

Nonlinear Adaptive Control for Hypersonic Vehicle at Subsonic Speeds

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ABSTRACT

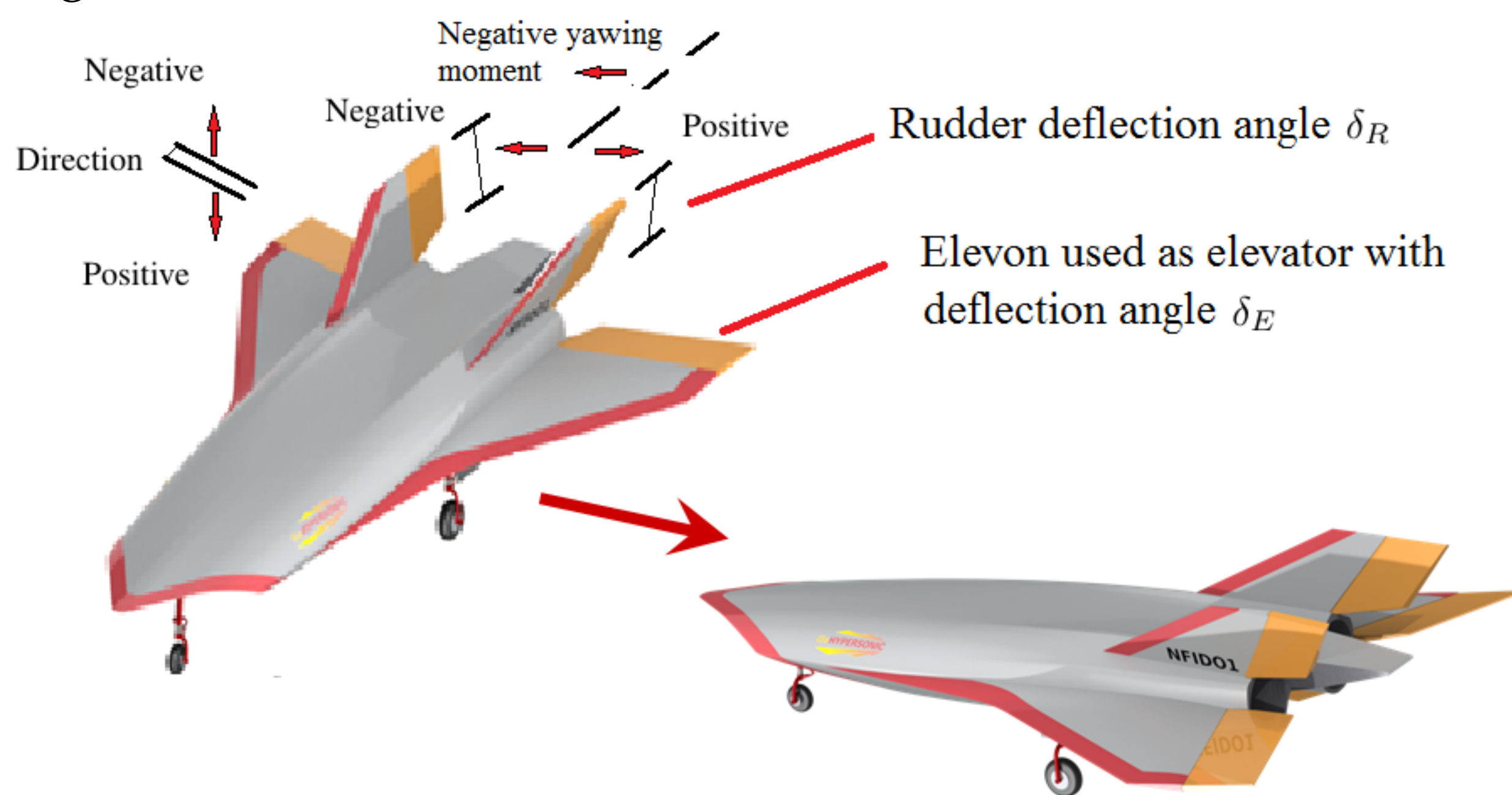
- Hypersonic vehicles are complex nonlinear systems with uncertain dynamics. This work presents a robust nonlinear adaptive (NA) control system for the operation of these vehicles at subsonic speeds. In this work, we only consider lateral dynamics with a fixed roll angle (five degrees of freedom, or 5-DOF).
- These dynamics are divided into subsystems for aircraft speed, flight-path angle, and yaw angle. A robust NA control design is implemented to provide asymptotic tracking regulation of these output quantities. Simulations of the design indicates that it successfully provides flight control.

CONTROL SYSTEM

- The design of the control system is considered under subsonic speed (where the GHI database goes up to $V_p < 320$ m/s, but our experiments are limited to the 0.2 Mach number range) and altitude (where $h < 4000$ m). The 5-DOF lateral dynamics are given by

$$\begin{aligned} \dot{V}_p &= \frac{1}{m} (T \cos \alpha \cos \beta - D \cos \beta + F_{Y_s} \sin \beta) - g \cos \beta \sin \gamma \\ \dot{\alpha} &= \frac{1}{m V_p \cos \beta} (-T \sin \alpha - L_i + mg \cos \gamma) + q - r \sin \alpha \tan \beta \\ \dot{\beta} &= \frac{1}{m V_p} (D \sin \beta + F_{Y_s} \cos \beta - T \cos \alpha \sin \beta + mg \sin \beta \sin \gamma) \\ &\quad - r \cos \alpha \\ \begin{bmatrix} \dot{q} \\ \dot{r} \end{bmatrix} &= M_1 \begin{bmatrix} q^2 \\ r^2 \end{bmatrix} + M_0 \begin{bmatrix} M \\ N \end{bmatrix} \\ \begin{bmatrix} \dot{\theta} \\ \dot{\psi} \end{bmatrix} &= \begin{bmatrix} q \\ r \sec \theta \end{bmatrix} \end{aligned}$$

where D, F_{Y_s}, L_i, M, N denote drag, lateral-force, lift, pitching, and yawing moments.



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ADAPTIVE CONTROL AND SIMULATIONS

- 1) The nonlinear adaptive control law for V_p subsystem is defined by

$$T = \frac{1}{g_A} (-f_A + \hat{F}_{A1}(z, \hat{\theta}_{A1}) - \hat{F}_{A2}(z, \hat{\theta}_{A2}) + v_A + u_{sA})$$

where: $g_A = \frac{\cos \alpha \cos \beta}{m}$, $v_A = -k_A \tilde{e}_A + \dot{V}_{des}$, $\tilde{e}_A = V_p - V_{des}$, and u_{sA} is stabilizing controller.

- 2) The control law for the γ subsystem is

$$\delta_{E_{des}} = \frac{1}{\hat{g}_B} (-f_B - \hat{F}_B(z, \hat{\theta}_B) + v_B + u_{sB})$$

where: $\hat{g}_B = \frac{\rho S V_p}{2m \cos \beta} \hat{\theta}_{L_{\delta E}}$, $v_B = -k_B \tilde{e}_B + \dot{\gamma}_{des}$, and $\tilde{e}_B = \gamma - \gamma_{des}$

- 3) The control law for ψ subsystem is defined by

$$\delta_{R_{des}} = \frac{1}{g_C} (-f_C - \hat{F}_C(z, \hat{\theta}_C) + v_C + u_{sC})$$

where: $g_C = M_o \bar{q} S b C_{n_{\delta R}} \sec \theta$, $v_C = -k_C \tilde{e}_C + \dot{\psi}_{des}$, $\tilde{e}_C = (\psi - \psi_{des}) + (\dot{\psi} - \dot{\psi}_{des})$

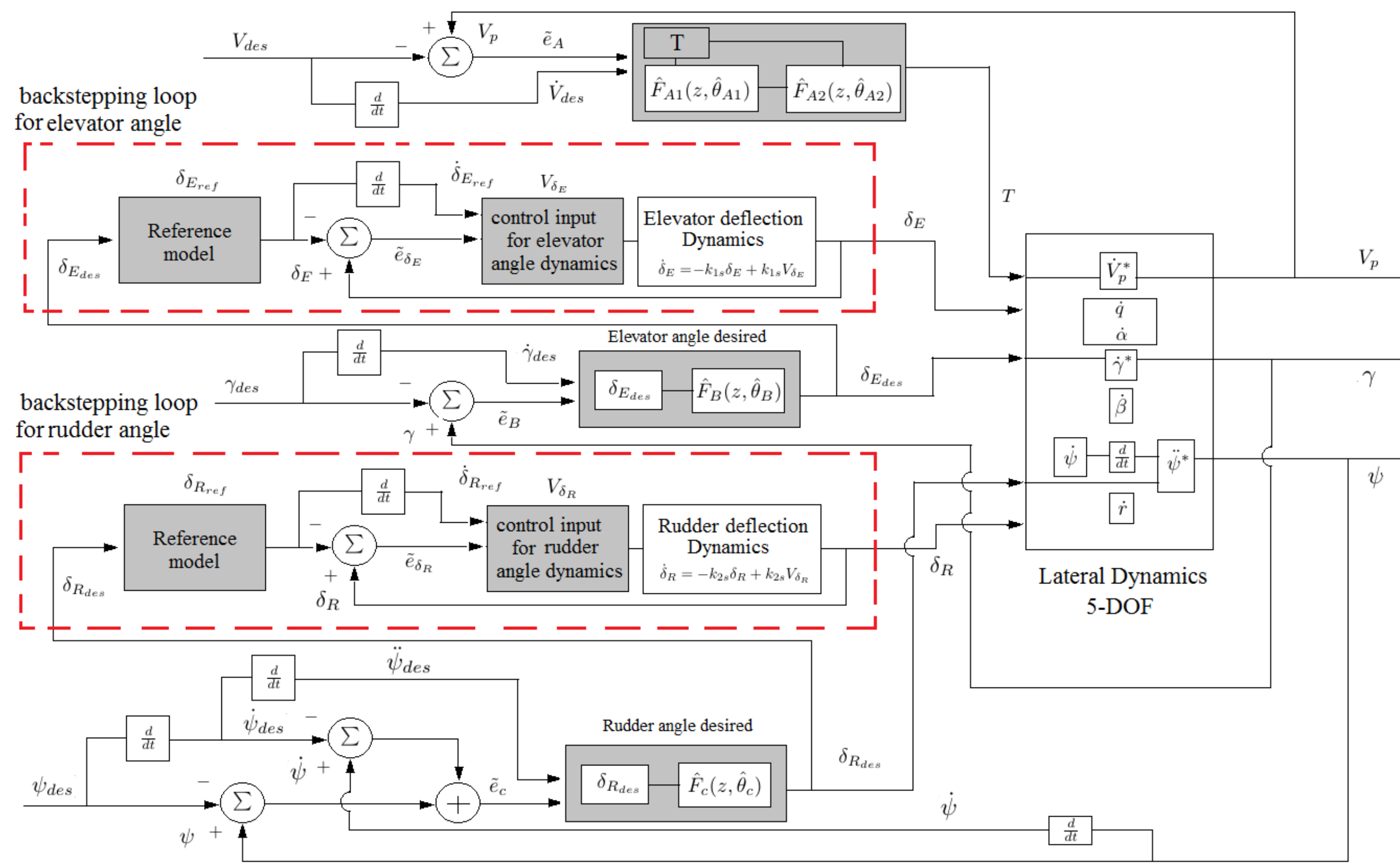


Figure 1: Block diagram of nonlinear adaptive control for 5-DOF lateral dynamics.

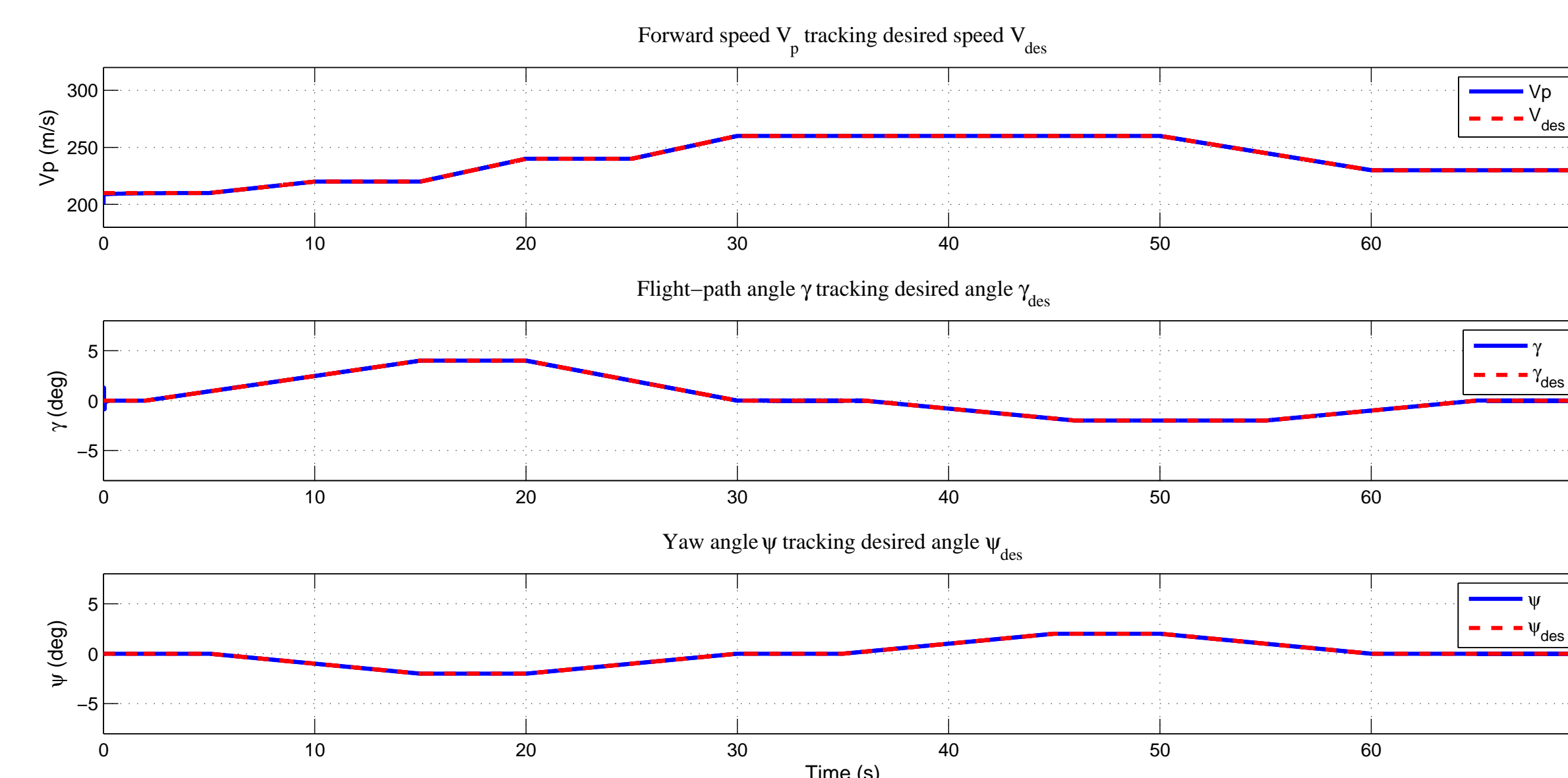


Figure 2: V_p , γ , and ψ tracking performance.

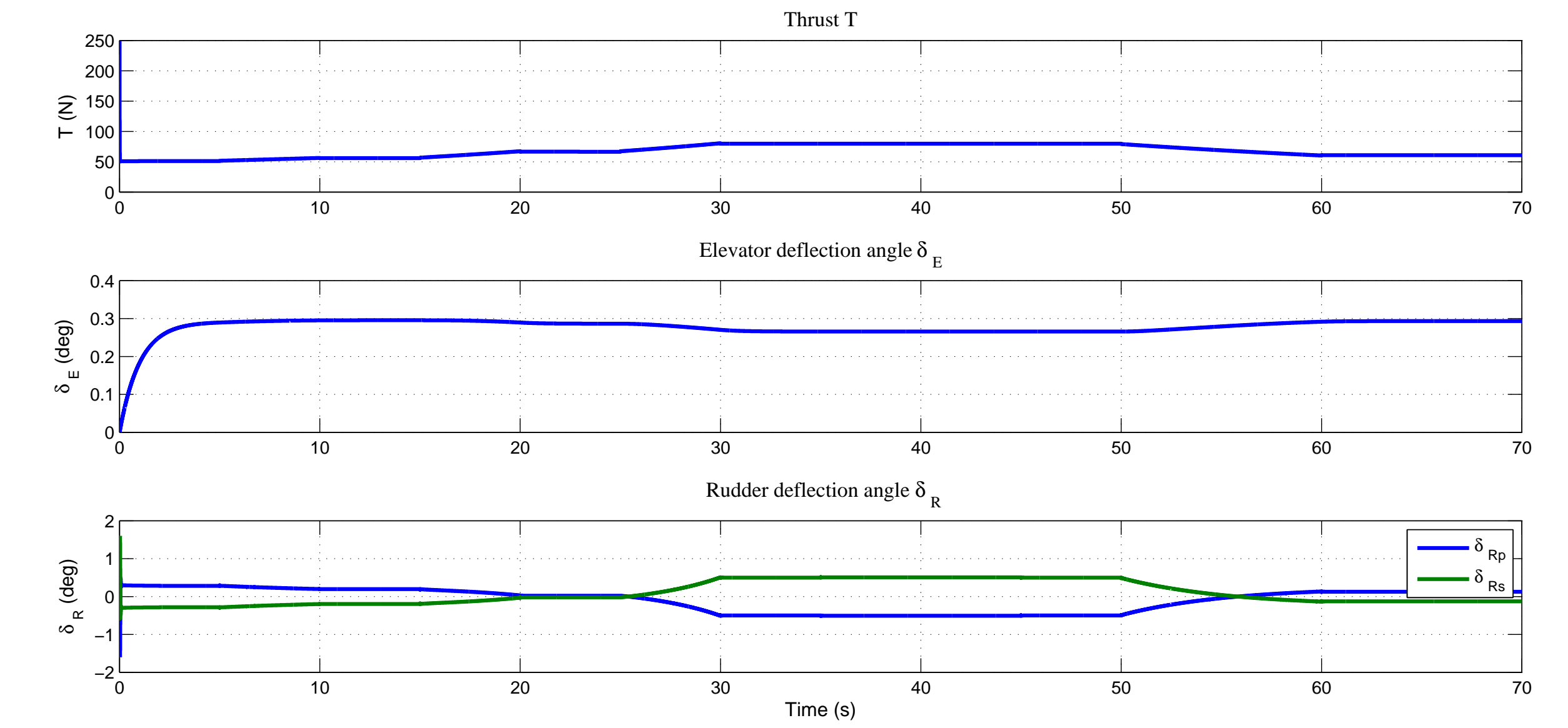


Figure 3: Control inputs T , δ_E , and δ_R .

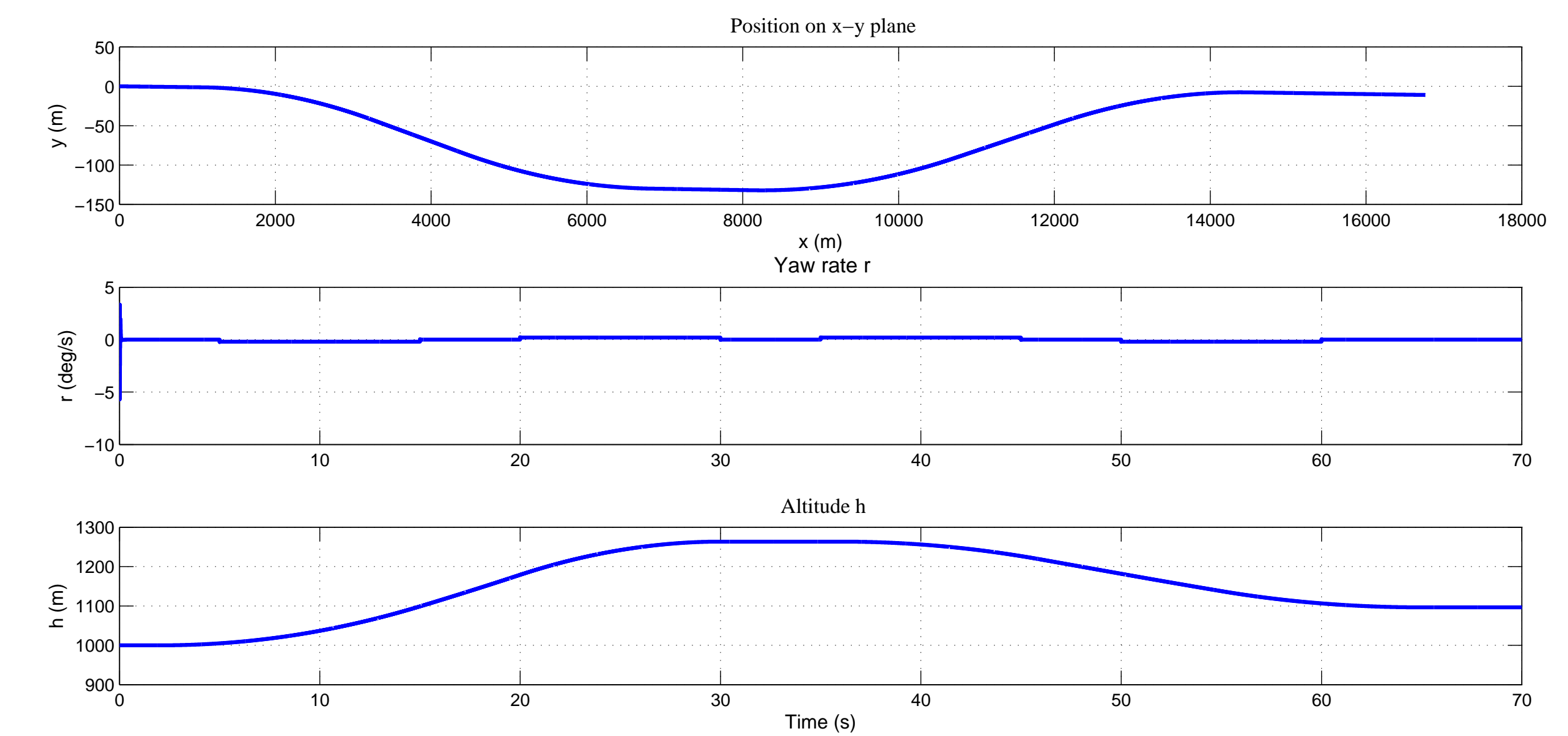


Figure 4: Position on x-y plane, yaw rate r , and altitude h .

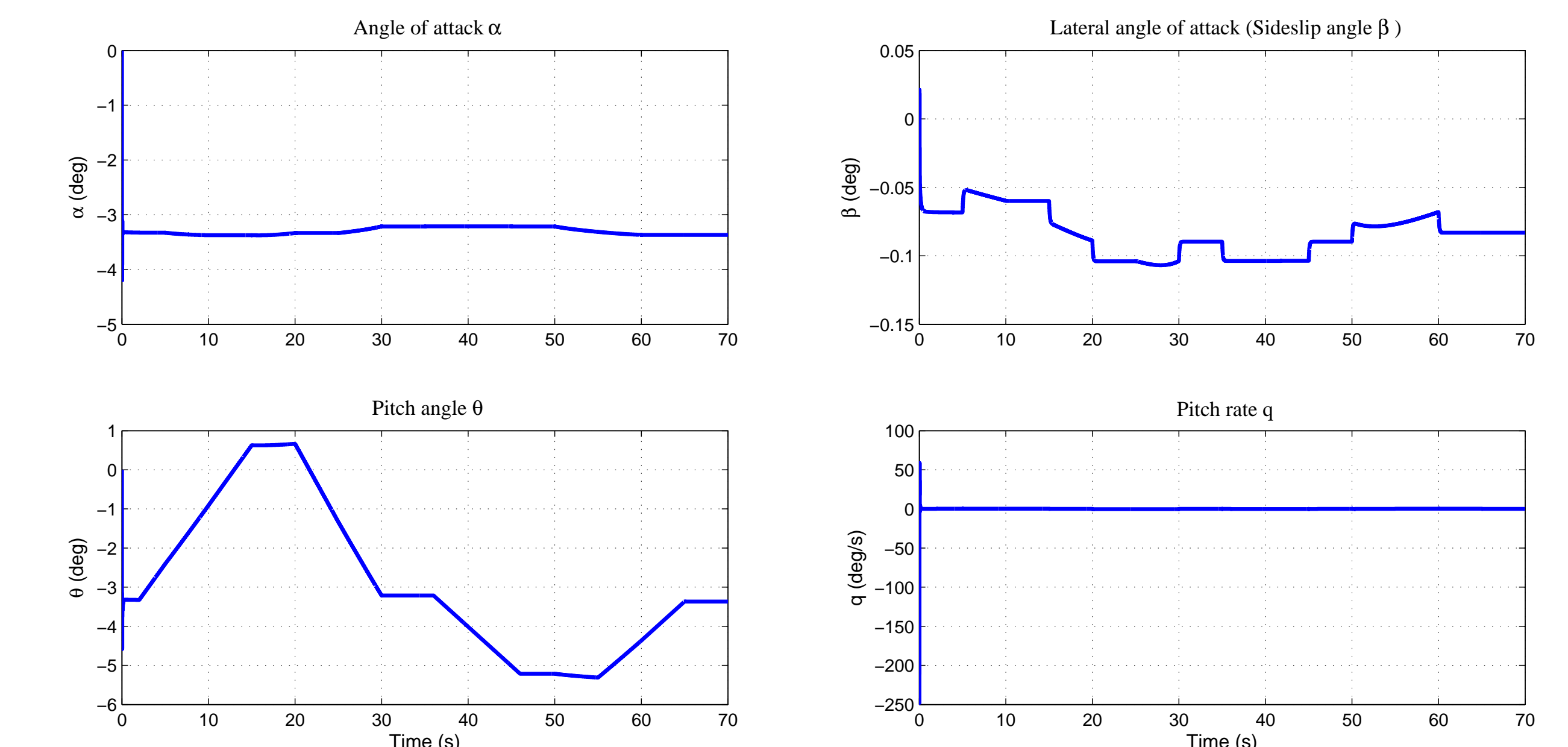


Figure 5: Flight states α , β , θ , and q behaviors.

CONCLUSION

- The adaptive control is a robust because the tracking of the outputs require less than 2.5 s.
- The control inputs also reach the stability condition in short time, without oscillation.