Research Horizons Day
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Closing the Certification Gaps in Aircraft Attitude Higher Order Sliding Mode Control

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Overview

The challenge of aircraft flight control is in addressing the model uncertainties and external disturbances. The nonlinear Higher Order Sliding Mode (HOSM) controllers are known for their robustness/insensitivity to matched bounded external disturbances/uncertainties. However, the HOSM controllers must be certified prior to be implemented in aircraft flight control system. Phase Margin (***PM***) and Gain Margin (***GM***) are the classical characteristics used for the linear control systems certification to quantify their robustness to un-modeled dynamics. There are certain standards imposed on ***PM*** and ***GM*** for the controller to be certified for controlling air space vehicles. In this research work, the conventional control system certification approach based on phase and gain margins are extended to nonlinear HOSM controllers. The proposed Practical Stability Phase Margin (***PSPM***) and Practical Stability Gain Margin (***PSGM***) are used to quantify the HOSM control system robustness to un-modeled dynamics. The tools/algorithms to identify ***PSPM*** and ***PSGM*** are developed using Describing Function-Harmonic Balance method. Theoretical developments are illustrated and validated on a case study of F-16 aircraft attitude control.

1. Problem formulation

Consider the following model of an F-16 aircraft:

$$\dot\theta = q\cos\varphi - \sin\varphi\,, \qquad \dot\varphi = p + q\sin\varphi\tan\theta + r\cos\varphi\tan\theta\,,$$
$$\dot\alpha = -\beta p + 0.0427\cos\theta\cos\varphi + 0.083589 + \tilde Z_\alpha \alpha + \tilde Z_q q + \tilde Z_\delta \delta_e,$$
$$\dot\beta = -0.9973r + \alpha p + 0.0427\cos\theta\sin\varphi + \tilde Y_\beta \beta + \tilde Y_p p + Y_{\delta_r}\delta_r + \tilde Y_{\delta_a}\delta_a,$$
$$\dot p = -0.1345pq - 0.8225qr + \tilde L_\beta \beta + \tilde L_p p + \tilde L_r r - 50.933\delta_a + \tilde L_{\delta_r}\delta_r,$$
$$\dot q = 0.9586pr - 0.0833(r^2 - p^2) - 1.94166 + \widetilde M_\alpha \alpha + \widetilde M_q q + \widetilde M_\delta \delta_e,$$
$$\dot r = -0.7256pq + 0.1345qr + \widetilde N_\beta \beta + \widetilde N_p p + \widetilde N_r r + 4.125\delta_a + \widetilde N_{\delta_r}\delta_r,$$
$$\dot\delta = -50(\delta - u).$$

where $x = [\varphi, \alpha, \beta]^T =$ a column vector of roll, attack and sideslip angles; $y = [p, q, r]^T =$ a column vector of roll, attack and sideslip angular rates; $\delta = [\delta_a, \delta_e, \delta_r]^T =$ a column vector of aileron, elevator and rudder deflections; the symbols of the form $\tilde G$ are unknown bounded smooth perturbations due to battle damages, failures and model uncertainties; $|\delta_i| \le 0.37$ rad, $\forall\, i = a, e, r$; $u \in \mathrm{R}^3$ is a control vector containing actuator inputs.

Task 1: Tracking errors: $e_x = x_c - x \to 0$ in finite-time.
Task 2: Introduce robustness metrics for designed HOSM.

2. Aircraft HOSM control design

Sliding variables: $\sigma_x = \dot e_x + c e_x,\ c \in \mathrm{R}^3 > \bar 0$.
For the given system,

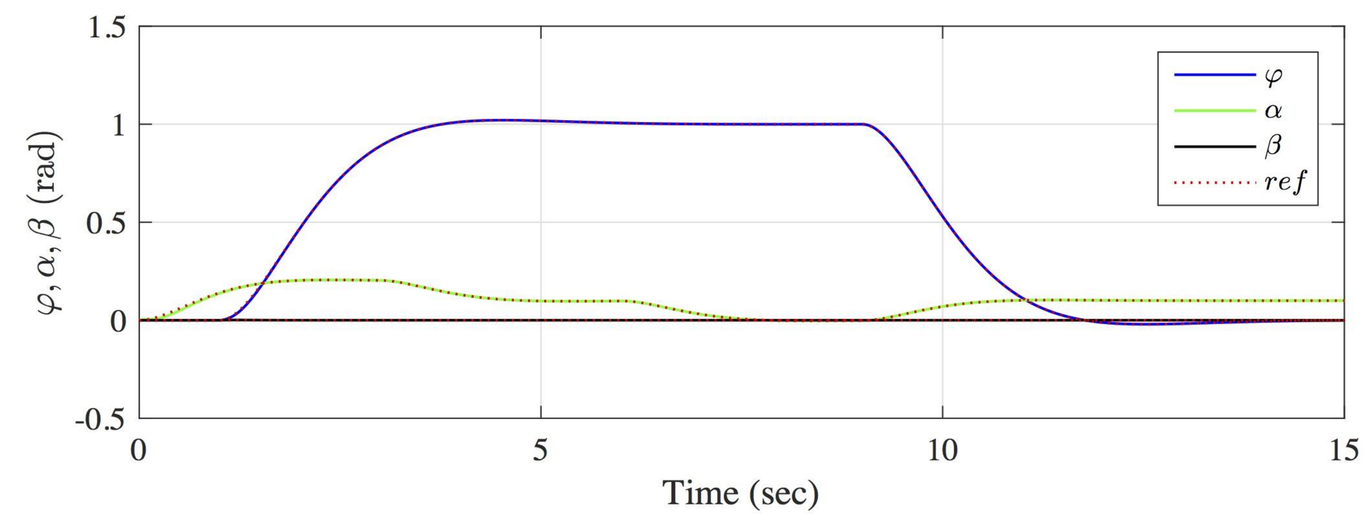
$$\ddot x = F_4(x, \dot x) + \vartheta + F(x, y, \delta),$$

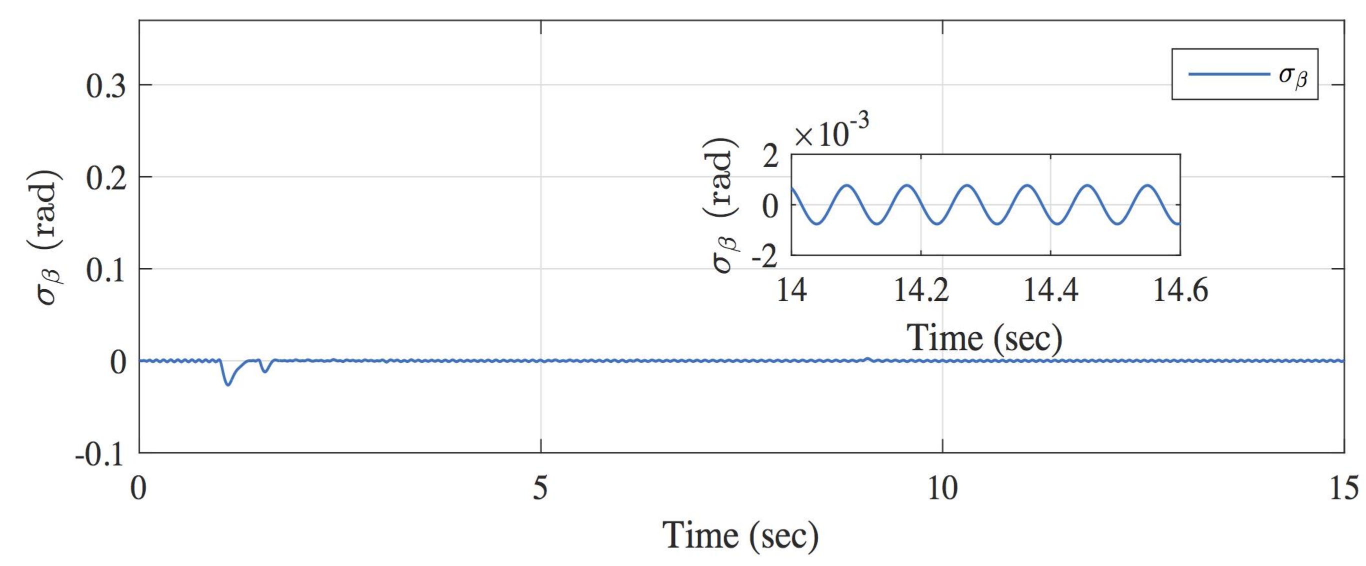
where $\vartheta = \gamma\delta$ and γ represents a constant value.
Now, $\dot\sigma = \ddot e_x + c\dot e_x = d_c + \vartheta + d,$ where d_c and d represent known and unknown terms respectively; $|d| \le$ constant L.
Therefore,

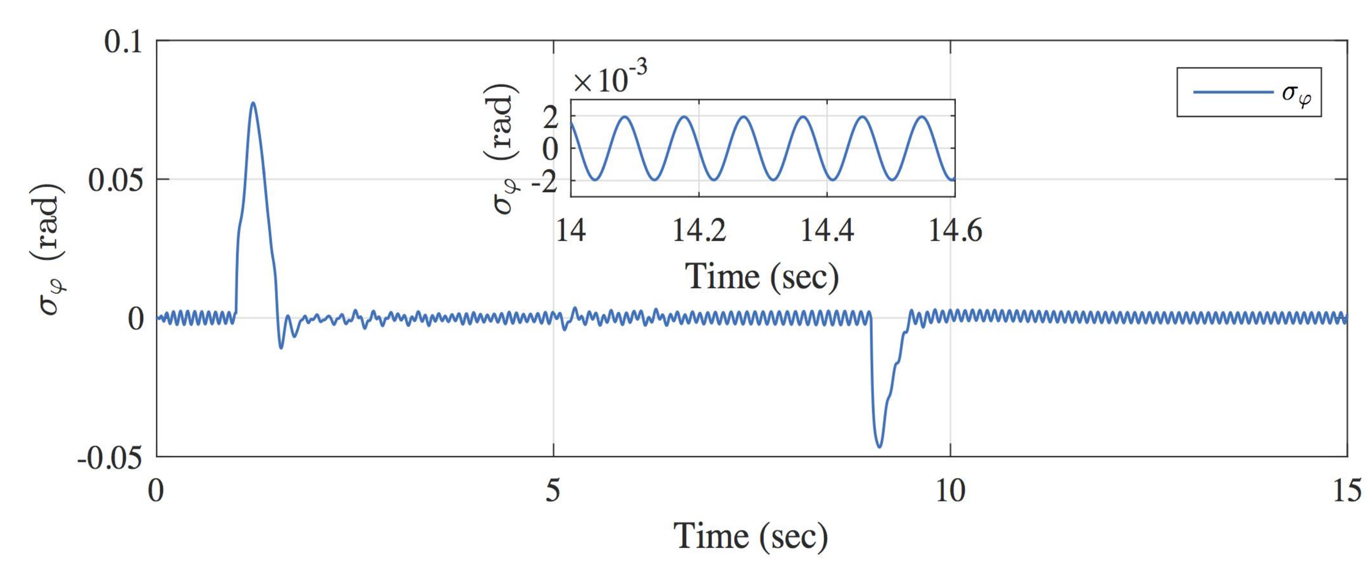
$$\vartheta = -d_c + \vartheta^*,$$
$$\vartheta^* = u,$$

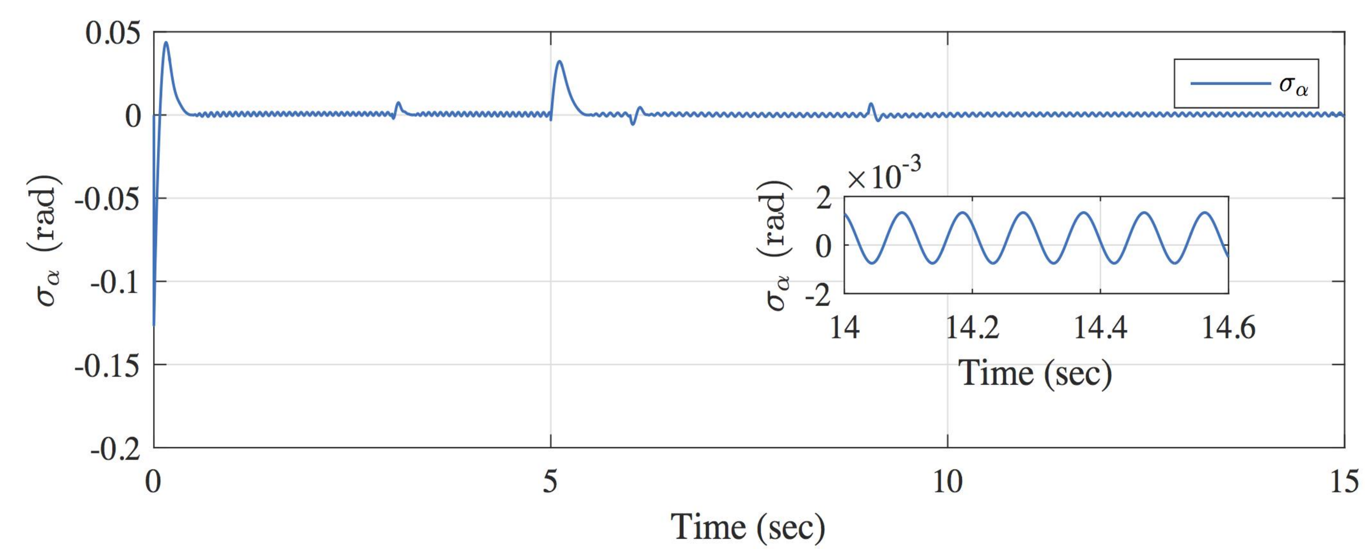
where u is given by HOSM control law.

3. Simulation results









Tracking errors	***PSPM***	***PGPM***
e_φ	79.10^o	14.12 dB
e_α	73.22^o	12.70 dB
e_β	79.40^o	14.25 dB

4. Discussion

The prime contributions of this research are as follows:

- Stability margins (***PM*** and ***GM***) are extended to practical stability margins (***PSPM*** and ***PSGM***) to quantify the aircraft HOSM control system to un-modeled dynamics presiding the tool for HOSM control certification.
- Proposed methodologies are demonstrated on a case study of controlling the attitude of F16 aircraft.

References

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