TAIL-SITTER VTOL UAV
- FULL-SCALE HOVER PROTOTYPE SYSTEM -

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Abstract

A demonstration system featuring a full-scale prototype VTOL UAV (Vertical Take Off and Landing Unmanned Aerial Vehicle) was manufactured and hover flight tests were conducted. The vehicle is a 'tail-sitter' jet-propelled UAV, and the system is featured by three guidance and navigation (GN) modes; 1)DGPS-INS (Differential Global Positioning System-Inertial Navigation System), 2)Laser Survey Equipment and 3)Stereo-view Video Cameras.

Even if which GN sensor was used, it was proved that sufficient stability and control for hover flights were obtained. Moreover, it was demonstrated that launch and recovery were accurate and convenient.

1 Introduction

Accurate and convenient recovery is one of the subjects on UAV operations. To solve this problem, the idea of giving VTOL capability to a UAV and capturing it directly by a recovery apparatus seems somehow promising. The Third Research Center of the Technical Research and Development Institute, Japan Defense Agency, with Fuji Heavy Industries Ltd., has been working on this subject for years. A general view of this research program is described in another paper "TAIL-SITTER VTOL UAV – RESEARCH PROJECT OVERVIEW-".

Various methods have been devised in order to give VTOL capability to a jet-propelled aircraft. The 'tail-sitter', which hovers in a nose-up vertical attitude, is the promising type for jet-propelled small UAVs because of mechanical and structural simplicity. The demonstration system featuring this type of UAV was manufactured and hover flight tests were conducted between 1994 and 2000.

2 System Description

Fig. 1 shows the flight test demonstration system. The flight vehicle is tethered to the top of the crane by the rope in order to prevent the damage at the time of falling on the ground. However, since the rope is completely slack during the flight, forces which the vehicle receive from the rope are small, and there is little influence of control on the vehicle. Major equipments and subsystems are described below.

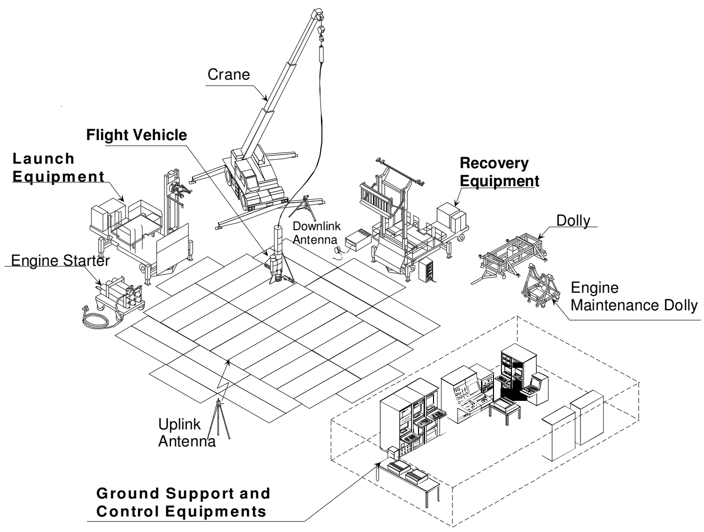

Fig. 1 Flight Test Demonstration System

2.1 Flight Vehicle

Fig. 2 shows the flight vehicle. It has a simple cylindrical fuselage and flat-plate wing and vertical tail sections since the system is intended only for hover flight. It is equipped with the turbo-jet engine which generates the thrust of 210kgf (with maximum bleed air-flow) in order to lift the vehicle with the mass of 200kg. The jet nozzle is the swivel nozzle using the ceramics bearing, and performs pitch and yaw attitude control according to thrust-vectoring (Fig. 3). The vehicle has RCS (Reaction Control System) valves on the both tips of the wing, and roll attitude control is performed using engine bleed-air.

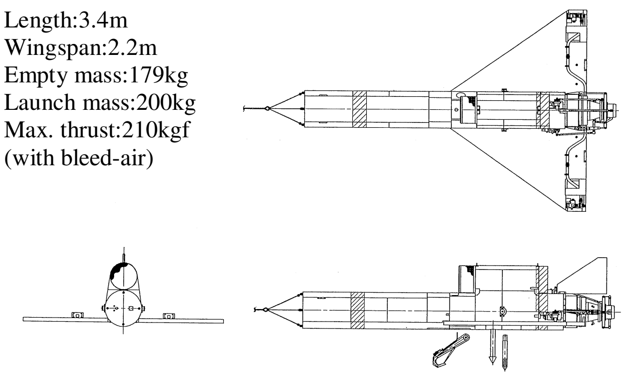

Fig. 2 Flight Vehicle

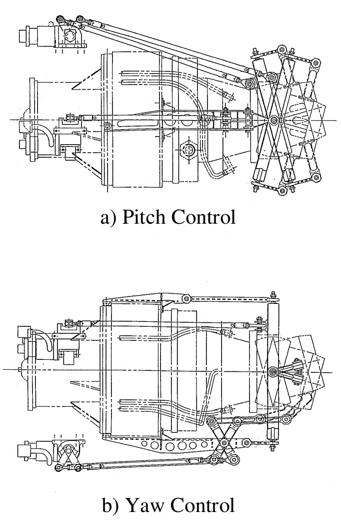

Fig. 3 Thrust-vectoring Mechanism

2.2 Launch Equipment

The launch equipment holds the vehicle by grasping near the center of gravity of the vehicle from the both sides of the fuselage. It has the 6-component balance which measures forces and moments of the vehicle. The engine starts, and the vehicle is released after checking the balance.

2.3 Recovery Equipment

Fig. 4 shows the recovery equipment which captures the vehicle in hover flight. Three types of capturing appliances are prepared.

a) Trap type: The optical sensors detect penetration of the probe attached on the vehicle, and the probe is restrained when the trap is closed.
b) Harp type: Many tensioned codes are arranged like a ‘harp’, and the probe attached on the vehicle is hooked in the codes.
c) Rope type: By swinging up the rope which spans across swinging arms, it hooks on the hook attached on the vehicle.

Details of three types of capturing appliances are described in another paper.

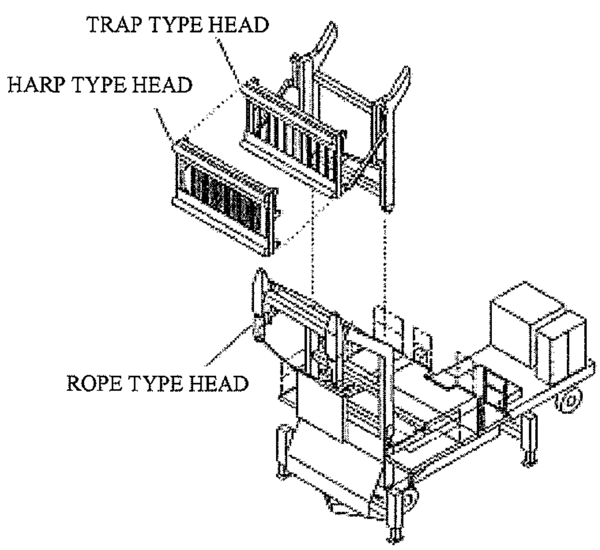

Fig. 4 Recovery Equipment

2.4 Guidance and Navigation System

Three modes of guidance and navigation are prepared.

a) DGPS-INS
b) Laser Survey Equipment for medium range
c) Stereo-view Video Cameras for short range

Fig. 5 shows the guidance and navigation system. The laser survey equipment on the ground tracks automatically the reflectors on the top of the vehicle fuselage, and the obtained position data is transmitted to the vehicle. The stereo-view video cameras are attached on the recovery equipment. The position of the colored mark on the fuselage is calculated by the principle of stereo-view from two sets of images, and the data is transmitted to the vehicle.

Guidance and navigation are performed using the precise position data based on the stereo-view video cameras when the vehicle is near the recovery equipment (short range navigation). The laser survey equipment is used in the wide range which is separated from the recovery equipment (medium range navigation). When the above methods cannot be used, position control is performed using DGPS-INS (independent navigation).

3 Physical Simulation

In advance of flight tests, the validity of flight control software was verified by performing the real-time physical simulation using some hardware of the system (hardware-in-the-loop simulation). The apparatus of the system used for the simulation are the flight control computer, the attitude sensor, the pitch control actuator, the taw control actuator, and RCS valves for roll control. Fig. 6 shows the block diagram outline of the simulation.

The simulation computer calculates engine performance, aerodynamic forces, and motion dynamics of the vehicle etc. Disturbance, such as gust, is also simulated. At this time, not only the aerodynamic forces loaded the surface outside the vehicle but the forces by the air-flow near the air intake of engine (ram drag) brings influence to the control. Moreover, the processing delays in each apparatus are also simulated.

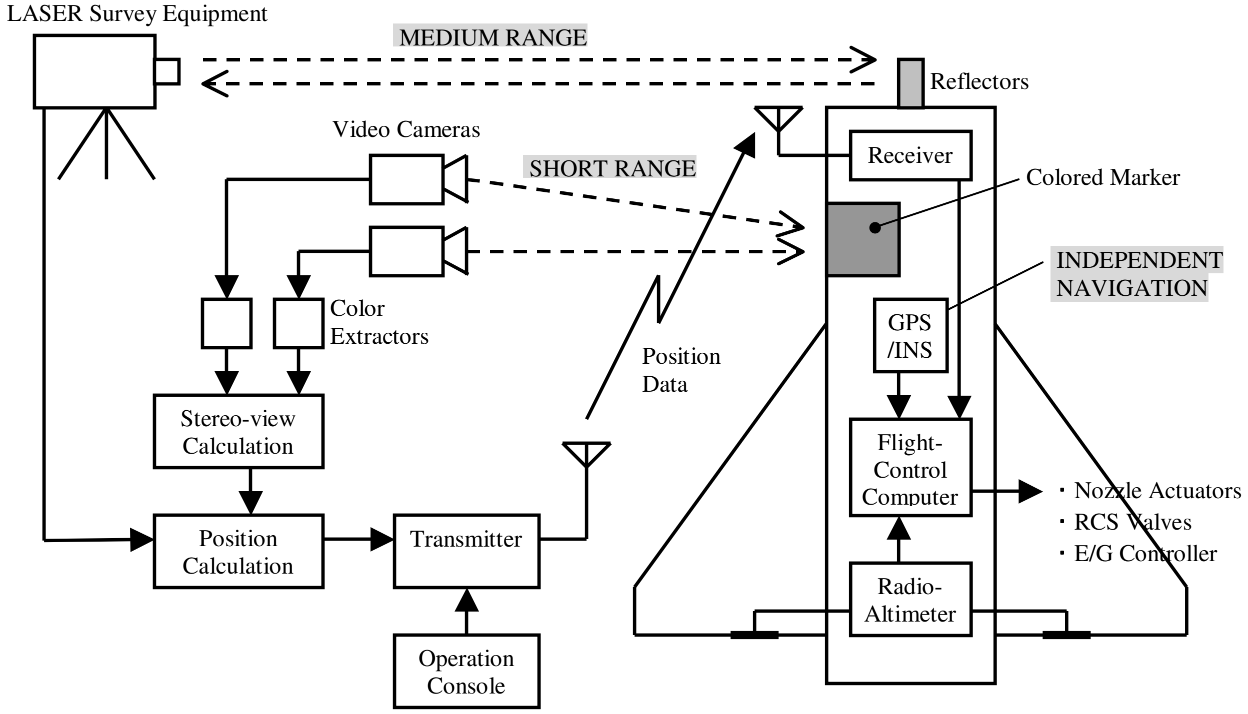

Fig. 5 Guidance and Navigation System

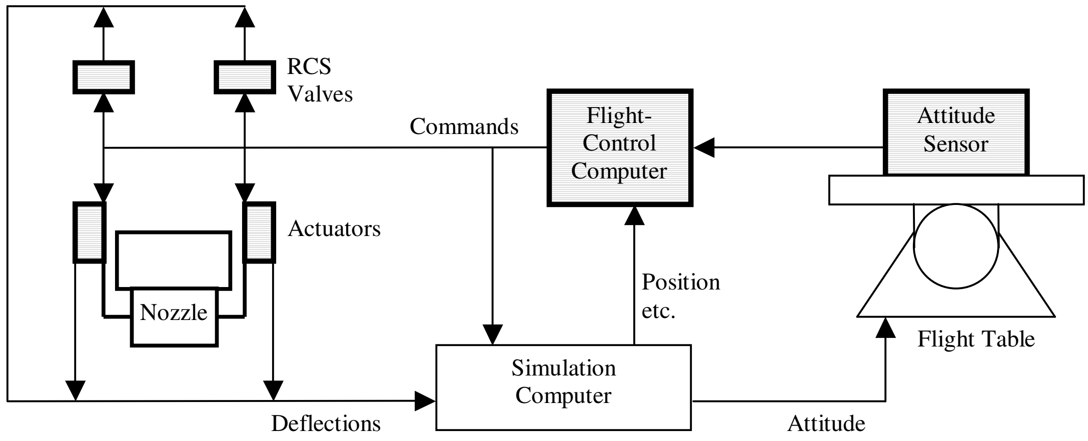

Fig. 6 Physical Simulation

4 Flight Tests

4.1 Phase One

The flight tests of launch, hover control and recovery using short range navigation by the stereo-view video cameras were conducted in 1996. The system which can perform the stable hover flight was completed solving minor problems. Moreover, all the three types of capturing appliances (trap type, harp type, rope type) succeeded in recovery. In these, the trap type recovered the vehicle most certainly because of little motion after capturing the vehicle.

4.2 Phase Two

In addition to short range navigation by the stereo-view video cameras, medium range navigation by the laser survey equipment and DGPS-INS navigation were added, and the flight tests of hover control were conducted in 2000. Trap type of capturing appliance was used for the recovery equipment. The controllability and maneuverability at hover were satisfying in every guidance and navigation mode, and the changes of each guidance and navigation mode were also performed smoothly. Moreover, it was proved that hover flight and recovery could be performed also in remarkable winds. The situation of the flight test is shown in Fig. 7.

5 Conclusions

The full-scale prototype system proved the stability and controllability at hover flight about tail-sitter jet-propelled VTOL UAV. As for guidance and navigation, it was proved that each of DGPS-INS, laser surveys, and stereo-view video cameras fully functioned. And it was shown that it is effective to use suitable guidance and navigation mode appropriately according to the range from the recovery equipment. Moreover, it was proved that recovery of VTOL UAV is performed certainly and easily.

Fig. 7 Flight Test