Development of a flying test bench using small UAVs

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


Experimental research of Landing Flight phase
1. Lifting body design
2. Controller design
3. Navigation and Guidance system design
Lifting body aircraft

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

Figure 1. Designed aircraft model
Aerodynamics forces were measured.

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

Figure 2. Wind tunnel experiments
Results of wind tunnel experiments

Maximum L/D is 4.58.
Pitching dynamics is statically stable.

Figure 3. Lift coefficient and Drag coefficient
Figure 4. Pitching moment coefficient
The linearized equations of motion were formulated. This gliding UAV was assumed to have a constant longitudinal forward velocity.

\[ \dot{x}_{\text{lon}} = A_{\text{lon}} x_{\text{lon}} + B_{\text{lon}} \delta_e \]

\[ x_{\text{lon}} = \begin{bmatrix} \alpha & q & \theta \end{bmatrix}^T \]

Longitudinal;

\[ \dot{x}_{\text{lat}} = A_{\text{lat}} x_{\text{lat}} + B_{\text{lat}} \delta_a \]

\[ x_{\text{lat}} = \begin{bmatrix} \beta & p & r & \phi \end{bmatrix}^T \]

Lateral-directional;

**Trim conditions;**

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

**Eigenvalues**

Longitudinal;

\[ \lambda_{sp} = -1.30 \pm 4.49i, \quad \lambda_{ph} = -0.66 \]

Lateral-directional;

\[ \lambda_{\text{roll}} = -4.03, \quad \lambda_{\text{Dutch roll}} = -0.92 \pm 7.83i \]

\[ \lambda_{\text{spiral}} = 0.73 \]

⇒ 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.

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

H-infinity controller was obtained. H-infinity norm of the transfer function from disturbances to controlled outputs was minimized.
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.
Longitudinal responses to gust disturbances were simulated.

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

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Altitude was 200m.

Launch

Waypoint tracking

Landing

Image of a blimp-like object launching from the ground, followed by waypoint tracking and landing.
Avionics

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Onboard
Rate gyro (3 axes)
Accelerometer (3 axes)

GPS

Geomagnetism sensor

Barometric altimeter

RC receiver

Wireless modem

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 (3 axes, onboard)
The heading was maintained to point to west. ⇒ Error of heading angle was controlled to zero.

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

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

Figure 10. Heading angle tracking
The UAV was controlled to track given waypoints.

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

Steady glide was attained.

The UAV passed through the desired waypoints.
Results of the flight tests (movie)
Conclusions

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.