Supporting Material

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This document serves as the supporting material for the authors' paper titled "An attitude stabilization approach integrated of passive and active scenarios for on-orbit refueling considering liquid transfer", providing reference for both reviewers and interested readers.

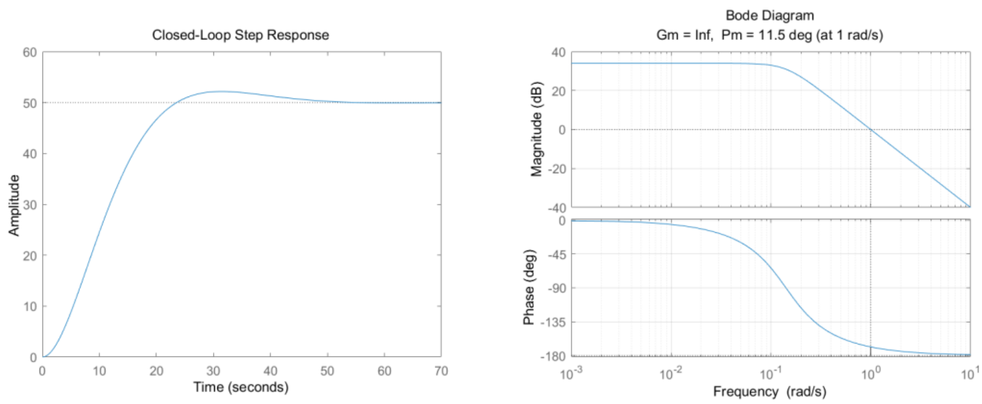
Part 1: Stability analysis in time and frequency domains

In Section 3.1 of the manuscript, the authors have derived the closed-loop state equations for the pitch channel and the yaw-roll coupling channel as follows.

$$\dot{\boldsymbol{X}}_1=\left[\boldsymbol{A}_1+\boldsymbol{b}_1\boldsymbol{K}_\theta\right]\boldsymbol{X}_1=\begin{bmatrix}0 & 1\\ -\lambda_{11}^*\lambda_{12}^* & \lambda_{11}^*+\lambda_{12}^*\end{bmatrix}\boldsymbol{X}_1 \tag{1.1}$$

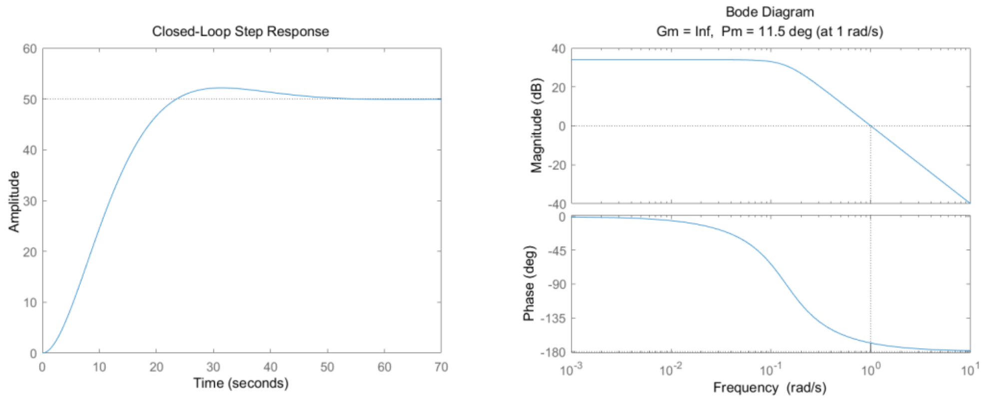
$$\dot{\boldsymbol{X}}_2=\left[\boldsymbol{A}_2+\boldsymbol{b}_2\boldsymbol{K}_{\phi\psi}\right]\boldsymbol{X}_2=\begin{bmatrix}0 & 1 & 0 & 0\\ -\lambda_{21}^*\lambda_{22}^* & \lambda_{21}^*+\lambda_{22}^* & 0 & 0\\ 0 & 0 & 0 & 1\\ 0 & 0 & -\lambda_{23}^*\lambda_{24}^* & \lambda_{23}^*+\lambda_{24}^*\end{bmatrix}\boldsymbol{X}_2 \tag{1.2}$$

When the closed-loop poles are set to -0.1 ± j0.1, the authors have plotted the step response and Bode diagram for analysis, as shown in the figures below. The patterns observed in both sets of figures are similar: the step response curves of the closed-loop system converge stably with small overshoot, exhibiting an infinite GM and a PM of 11.5 degree, both indicating the stability of the closed-loop system. The above analysis is based solely on the pole values taken from the example in this paper. Readers can apply our method to any constant pole values they choose.



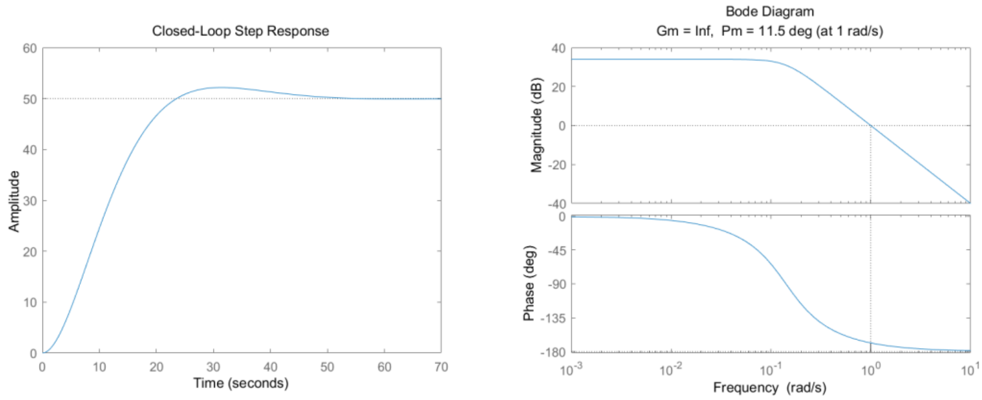
(a) time domain （b）frequency domain

Fig.1 Stability analysis in time and frequency domains for the pitch channel



(a) time domain （b） frequency domain

Fig.2 Stability analysis in time and frequency domains for the yaw channel



(a) time domain （b） frequency domain

Fig.3 Stability analysis in time and frequency domains for the roll channel

Part 2: Simulations with different orbital heights and desired poles

To further demonstrate the correctness of the conclusions, the authors consider simulations with different orbital heights and desired poles shown in Table 1. Twelve parameter combinations, consisting of three different orbital heights and four poles with different real parts, were selected to validate the DPA-UE method proposed in this paper. Among them, the parameters of case 5 are consistent with the example provided in the manuscript.

Table 1 Simulations with different orbit heights and desired poles

Case	$h(km)$	Pole	
		$\lambda_{11}^* / \lambda_{21}^* / \lambda_{23}^*$	$\lambda_{12}^* / \lambda_{22}^* / \lambda_{24}^*$
1	500	$-0.1+0.1j$	$-0.1-0.1j$
2	500	$-0.2+0.1j$	$-0.2-0.1j$
3	500	$-0.5+0.2j$	$-0.5-0.2j$
4	500	$-3+0.5j$	$-3-0.5j$
5(example in the manuscript)	1000	$-0.1+0.1j$	$-0.1-0.1j$
6	1000	$-0.2+0.1j$	$-0.2-0.1j$
7	1000	$-0.5+0.2j$	$-0.5-0.2j$
8	1000	$-3+0.5j$	$-3-0.5j$
9	2000	$-0.1+0.1j$	$-0.1-0.1j$
10	2000	$-0.2+0.1j$	$-0.2-0.1j$
11	2000	$-0.5+0.2j$	$-0.5-0.2j$
12	2000	$-3+0.5j$	$-3-0.5j$

All other parameters remain the same as in the original manuscript. The results corresponding to these cases are shown in Fig.4 to Fig.6, which show the method proposed in this paper can converge in all these cases. As shown in Fig.4, different orbit heights have very little influence on the attitude control process, and the curves of the three orbit heights almost coincide, while the selection of poles has a great influence on the curves. Comparing with Fig.14 to Fig.16 in the original manuscript, it can be found that by using the method proposed in this paper and configuring desired poles with different negative real parts, different convergence speeds and energy consumptions can be achieved. When a smaller negative real part from the original manuscript is chosen, a smoother control can be realized, which is more consistent with engineering practice.

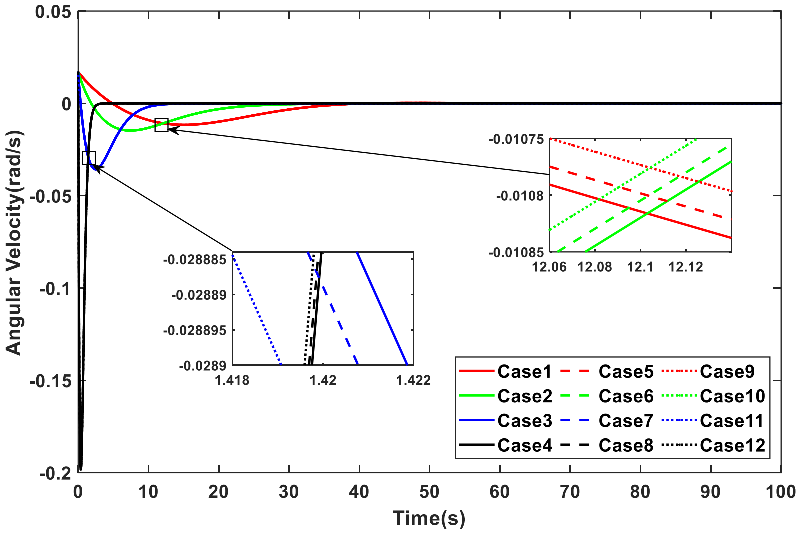


Fig.4 History of the angular velocity of pitch motion

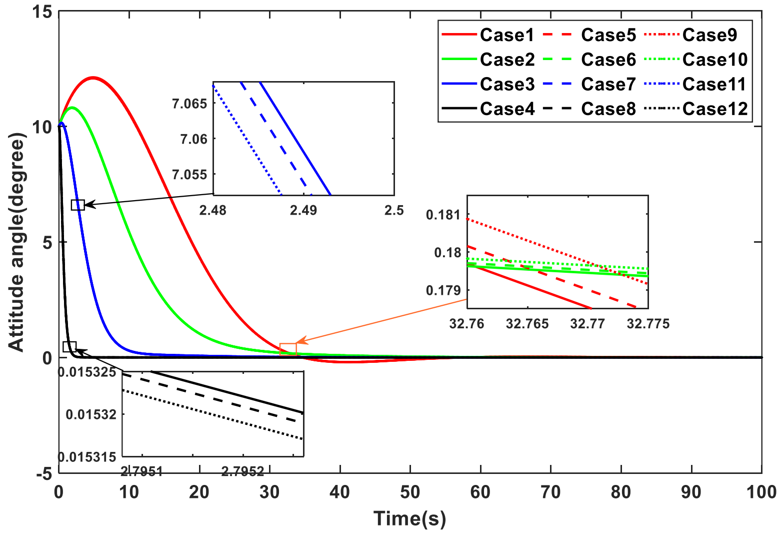


Fig.5 History of the control torque of pitch motion

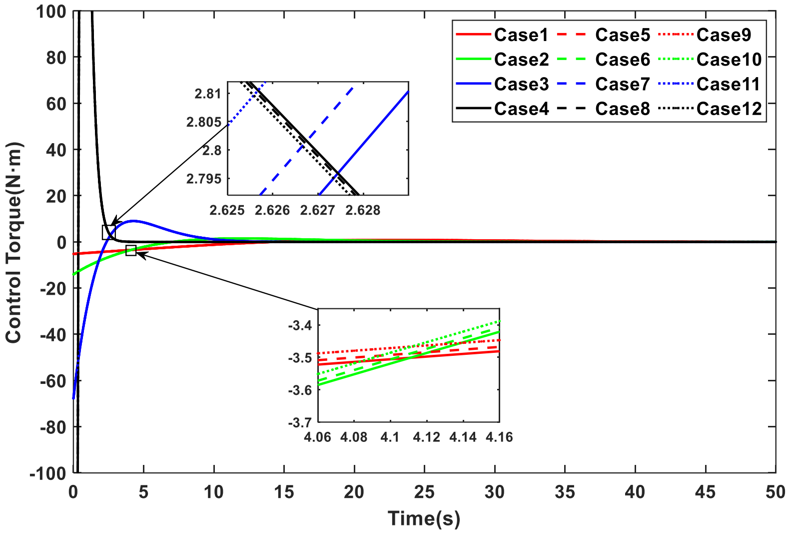


Fig.6 History of the control torque of pitch motion