# Dynamic Surface Control Approach for UAV Firefighting System

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# Outline

1. Motivation
2. Dynamic Surface Control
3. Controller Design
4. Numerical Simulation
5. Conclusion

# Background

## Aircraft capability to cope with disasters

Rescue

Transportation

Reconnaissance

# Background

## Aerial Firefighting

Problem

Advantage

- High workload for the pilot
- No need for a fire hydrant

⇨ Leading to risk for mission

- The ability to drop a large amount of water

Aerial Firefighting （USAF）

Autonomous control addresses this problem

⇨ Great performance in the case of forest fire

# Problems for designing UAV firefighting system

Dramatical mass variation ⇨ Time varying system

- Effect by unmeasurable force with mass variation
- Strong nonlinearity is appeared at the dynamics

# Problems for designing UAV firefighting system

Conventional method
(State feedback control)

↓

Time varying system

↓

**Deterioration control performance and Flight instability**

# Problems for designing UAV firefighting system

Proposed some methods

- Gain schedule control
- Adaptive backstepping control
- Controllers with high robustness

Time varying system

These methods have left some problems for application.

# Proposed method

## Dynamic Surface Control

⇨ DSC method incorporates a filter between each

**with Extended State Observer**

subsystem to simplify the back-stepping control.

is adopted into the UAV firefighting system.

## Extended State Observer

⇨ To compensate the effect by unmeasurable quantities

- Aerodynamic force and moment
- Disturbance
- The effect by time varying system

# Objectives

- ➢Designing flight control system for the UAV firefighting system.
- ➢Verifying the effectiveness of proposed method by the numerical simulation.

<u>Works to do</u>

- Applying DSC with ESO into the UAV firefighting system.
- Comparison of control performance (DSC with ESO vs LQI)

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In the nonlinear controllers

Back-stepping control ⇨ effective method

Virtual Input

$$x_{(i+1)d} = \frac{1}{g_i}(-k_i s_i + \dot{x}_{id} - f_i - g_{i-1}s_{i-1}) \qquad \because s_i = x_i - x_{id}$$

However

This method faces difficulty for application.

$x_{id}$ includes uncertainty

➡ Explosion terms arise in virtual input.

Tedious and complex for application

# Dynamic surface control

**Virtual Input**

$$x_{ic} = \frac{1}{g_{i-1}}(-k_{i-1}s_{i-1} + \dot{x}_{i-1d} - f_{i-1}) \qquad \text{(i-1 th)}$$

$$\because s_i = x_i - x_{id}$$

Filter

**2nd Order Filter** ➡ Smoothing derivative of $x_{id}$

$$\ddot{x}_{id} + 2\zeta\omega\dot{x}_{id} + \omega^2 x_{id} = \omega^2 x_{ic}$$

$\dot{x}_{id}$

➡ Relief sudden signal rise

**Actual Input**

$$x_{(i+1)c} = \frac{1}{g_i}(-k_i s_i + \dot{x}_{id} - f_i) \qquad \text{(i th)} \qquad (i = 1, \cdots, n-1)$$

$$u = \frac{1}{g_n}(-k_n s_n + \dot{x}_{nd} - f_n)$$

➡ The calculation of virtual input $x_{ic}$ is simplified

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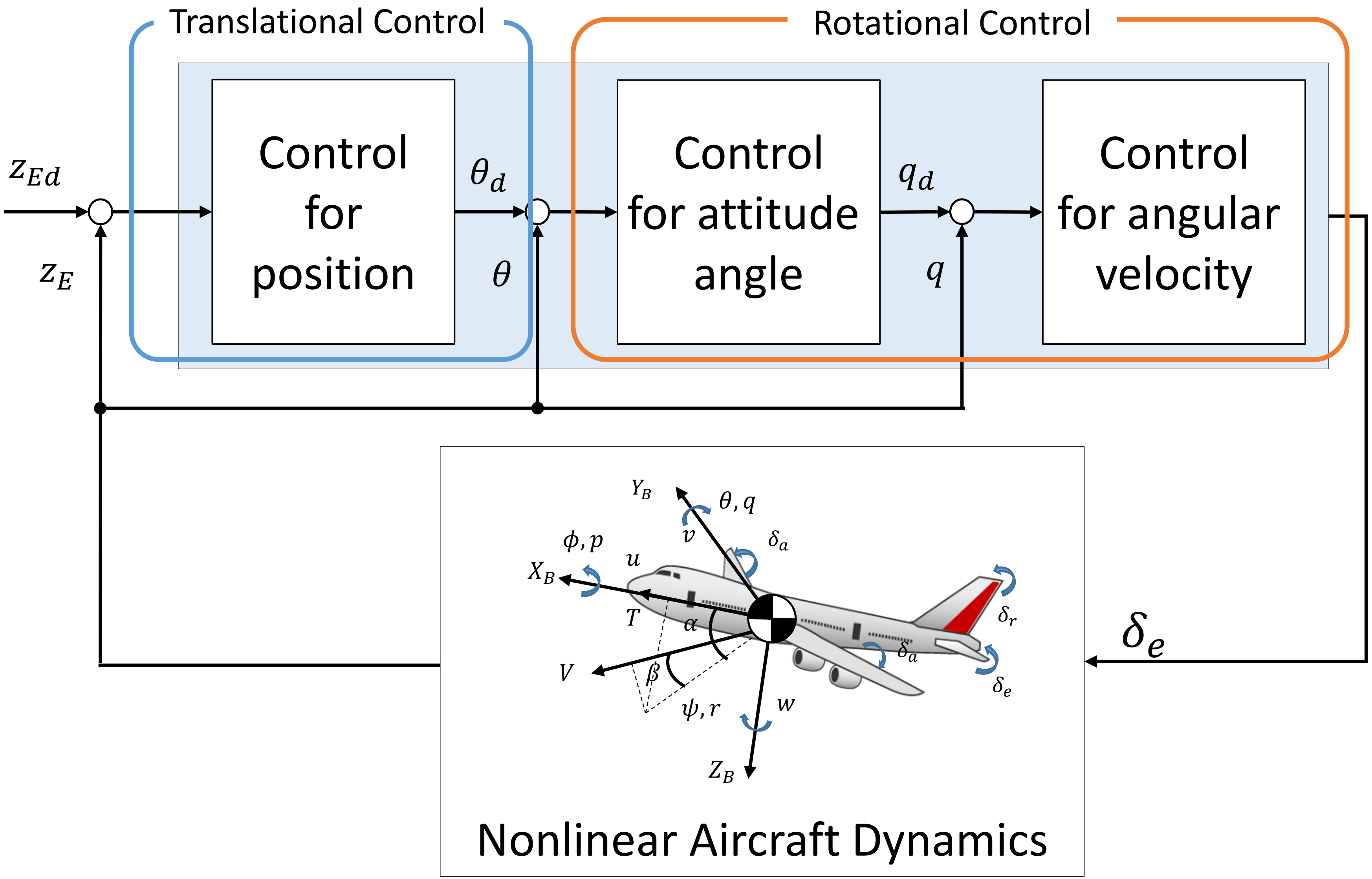
# Flight Control System



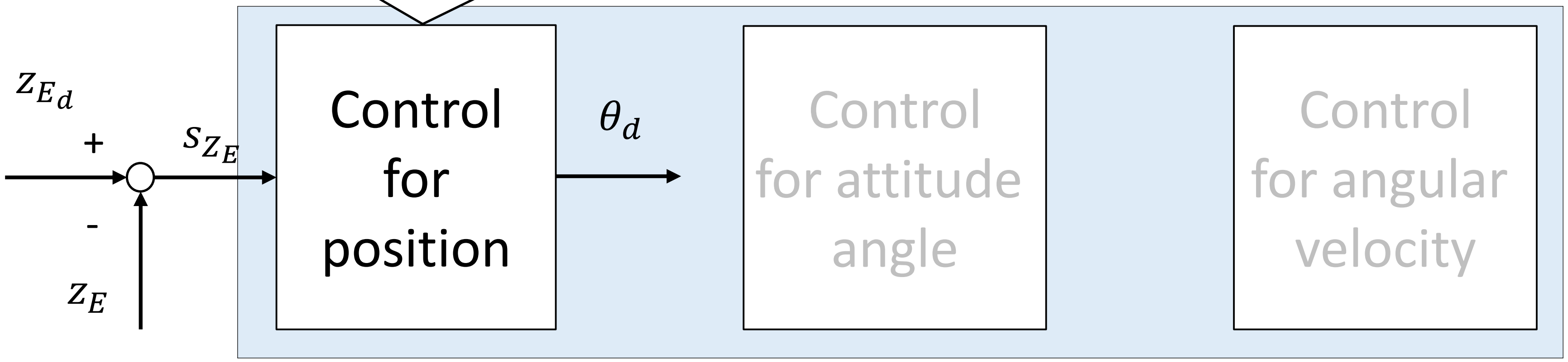
# Translational control

**Control for position**

Tracking error

$$s_{z_E} = z_E - z_{Ed}$$

$$\theta_d = \arcsin \frac{\left(-k_{zP} s_{z_E} - k_{zI} \int s_{z_E} dt - k_{zD} \dot{s}_{z_E}\right)}{V}$$



# Dynamic Transformation

## Aircraft dynamics

$$\dot{\theta} = q \qquad \dot{q} = \frac{1}{I_{yy}}\left(\frac{\rho V^2 S\bar{c}}{2} C_m + z_p T\right) + d$$

**Transformation**

## Nonlinear system

$$\dot{x}_1 = f_1 + g_1 x_2 \qquad \dot{x}_2 = (f_{2n} + \Delta f_2) + (g_{2n} + \Delta g_2)\delta_e + d$$

$$x_1 = \theta$$

$$f_1 = 0,\ g_1 = 1$$

$$x_2 = q$$

$$f_2 = \frac{\rho V^2 S\bar{c}}{2I_{yy}}\left(C_{m_\alpha}\alpha + \frac{\bar{c}}{2V}\left(C_{m_{\dot{\alpha}}}\dot{\alpha} + C_{m_q} q\right)\right) + \frac{z_p T}{I_{yy}}$$

$$f_{2n} = \frac{\rho V^2 S\bar{c}}{2I_{yy_0}}\left\{C_{m_\alpha}\alpha + \frac{\bar{c}}{2V}\left(C_{m_{\dot{\alpha}}}\dot{\alpha} + C_{m_q} q\right)\right\} + \frac{z_p T}{I_{yy_0}}$$

$$g_2 = \frac{\rho V^2 S\bar{c}}{2I_{yy}} C_{m_{\delta_e}}$$

$$g_{2n} = \frac{\rho V^2 S\bar{c}}{2I_{yy_0}} C_{m_{\delta_e}}$$

# Rotational control

## Control for attitude angle

Tracking error

$$s_1 = \theta - \theta_d$$

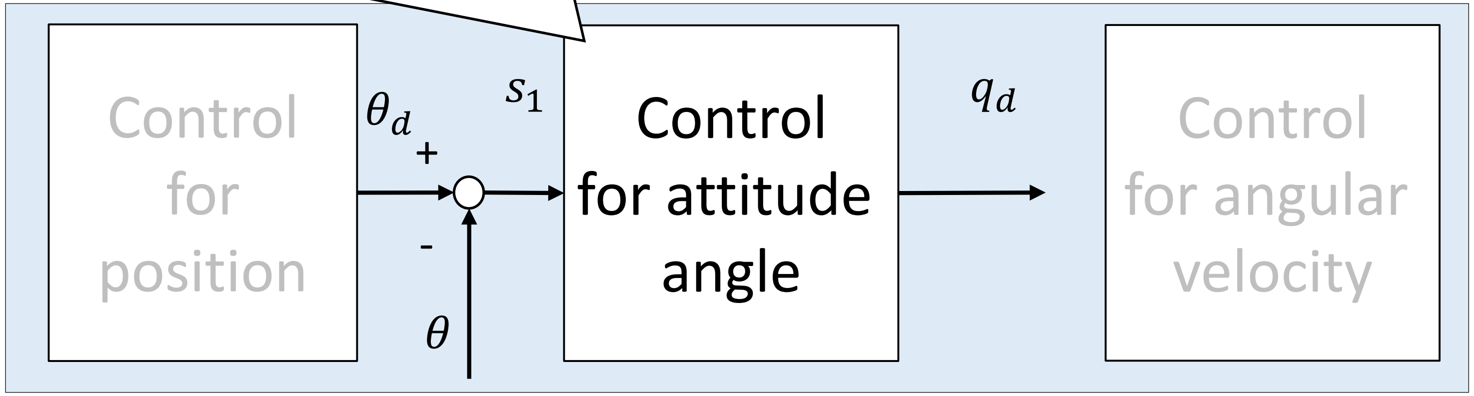
Virtual Input

$$x_{2c} = \frac{\left(-k_1 s_1 + \dot{\theta}_d\right)}{g_1}$$

2nd order filter

$$\ddot{x}_{2d} + 2\zeta\omega\dot{x}_{2d} + \omega^2 x_{2d} = \omega^2 x_{2c}$$

$$\therefore x_{2d} \rightarrow q_d$$



# Rotational control

## Control for angular velocity

**Tracking error**

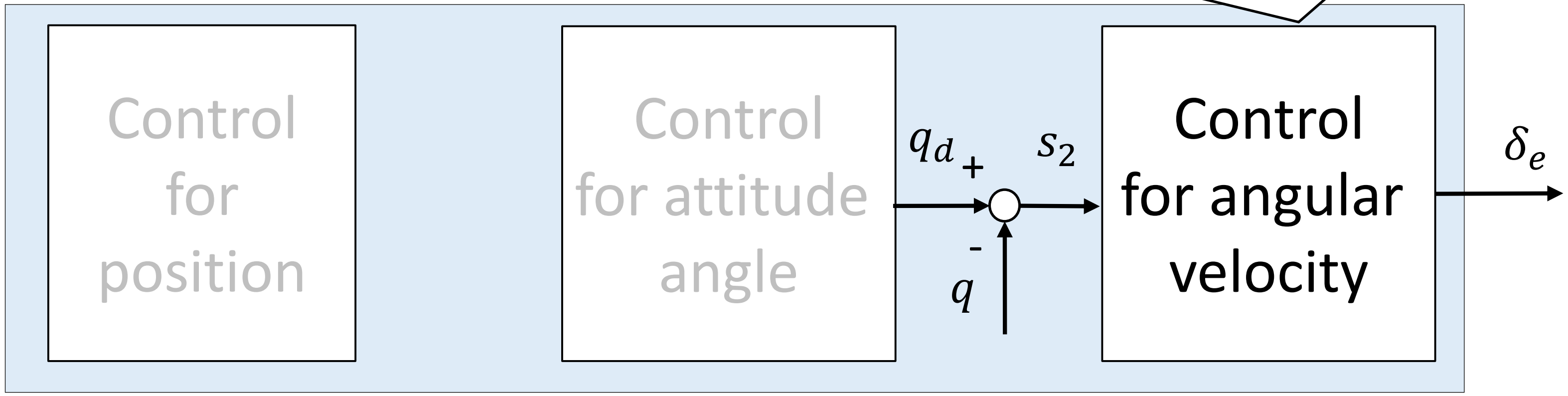
$$s_2 = q - q_d$$

**Actual Input**

$$\delta_e = \frac{\left(-f_{2n} - k_2 s_2 + \dot{q} - \widehat{D}_2\right)}{g_{2n}}$$

$$e_2 = \hat{q} - q$$
$$\dot{\hat{q}} = \widehat{D}_2 - k_{o1} e_2 + f_{2n} + g_{2N} \delta_e$$

$$\dot{\widehat{D}}_2 = k_{o2} e_2$$



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# Setting


### Specification

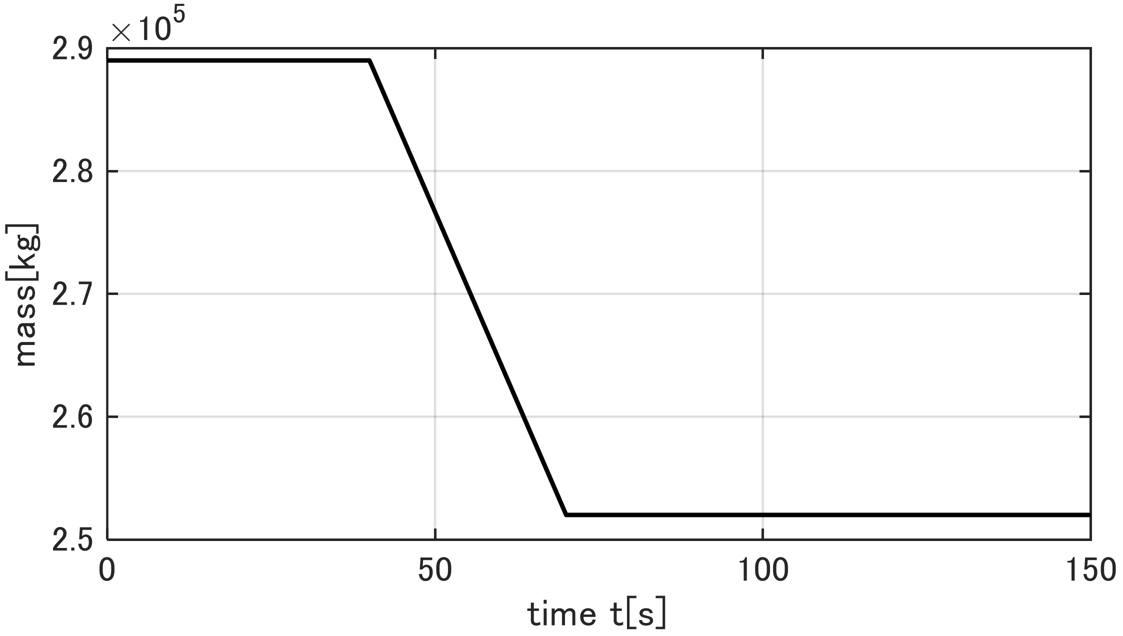
| | |
|---|---|
| Aircraft | B747 |
| Wing area $S[\mathrm{m}^2]$ | 511 |
| Wing span $b[\mathrm{m}]$ | 59.6 |
| MAC $\bar{c}[\mathrm{m}]$ | 8.32 |
| Mass $m[\mathrm{kg}]$ | 289,000 |

### Initial values

| | |
|---|---|
| Velocity $V_0[\mathrm{m/s}]$ | 84.88 |
| Pitch angle $\theta_0[\mathrm{rad}]$ | 0.02564 |
| Pitch angular velocity $q[\mathrm{rad/s}]$ | 0 |
| Angle of attack $\alpha_0$ $[\mathrm{rad}]$ | 0.02564 |
| Thrust trim $T_{trim}$ $[\mathrm{N}]$ | 268,425 |

# Setting

## Mass variation




## Disturbance

$$\dot{q} = \frac{1}{I_{yy}}\left(\frac{\rho V^2 S\bar{c}}{2} C_m + z_p T\right) + d$$

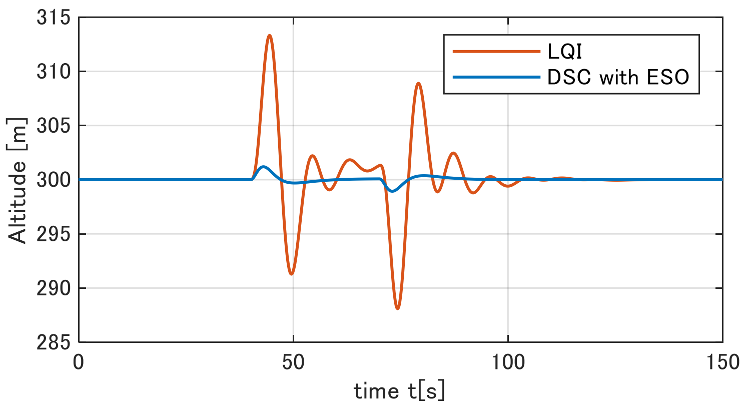
$$d = \begin{cases} 0.1 & 40 \leq t \leq 70 \\ 0 & others \end{cases}$$

Comparison control performance between

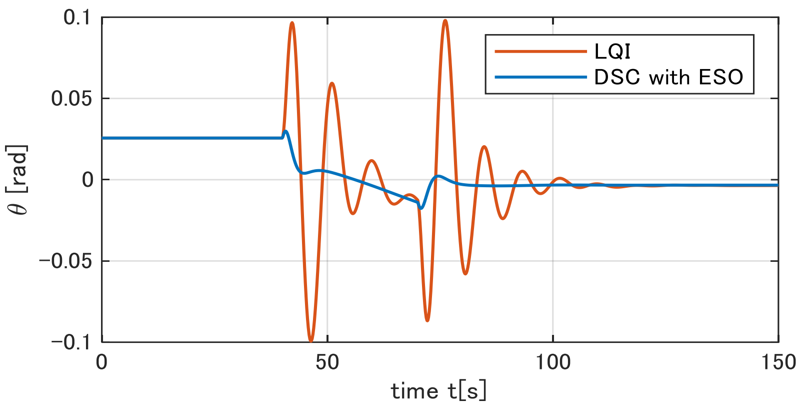
<u>DSC with ESO</u> and <u>LQI control</u>

# Results (LQI vs DSC with ESO)

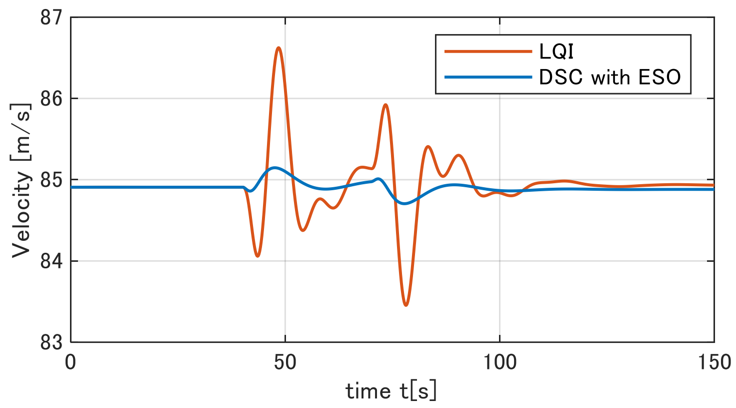
## Altitude



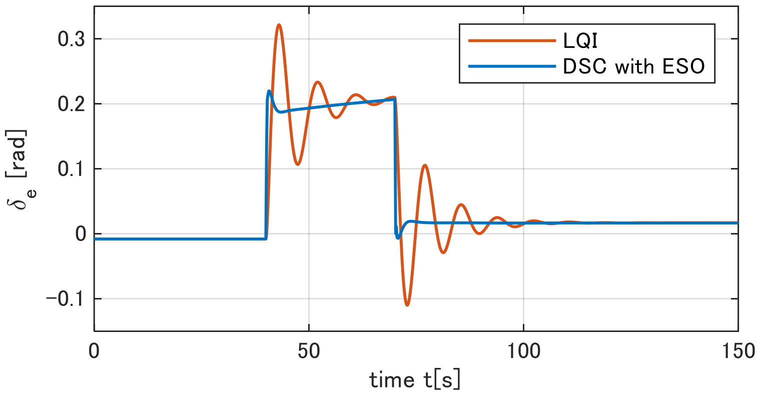

## Pitch angle



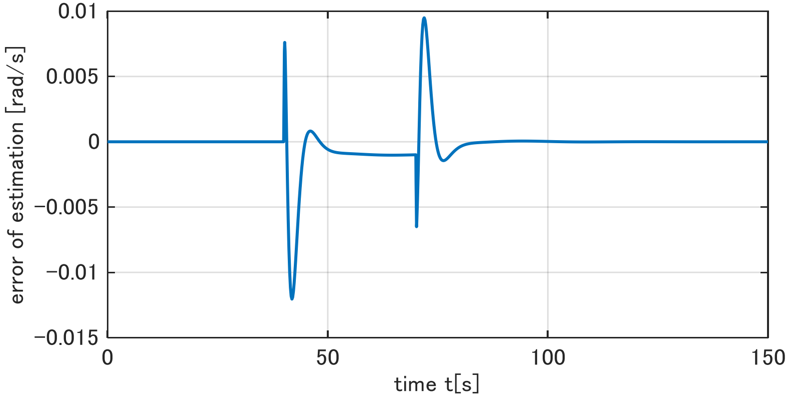

## Velocity




## Elevator deflection

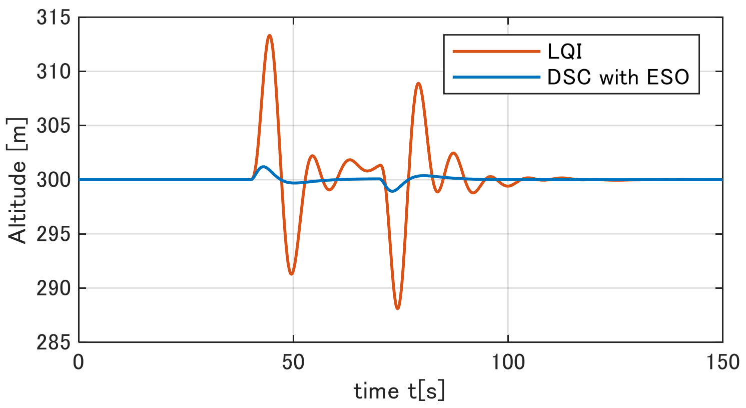



## Error of estimation

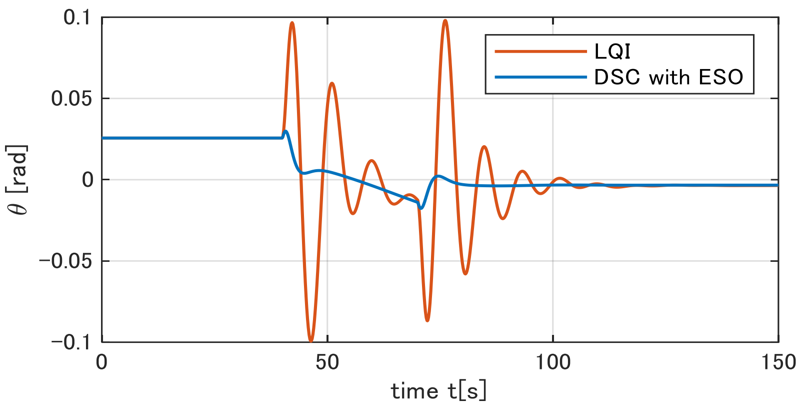


# Results (LQI vs DSC with ESO)

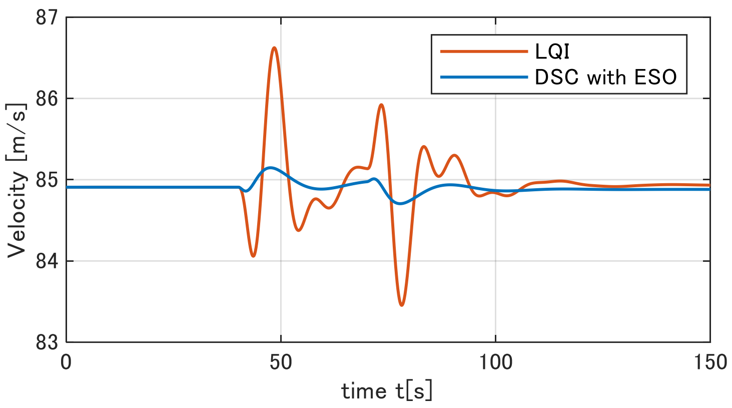
## Altitude



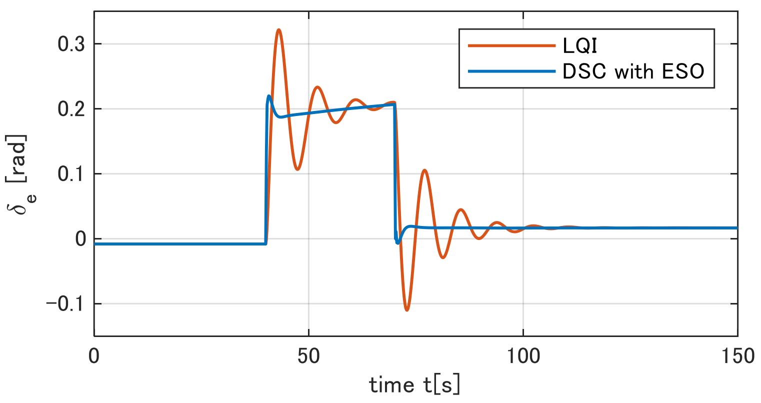

## Pitch angle




## Velocity




## Elevator deflection

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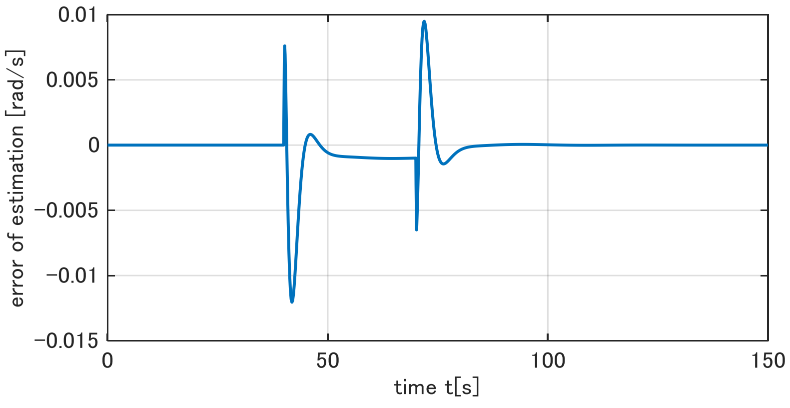

# 5.Concusion

- We propose the flight control system for UAV fire fighting system by using DSC with ESO.
- The numerical simulation results show the effectiveness of the proposed method.

Thank you for your attention.