Osaka Prefecture University

Development of a flying test bench using small UAVs

Shuichi Furukawa
Jin Fujinaga
Hiroshi Tokutake
and
Shigeru Sunada

Osaka Prefecture University

Contents

Motivations

1. Experiments of the next generation Re-Entry Vehicles are expensive.
⇒ The research using a small model is more inexpensive.

2. Some UAVs realized an autonomous flight.
⇒ UAVs can be used as a test bench for an advanced flight control.

A small Re-Entry Vehicle test-model with an ability of autonomous flight was developed.

Introductions

1. A Gliding UAV of lifting body was developed.

2. The modeling of dynamics was constructed from the results of wind tunnel experiments.

3. Guidance-Navigation and control systems were designed.

4. Flight tests were carried out.

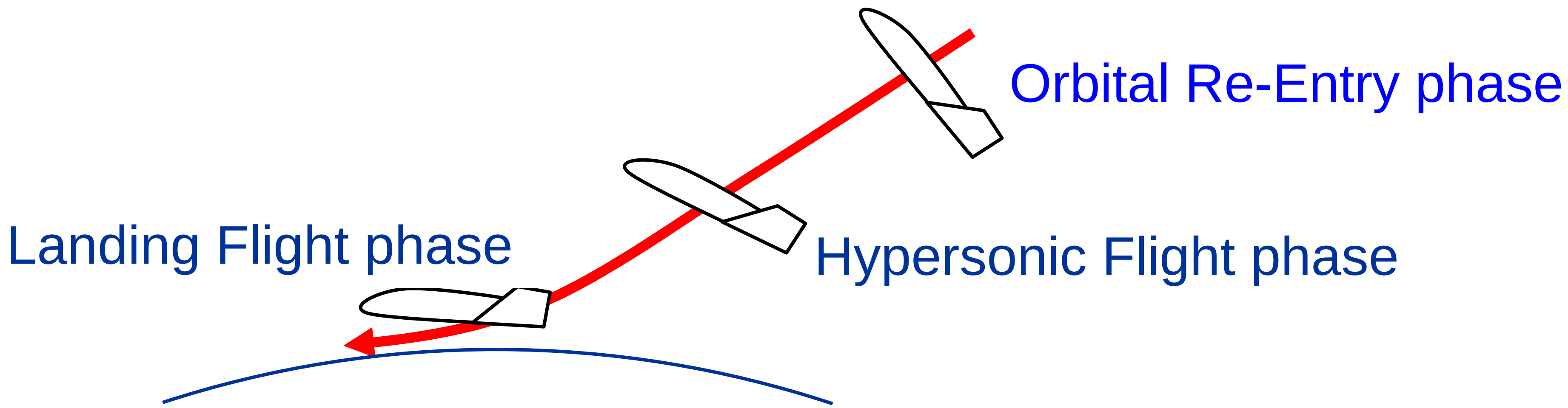
Flight profile

The flight of Re-Entry Vehicle is divided into several phases.

⇒Orbital Re-Entry phase, Hypersonic Flight phase, Landing Flight phase.

Experimental research of Landing Flight phase

1. Lifting body design
2. Controller design
3. Navigation and Guidance system design



Lifting body aircraft

Osaka Prefecture University

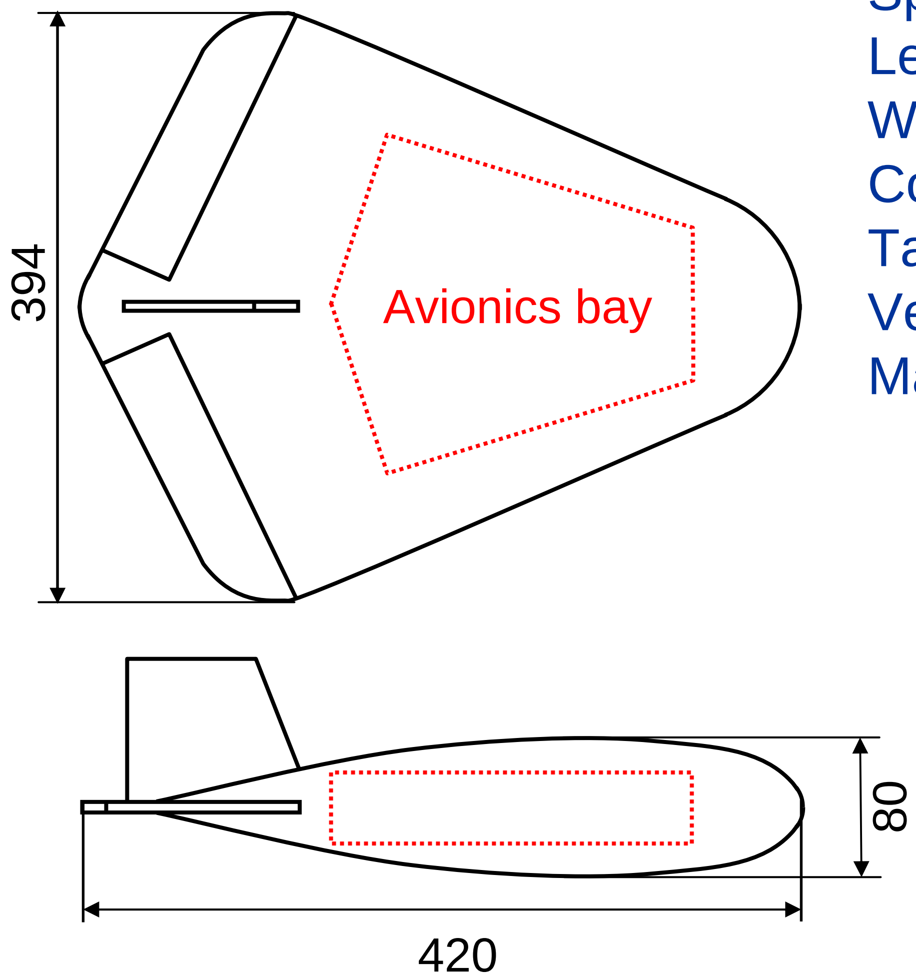


Figure 1. Designed aircraft model

Span: 39cm
Length: 42cm
Weight: 350g
Control surfaces: Elevons
Tail: Vertical tail
Velocity: 6.4m/s(AOA=27 deg)
Made of styrene foam

Wind tunnel experiments

Aerodynamics forces were measured.

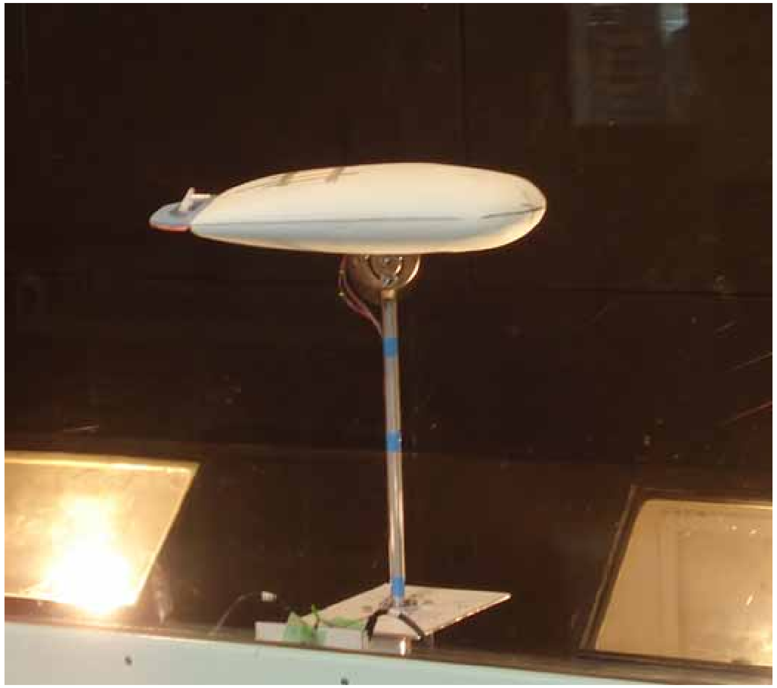
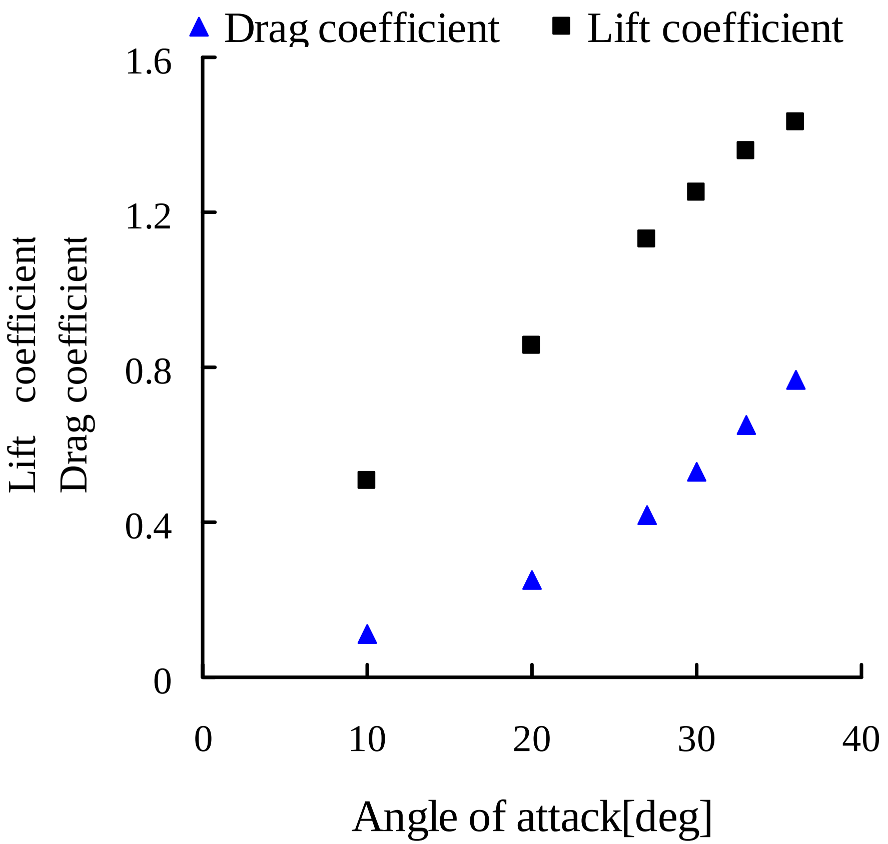


Figure 2. Wind tunnel experiments

Wind velocity:	4m/s
Angle of attack:	10-36deg
Elevons angle:	-5-15deg
Reynolds number :	~10^5

Results of wind tunnel experiments



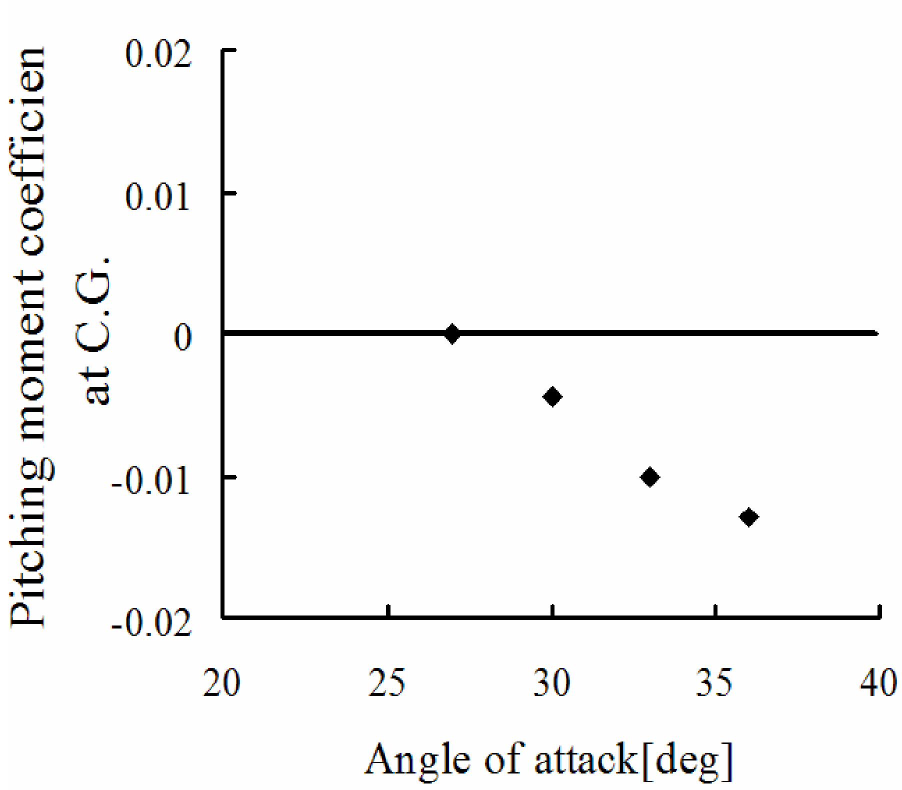


Figure 3. Lift coefficient and Drag coefficient

Figure 4. Pitching moment coefficient

Maximum L/D is 4.58.

Pitching dynamics is statically stable.

Modeling of dynamics

The linearized equations of motion were formulated.
This gliding UAV was assumed to have a constant longitudinal forward velocity.

Longitudinal;

$$\dot{x}_{lon} = A_{lon} x_{lon} + B_{lon} \delta_e$$

$$x_{lon} = [\alpha \quad q \quad \theta]^T$$

Lateral-directional;

$$\dot{x}_{lat} = A_{lat} x_{lat} + B_{lat} \delta_a$$

$$x_{lat} = [\beta \quad p \quad r \quad \phi]^T$$

Eigenvalues

Longitudinal;

$$\lambda_{sp} = -1.30 \pm 4.49i, \qquad \lambda_{ph} = -0.66$$

Lateral-directional;

$$\lambda_{roll} = -4.03, \ \lambda_{Dutch\ roll} = -0.92 \pm 7.83i$$

$$\lambda_{spiral} = 0.73$$

Trim conditions;

Velocity:	6.4 m/s
Angle of attack:	27deg
Path angle:	-25deg

⇒There is no pair of complex values for the phugoid mode.

⇒Spiral mode is unstable.

Controller design (longitudinal dynamics)

Design requirements;

1. Robust stabilities subject to multiplicative uncertainties at output side are ensured.
2. Responses to longitudinal gust are suppressed.
3. Deflection angles of elevons are suppressed.

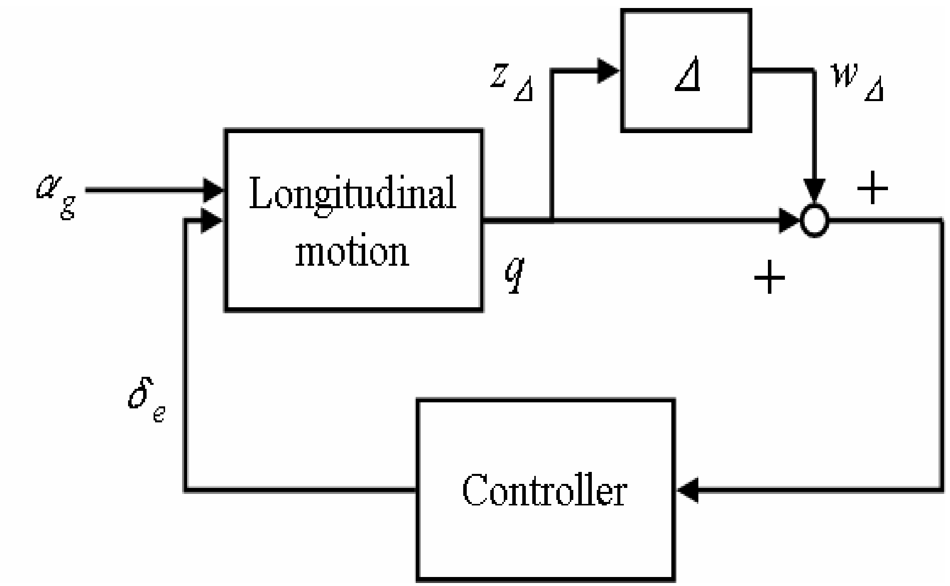


Figure 5. Block diagram for longitudinal dynamics

H-infinity controller was obtained.
H-infinity norm of the transfer function from disturbances to controlled outputs was minimized.

Controller design (lateral-directional dynamics)

Osaka Prefecture University

Design requirements;

1. Robust stabilities subject to multiplicative uncertainties at input side are ensured.
2. Responses to lateral-directional gust are suppressed.
3. Deflection angles of elevons are suppressed.
4. Sensor noises are taken into account.

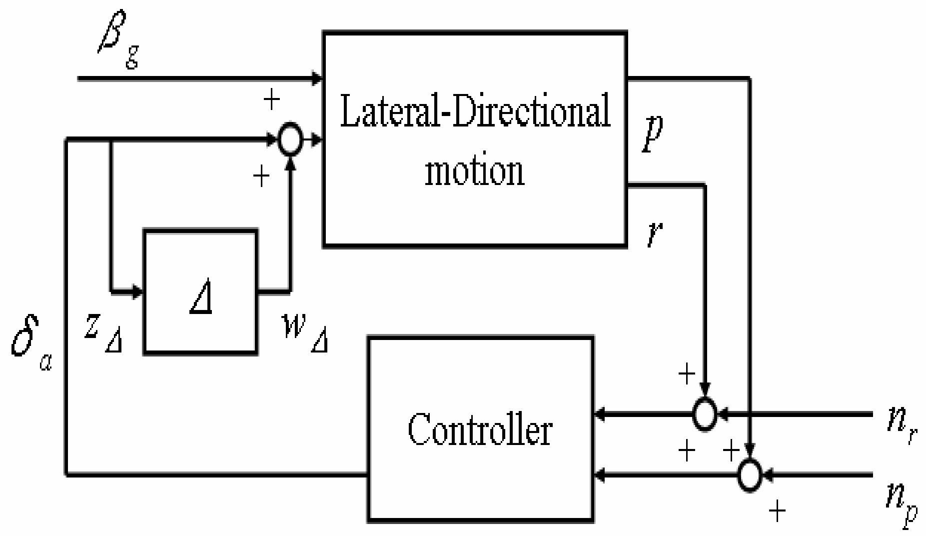


Figure 6. Block diagram for lateral-directional dynamics

(Lateral-directional inner loop)

H-infinity controller was obtained.
H-infinity norm of the transfer function from disturbances to controlled outputs was minimized.

Navigation and guidance system

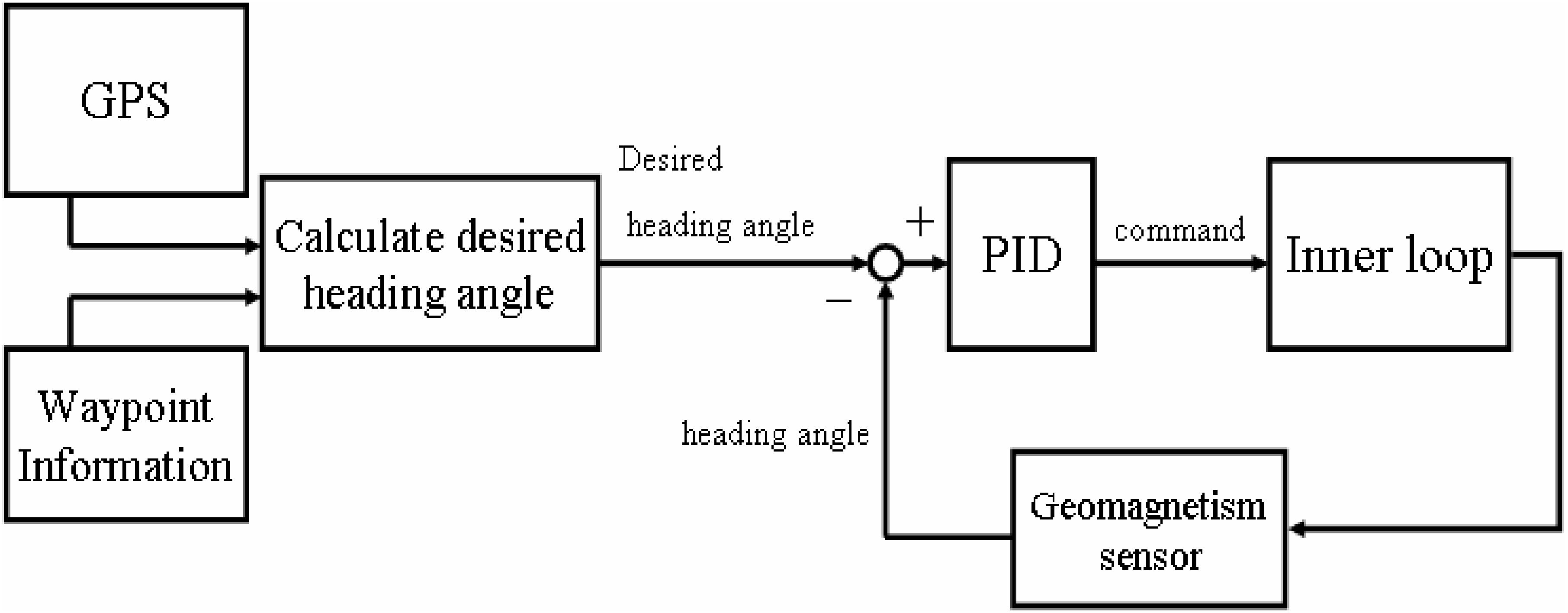


Figure 7. Guidance system

- The guidance and navigation system attained a waypoint tracking.
- Bank command was determined by heading error using PID controller.
- Bank command was input to lateral-directional inner-loop system.

Numerical simulations

Longitudinal responses to gust disturbances were simulated.

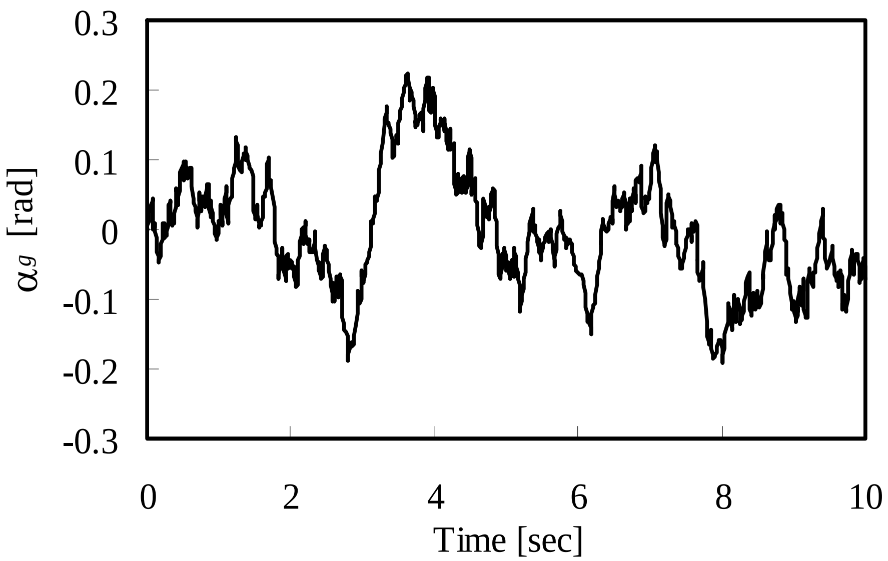


Figure 8. Input gust component

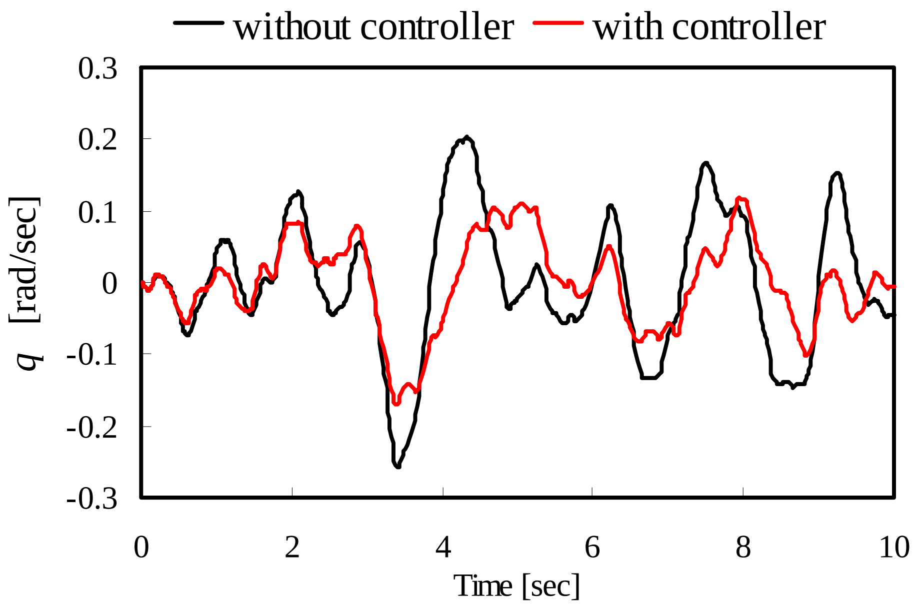


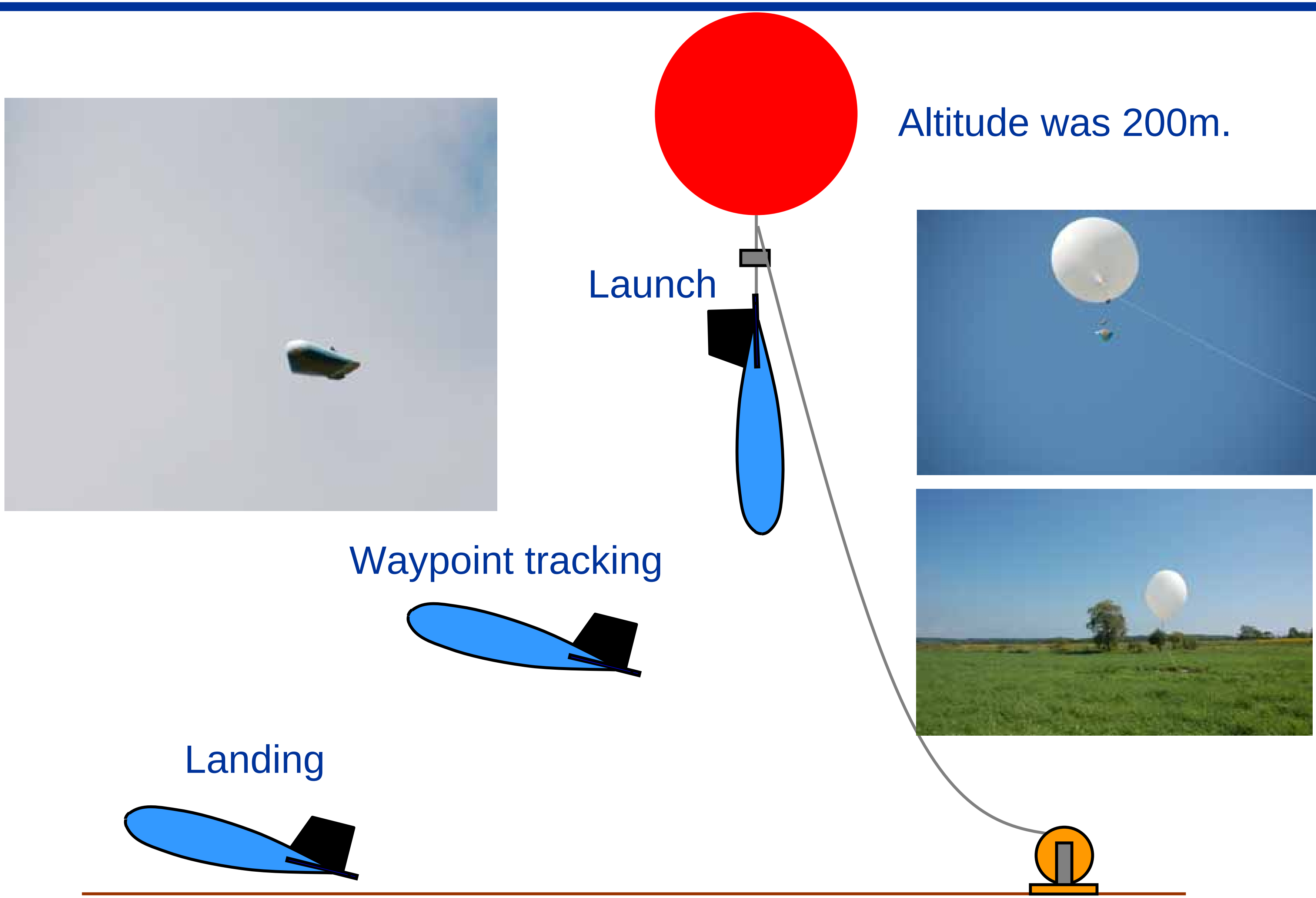
Figure 9. Response of pitch rate

The designed controller decreases the pitching rate caused by the gust.

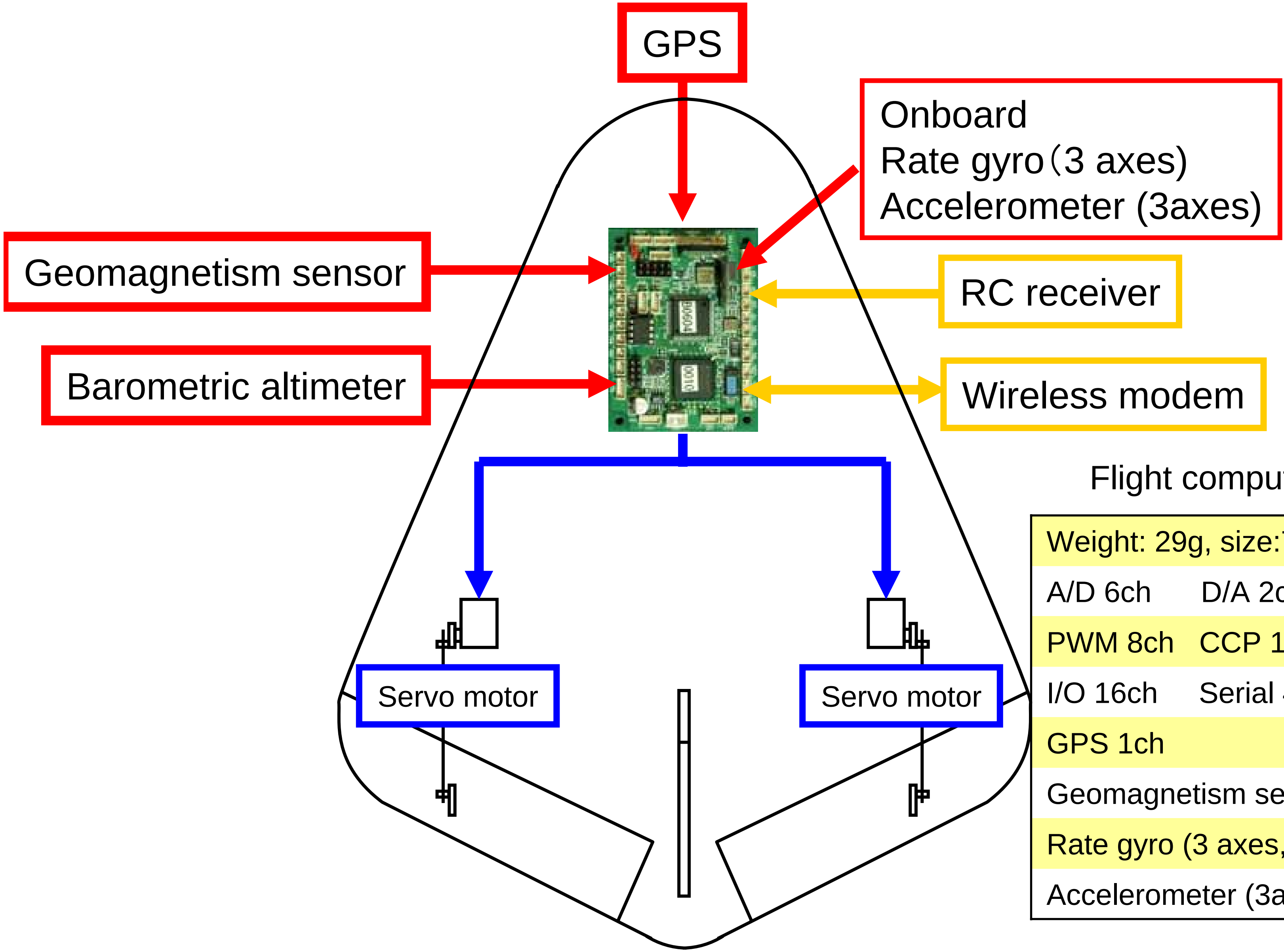
Flight tests

Osaka Prefecture University

Altitude was 200m.



Avionics



Flight computer MAVC1

Weight: 29g, size:75mm×55mm	
A/D 6ch	D/A 2ch
PWM 8ch	CCP 10ch
I/O 16ch	Serial 4ch
GPS 1ch	
Geomagnetism sensor 1ch	
Rate gyro (3 axes, onboard)	
Accelerometer (3axes, onboard)	

Results of the flight tests (1)

Osaka Prefecture University

The heading was maintained to point to west.
⇒Error of heading angle was controlled to zero.

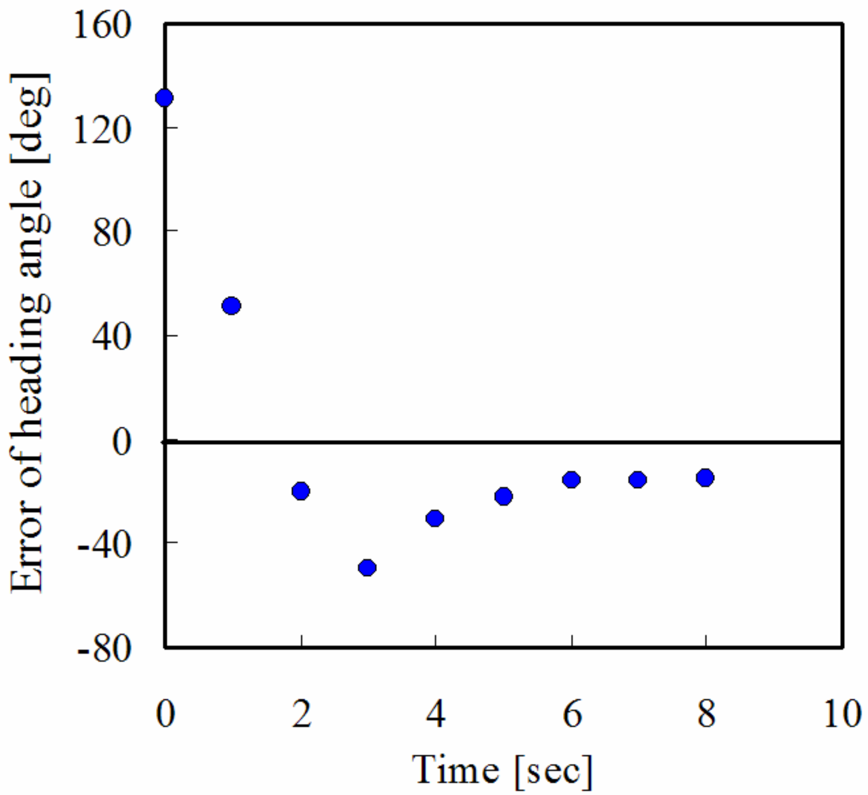


Figure 10. Heading angle tracking

Launch altitude: about 35m
Wind: 4m/s from west

- The steady glide was attained.
- The heading was stabilized nearly at the desired heading direction.

Results of the flight tests (2)

Osaka Prefecture University

The UAV was controlled to track given waypoints.

Launch altitude: about 200m   Wind:1m/s from east on the ground

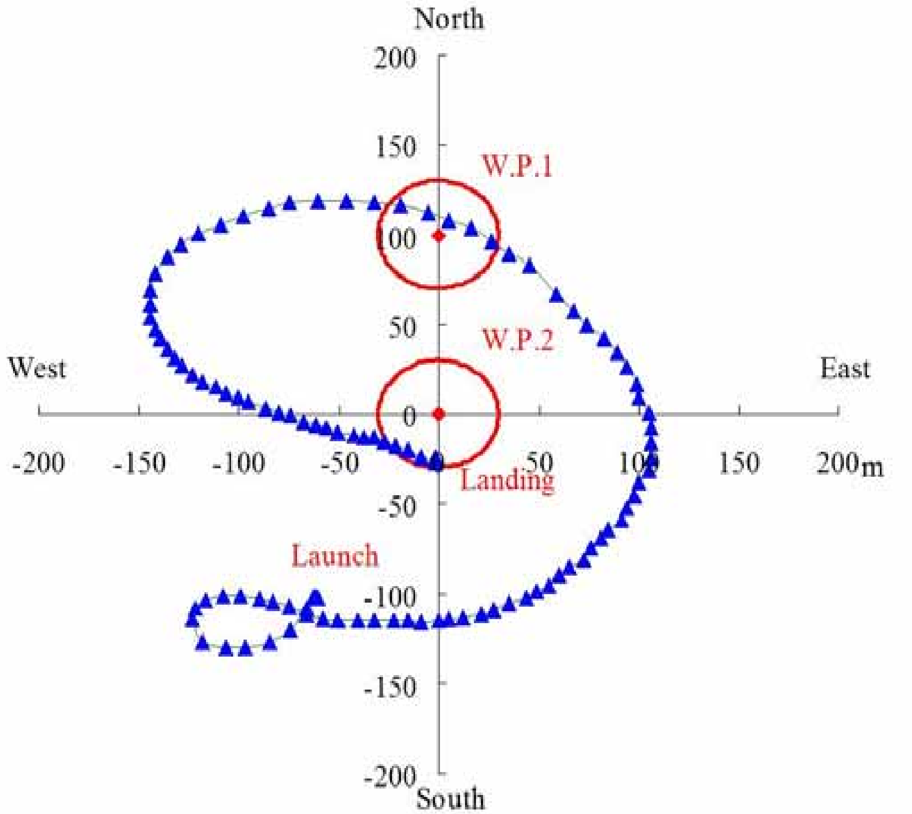


Figure 11. Waypoint tracking record

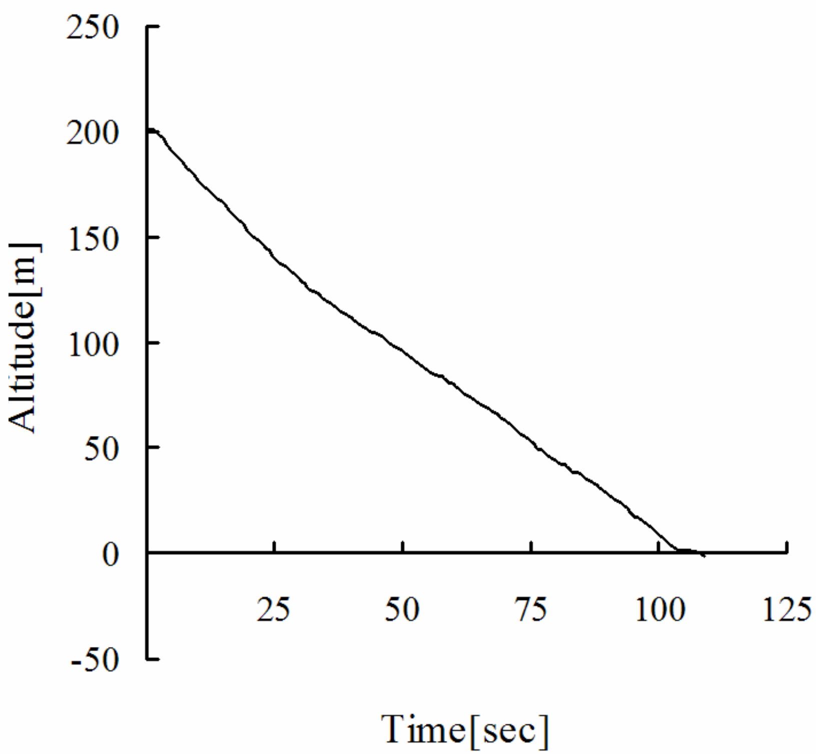


Figure 12. Altitude record

- Steady glide was attained.
- The UAV passed through the desired waypoints.

Results of the flight tests (movie)

Conclusions

Osaka Prefecture University

1. Lifting body aircraft was developed for landing flight phase.
2. The modeling of the dynamics was constructed from Wind tunnel experiments.
3. The robust controllers were designed, and gust responses were suppressed.
4. Navigation and guidance system was designed
5. Flight tests were carried out.

FUTURE WORKS

- Flight systems for several trim conditions are designed.
- The controllers per altitude are scheduled.
- The flight tests at higher altitude are performed.
- The other flight phases are challenged.