Test Results of Guidance and Recovery
Using Rocket Recovery Demonstrator Vehicle

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Abstract

In order to build low cost rocket recovery technology, we developed recovery demonstrator using the ram-air parachute (paraglider type) which is one of the reuse technology of flyer. We show the results of test flight dropped from helicopter in Taiki-cho, Hokkaido in February, 2004.

ロケット回収実験機の誘導・回収実験結果

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摘要

低コストなロケット回収技術を構築するため、宇宙用飛翔体の再利用技术のひとつであるラムエアパラシュート（パラグライダータイプ）を用いたロケット回収実験機の開発を行った。2004年2月に実施したロケット回収実験機による誘導・回収実験結果について述べる。

1. INTRODUCTION

Rocket recovery technology is necessary to develop Air-breathing rocket engines in the near future. Paraglider recovery system is planned as one of the most simple, safety and mobile recovery system in the world. We planned the demonstration of the guidance with the paraglider.
2. OUTLINE

2.1 Recovery Demonstrator Vehicle

Fig. 2.1 shows the outline of the demonstrator vehicle. Total length is 3398mm, total weight is about 260kg, diameter of the body is 400mm. This demonstrator has IMU and GPS for attitude control and navigation and paraglider guidance. Four-tail-wing control system is installed for pitch, yaw and roll control, and two reel drive systems are used to control the paraglider control lines. FCU manages all of the modes and sequences and control and guidance system. Telecommunication receiver and antenna system are installed for emergency operations. In the back of the vehicle, there are a pilot chute, a drogue chute and a paraglider. Figure 2.1.2 shows a picture after airbag deployment. The airbag for cars deploys before landing to ease the body shock.

Fig. 2.1.1 Demonstrator vehicle outline           Fig. 2.1.2 Picture after airbag deployment

2.2 Paraglider

Fig. 2.2 shows the outline of the parachute. A pilot-chute and a drogue chute are pulled out after releasing the latch of the rear lid of the body, and a main-chute is pulled out next. The main-chute is paraglider type ram-air parachute. The body turns to horizontal attitude after main-chute deployment, and glide guidance can be started. Direction of the paraglider is controlled toward the right side or left side by pulling right or left control lines respectively, and altitude direction can be controlled by pulling both side of control lines. The control lines on each side is driven by the electric actuator, and electric actuators are operated by the commands from FCU.

Fig. 2.2 Outline of the parachute
2.3 Drop Test Flight Profile

Fig. 2.3 shows the flight test profile.

Step 1: Attitude control while suspended from helicopter
Step 2: Separation. Sequence start
Step 3: Deploy the pilot chute and drogue chute
Step 4: Deploy main chute (paraglider)
Step 5: Turn to horizontal attitude for paraglider reel control
Step 6: Guidance start
Step 7: Flare the paraglider at 60m altitude from ground
Step 8: Deploy the airbag for shock reduction

2.3.1 Attitude Control

We defined K system coordinates, which describe the straight line from planned dropped point towards target point as X-axis, the geodetic direction as Z-axis and the direction of a crossing range as Y-axis. We set origin at the target point. The independent gains are set as a direction angle error, a course angle error, and an altitude error and a crossing range error. All data through limiters linearly combined to generate guidance control commands.

3. CONTROL SYSTEMS

3.1 Tail Wings Control

This demonstrator has 4 control tail wings for pitch, yaw, and roll control before deployment of the parachute. After the separation from helicopter, flight sequence starts by separation signal. Fig. 3.1 shows control block diagram. This demonstrator glides from helicopter with this aerodynamic control system to maintain the appropriate attitude for the parachute deployment.

3.2 Paraglider Guidance Control

Fig. 3.2 shows outline of the paraglider guidance control.

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4. FLIGHT DATA

4.1 Flight Sequence

Fig. 4.1 shows results of the flight sequence. The parachute deployment sequence, the airbag ignition system sequence, the sequence of paraglider control, etc. were performed normally as planned in Fig. 2.3. Followings are the paraglider control operation, (1) control lines lock release operation, (2) issue of right and left control lines commands, and, (3) flare operation.

![Flight Sequence Diagram](image)

4.2 Trajectory during Flight

Fig. 4.2 shows the trajectory during flight. The condition during flight was the west wind at 20 m/s of velocity. The vehicle was dropped while the helicopter flies toward the direction of west-southwest about 40 m/s of airspeed in flight area. The drop point was changed about 600m closer to the target point than scheduled point because of head wind. Although it flew toward the negative direction of a down range after the main chute deployment and before the guidance control start, direction was changed into positive of a down range after the guidance control started. The vehicle altitude became 200m lower than the scheduled altitude while turning to positive direction, it ends up landing before about 700m from the target point. The flight trajectory turned to the direction to the target point, and guidance control worked correctly.

![Flight Trajectory Diagram](image)
4.3 Attitude History
Fig. 4.3 shows the attitude history. Attitude control to achieve 60-degree pitch target and 0-degree yaw and roll target after drop was performed normally.

4.4 Attitude Control Operation
Fig. 4.4 shows result of the attitude control. The elevator command, the rudder command and aileron command generated from altitude angle error and angular velocity were correctly divided into 4 angles of 4 tail wings.

Fig. 4.2 Trajectory during flight

Fig. 4.3 Attitude history

Fig. 4.4 Results of attitude control
4.5 Glide Guidance Control Operation

Fig. 4.5 shows result of the glide guidance control. Following four sections of glide guidance control operation was characterized.

Section □: The glide state with no control (during control line lock release operation after ram-air parachute deployment).
Section △: Turn operation with a short cycle.
Section □: Turn operation with a long cycle under a target altitude.
Section △: Control operation for stable flight.

![Fig. 4.5 Glide guidance control operation data]

5. CONCLUSION

This experiment gave us following advantages.
□. Attitude control operation by tail wings for parachute deployment attitude
□. Deployment of a parachute, and turning to horizontal attitude
□. Guidance control operation by the ram-air parachute
□. Validity of guidance control logic
□. Acquisition of flight data

By this experiment, the technology of a body mechanism, avionics and guidance software etc., required to build the rocket recovery system with paraglider, was obtained. From now on, the result obtained here is analyzed and formulization of the dynamics model of a ram-air parachute will be attained.

REFERENCES