7r} - K_{63r} \mathbf{X} \mathbf{Z}_{7r} + K_{102r} \mathbf{Z} \mathbf{Z}_{7r} \\
&\quad + K_{111r} \mathbf{M} \mathbf{X}_{7r} + K_{75r} \mathbf{M} \mathbf{Y}_{7r} \\
D_{189r} &= K_{98r} \mathbf{Y} \mathbf{Z}_{7r} - K_{64r} \mathbf{X} \mathbf{Z}_{7r} + K_{103r} \mathbf{Z} \mathbf{Z}_{7r} \\
&\quad + K_{112r} \mathbf{M} \mathbf{X}_{7r} + K_{76r} \mathbf{M} \mathbf{Y}_{7r} \\
D_{190r} &= K_{99r} \mathbf{Y} \mathbf{Z}_{7r} + K_{104r} \mathbf{Z} \mathbf{Z}_{7r} - \mathbf{X} \mathbf{Z}_{7r} c_{3r} \\
&\quad + K_{113r} \mathbf{M} \mathbf{X}_{7r} + K_{77r} \mathbf{M} \mathbf{Y}_{7r} \\
D_{191r} &= \mathbf{Y} \mathbf{Z}_{7r} c_{4r} + \mathbf{Z} \mathbf{Z}_{7r} s_{4r} \\
D_{192r} &= K_{121r} \mathbf{Y} \mathbf{Z}_{7r} - K_{85r} \mathbf{X} \mathbf{Z}_{7r} + K_{122r} \mathbf{Z} \mathbf{Z}_{7r} \\
&\quad + K_{92r}^2 \mathbf{X} \mathbf{Y}_{7r} - K_{93r}^2 \mathbf{X} \mathbf{Y}_{7r} + K_{123r} \mathbf{M} \mathbf{X}_{7r} \\
&\quad + K_{87r} \mathbf{M} \mathbf{Y}_{7r} - K_{92r} K_{93r} \mathbf{X} \mathbf{X}_{7r} - K_{93r} K_{94r} \mathbf{X} \mathbf{Z}_{7r} \\
&\quad + K_{92r} K_{93r} \mathbf{Y} \mathbf{Y}_{7r} + K_{92r} K_{94r} \mathbf{Y} \mathbf{Z}_{7r} \\
\dot{H}_{7r} &= [D_{147r} + D_{140r} \ddot{\psi} + D_{144r} \ddot{q}_{1r} + D_{142r} \ddot{q}w + D_{145r} \ddot{q}_{2r} + D_{146r} \ddot{q}_{3r} + D_{141r} \ddot{q}_{imu} + D_{143r} \ddot{q}_{torso} + D_{139r} \ddot{x} \quad D_{156r} + D_{149r} \ddot{\psi} + D_{157r} \ddot{q}w \\
\bar{\omega}_{8r} &= {}^{8r}A_{7r} \bar{\omega}_{7r} + \dot{q}_{8r} \bar{e}_{8r} \\
\bar{\omega}_{8r} &= [K_{94r} s_{5r} - K_{92r} c_{5r} \quad -K_{93r} - \dot{q}_{5r} \quad K_{94r} c_{5r} + K_{92r} s_{5r} \quad] \\
K_{127r} &= K_{94r} s_{5r} - K_{92r} c_{5r} \\
K_{128r} &= -K_{93r} - \dot{q}_{5r} \\
K_{129r} &= K_{94r} c_{5r} + K_{92r} s_{5r} \\
\bar{\omega}_{8r} &= [K_{127r} \quad K_{128r} \quad K_{129r} \quad] \\
\bar{\omega}_{8r} &= [s_{5r} (K_{100r} \dot{\psi} + K_{103r} \dot{q}_{1r} + K_{101r} \dot{q}w + K_{104r} \dot{q}_{2r} + K_{101r} \dot{q}_{imu} + K_{102r} \dot{q}_{torso} + \dot{q}_{3r} s_{4r}) + c_{5r} (\dot{q}_{4r} + K_{61r} \dot{\psi} + K_{64r} \dot{q}_{1r} + K_{62r} \dot{q}w \\
K_{130r} &= K_{61r} c_{5r} + K_{100r} s_{5r} \\
K_{131r} &= K_{62r} c_{5r} + K_{101r} s_{5r} \\
K_{132r} &= K_{63r} c_{5r} + K_{102r} s_{5r} \\
K_{133r} &= K_{64r} c_{5r} + K_{103r} s_{5r} \\
K_{134r} &= c_{3r} c_{5r} + K_{104r} s_{5r} \\
K_{135r} &= s_{4r} s_{5r} \\
K_{136r} &= K_{100r} c_{5r} - K_{61r} s_{5r} \\
K_{137r} &= K_{101r} c_{5r} - K_{62r} s_{5r} \\
K_{138r} &= K_{102r} c_{5r} - K_{63r} s_{5r} \\
K_{139r} &= K_{103r} c_{5r} - K_{64r} s_{5r} \\
K_{140r} &= K_{104r} c_{5r} - c_{3r} s_{5r} \\
K_{141r} &= c_{5r} s_{4r} \\
\bar{\omega}_{8r} &= [K_{130r} \dot{\psi} + K_{133r} \dot{q}_{1r} + K_{131r} \dot{q}w + K_{134r} \dot{q}_{2r} + K_{135r} \dot{q}_{3r} + K_{131r} \dot{q}_{imu} + K_{132r} \dot{q}_{torso} + \dot{q}_{4r} c_{5r} \quad -\dot{q}_{5r} - K_{95r} \dot{\psi} - K_{98r} \dot{q}_{1r} - K_{99r} \dot{q}w \\
\bar{v}_{8r} &= {}^{8r}A_{7r} (\bar{v}_{7r} + \bar{\omega}_{7r} \times \bar{F}_{8r}) \\
\bar{v}_{8r} &= [c_{5r} (K_{69r} - K_{94r} L_8) + s_{5r} (K_{106r} - K_{92r} L_8) \quad -K_{105r} \quad c_{5r} (K_{106r} - K_{92r} L_8) - s_{5r} (K_{69r} - K_{94r} L_8) \quad] \\
K_{142r} &= c_{5r} (K_{69r} - K_{94r} L_8) + s_{5r} (K_{106r} \\
&\quad - K_{92r} L_8) \\
K_{143r} &= c_{5r} (K_{106r} - K_{92r} L_8) - s_{5r} (K_{69r} \\
&\quad - K_{94r} L_8) \\
\bar{v}_{8r} &= [K_{142r} \quad -K_{105r} \quad K_{143r} \quad] \\
\bar{v}_{8r} &= [c_{5r} (K_{72r} \dot{\psi} - L_8 (K_{100r} \dot{\psi} + K_{103r} \dot{q}_{1r} + K_{101r} \dot{q}w + K_{104r} \dot{q}_{2r} + K_{101r} \dot{q}_{imu} + K_{102r} \dot{q}_{torso} + \dot{q}_{3r} s_{4r}) + K_{76r} \dot{q}_{1r} + K_{74r} \dot{q}w + K_{77r} \dot{q}w \\
K_{144r} &= K_{71r} c_{5r} + K_{114r} s_{5r} \\
K_{145r} &= c_{5r} (K_{72r} - K_{100r} L_8) + s_{5r} (K_{115r} \\
&\quad + K_{61r} L_8) \\
K_{146r} &= c_{5r} (K_{73r} - K_{101r} L_8) + s_{5r} (K_{116r} \\
&\quad + K_{62r} L_8) \\
K_{147r} &= c_{5r} (K_{74r} - K_{101r} L_8) + s_{5r} (K_{117r} \\
&\quad + K_{62r} L_8)
\end{aligned}$$

$$\begin{aligned}
D_{205r} &= K_{164r}m_{8r} - K_{128r}^2\mathbf{MX}_{8r} - K_{129r}^2\mathbf{MX}_{8r} \\
&\quad - K_{163r}\mathbf{MY}_{8r} - K_{121r}\mathbf{MZ}_{8r} + K_{127r}K_{128r}\mathbf{MY}_{8r} \\
&\quad + K_{127r}K_{129r}\mathbf{MZ}_{8r} \\
D_{206r} &= -K_{107r}m_{8r} \\
D_{207r} &= K_{136r}\mathbf{MX}_{8r} - K_{108r}m_{8r} - K_{130r}\mathbf{MZ}_{8r} \\
D_{208r} &= K_{137r}\mathbf{MX}_{8r} - K_{109r}m_{8r} - K_{131r}\mathbf{MZ}_{8r} \\
D_{209r} &= K_{137r}\mathbf{MX}_{8r} - K_{110r}m_{8r} - K_{131r}\mathbf{MZ}_{8r} \\
D_{210r} &= K_{138r}\mathbf{MX}_{8r} - K_{111r}m_{8r} - K_{132r}\mathbf{MZ}_{8r} \\
D_{211r} &= K_{139r}\mathbf{MX}_{8r} - K_{112r}m_{8r} - K_{133r}\mathbf{MZ}_{8r} \\
D_{212r} &= K_{140r}\mathbf{MX}_{8r} - K_{113r}m_{8r} - K_{134r}\mathbf{MZ}_{8r} \\
D_{213r} &= K_{141r}\mathbf{MX}_{8r} - K_{135r}\mathbf{MZ}_{8r} \\
D_{214r} &= -\mathbf{MZ}_{8r}c_{5r} - \mathbf{MX}_{8r}s_{5r} \\
D_{215r} &= K_{165r}m_{8r} - K_{127r}^2\mathbf{MY}_{8r} - K_{129r}^2\mathbf{MY}_{8r} \\
&\quad + K_{163r}\mathbf{MX}_{8r} - K_{162r}\mathbf{MZ}_{8r} + K_{127r}K_{128r}\mathbf{MX}_{8r} \\
&\quad + K_{128r}K_{129r}\mathbf{MZ}_{8r} \\
D_{216r} &= K_{153r}m_{8r} \\
D_{217r} &= K_{154r}m_{8r} + K_{95r}\mathbf{MX}_{8r} + K_{130r}\mathbf{MY}_{8r} \\
D_{218r} &= K_{155r}m_{8r} + K_{96r}\mathbf{MX}_{8r} + K_{131r}\mathbf{MY}_{8r} \\
D_{219r} &= K_{156r}m_{8r} + K_{96r}\mathbf{MX}_{8r} + K_{131r}\mathbf{MY}_{8r} \\
D_{220r} &= K_{157r}m_{8r} + K_{97r}\mathbf{MX}_{8r} + K_{132r}\mathbf{MY}_{8r} \\
D_{221r} &= K_{158r}m_{8r} + K_{98r}\mathbf{MX}_{8r} + K_{133r}\mathbf{MY}_{8r} \\
D_{222r} &= K_{159r}m_{8r} + K_{99r}\mathbf{MX}_{8r} + K_{134r}\mathbf{MY}_{8r} \\
D_{223r} &= K_{160r}m_{8r} + \mathbf{MX}_{8r}c_{4r} + K_{135r}\mathbf{MY}_{8r} \\
D_{224r} &= K_{161r}m_{8r} + \mathbf{MY}_{8r}c_{5r} \\
D_{225r} &= K_{166r}m_{8r} - K_{127r}^2\mathbf{MZ}_{8r} - K_{128r}^2\mathbf{MZ}_{8r} \\
&\quad + K_{121r}\mathbf{MX}_{8r} + K_{162r}\mathbf{MY}_{8r} + K_{127r}K_{129r}\mathbf{MX}_{8r} \\
&\quad + K_{128r}K_{129r}\mathbf{MY}_{8r} \\
m_{8r}\bar{a}_{G(8r)} &= [D_{205r} + D_{197r}\bar{\psi} + D_{201r}\bar{q}_{1r} + D_{199r}\bar{q}w + D_{202r}\bar{q}_{2r} + D_{203r}\bar{q}_{3r} + D_{204r}\bar{q}_{4r} + D_{198r}\bar{q}_{imu} + D_{200r}\bar{q}_{torso} + D_{196r}\bar{x} - \mathbf{MZ}_{8r}\bar{q}_{5r} \\
&\quad \bar{H}_{8r} = \mathbf{MS}_{8r} \times \bar{a}_{8r} + J_{8r}\bar{\alpha}_{8r} + \bar{\omega}_{8r} \times J_{8r}\bar{\omega}_{8r} \\
&\quad \bar{H}_{8r} = [K_{128r}(K_{127r}\mathbf{XZ}_{8r} + K_{128r}\mathbf{YZ}_{8r} + K_{129r}\mathbf{ZZ}_{8r}) - K_{129r}(K_{127r}\mathbf{XY}_{8r} + K_{128r}\mathbf{YY}_{8r} + K_{129r}\mathbf{YZ}_{8r}) + \mathbf{MZ}_{8r}(K_{108r}\bar{\psi} - K_{165r} + L \\
D_{226r} &= K_{153r}\mathbf{MY}_{8r} + K_{107r}\mathbf{MZ}_{8r} \\
D_{227r} &= K_{130r}\mathbf{XX}_{8r} - K_{95r}\mathbf{XY}_{8r} + K_{136r}\mathbf{XZ}_{8r} \\
&\quad + K_{154r}\mathbf{MY}_{8r} + K_{108r}\mathbf{MZ}_{8r} \\
D_{228r} &= K_{131r}\mathbf{XX}_{8r} - K_{96r}\mathbf{XY}_{8r} + K_{137r}\mathbf{XZ}_{8r} \\
&\quad + K_{155r}\mathbf{MY}_{8r} + K_{109r}\mathbf{MZ}_{8r} \\
D_{229r} &= K_{131r}\mathbf{XX}_{8r} - K_{96r}\mathbf{XY}_{8r} + K_{137r}\mathbf{XZ}_{8r} \\
&\quad + K_{156r}\mathbf{MY}_{8r} + K_{110r}\mathbf{MZ}_{8r} \\
D_{230r} &= K_{132r}\mathbf{XX}_{8r} - K_{97r}\mathbf{XY}_{8r} + K_{138r}\mathbf{XZ}_{8r} \\
&\quad + K_{157r}\mathbf{MY}_{8r} + K_{111r}\mathbf{MZ}_{8r} \\
D_{231r} &= K_{133r}\mathbf{XX}_{8r} - K_{98r}\mathbf{XY}_{8r} + K_{139r}\mathbf{XZ}_{8r} \\
&\quad + K_{158r}\mathbf{MY}_{8r} + K_{112r}\mathbf{MZ}_{8r} \\
D_{232r} &= K_{134r}\mathbf{XX}_{8r} - K_{99r}\mathbf{XY}_{8r} + K_{140r}\mathbf{XZ}_{8r} \\
&\quad + K_{159r}\mathbf{MY}_{8r} + K_{113r}\mathbf{MZ}_{8r} \\
D_{233r} &= K_{135r}\mathbf{XX}_{8r} + K_{141r}\mathbf{XZ}_{8r} - \mathbf{XY}_{8r}c_{4r} \\
&\quad + K_{160r}\mathbf{MY}_{8r} \\
D_{234r} &= \mathbf{XX}_{8r}c_{5r} - \mathbf{XZ}_{8r}s_{5r} + K_{161r}\mathbf{MY}_{8r} \\
D_{235r} &= K_{162r}\mathbf{XX}_{8r} - K_{121r}\mathbf{XY}_{8r} + K_{163r}\mathbf{XZ}_{8r} \\
&\quad + K_{128r}^2\mathbf{YZ}_{8r} - K_{129r}^2\mathbf{YZ}_{8r} + K_{166r}\mathbf{MY}_{8r} \\
&\quad - K_{165r}\mathbf{MZ}_{8r} - K_{127r}K_{129r}\mathbf{XY}_{8r} + K_{127r}K_{128r}\mathbf{XZ}_{8r} \\
&\quad - K_{128r}K_{129r}\mathbf{YY}_{8r} + K_{128r}K_{129r}\mathbf{ZZ}_{8r} \\
D_{236r} &= K_{144r}\mathbf{MZ}_{8r} - K_{153r}\mathbf{MX}_{8r} \\
D_{237r} &= K_{130r}\mathbf{XY}_{8r} - K_{95r}\mathbf{YY}_{8r} + K_{136r}\mathbf{YZ}_{8r} \\
&\quad - K_{154r}\mathbf{MX}_{8r} + K_{145r}\mathbf{MZ}_{8r} \\
D_{238r} &= K_{131r}\mathbf{XY}_{8r} - K_{96r}\mathbf{YY}_{8r} + K_{137r}\mathbf{YZ}_{8r} \\
&\quad - K_{155r}\mathbf{MX}_{8r} + K_{146r}\mathbf{MZ}_{8r} \\
D_{239r} &= K_{131r}\mathbf{XY}_{8r} - K_{96r}\mathbf{YY}_{8r} + K_{137r}\mathbf{YZ}_{8r} \\
&\quad - K_{156r}\mathbf{MX}_{8r} + K_{147r}\mathbf{MZ}_{8r} \\
D_{240r} &= K_{132r}\mathbf{XY}_{8r} - K_{97r}\mathbf{YY}_{8r} + K_{138r}\mathbf{YZ}_{8r} \\
&\quad - K_{157r}\mathbf{MX}_{8r} + K_{148r}\mathbf{MZ}_{8r} \\
D_{241r} &= K_{133r}\mathbf{XY}_{8r} - K_{98r}\mathbf{YY}_{8r} + K_{139r}\mathbf{YZ}_{8r} \\
&\quad - K_{158r}\mathbf{MX}_{8r} + K_{149r}\mathbf{MZ}_{8r} \\
D_{242r} &= K_{134r}\mathbf{XY}_{8r} - K_{99r}\mathbf{YY}_{8r} + K_{140r}\mathbf{YZ}_{8r} \\
&\quad - K_{159r}\mathbf{MX}_{8r} + K_{150r}\mathbf{MZ}_{8r} \\
D_{243r} &= K_{135r}\mathbf{XY}_{8r} + K_{141r}\mathbf{YZ}_{8r} - \mathbf{YY}_{8r}c_{4r}
\end{aligned}$$

$$\begin{aligned}
& -K_{160r}\mathbf{MX}_{8r} + K_{151r}\mathbf{MZ}_{8r} \\
D_{244r} &= \mathbf{XY}_{8r}c_{5r} - \mathbf{YZ}_{8r}s_{5r} - K_{161r}\mathbf{MX}_{8r} \\
& + K_{152r}\mathbf{MZ}_{8r} \\
D_{245r} &= K_{162r}\mathbf{XY}_{8r} - K_{121r}\mathbf{YY}_{8r} + K_{163r}\mathbf{YZ}_{8r} \\
& - K_{127r}^2\mathbf{XZ}_{8r} + K_{129r}^2\mathbf{XZ}_{8r} - K_{166r}\mathbf{MX}_{8r} \\
& + K_{164r}\mathbf{MZ}_{8r} + K_{127r}K_{129r}\mathbf{XX}_{8r} + K_{128r}K_{129r}\mathbf{XY}_{8r} \\
& - K_{127r}K_{128r}\mathbf{YZ}_{8r} - K_{127r}K_{129r}\mathbf{ZZ}_{8r} \\
D_{246r} &= -K_{107r}\mathbf{MX}_{8r} - K_{144r}\mathbf{MY}_{8r} \\
D_{247r} &= K_{130r}\mathbf{XZ}_{8r} - K_{95r}\mathbf{YZ}_{8r} + K_{136r}\mathbf{ZZ}_{8r} \\
& - K_{108r}\mathbf{MX}_{8r} - K_{145r}\mathbf{MY}_{8r} \\
D_{248r} &= K_{131r}\mathbf{XZ}_{8r} - K_{96r}\mathbf{YZ}_{8r} + K_{137r}\mathbf{ZZ}_{8r} \\
& - K_{109r}\mathbf{MX}_{8r} - K_{146r}\mathbf{MY}_{8r} \\
D_{249r} &= K_{131r}\mathbf{XZ}_{8r} - K_{96r}\mathbf{YZ}_{8r} + K_{137r}\mathbf{ZZ}_{8r} \\
& - K_{110r}\mathbf{MX}_{8r} - K_{147r}\mathbf{MY}_{8r} \\
D_{250r} &= K_{132r}\mathbf{XZ}_{8r} - K_{97r}\mathbf{YZ}_{8r} + K_{138r}\mathbf{ZZ}_{8r} \\
& - K_{111r}\mathbf{MX}_{8r} - K_{148r}\mathbf{MY}_{8r} \\
D_{251r} &= K_{133r}\mathbf{XZ}_{8r} - K_{98r}\mathbf{YZ}_{8r} + K_{139r}\mathbf{ZZ}_{8r} \\
& - K_{112r}\mathbf{MX}_{8r} - K_{149r}\mathbf{MY}_{8r} \\
D_{252r} &= K_{134r}\mathbf{XZ}_{8r} - K_{99r}\mathbf{YZ}_{8r} + K_{140r}\mathbf{ZZ}_{8r} \\
& - K_{113r}\mathbf{MX}_{8r} - K_{150r}\mathbf{MY}_{8r} \\
D_{253r} &= K_{135r}\mathbf{XZ}_{8r} + K_{141r}\mathbf{ZZ}_{8r} - \mathbf{YZ}_{8r}c_{4r} \\
& - K_{151r}\mathbf{MY}_{8r} \\
D_{254r} &= \mathbf{XZ}_{8r}c_{5r} - \mathbf{ZZ}_{8r}s_{5r} - K_{152r}\mathbf{MY}_{8r} \\
D_{255r} &= K_{162r}\mathbf{XZ}_{8r} - K_{121r}\mathbf{YZ}_{8r} + K_{163r}\mathbf{ZZ}_{8r} \\
& + K_{127r}^2\mathbf{XY}_{8r} - K_{128r}^2\mathbf{XY}_{8r} + K_{165r}\mathbf{MX}_{8r} \\
& - K_{164r}\mathbf{MY}_{8r} - K_{127r}K_{128r}\mathbf{XX}_{8r} - K_{128r}K_{129r}\mathbf{XZ}_{8r} \\
& + K_{127r}K_{128r}\mathbf{YY}_{8r} + K_{127r}K_{129r}\mathbf{YZ}_{8r} \\
\dot{H}_{8r} &= [D_{205r} + D_{197r}\ddot{\psi} + D_{201r}\ddot{q}_{1r} + D_{199r}\ddot{q}w + D_{202r}\ddot{q}_2r + D_{203r}\ddot{q}_3r + D_{204r}\ddot{q}_4r + D_{198r}\ddot{q}_{imu} + D_{200r}\ddot{q}_{torso} + D_{196r}\ddot{x} - \mathbf{MZ}_{8r}\ddot{q}_{5r} \\
\bar{\omega}_{9r} &= {}^{9r}A_{8r}\bar{\omega}_{8r} + \dot{q}_9r\bar{e}_9r \\
\bar{\omega}_{9r} &= [-K_{127r} - \dot{q}_{6r} \quad -K_{128r}c_{6r} - K_{129r}s_{6r} \quad K_{129r}c_{6r} - K_{128r}s_{6r} \quad] \\
K_{169r} &= -K_{127r} - \dot{q}_{6r} \\
K_{170r} &= -K_{128r}c_{6r} - K_{129r}s_{6r} \\
K_{171r} &= K_{129r}c_{6r} - K_{128r}s_{6r} \\
\bar{\omega}_{9r} &= [K_{169r} \quad K_{170r} \quad K_{171r} \quad] \\
\bar{\omega}_{9r} &= [-\dot{q}_{6r} - K_{130r}\dot{\psi} - K_{133r}\dot{q}_{1r} - K_{131r}\dot{q}w - K_{134r}\dot{q}_2r - K_{135r}\dot{q}_3r - K_{131r}\dot{q}_{imu} - K_{132r}\dot{q}_{torso} - \dot{q}_{4r}c_{5r} \quad c_{6r}(\dot{q}_{5r} + K_{95r}\dot{\psi} + K_{98r}\dot{\psi} \\
K_{172r} &= K_{95r}c_{6r} - K_{136r}s_{6r} \\
K_{173r} &= K_{96r}c_{6r} - K_{137r}s_{6r} \\
K_{174r} &= K_{97r}c_{6r} - K_{138r}s_{6r} \\
K_{175r} &= K_{98r}c_{6r} - K_{139r}s_{6r} \\
K_{176r} &= K_{99r}c_{6r} - K_{140r}s_{6r} \\
K_{177r} &= c_{4r}c_{6r} - K_{141r}s_{6r} \\
K_{178r} &= s_{5r}s_{6r} \\
K_{179r} &= K_{136r}c_{6r} + K_{95r}s_{6r} \\
K_{180r} &= K_{137r}c_{6r} + K_{96r}s_{6r} \\
K_{181r} &= K_{138r}c_{6r} + K_{97r}s_{6r} \\
K_{182r} &= K_{139r}c_{6r} + K_{98r}s_{6r} \\
K_{183r} &= K_{140r}c_{6r} + K_{99r}s_{6r} \\
K_{184r} &= c_{4r}s_{6r} + K_{141r}c_{6r} \\
K_{185r} &= -c_{6r}s_{5r} \\
\bar{\omega}_{9r} &= [-\dot{q}_{6r} - K_{130r}\dot{\psi} - K_{133r}\dot{q}_{1r} - K_{131r}\dot{q}w - K_{134r}\dot{q}_2r - K_{135r}\dot{q}_3r - K_{131r}\dot{q}_{imu} - K_{132r}\dot{q}_{torso} - \dot{q}_{4r}c_{5r} \quad K_{172r}\dot{\psi} + K_{175r}\dot{q}_{1r} + K_{178r}\dot{\psi} \\
\bar{v}_{9r} &= {}^{9r}A_{8r}(\bar{v}_{8r} + \bar{\omega}_{8r} \times \bar{P}_{9r}) \\
\bar{v}_{9r} &= [-K_{142r} \quad K_{105r}c_{6r} - K_{143r}s_{6r} \quad K_{143r}c_{6r} + K_{105r}s_{6r} \quad] \\
K_{186r} &= K_{105r}c_{6r} - K_{143r}s_{6r} \\
K_{187r} &= K_{143r}c_{6r} + K_{105r}s_{6r} \\
\bar{v}_{9r} &= [-K_{142r} \quad K_{186r} \quad K_{187r} \quad] \\
\bar{v}_{9r} &= [-K_{145r}\dot{\psi} - K_{149r}\dot{q}_{1r} - K_{147r}\dot{q}w - K_{150r}\dot{q}_2r - K_{151r}\dot{q}_3r - K_{152r}\dot{q}_4r - K_{146r}\dot{q}_{imu} - K_{148r}\dot{q}_{torso} - K_{144r}\ddot{x} \quad c_{6r}(K_{108r}\dot{\psi} + K_{109r}\dot{\psi} \\
K_{188r} &= K_{107r}c_{6r} - K_{153r}s_{6r} \\
K_{189r} &= K_{108r}c_{6r} - K_{154r}s_{6r} \\
K_{190r} &= K_{109r}c_{6r} - K_{155r}s_{6r} \\
K_{191r} &= K_{110r}c_{6r} - K_{156r}s_{6r} \\
K_{192r} &= K_{111r}c_{6r} - K_{157r}s_{6r} \\
K_{193r} &= K_{112r}c_{6r} - K_{158r}s_{6r} \\
K_{194r} &= K_{113r}c_{6r} - K_{159r}s_{6r}
\end{aligned}$$

$$\begin{aligned}
K_{195r} &= -K_{160r}s_{6r} \\
K_{196r} &= -K_{161r}s_{6r} \\
K_{197r} &= K_{153r}c_{6r} + K_{107r}s_{6r} \\
K_{198r} &= K_{154r}c_{6r} + K_{108r}s_{6r} \\
K_{199r} &= K_{155r}c_{6r} + K_{109r}s_{6r} \\
K_{200r} &= K_{156r}c_{6r} + K_{110r}s_{6r} \\
K_{201r} &= K_{157r}c_{6r} + K_{111r}s_{6r} \\
K_{202r} &= K_{158r}c_{6r} + K_{112r}s_{6r} \\
K_{203r} &= K_{159r}c_{6r} + K_{113r}s_{6r} \\
K_{204r} &= K_{160r}c_{6r} \\
K_{205r} &= K_{161r}c_{6r} \\
\bar{v}_{9r} &= [-K_{145r}\bar{\psi} - K_{149r}\bar{q}_{1r} - K_{147r}\bar{q}_w - K_{150r}\bar{q}_{2r} - K_{151r}\bar{q}_{3r} - K_{152r}\bar{q}_{4r} - K_{146r}\bar{q}_{imu} - K_{148r}\bar{q}_{tors} - K_{144r}\bar{x} \quad K_{189r}\bar{\psi} + K_{193r}\bar{q}_{1r} \\
\bar{\alpha}_{9r} &= {}^{9r}A_{8r}\bar{\alpha}_{8r} + \bar{q}_{9r}e_{9r} + \bar{q}_{9r}(\bar{\omega}_{9r} \times \bar{e}_{9r}) \\
\bar{\alpha}_{9r} &= [-K_{162r} - \bar{q}_{6r} - K_{130r}\bar{\psi} - K_{133r}\bar{q}_{1r} - K_{131r}\bar{q}_w - K_{134r}\bar{q}_{2r} - K_{135r}\bar{q}_{3r} - K_{131r}\bar{q}_{imu} - K_{132r}\bar{q}_{tors} - \bar{q}_{4r}c_{5r} \quad c_{6r}(K_{121r} + \bar{q}_{1r} \\
K_{206r} &= K_{121r}c_{6r} - K_{171r}\bar{q}_{6r} - K_{163r}s_{6r} \\
K_{207r} &= K_{170r}\bar{q}_{6r} + K_{163r}c_{6r} + K_{121r}s_{6r} \\
\bar{\alpha}_{9r} &= [-K_{162r} - \bar{q}_{6r} - K_{130r}\bar{\psi} - K_{133r}\bar{q}_{1r} - K_{131r}\bar{q}_w - K_{134r}\bar{q}_{2r} - K_{135r}\bar{q}_{3r} - K_{131r}\bar{q}_{imu} - K_{132r}\bar{q}_{tors} - \bar{q}_{4r}c_{5r} \quad K_{206r} + K_{172r}\bar{q}_{1r} \\
\bar{\alpha}_{9r} &= {}^{9r}A_{8r}(\bar{a}_{8r} + \bar{\alpha}_{8r} \times \bar{F}_{9r} + \bar{\omega}_{8r} \times (\bar{\omega}_{8r} \times \bar{F}_{9r})) \\
\bar{\alpha}_{9r} &= [-K_{164r} - K_{145r}\bar{\psi} - K_{149r}\bar{q}_{1r} - K_{147r}\bar{q}_w - K_{150r}\bar{q}_{2r} - K_{151r}\bar{q}_{3r} - K_{152r}\bar{q}_{4r} - K_{146r}\bar{q}_{imu} - K_{148r}\bar{q}_{tors} - K_{144r}\bar{x} \quad c_{6r}(K_{121r} + \bar{q}_{1r} \\
K_{208r} &= -K_{165r}c_{6r} - K_{166r}s_{6r} \\
K_{209r} &= K_{166r}c_{6r} - K_{165r}s_{6r} \\
\bar{a}_{9r} &= [-K_{164r} - K_{145r}\bar{\psi} - K_{149r}\bar{q}_{1r} - K_{147r}\bar{q}_w - K_{150r}\bar{q}_{2r} - K_{151r}\bar{q}_{3r} - K_{152r}\bar{q}_{4r} - K_{146r}\bar{q}_{imu} - K_{148r}\bar{q}_{tors} - K_{144r}\bar{x} \quad K_{208r} + \\
\bar{g}_{9r} &= {}^{9r}A_{8r}\bar{g}_{8r} \\
\bar{g}_{9r} &= [-K_{167r}g \quad K_{125r}g^c_{6r} - K_{168r}g^s_{6r} \quad K_{168r}g^c_{6r} + K_{125r}g^s_{6r} \quad] \\
K_{210r} &= K_{125r}c_{6r} - K_{168r}s_{6r} \\
K_{211r} &= K_{168r}c_{6r} + K_{125r}s_{6r} \\
\bar{g}_{9r} &= [-K_{167r}g \quad K_{210r}g \quad K_{211r}g \quad] \\
m_{9r}\bar{S}_{9r}^{\times}\bar{g}_{9r} &= \mathbf{M}\mathbf{S}_{9r} \times \bar{g}_{9r} \\
m_{9r}\bar{S}_{9r}^{\times}\bar{g}_{9r} &= [K_{211r}\mathbf{M}\mathbf{Y}_{9r}g - K_{210r}\mathbf{M}\mathbf{Z}_{9r}g \quad -K_{211r}\mathbf{M}\mathbf{X}_{9r}g - K_{167r}\mathbf{M}\mathbf{Z}_{9r}g \quad K_{210r}\mathbf{M}\mathbf{X}_{9r}g + K_{167r}\mathbf{M}\mathbf{Y}_{9r}g \quad] \\
D_{256r} &= K_{211r}\mathbf{M}\mathbf{Y}_{9r} - K_{210r}\mathbf{M}\mathbf{Z}_{9r} \\
D_{257r} &= -K_{211r}\mathbf{M}\mathbf{X}_{9r} - K_{167r}\mathbf{M}\mathbf{Z}_{9r} \\
D_{258r} &= K_{210r}\mathbf{M}\mathbf{X}_{9r} + K_{167r}\mathbf{M}\mathbf{Y}_{9r} \\
m_{9r}\bar{S}_{9r}^{\times}\bar{g}_{9r} &= [D_{256r}g \quad D_{257r}g \quad D_{258r}g \quad] \\
m_{9r}\bar{a}_G(9r) &= m_{9r}\bar{a}_r + \bar{\alpha}_{9r} \times \mathbf{M}\mathbf{S}_{9r} + \bar{\omega}_{9r} \times (\bar{\omega}_{9r} \times \mathbf{M}\mathbf{S}_{9r}) \\
m_{9r}\bar{a}_G(9r) &= [\mathbf{M}\mathbf{Z}_{9r}(K_{206r} + K_{172r}\bar{\psi} + K_{175r}\bar{q}_{1r} + K_{173r}\bar{q}_w + K_{176r}\bar{q}_{2r} + K_{177r}\bar{q}_{3r} + K_{178r}\bar{q}_{4r} + K_{173r}\bar{q}_{imu} + K_{174r}\bar{q}_{tors} + \bar{q}_{5r}c_{6r}) - \mathbf{M}\mathbf{Y}_{9r} \\
D_{259r} &= -K_{144r}m_{9r} \\
D_{260r} &= K_{172r}\mathbf{M}\mathbf{Z}_{9r} - K_{179r}\mathbf{M}\mathbf{Y}_{9r} - K_{145r}m_{9r} \\
D_{261r} &= K_{173r}\mathbf{M}\mathbf{Z}_{9r} - K_{180r}\mathbf{M}\mathbf{Y}_{9r} - K_{146r}m_{9r} \\
D_{262r} &= K_{173r}\mathbf{M}\mathbf{Z}_{9r} - K_{180r}\mathbf{M}\mathbf{Y}_{9r} - K_{147r}m_{9r} \\
D_{263r} &= K_{174r}\mathbf{M}\mathbf{Z}_{9r} - K_{181r}\mathbf{M}\mathbf{Y}_{9r} - K_{148r}m_{9r} \\
D_{264r} &= K_{175r}\mathbf{M}\mathbf{Z}_{9r} - K_{182r}\mathbf{M}\mathbf{Y}_{9r} - K_{149r}m_{9r} \\
D_{265r} &= K_{176r}\mathbf{M}\mathbf{Z}_{9r} - K_{183r}\mathbf{M}\mathbf{Y}_{9r} - K_{150r}m_{9r} \\
D_{266r} &= K_{177r}\mathbf{M}\mathbf{Z}_{9r} - K_{184r}\mathbf{M}\mathbf{Y}_{9r} - K_{151r}m_{9r} \\
D_{267r} &= K_{178r}\mathbf{M}\mathbf{Z}_{9r} - K_{185r}\mathbf{M}\mathbf{Y}_{9r} - K_{152r}m_{9r} \\
D_{268r} &= \mathbf{M}\mathbf{Z}_{9r}c_{6r} - \mathbf{M}\mathbf{Y}_{9r}s_{6r} \\
D_{269r} &= K_{206r}\mathbf{M}\mathbf{Z}_{9r} - K_{170r}^2\mathbf{M}\mathbf{X}_{9r} - K_{171r}^2\mathbf{M}\mathbf{X}_{9r} \\
&\quad - K_{207r}\mathbf{M}\mathbf{Y}_{9r} - K_{164r}m_{9r} + K_{169r}K_{170r}\mathbf{M}\mathbf{Y}_{9r} \\
&\quad + K_{169r}K_{171r}\mathbf{M}\mathbf{Z}_{9r} \\
D_{270r} &= K_{188r}m_{9r} \\
D_{271r} &= K_{189r}m_{9r} + K_{179r}\mathbf{M}\mathbf{X}_{9r} + K_{130r}\mathbf{M}\mathbf{Z}_{9r} \\
D_{272r} &= K_{190r}m_{9r} + K_{180r}\mathbf{M}\mathbf{X}_{9r} + K_{131r}\mathbf{M}\mathbf{Z}_{9r} \\
D_{273r} &= K_{191r}m_{9r} + K_{180r}\mathbf{M}\mathbf{X}_{9r} + K_{131r}\mathbf{M}\mathbf{Z}_{9r} \\
D_{274r} &= K_{192r}m_{9r} + K_{181r}\mathbf{M}\mathbf{X}_{9r} + K_{132r}\mathbf{M}\mathbf{Z}_{9r} \\
D_{275r} &= K_{193r}m_{9r} + K_{182r}\mathbf{M}\mathbf{X}_{9r} + K_{133r}\mathbf{M}\mathbf{Z}_{9r} \\
D_{276r} &= K_{194r}m_{9r} + K_{183r}\mathbf{M}\mathbf{X}_{9r} + K_{134r}\mathbf{M}\mathbf{Z}_{9r} \\
D_{277r} &= K_{195r}m_{9r} + K_{184r}\mathbf{M}\mathbf{X}_{9r} + K_{135r}\mathbf{M}\mathbf{Z}_{9r} \\
D_{278r} &= K_{196r}m_{9r} + \mathbf{M}\mathbf{Z}_{9r}c_{5r} + K_{185r}\mathbf{M}\mathbf{X}_{9r} \\
D_{279r} &= \mathbf{M}\mathbf{X}_{9r}s_{6r} \\
D_{280r} &= K_{208r}m_{9r} - K_{169r}^2\mathbf{M}\mathbf{Y}_{9r} - K_{171r}^2\mathbf{M}\mathbf{Y}_{9r} \\
&\quad + K_{207r}\mathbf{M}\mathbf{X}_{9r} + K_{162r}\mathbf{M}\mathbf{Z}_{9r} + K_{169r}K_{170r}\mathbf{M}\mathbf{X}_{9r} \\
&\quad + K_{170r}K_{171r}\mathbf{M}\mathbf{Z}_{9r}
\end{aligned}$$

$$\begin{aligned}
D_{281r} &= K_{197r}m_{9r} \\
D_{282r} &= K_{198r}m_{9r} - K_{172r}M\mathbf{X}_{9r} - K_{130r}M\mathbf{Y}_{9r} \\
D_{283r} &= K_{199r}m_{9r} - K_{173r}M\mathbf{X}_{9r} - K_{131r}M\mathbf{Y}_{9r} \\
D_{284r} &= K_{200r}m_{9r} - K_{173r}M\mathbf{X}_{9r} - K_{131r}M\mathbf{Y}_{9r} \\
D_{285r} &= K_{201r}m_{9r} - K_{174r}M\mathbf{X}_{9r} - K_{132r}M\mathbf{Y}_{9r} \\
D_{286r} &= K_{202r}m_{9r} - K_{175r}M\mathbf{X}_{9r} - K_{133r}M\mathbf{Y}_{9r} \\
D_{287r} &= K_{203r}m_{9r} - K_{176r}M\mathbf{X}_{9r} - K_{134r}M\mathbf{Y}_{9r} \\
D_{288r} &= K_{204r}m_{9r} - K_{177r}M\mathbf{X}_{9r} - K_{135r}M\mathbf{Y}_{9r} \\
D_{289r} &= K_{205r}m_{9r} - M\mathbf{Y}_{9r}c_{5r} - K_{178r}M\mathbf{X}_{9r} \\
D_{290r} &= -M\mathbf{X}_{9r}c_{6r} \\
D_{291r} &= K_{209r}m_{9r} - K_{169r}^2M\mathbf{Z}_{9r} - K_{170r}^2M\mathbf{Z}_{9r} \\
&\quad - K_{206r}M\mathbf{X}_{9r} - K_{162r}M\mathbf{Y}_{9r} + K_{169r}K_{171r}M\mathbf{X}_{9r} \\
&\quad + K_{170r}K_{171r}M\mathbf{Y}_{9r} \\
m_{9r}\bar{a}_{G(9r)} &= [D_{269r} + D_{260r}\bar{\psi} + D_{264r}\bar{q}_{1r} + D_{262r}\bar{q}_w + D_{265r}\bar{q}_{2r} + D_{266r}\bar{q}_{3r} + D_{267r}\bar{q}_{4r} + D_{268r}\bar{q}_{5r} + D_{261r}\bar{q}_{imu} + D_{263r}\bar{q}_{tors} + D_{259r}\bar{\dot{x}} \\
&\quad \bar{H}_{9r} = M\mathbf{S}_{9r} \times \bar{a}_{9r} + J_{9r}\bar{\alpha}_{9r} + \bar{\omega}_{9r} \times J_{9r}\bar{\omega}_{9r} \\
&\quad \bar{H}_{9r} = [K_{170r}(K_{169r}\mathbf{XZ}_{9r} + K_{170r}\mathbf{YZ}_{9r} + K_{171r}\mathbf{ZZ}_{9r}) - K_{171r}(K_{169r}\mathbf{XY}_{9r} + K_{170r}\mathbf{YY}_{9r} + K_{171r}\mathbf{YZ}_{9r}) + \mathbf{XY}_{9r}(K_{206r} + K_{172r}\bar{\psi} + K_{173r}\bar{\psi} \\
D_{292r} &= K_{197r}M\mathbf{Y}_{9r} - K_{188r}M\mathbf{Z}_{9r} \\
D_{293r} &= K_{172r}\mathbf{XY}_{9r} - K_{130r}\mathbf{XX}_{9r} + K_{179r}\mathbf{XZ}_{9r} \\
&\quad + K_{198r}M\mathbf{Y}_{9r} - K_{189r}M\mathbf{Z}_{9r} \\
D_{294r} &= K_{173r}\mathbf{XY}_{9r} - K_{131r}\mathbf{XX}_{9r} + K_{180r}\mathbf{XZ}_{9r} \\
&\quad + K_{199r}M\mathbf{Y}_{9r} - K_{190r}M\mathbf{Z}_{9r} \\
D_{295r} &= K_{173r}\mathbf{XY}_{9r} - K_{131r}\mathbf{XX}_{9r} + K_{180r}\mathbf{XZ}_{9r} \\
&\quad + K_{200r}M\mathbf{Y}_{9r} - K_{191r}M\mathbf{Z}_{9r} \\
D_{296r} &= K_{174r}\mathbf{XY}_{9r} - K_{132r}\mathbf{XX}_{9r} + K_{181r}\mathbf{XZ}_{9r} \\
&\quad + K_{201r}M\mathbf{Y}_{9r} - K_{192r}M\mathbf{Z}_{9r} \\
D_{297r} &= K_{175r}\mathbf{XY}_{9r} - K_{133r}\mathbf{XX}_{9r} + K_{182r}\mathbf{XZ}_{9r} \\
&\quad + K_{202r}M\mathbf{Y}_{9r} - K_{193r}M\mathbf{Z}_{9r} \\
D_{298r} &= K_{176r}\mathbf{XY}_{9r} - K_{134r}\mathbf{XX}_{9r} + K_{183r}\mathbf{XZ}_{9r} \\
&\quad + K_{203r}M\mathbf{Y}_{9r} - K_{194r}M\mathbf{Z}_{9r} \\
D_{299r} &= K_{177r}\mathbf{XY}_{9r} - K_{135r}\mathbf{XX}_{9r} + K_{184r}\mathbf{XZ}_{9r} \\
&\quad + K_{204r}M\mathbf{Y}_{9r} - K_{195r}M\mathbf{Z}_{9r} \\
D_{300r} &= K_{178r}\mathbf{XY}_{9r} + K_{185r}\mathbf{XZ}_{9r} - \mathbf{XX}_{9r}c_{5r} \\
&\quad + K_{205r}M\mathbf{Y}_{9r} - K_{196r}M\mathbf{Z}_{9r} \\
D_{301r} &= \mathbf{XY}_{9r}c_{6r} + \mathbf{XZ}_{9r}s_{6r} \\
D_{302r} &= K_{206r}\mathbf{XY}_{9r} - K_{162r}\mathbf{XX}_{9r} + K_{207r}\mathbf{XZ}_{9r} \\
&\quad + K_{170r}^2\mathbf{YZ}_{9r} - K_{171r}^2\mathbf{YZ}_{9r} + K_{209r}M\mathbf{Y}_{9r} \\
&\quad - K_{208r}M\mathbf{Z}_{9r} - K_{169r}K_{171r}\mathbf{XY}_{9r} + K_{169r}K_{170r}\mathbf{XZ}_{9r} \\
&\quad - K_{170r}K_{171r}\mathbf{YY}_{9r} + K_{170r}K_{171r}\mathbf{ZZ}_{9r} \\
D_{303r} &= -K_{197r}M\mathbf{X}_{9r} - K_{144r}M\mathbf{Z}_{9r} \\
D_{304r} &= K_{172r}\mathbf{YY}_{9r} - K_{130r}\mathbf{XY}_{9r} + K_{179r}\mathbf{YZ}_{9r} \\
&\quad - K_{198r}M\mathbf{X}_{9r} - K_{145r}M\mathbf{Z}_{9r} \\
D_{305r} &= K_{173r}\mathbf{YY}_{9r} - K_{131r}\mathbf{XY}_{9r} + K_{180r}\mathbf{YZ}_{9r} \\
&\quad - K_{199r}M\mathbf{X}_{9r} - K_{146r}M\mathbf{Z}_{9r} \\
D_{306r} &= K_{173r}\mathbf{YY}_{9r} - K_{131r}\mathbf{XY}_{9r} + K_{180r}\mathbf{YZ}_{9r} \\
&\quad - K_{200r}M\mathbf{X}_{9r} - K_{147r}M\mathbf{Z}_{9r} \\
D_{307r} &= K_{174r}\mathbf{YY}_{9r} - K_{132r}\mathbf{XY}_{9r} + K_{181r}\mathbf{YZ}_{9r} \\
&\quad - K_{201r}M\mathbf{X}_{9r} - K_{148r}M\mathbf{Z}_{9r} \\
D_{308r} &= K_{175r}\mathbf{YY}_{9r} - K_{133r}\mathbf{XY}_{9r} + K_{182r}\mathbf{YZ}_{9r} \\
&\quad - K_{202r}M\mathbf{X}_{9r} - K_{149r}M\mathbf{Z}_{9r} \\
D_{309r} &= K_{176r}\mathbf{YY}_{9r} - K_{134r}\mathbf{XY}_{9r} + K_{183r}\mathbf{YZ}_{9r} \\
&\quad - K_{203r}M\mathbf{X}_{9r} - K_{150r}M\mathbf{Z}_{9r} \\
D_{310r} &= K_{177r}\mathbf{YY}_{9r} - K_{135r}\mathbf{XY}_{9r} + K_{184r}\mathbf{YZ}_{9r} \\
&\quad - K_{204r}M\mathbf{X}_{9r} - K_{151r}M\mathbf{Z}_{9r} \\
D_{311r} &= K_{178r}\mathbf{YY}_{9r} + K_{185r}\mathbf{YZ}_{9r} - \mathbf{XY}_{9r}c_{5r} \\
&\quad - K_{205r}M\mathbf{X}_{9r} - K_{152r}M\mathbf{Z}_{9r} \\
D_{312r} &= \mathbf{YY}_{9r}c_{6r} + \mathbf{YZ}_{9r}s_{6r} \\
D_{313r} &= K_{206r}\mathbf{YY}_{9r} - K_{162r}\mathbf{XY}_{9r} + K_{207r}\mathbf{YZ}_{9r} \\
&\quad - K_{169r}^2\mathbf{XZ}_{9r} + K_{171r}^2\mathbf{XZ}_{9r} - K_{209r}M\mathbf{X}_{9r} \\
&\quad - K_{164r}M\mathbf{Z}_{9r} + K_{169r}K_{171r}\mathbf{XX}_{9r} + K_{170r}K_{171r}\mathbf{XY}_{9r} \\
&\quad - K_{169r}K_{170r}\mathbf{YZ}_{9r} - K_{169r}K_{171r}\mathbf{ZZ}_{9r} \\
D_{314r} &= K_{188r}M\mathbf{X}_{9r} + K_{144r}M\mathbf{Y}_{9r} \\
D_{315r} &= K_{172r}\mathbf{YZ}_{9r} - K_{130r}\mathbf{XZ}_{9r} + K_{179r}\mathbf{ZZ}_{9r} \\
&\quad + K_{189r}M\mathbf{X}_{9r} + K_{145r}M\mathbf{Y}_{9r} \\
D_{316r} &= K_{173r}\mathbf{YZ}_{9r} - K_{131r}\mathbf{XZ}_{9r} + K_{180r}\mathbf{ZZ}_{9r}
\end{aligned}$$

$$\begin{aligned}
& + K_{190r} \mathbf{MX}_{9r} + K_{146r} \mathbf{MY}_{9r} \\
D_{317r} &= K_{173r} \mathbf{YZ}_{9r} - K_{131r} \mathbf{XZ}_{9r} + K_{180r} \mathbf{ZZ}_{9r} \\
& + K_{191r} \mathbf{MX}_{9r} + K_{147r} \mathbf{MY}_{9r} \\
D_{318r} &= K_{174r} \mathbf{YZ}_{9r} - K_{132r} \mathbf{XZ}_{9r} + K_{181r} \mathbf{ZZ}_{9r} \\
& + K_{192r} \mathbf{MX}_{9r} + K_{148r} \mathbf{MY}_{9r} \\
D_{319r} &= K_{175r} \mathbf{YZ}_{9r} - K_{133r} \mathbf{XZ}_{9r} + K_{182r} \mathbf{ZZ}_{9r} \\
& + K_{193r} \mathbf{MX}_{9r} + K_{149r} \mathbf{MY}_{9r} \\
D_{320r} &= K_{176r} \mathbf{YZ}_{9r} - K_{134r} \mathbf{XZ}_{9r} + K_{183r} \mathbf{ZZ}_{9r} \\
& + K_{194r} \mathbf{MX}_{9r} + K_{150r} \mathbf{MY}_{9r} \\
D_{321r} &= K_{177r} \mathbf{YZ}_{9r} - K_{135r} \mathbf{XZ}_{9r} + K_{184r} \mathbf{ZZ}_{9r} \\
& + K_{195r} \mathbf{MX}_{9r} + K_{151r} \mathbf{MY}_{9r} \\
D_{322r} &= K_{178r} \mathbf{YZ}_{9r} + K_{185r} \mathbf{ZZ}_{9r} - \mathbf{XZ}_{9r} c_{5r} \\
& + K_{196r} \mathbf{MX}_{9r} + K_{152r} \mathbf{MY}_{9r} \\
D_{323r} &= \mathbf{YZ}_{9r} c_{6r} + \mathbf{ZZ}_{9r} s_{6r} \\
D_{324r} &= K_{206r} \mathbf{YZ}_{9r} - K_{162r} \mathbf{XZ}_{9r} + K_{207r} \mathbf{ZZ}_{9r} \\
& + K_{169r}^2 \mathbf{XY}_{9r} - K_{170r}^2 \mathbf{XY}_{9r} + K_{208r} \mathbf{MX}_{9r} \\
& + K_{164r} \mathbf{MY}_{9r} - K_{169r} K_{170r} \mathbf{XX}_{9r} - K_{170r} K_{171r} \mathbf{XZ}_{9r} \\
& + K_{169r} K_{170r} \mathbf{YY}_{9r} + K_{169r} K_{171r} \mathbf{YZ}_{9r} \\
\dot{H}_{9r} &= [D_{269r} + D_{260r} \ddot{\psi} + D_{264r} \ddot{q}_{1r} + D_{262r} \ddot{q}w + D_{265r} \ddot{q}_2r + D_{266r} \ddot{q}_3r + D_{267r} \ddot{q}_4r + D_{268r} \ddot{q}_5r + D_{261r} \ddot{q}_{imu} + D_{263r} \ddot{q}_{torso} + D_{259r} \ddot{\alpha} \\
\bar{\omega}_{10r} &= {}^{10r}A_{9r} \bar{\omega}_{9r} + \dot{q}_{10r} \bar{e}_{10r} \\
\bar{\omega}_{10r} &= [K_{171r} s_{7r} - K_{169r} c_{7r} \quad -K_{171r} c_{7r} - K_{169r} s_{7r} \quad -K_{170r} - \dot{q}_{7r} \quad] \\
K_{212r} &= K_{171r} s_{7r} - K_{169r} c_{7r} \\
K_{213r} &= -K_{171r} c_{7r} - K_{169r} s_{7r} \\
K_{214r} &= -K_{170r} - \dot{q}_{7r} \\
\bar{\omega}_{10r} &= [K_{212r} \quad K_{213r} \quad K_{214r} \quad] \\
\bar{\omega}_{10r} &= [s_{7r}(K_{179r} \dot{\psi} + K_{182r} \dot{q}_{1r} + K_{180r} \dot{q}w + K_{183r} \dot{q}_2r + K_{184r} \dot{q}_3r + K_{185r} \dot{q}_4r + K_{180r} \dot{q}_{imu} + K_{181r} \dot{q}_{torso} + \dot{q}_{5r} s_{6r}) + c_{7r}(\dot{q}_6r + K_{130r} \dot{\psi} \\
K_{215r} &= K_{130r} c_{7r} + K_{179r} s_{7r} \\
K_{216r} &= K_{131r} c_{7r} + K_{180r} s_{7r} \\
K_{217r} &= K_{132r} c_{7r} + K_{181r} s_{7r} \\
K_{218r} &= K_{133r} c_{7r} + K_{182r} s_{7r} \\
K_{219r} &= K_{134r} c_{7r} + K_{183r} s_{7r} \\
K_{220r} &= K_{135r} c_{7r} + K_{184r} s_{7r} \\
K_{221r} &= c_{5r} c_{7r} + K_{185r} s_{7r} \\
K_{222r} &= s_{6r} s_{7r} \\
K_{223r} &= K_{130r} s_{7r} - K_{179r} c_{7r} \\
K_{224r} &= K_{131r} s_{7r} - K_{180r} c_{7r} \\
K_{225r} &= K_{132r} s_{7r} - K_{181r} c_{7r} \\
K_{226r} &= K_{133r} s_{7r} - K_{182r} c_{7r} \\
K_{227r} &= K_{134r} s_{7r} - K_{183r} c_{7r} \\
K_{228r} &= K_{135r} s_{7r} - K_{184r} c_{7r} \\
K_{229r} &= c_{5r} s_{7r} - K_{185r} c_{7r} \\
K_{230r} &= -c_{7r} s_{6r} \\
\bar{\omega}_{10r} &= [K_{215r} \dot{\psi} + K_{218r} \dot{q}_{1r} + K_{216r} \dot{q}w + K_{219r} \dot{q}_2r + K_{220r} \dot{q}_3r + K_{221r} \dot{q}_4r + K_{222r} \dot{q}_5r + K_{216r} \dot{q}_{imu} + K_{217r} \dot{q}_{torso} + \dot{q}_6r c_{7r} \quad -K_{223r} \dot{\psi} \\
\bar{v}_{10r} &= {}^{10r}A_{9r} (\bar{v}_{9r} + \bar{\omega}_{9r} \times \bar{P}_{10r}) \\
\bar{v}_{10r} &= [c_{7r}(K_{142r} - K_{171r} L_9) + s_{7r}(K_{187r} - K_{169r} L_9) \quad s_{7r}(K_{142r} - K_{171r} L_9) - c_{7r}(K_{187r} - K_{169r} L_9) \quad -K_{186r} \quad] \\
K_{231r} &= c_{7r}(K_{142r} - K_{171r} L_9) + s_{7r}(K_{187r} \\
& - K_{169r} L_9) \\
K_{232r} &= s_{7r}(K_{142r} - K_{171r} L_9) - c_{7r}(K_{187r} \\
& - K_{169r} L_9) \\
\bar{v}_{10r} &= [K_{231r} \quad K_{232r} \quad -K_{186r} \quad] \\
\bar{v}_{10r} &= [c_{7r}(K_{145r} \dot{\psi} + K_{149r} \dot{q}_{1r} + K_{147r} \dot{q}w + K_{150r} \dot{q}_2r + K_{151r} \dot{q}_3r + K_{152r} \dot{q}_4r + K_{146r} \dot{q}_{imu} + K_{148r} \dot{q}_{torso} + K_{144r} \dot{x} - L_9(K_{179r} \dot{\psi} + K_{180r} \dot{q}w \\
K_{233r} &= K_{144r} c_{7r} + K_{197r} s_{7r} \\
K_{234r} &= c_{7r}(K_{145r} - K_{179r} L_9) + s_{7r}(K_{198r} \\
& + K_{130r} L_9) \\
K_{235r} &= c_{7r}(K_{146r} - K_{180r} L_9) + s_{7r}(K_{199r} \\
& + K_{131r} L_9) \\
K_{236r} &= c_{7r}(K_{147r} - K_{180r} L_9) + s_{7r}(K_{200r} \\
& + K_{131r} L_9) \\
K_{237r} &= c_{7r}(K_{148r} - K_{181r} L_9) + s_{7r}(K_{201r} \\
& + K_{132r} L_9) \\
K_{238r} &= c_{7r}(K_{149r} - K_{182r} L_9) + s_{7r}(K_{202r} \\
& + K_{133r} L_9) \\
K_{239r} &= c_{7r}(K_{150r} - K_{183r} L_9) + s_{7r}(K_{203r}
\end{aligned}$$

$$\begin{aligned}
& + K_{134r}L_9) \\
K_{240r} &= c_{7r}(K_{151r} - K_{184r}L_9) + s_{7r}(K_{204r} \\
& + K_{135r}L_9) \\
K_{241r} &= s_{7r}(K_{205r} + L_9c_{5r}) + c_{7r}(K_{152r} \\
& - K_{185r}L_9) \\
K_{242r} &= -L_9c_{7r}s_{6r} \\
K_{243r} &= L_9s_{7r} \\
K_{244r} &= K_{144r}s_{7r} - K_{197r}c_{7r} \\
K_{245r} &= s_{7r}(K_{145r} - K_{179r}L_9) - c_{7r}(K_{198r} \\
& + K_{130r}L_9) \\
K_{246r} &= s_{7r}(K_{146r} - K_{180r}L_9) - c_{7r}(K_{199r} \\
& + K_{131r}L_9) \\
K_{247r} &= s_{7r}(K_{147r} - K_{180r}L_9) - c_{7r}(K_{200r} \\
& + K_{131r}L_9) \\
K_{248r} &= s_{7r}(K_{148r} - K_{181r}L_9) - c_{7r}(K_{201r} \\
& + K_{132r}L_9) \\
K_{249r} &= s_{7r}(K_{149r} - K_{182r}L_9) - c_{7r}(K_{202r} \\
& + K_{133r}L_9) \\
K_{250r} &= s_{7r}(K_{150r} - K_{183r}L_9) - c_{7r}(K_{203r} \\
& + K_{134r}L_9) \\
K_{251r} &= s_{7r}(K_{151r} - K_{184r}L_9) - c_{7r}(K_{204r} \\
& + K_{135r}L_9) \\
K_{252r} &= s_{7r}(K_{152r} - K_{185r}L_9) - c_{7r}(K_{205r} \\
& + L_9c_{5r}) \\
K_{253r} &= -L_9s_{6r}s_{7r} \\
K_{254r} &= -L_9c_{7r} \\
\bar{v}_{10r} &= [K_{234r}\dot{\psi} + K_{238r}\dot{q}_{1r} + K_{236r}\dot{q}_w + K_{239r}\dot{q}_{2r} + K_{240r}\dot{q}_{3r} + K_{241r}\dot{q}_{4r} + K_{242r}\dot{q}_{5r} + K_{243r}\dot{q}_{6r} + K_{235r}\dot{q}_{imu} + K_{237r}\dot{q}_{tors} + K_{233r}\dot{q}_{tors} \\
\bar{\alpha}_{10r} &= {}^{10r}A_{9r}\bar{\alpha}_{9r} + \dot{q}_{10r}\bar{e}_{10r} + \dot{q}_{10r}(\bar{\omega}_{10r} \times \bar{e}_{10r}) \\
\bar{\alpha}_{10r} &= [s_{7r}(K_{207r} + K_{179r}\ddot{\psi} + K_{182r}\ddot{q}_{1r} + K_{180r}\ddot{q}_w + K_{183r}\ddot{q}_{2r} + K_{184r}\ddot{q}_{3r} + K_{185r}\ddot{q}_{4r} + K_{180r}\ddot{q}_{imu} + K_{181r}\ddot{q}_{tors} + \ddot{q}_{5r}s_{6r}) - K_{213r}\ddot{q}_{tors} \\
K_{255r} &= K_{162r}c_{7r} - K_{213r}\dot{q}_{7r} + K_{207r}s_{7r} \\
K_{256r} &= K_{212r}\dot{q}_{7r} - K_{207r}c_{7r} + K_{162r}s_{7r} \\
\bar{\alpha}_{10r} &= [K_{255r} + K_{215r}\ddot{\psi} + K_{218r}\ddot{q}_{1r} + K_{216r}\ddot{q}_w + K_{219r}\ddot{q}_{2r} + K_{220r}\ddot{q}_{3r} + K_{221r}\ddot{q}_{4r} + K_{222r}\ddot{q}_{5r} + K_{216r}\ddot{q}_{imu} + K_{217r}\ddot{q}_{tors} + \ddot{q}_{6r}c_{7r} \\
\bar{\alpha}_{10r} &= {}^{10r}A_{9r}(\bar{a}_{9r} + \bar{\alpha}_{9r} \times \bar{P}_{10r} + \bar{\omega}_{9r} \times (\bar{\omega}_{9r} \times \bar{P}_{10r})) \\
\bar{\alpha}_{10r} &= [c_{7r}(K_{164r} + K_{145r}\ddot{\psi} + K_{149r}\ddot{q}_{1r} + K_{147r}\ddot{q}_w + K_{150r}\ddot{q}_{2r} + K_{151r}\ddot{q}_{3r} + K_{152r}\ddot{q}_{4r} + K_{146r}\ddot{q}_{imu} + K_{148r}\ddot{q}_{tors} + K_{144r}\ddot{x} - L_9(K_{234r}\dot{\psi} + K_{238r}\dot{q}_{1r} + K_{236r}\dot{q}_w + K_{239r}\dot{q}_{2r} + K_{240r}\dot{q}_{3r} + K_{241r}\dot{q}_{4r} + K_{242r}\dot{q}_{5r} + K_{243r}\dot{q}_{6r} + K_{235r}\dot{q}_{imu} + K_{237r}\dot{q}_{tors} + K_{233r}\dot{q}_{tors}) \\
K_{257r} &= K_{164r}c_{7r} + K_{209r}s_{7r} - K_{207r}L_9c_{7r} \\
& + K_{162r}L_9s_{7r} + K_{169r}K_{170r}L_9c_{7r} \\
& - K_{170r}K_{171r}L_9s_{7r} \\
K_{258r} &= K_{164r}s_{7r} - K_{209r}c_{7r} - K_{162r}L_9c_{7r} \\
& - K_{207r}L_9s_{7r} + K_{170r}K_{171r}L_9c_{7r} \\
& + K_{169r}K_{170r}L_9s_{7r} \\
K_{259r} &= -K_{208r} - K_{169r}^2L_9 - K_{171r}^2L_9 \\
\bar{a}_{10r} &= [K_{257r} + K_{234r}\ddot{\psi} + K_{238r}\ddot{q}_{1r} + K_{236r}\ddot{q}_w + K_{239r}\ddot{q}_{2r} + K_{240r}\ddot{q}_{3r} + K_{241r}\ddot{q}_{4r} + K_{242r}\ddot{q}_{5r} + K_{243r}\ddot{q}_{6r} + K_{235r}\ddot{q}_{imu} + K_{237r}\ddot{q}_{tors} + K_{233r}\ddot{q}_{tors} \\
\bar{g}_{10r} &= {}^{10r}A_{9r}\bar{g}_{9r} \\
\bar{g}_{10r} &= [K_{167r}g_{c7r} + K_{211r}g_{s7r} \quad K_{167r}g_{s7r} - K_{211r}g_{c7r} \quad -K_{210r}g \quad] \\
K_{260r} &= K_{167r}c_{7r} + K_{211r}s_{7r} \\
K_{261r} &= K_{167r}s_{7r} - K_{211r}c_{7r} \\
\bar{g}_{10r} &= [K_{260r}g \quad K_{261r}g \quad -K_{210r}g \quad] \\
m_{10r}\bar{S}_{10r}^{\times}\bar{g}_{10r} &= \mathbf{MS}_{10r} \times \bar{g}_{10r} \\
m_{10r}\bar{S}_{10r}^{\times}\bar{g}_{10r} &= [-K_{210r}\mathbf{MY}_{10rg} - K_{261r}\mathbf{MZ}_{10rg} \quad K_{210r}\mathbf{MX}_{10rg} + K_{260r}\mathbf{MZ}_{10rg} \quad K_{261r}\mathbf{MX}_{10rg} - K_{260r}\mathbf{MY}_{10rg} \quad] \\
D_{325r} &= -K_{210r}\mathbf{MY}_{10r} - K_{261r}\mathbf{MZ}_{10r} \\
D_{326r} &= K_{210r}\mathbf{MX}_{10r} + K_{260r}\mathbf{MZ}_{10r} \\
D_{327r} &= K_{261r}\mathbf{MX}_{10r} - K_{260r}\mathbf{MY}_{10r} \\
m_{10r}\bar{S}_{10r}^{\times}\bar{g}_{10r} &= [D_{325r}g \quad D_{326r}g \quad D_{327r}g \quad] \\
m_{10r}\bar{a}_G(10r) &= m_{10r}\bar{a}_{10r} + \bar{\alpha}_{10r} \times \mathbf{MS}_{10r} + \bar{\omega}_{10r} \times (\bar{\omega}_{10r} \times \mathbf{MS}_{10r}) \\
m_{10r}\bar{a}_G(10r) &= [m_{10r}(K_{257r} + K_{234r}\ddot{\psi} + K_{238r}\ddot{q}_{1r} + K_{236r}\ddot{q}_w + K_{239r}\ddot{q}_{2r} + K_{240r}\ddot{q}_{3r} + K_{241r}\ddot{q}_{4r} + K_{242r}\ddot{q}_{5r} + K_{243r}\ddot{q}_{6r} + K_{235r}\ddot{q}_{imu} + K_{237r}\ddot{q}_{tors} + K_{233r}\ddot{q}_{tors}) \\
D_{328r} &= K_{233r}m_{10r} \\
D_{329r} &= K_{234r}m_{10r} + K_{172r}\mathbf{MY}_{10r} + K_{223r}\mathbf{MZ}_{10r} \\
D_{330r} &= K_{235r}m_{10r} + K_{173r}\mathbf{MY}_{10r} + K_{224r}\mathbf{MZ}_{10r} \\
D_{331r} &= K_{236r}m_{10r} + K_{173r}\mathbf{MY}_{10r} + K_{224r}\mathbf{MZ}_{10r} \\
D_{332r} &= K_{237r}m_{10r} + K_{174r}\mathbf{MY}_{10r} + K_{225r}\mathbf{MZ}_{10r} \\
D_{333r} &= K_{238r}m_{10r} + K_{175r}\mathbf{MY}_{10r} + K_{226r}\mathbf{MZ}_{10r}
\end{aligned}$$

$$\begin{aligned}
D_{334r} &= K_{239r}m_{10r} + K_{176r}\mathbf{MY}_{10r} + K_{227r}\mathbf{MZ}_{10r} \\
D_{335r} &= K_{240r}m_{10r} + K_{177r}\mathbf{MY}_{10r} + K_{228r}\mathbf{MZ}_{10r} \\
D_{336r} &= K_{241r}m_{10r} + K_{178r}\mathbf{MY}_{10r} + K_{229r}\mathbf{MZ}_{10r} \\
D_{337r} &= K_{242r}m_{10r} + \mathbf{MY}_{10r}c_{6r} + K_{230r}\mathbf{MZ}_{10r} \\
D_{338r} &= K_{243r}m_{10r} + \mathbf{MZ}_{10r}s_{7r} \\
D_{339r} &= K_{257r}m_{10r} - K_{213r}^2\mathbf{MX}_{10r} - K_{214r}^2\mathbf{MX}_{10r} \\
&\quad + K_{206r}\mathbf{MY}_{10r} + K_{256r}\mathbf{MZ}_{10r} + K_{212r}K_{213r}\mathbf{MY}_{10r} \\
&\quad + K_{212r}K_{214r}\mathbf{MZ}_{10r} \\
D_{340r} &= K_{244r}m_{10r} \\
D_{341r} &= K_{245r}m_{10r} - K_{172r}\mathbf{MX}_{10r} - K_{215r}\mathbf{MZ}_{10r} \\
D_{342r} &= K_{246r}m_{10r} - K_{173r}\mathbf{MX}_{10r} - K_{216r}\mathbf{MZ}_{10r} \\
D_{343r} &= K_{247r}m_{10r} - K_{173r}\mathbf{MX}_{10r} - K_{216r}\mathbf{MZ}_{10r} \\
D_{344r} &= K_{248r}m_{10r} - K_{174r}\mathbf{MX}_{10r} - K_{217r}\mathbf{MZ}_{10r} \\
D_{345r} &= K_{249r}m_{10r} - K_{175r}\mathbf{MX}_{10r} - K_{218r}\mathbf{MZ}_{10r} \\
D_{346r} &= K_{250r}m_{10r} - K_{176r}\mathbf{MX}_{10r} - K_{219r}\mathbf{MZ}_{10r} \\
D_{347r} &= K_{251r}m_{10r} - K_{177r}\mathbf{MX}_{10r} - K_{220r}\mathbf{MZ}_{10r} \\
D_{348r} &= K_{252r}m_{10r} - K_{178r}\mathbf{MX}_{10r} - K_{221r}\mathbf{MZ}_{10r} \\
D_{349r} &= K_{253r}m_{10r} - \mathbf{MX}_{10r}c_{6r} - K_{222r}\mathbf{MZ}_{10r} \\
D_{350r} &= K_{254r}m_{10r} - \mathbf{MZ}_{10r}c_{7r} \\
D_{351r} &= K_{258r}m_{10r} - K_{212r}^2\mathbf{MY}_{10r} - K_{214r}^2\mathbf{MY}_{10r} \\
&\quad - K_{206r}\mathbf{MX}_{10r} - K_{255r}\mathbf{MZ}_{10r} + K_{212r}K_{213r}\mathbf{MX}_{10r} \\
&\quad + K_{213r}K_{214r}\mathbf{MZ}_{10r} \\
D_{352r} &= -K_{188r}m_{10r} \\
D_{353r} &= K_{215r}\mathbf{MY}_{10r} - K_{223r}\mathbf{MX}_{10r} - K_{189r}m_{10r} \\
D_{354r} &= K_{216r}\mathbf{MY}_{10r} - K_{224r}\mathbf{MX}_{10r} - K_{190r}m_{10r} \\
D_{355r} &= K_{216r}\mathbf{MY}_{10r} - K_{224r}\mathbf{MX}_{10r} - K_{191r}m_{10r} \\
D_{356r} &= K_{217r}\mathbf{MY}_{10r} - K_{225r}\mathbf{MX}_{10r} - K_{192r}m_{10r} \\
D_{357r} &= K_{218r}\mathbf{MY}_{10r} - K_{226r}\mathbf{MX}_{10r} - K_{193r}m_{10r} \\
D_{358r} &= K_{219r}\mathbf{MY}_{10r} - K_{227r}\mathbf{MX}_{10r} - K_{194r}m_{10r} \\
D_{359r} &= K_{220r}\mathbf{MY}_{10r} - K_{228r}\mathbf{MX}_{10r} - K_{195r}m_{10r} \\
D_{360r} &= K_{221r}\mathbf{MY}_{10r} - K_{229r}\mathbf{MX}_{10r} - K_{196r}m_{10r} \\
D_{361r} &= K_{222r}\mathbf{MY}_{10r} - K_{230r}\mathbf{MX}_{10r} \\
D_{362r} &= \mathbf{MY}_{10r}c_{7r} - \mathbf{MX}_{10r}s_{7r} \\
D_{363r} &= K_{259r}m_{10r} - K_{212r}^2\mathbf{MZ}_{10r} - K_{213r}^2\mathbf{MZ}_{10r} \\
&\quad - K_{256r}\mathbf{MX}_{10r} + K_{255r}\mathbf{MY}_{10r} + K_{212r}K_{214r}\mathbf{MX}_{10r} \\
&\quad + K_{213r}K_{214r}\mathbf{MY}_{10r} \\
m_{10r}\bar{a}_G(10r) &= [D_{339r} + D_{329r}\ddot{\psi} + D_{333r}\ddot{q}_{1r} + D_{331r}\ddot{q}_w + D_{334r}\ddot{q}_{2r} + D_{335r}\ddot{q}_{3r} + D_{336r}\ddot{q}_{4r} + D_{337r}\ddot{q}_{5r} + D_{338r}\ddot{q}_{6r} + D_{330r}\ddot{q}_{imu} + D_{332r}\ddot{q}_{tors} \\
&\quad \dot{H}_{10r} = \mathbf{MS}_{10r} \times \bar{a}_{10r} + J_{10r}\bar{a}_{10r} + \bar{\omega}_{10r} \times J_{10r}\bar{\omega}_{10r} \\
&\quad \dot{H}_{10r} = [K_{213r}(K_{212r}\mathbf{XX}_{10r} + K_{213r}\mathbf{YZ}_{10r} + K_{214r}\mathbf{ZZ}_{10r}) - K_{214r}(K_{212r}\mathbf{XY}_{10r} + K_{213r}\mathbf{YY}_{10r} + K_{214r}\mathbf{YZ}_{10r}) - \mathbf{MY}_{10r}(K_{189r}\ddot{\psi} - K_{189r}\ddot{\psi} - K_{189r}\ddot{\psi}) \\
D_{364r} &= -K_{188r}\mathbf{MY}_{10r} - K_{244r}\mathbf{MZ}_{10r} \\
D_{365r} &= K_{215r}\mathbf{XX}_{10r} + K_{223r}\mathbf{XY}_{10r} - K_{172r}\mathbf{XZ}_{10r} \\
&\quad - K_{189r}\mathbf{MY}_{10r} - K_{245r}\mathbf{MZ}_{10r} \\
D_{366r} &= K_{216r}\mathbf{XX}_{10r} + K_{224r}\mathbf{XY}_{10r} - K_{173r}\mathbf{XZ}_{10r} \\
&\quad - K_{190r}\mathbf{MY}_{10r} - K_{246r}\mathbf{MZ}_{10r} \\
D_{367r} &= K_{216r}\mathbf{XX}_{10r} + K_{224r}\mathbf{XY}_{10r} - K_{173r}\mathbf{XZ}_{10r} \\
&\quad - K_{191r}\mathbf{MY}_{10r} - K_{247r}\mathbf{MZ}_{10r} \\
D_{368r} &= K_{217r}\mathbf{XX}_{10r} + K_{225r}\mathbf{XY}_{10r} - K_{174r}\mathbf{XZ}_{10r} \\
&\quad - K_{192r}\mathbf{MY}_{10r} - K_{248r}\mathbf{MZ}_{10r} \\
D_{369r} &= K_{218r}\mathbf{XX}_{10r} + K_{226r}\mathbf{XY}_{10r} - K_{175r}\mathbf{XZ}_{10r} \\
&\quad - K_{193r}\mathbf{MY}_{10r} - K_{249r}\mathbf{MZ}_{10r} \\
D_{370r} &= K_{219r}\mathbf{XX}_{10r} + K_{227r}\mathbf{XY}_{10r} - K_{176r}\mathbf{XZ}_{10r} \\
&\quad - K_{194r}\mathbf{MY}_{10r} - K_{250r}\mathbf{MZ}_{10r} \\
D_{371r} &= K_{220r}\mathbf{XX}_{10r} + K_{228r}\mathbf{XY}_{10r} - K_{177r}\mathbf{XZ}_{10r} \\
&\quad - K_{195r}\mathbf{MY}_{10r} - K_{251r}\mathbf{MZ}_{10r} \\
D_{372r} &= K_{221r}\mathbf{XX}_{10r} + K_{229r}\mathbf{XY}_{10r} - K_{178r}\mathbf{XZ}_{10r} \\
&\quad - K_{196r}\mathbf{MY}_{10r} - K_{252r}\mathbf{MZ}_{10r} \\
D_{373r} &= K_{222r}\mathbf{XX}_{10r} + K_{230r}\mathbf{XY}_{10r} - \mathbf{XZ}_{10r}c_{6r} \\
&\quad - K_{253r}\mathbf{MZ}_{10r} \\
D_{374r} &= \mathbf{XX}_{10r}c_{7r} + \mathbf{XY}_{10r}s_{7r} - K_{254r}\mathbf{MZ}_{10r} \\
D_{375r} &= K_{255r}\mathbf{XX}_{10r} + K_{256r}\mathbf{XY}_{10r} - K_{206r}\mathbf{XZ}_{10r} \\
&\quad + K_{213r}^2\mathbf{YZ}_{10r} - K_{214r}^2\mathbf{YZ}_{10r} + K_{259r}\mathbf{MY}_{10r} \\
&\quad - K_{258r}\mathbf{MZ}_{10r} - K_{212r}K_{214r}\mathbf{XY}_{10r} + K_{212r}K_{213r}\mathbf{XZ}_{10r} \\
&\quad - K_{213r}K_{214r}\mathbf{YY}_{10r} + K_{213r}K_{214r}\mathbf{ZZ}_{10r}
\end{aligned}$$

$$\begin{aligned}
D_{376r} &= K_{188r}\mathbf{MX}_{10r} + K_{233r}\mathbf{MZ}_{10r} \\
D_{377r} &= K_{215r}\mathbf{XY}_{10r} + K_{223r}\mathbf{YY}_{10r} - K_{172r}\mathbf{YZ}_{10r} \\
&\quad + K_{189r}\mathbf{MX}_{10r} + K_{234r}\mathbf{MZ}_{10r} \\
D_{378r} &= K_{216r}\mathbf{XY}_{10r} + K_{224r}\mathbf{YY}_{10r} - K_{173r}\mathbf{YZ}_{10r} \\
&\quad + K_{190r}\mathbf{MX}_{10r} + K_{235r}\mathbf{MZ}_{10r} \\
D_{379r} &= K_{216r}\mathbf{XY}_{10r} + K_{224r}\mathbf{YY}_{10r} - K_{173r}\mathbf{YZ}_{10r} \\
&\quad + K_{191r}\mathbf{MX}_{10r} + K_{236r}\mathbf{MZ}_{10r} \\
D_{380r} &= K_{217r}\mathbf{XY}_{10r} + K_{225r}\mathbf{YY}_{10r} - K_{174r}\mathbf{YZ}_{10r} \\
&\quad + K_{192r}\mathbf{MX}_{10r} + K_{237r}\mathbf{MZ}_{10r} \\
D_{381r} &= K_{218r}\mathbf{XY}_{10r} + K_{226r}\mathbf{YY}_{10r} - K_{175r}\mathbf{YZ}_{10r} \\
&\quad + K_{193r}\mathbf{MX}_{10r} + K_{238r}\mathbf{MZ}_{10r} \\
D_{382r} &= K_{219r}\mathbf{XY}_{10r} + K_{227r}\mathbf{YY}_{10r} - K_{176r}\mathbf{YZ}_{10r} \\
&\quad + K_{194r}\mathbf{MX}_{10r} + K_{239r}\mathbf{MZ}_{10r} \\
D_{383r} &= K_{220r}\mathbf{XY}_{10r} + K_{228r}\mathbf{YY}_{10r} - K_{177r}\mathbf{YZ}_{10r} \\
&\quad + K_{195r}\mathbf{MX}_{10r} + K_{240r}\mathbf{MZ}_{10r} \\
D_{384r} &= K_{221r}\mathbf{XY}_{10r} + K_{229r}\mathbf{YY}_{10r} - K_{178r}\mathbf{YZ}_{10r} \\
&\quad + K_{196r}\mathbf{MX}_{10r} + K_{241r}\mathbf{MZ}_{10r} \\
D_{385r} &= K_{222r}\mathbf{XY}_{10r} + K_{230r}\mathbf{YY}_{10r} - \mathbf{YZ}_{10r}c_{6r} \\
&\quad + K_{242r}\mathbf{MZ}_{10r} \\
D_{386r} &= \mathbf{XY}_{10r}c_{7r} + \mathbf{YY}_{10r}s_{7r} + K_{243r}\mathbf{MZ}_{10r} \\
D_{387r} &= K_{255r}\mathbf{XY}_{10r} + K_{256r}\mathbf{YY}_{10r} - K_{206r}\mathbf{YZ}_{10r} \\
&\quad - K_{212r}^2\mathbf{XZ}_{10r} + K_{214r}^2\mathbf{XZ}_{10r} - K_{259r}\mathbf{MX}_{10r} \\
&\quad + K_{257r}\mathbf{MZ}_{10r} + K_{212r}K_{214r}\mathbf{XX}_{10r} + K_{213r}K_{214r}\mathbf{XY}_{10r} \\
&\quad - K_{212r}K_{213r}\mathbf{YZ}_{10r} - K_{212r}K_{214r}\mathbf{ZZ}_{10r} \\
D_{388r} &= K_{244r}\mathbf{MX}_{10r} - K_{233r}\mathbf{MY}_{10r} \\
D_{389r} &= K_{215r}\mathbf{XZ}_{10r} + K_{223r}\mathbf{YZ}_{10r} - K_{172r}\mathbf{ZZ}_{10r} \\
&\quad + K_{245r}\mathbf{MX}_{10r} - K_{234r}\mathbf{MY}_{10r} \\
D_{390r} &= K_{216r}\mathbf{XZ}_{10r} + K_{224r}\mathbf{YZ}_{10r} - K_{173r}\mathbf{ZZ}_{10r} \\
&\quad + K_{246r}\mathbf{MX}_{10r} - K_{235r}\mathbf{MY}_{10r} \\
D_{391r} &= K_{216r}\mathbf{XZ}_{10r} + K_{224r}\mathbf{YZ}_{10r} - K_{173r}\mathbf{ZZ}_{10r} \\
&\quad + K_{247r}\mathbf{MX}_{10r} - K_{236r}\mathbf{MY}_{10r} \\
D_{392r} &= K_{217r}\mathbf{XZ}_{10r} + K_{225r}\mathbf{YZ}_{10r} - K_{174r}\mathbf{ZZ}_{10r} \\
&\quad + K_{248r}\mathbf{MX}_{10r} - K_{237r}\mathbf{MY}_{10r} \\
D_{393r} &= K_{218r}\mathbf{XZ}_{10r} + K_{226r}\mathbf{YZ}_{10r} - K_{175r}\mathbf{ZZ}_{10r} \\
&\quad + K_{249r}\mathbf{MX}_{10r} - K_{238r}\mathbf{MY}_{10r} \\
D_{394r} &= K_{219r}\mathbf{XZ}_{10r} + K_{227r}\mathbf{YZ}_{10r} - K_{176r}\mathbf{ZZ}_{10r} \\
&\quad + K_{250r}\mathbf{MX}_{10r} - K_{239r}\mathbf{MY}_{10r} \\
D_{395r} &= K_{220r}\mathbf{XZ}_{10r} + K_{228r}\mathbf{YZ}_{10r} - K_{177r}\mathbf{ZZ}_{10r} \\
&\quad + K_{251r}\mathbf{MX}_{10r} - K_{240r}\mathbf{MY}_{10r} \\
D_{396r} &= K_{221r}\mathbf{XZ}_{10r} + K_{229r}\mathbf{YZ}_{10r} - K_{178r}\mathbf{ZZ}_{10r} \\
&\quad + K_{252r}\mathbf{MX}_{10r} - K_{241r}\mathbf{MY}_{10r} \\
D_{397r} &= K_{222r}\mathbf{XZ}_{10r} + K_{230r}\mathbf{YZ}_{10r} - \mathbf{ZZ}_{10r}c_{6r} \\
&\quad + K_{253r}\mathbf{MX}_{10r} - K_{242r}\mathbf{MY}_{10r} \\
D_{398r} &= \mathbf{XZ}_{10r}c_{7r} + \mathbf{YZ}_{10r}s_{7r} + K_{254r}\mathbf{MX}_{10r} \\
&\quad - K_{243r}\mathbf{MY}_{10r} \\
D_{399r} &= K_{255r}\mathbf{XZ}_{10r} + K_{256r}\mathbf{YZ}_{10r} - K_{206r}\mathbf{ZZ}_{10r} \\
&\quad + K_{212r}^2\mathbf{XY}_{10r} - K_{213r}^2\mathbf{XY}_{10r} + K_{258r}\mathbf{MX}_{10r} \\
&\quad - K_{257r}\mathbf{MY}_{10r} - K_{212r}K_{213r}\mathbf{XX}_{10r} - K_{213r}K_{214r}\mathbf{XZ}_{10r} \\
&\quad + K_{212r}K_{213r}\mathbf{YY}_{10r} + K_{212r}K_{214r}\mathbf{YZ}_{10r} \\
\dot{H}_{10r} &= [D_{339r} + D_{329r}\ddot{\psi} + D_{333r}\ddot{q}_{1r} + D_{331r}\ddot{q}w + D_{334r}\ddot{q}_2r + D_{335r}\ddot{q}_3r + D_{336r}\ddot{q}_4r + D_{337r}\ddot{q}_5r + D_{338r}\ddot{q}_6r + D_{330r}\ddot{q}_{imu} + D_{332r}\ddot{q}_{tors} \\
&\quad (1)
\end{aligned}$$

References

- [1] Thomas R Kane and David A Levinson. The use of kane's dynamical equations in robotics. *The International Journal of Robotics Research*, 2(3):3–21, 1983.