ICAS 2016

30th Congress of the International Council
of the Aeronautical Sciences
DCC, Daejeon, Korea ; September 25-30, 2016

LAND-BASED FLIGHT TEST FOR SHIPBOARD LANDING OF TILT ROTOR UAV

**Chang-Sun Yoo*, Eun-Young Jang*, Bok-Sub Song*, Am Cho*, Bun-Jin Park*,
Yu-Shin Kim*, Young-Shin Kang*, Sam-Ok Koo***
*Korea Aerospace Research Institute

Keywords: Tilt rotor UAV, shipboard landing, flight simulation, vertical take-off and landing

Abstract

Tilt Rotor UAV of KARI that has been developed for land operation, is going to expand its mission to oceanic operation with shipboard takeoff and landing. In oceanic operation, UAV suffers from severe conditions such as salty, windy and moist, etc. The landing point is also not stationary with ship movement by sea wave and is located under air wake, which make the landing of UAV difficult. Therefore the oceanic operation of tilt rotor UAV has to be analyzed and evaluated through simulation and test under each condition – ship movement from sea wave, non-uniform wind due to air wake, etc. KARI has conducted the modelling and simulation of ship movement from sea wave and analyzed the effect of air wake at approach and landing of UAV. This paper introduces the configuration of UAV systems for flight test and gives the flight test result for shipboard landing with ship operation environment on the land

1 Introduction

Tilt rotor UAV of KARI has models of TR-100, TR-60, and TR-40, which have each overall length of 5m, 3m, and 2m and each successful flight in 2012, 2013, and 2007. Now TR-60 has maximum take-off weight 200kg, payload 30kg, and endurance 6 hours and maximum speed 250km/h and aims to be for oceanic operation research of UAV. In order to be operated in ocean, TR-60 has been revised to TR-60M, which has a skid type of landing gear, a precise relative navigation and data link with tracking antenna and stabilized system for shipboard landing. In oceanic environment, UAV has to suffer from much severer conditions than the one on the ground because of small landing area, non-uniform wind and moving landing point, etc. Furthermore the UAV system is exposed to the salty and moist environment and must be protected from the infiltration. In order to overcome the severe environment in ocean, KARI has developed the flight simulator for the environment of UAV oceanic operation, which is able to be used for its analysis and evaluation prior to actual flight. In the previous study, the modeling of ship dynamics has been studied and integrated into simulation environment. Especially, the effects of sea wave according to sea state has been modelled and the approach and shipboard landing of tilt rotor UAV has been evaluated through simulation [1] [2]. Actually the ship is exposed to the effect of gust, turbulence, air wake on the superstructure of ship as well as the maneuver of ship from wind and sea wave. As the air wake on the shipboard affects the flying quality, the superstructure on the ship is designed to mitigate the generation of air wake in the construction of ship [3]. In order to analyze and predict the effect of air wake, the air wake modeling for a ship superstructure of 2,400ton displacement has been conducted and added to aircraft simulation model and evaluated through integrated simulation of ship and tilt rotor UAV [4].

This paper introduces the configuration of TR-60M systems that consists of aircraft, RTK-GPS/INS system, data link, and ground control system and finally gives the flight test result for shipboard approach and automatic landing on the land prior to ship operation, in which the performance of position control for shipboard automatic landing is shown.

CHANG-SUN YOO, EUN-YOUNG JANG, BOK-SUB SONG, AM CHO, BUM-JIN PARK, YU-SHIN KIM, YOUNG-SHIN KANG, SAM-OK KOO

2 System Configuration

2.1 TR-60M Aircraft

TR-60M is the tilt rotor UAV for oceanic operation as a derivative of TR-60, which also has overall length 3m, maximum speed 250kph, and endurance 6hr like Fig. 1. For oceanic operation, it has the skid type of landing gear replaced for 3 wheels type of one and has dual type of data link with C/UHF frequency, so that may enhance the reliability of control and command communication. In order to land on the shipboard, the relative precision navigation system based on the RTK-GPS/INS is used.

Table. 1 Specification of TR-60M

	Specification
Overall length (m)	3
Max. speed (km/h)	250
Endurance (hr)	6
Payload (kg)	30

Fig. 1. The Configuration of TR-60M UAV

2.2 RTK-GPS/INS System

RTK-GPS/INS system provides relative navigation based on the carrier phase of GPS signals and consists of the ground reference system and the onboard system shown in Fig. 2. The ground system is located on the shipboard landing deck with inertia navigation system and extracts the error information of GPS signal and transmits it to the onboard system by 10Hz. In the onboard system, the precise navigation is obtained by excluding the GPS signal errors with errors information received from the ground system. On the ship deck, it's not easy to conduct the initial alignment of inertia navigation system because there is the ship movement and it's not available of

magnetometer. In order to solve the problem of initial alignment, the dual GPS antennas are used each on the ground and the onboard system. The initial alignment of the inertial navigation system is calculated with the pitch and heading information from two GPS antennas. The positioning errors may happen due to the time delay on the data link from movement of ship and aircraft. Through calibrating the time delay errors with the velocity information, the relative navigation accuracy was obtained by 2.3cm.
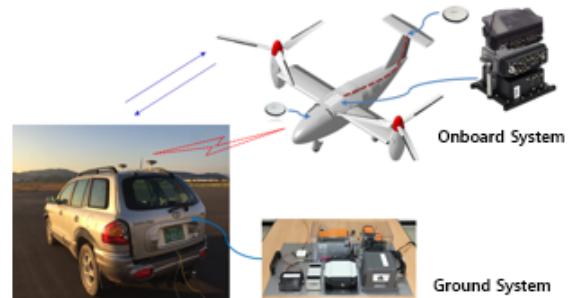

Fig. 2. The Configuration of RTK-GPS/INS

2.3 Data Link

Data link system consists of the dual frequency ground and onboard system of C and UHF band in order to enhance the reliability of communication. The C band frequency is used as the primary communication system and the UHF as the secondary system. The tracking antenna on the ground is also used for tracking the aircraft during communication. The communication range is near to 50km and was evaluated through the flight test of the light aircraft with onboard system like Fig.3, which took off on the runway of Goheung Aeronautical Center and flew to 50km distance south-western from the center and confirmed the data link active at the distance.

Fig. 3. The Data Link System and Test

2.4 Ground Control System

Ground control system (GCS) for TR-60M was developed to be compatible to oceanic operation of aircraft. With the transportation and infiltration considered, the GCS system is based on the portable and rugged system like Fig.4. In order to implement the shipboard landing, the operation mode based on RTK-GPS/INS relative navigation was added and the operation mode for dual data link of C/UHF band frequency was also implemented.
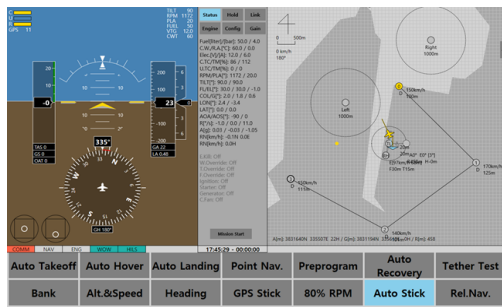
(a) The View of Ground Control System

(b) The Portable and Rugged System

Fig. 4. The Ground Control System

3 Flight Test

3.1 Flight Operational Procedure

Through checking the operation status of critical flight control system by HILS, the TR-60M system was confirmed to be operate normally. In order to perform the flight test, the operational procedure of TR-60M is planned, which consists of automatic take-off, hovering, mission flight, return to take-off point, offset hovering, hovering, and automatic landing. The offset hovering is the flight mode that the TR-60M follows up the ship with the same speed as the ship at the designated altitude and positions

before moving to the hovering position on the ship deck. For example, the offset hovering point may be located at the left and right alongside, or straight rear side like Fig.5.
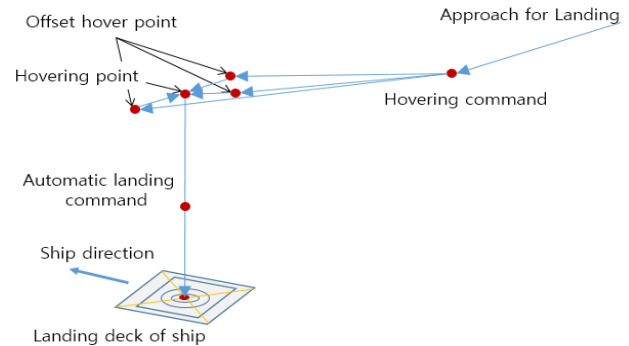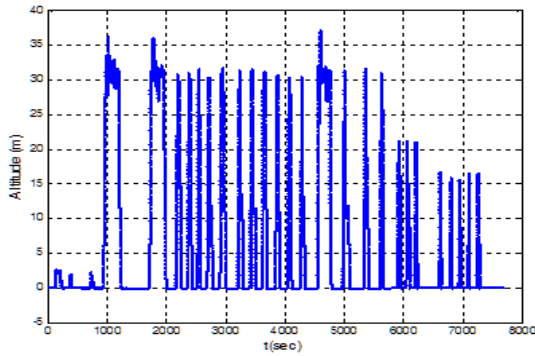

Fig. 5. The Shipboard Landing Procedure
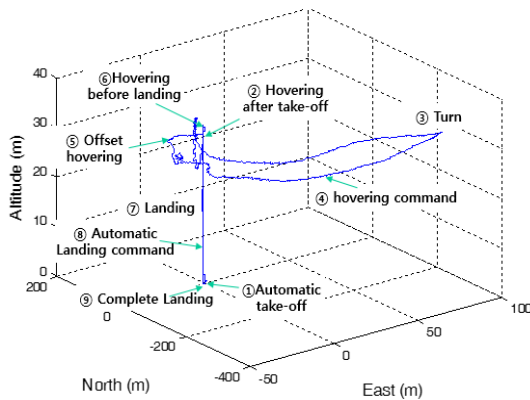
3.2 Flight Test

Flight test was conducted under the weather condition of wind speed 1.5~5m/sec, visibility range 2,000m, and temperature 9.1°C. The RTK-GPS/INS navigation system was used for the precise relative positioning of aircraft. At the take-off, the take-off point was set as origin (0, 0) in the RTK-GPS/INS system. The aircraft is guided and controlled to land again to this point after mission flight according to the flight operational procedure like Fig.6. The 25 times of flight test for the shipboard automatic landing was performed and the aircraft position after landing was compared to the origin point in order to evaluate the performance of position control at the landing. The result of flight test showed that the position errors was 0.96m CEP like Fig.7. It is acceptable for the shipboard landing, comparing that the size of harpoon grid is ϕ2.75m [5].
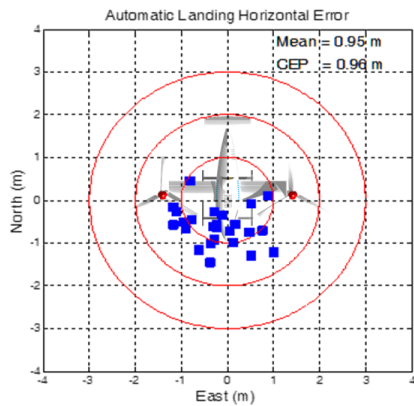

Fig. 6. The Land-based Shipboard Landing

CHANG-SUN YOO, EUN-YOUNG JANG, BOK-SUB SONG, AM CHO, BUM-JIN PARK, YU-SHIN KIM, YOUNG-SHIN KANG, SAM-OK KOO

(a) The Trial of Shipboard Landing Flight

(b) The Flight Operational Procedure

(c) The Performance of Shipboard Automatic Landing

Fig. 7. The Result of Shipboard Landing Flight Test

4 Conclusion

TR-60M, the tilt rotor UAV, has developed by KARI for oceanic operation as a derivative of TR-60, which has the skid type of landing gear, the dual type of data link with C/UHF frequency and RTK-GPS/INS relative precise navigation system. In oceanic environment, UAV has to suffer from much severer conditions than the one on the ground. The UAV system is exposed to the salty and moist environment and must be protected from the infiltration. In order to overcome the severe environment in ocean, KARI has performed the HILS and the land-based flight test for shipboard landing in order to evaluate a variety of oceanic operation of TR-60M according to the approach and automatic landing operational procedure. The result of the flight test showed that the positioning errors at automatic landing were 0.96m CEP bounded with maximum radius 1.58m and were acceptable with the success of 22 times of 25 times when comparing the condition of landing within harpoon grid of ϕ2.75m.

References

[1] Yoo C. S., Cho A., Park B. J., Kang Y. S. Sea wave modeling and shipboard landing simulation of tilt rotor unmanned aerial vehicle, *Proc of the International Conference on Control, Automation and Systems*,Gwangju, 2013

[2] Yoo C. S., Cho A., Park B. J., Kang Y. S. Sea Wave Modeling Analysis and Simulation for Shipboard Landing of Tilt Rotor Unmanned Aerial Vehicle, *J. of the Korean Society for Aeronautical and Space Science*, Vol. 42, No. 9, pp 731-738, 2014

[3] Hodge S. J., Forrest J. S., Padfield G. D., Owen I. Simulating the environment at the helicopter-ship dynamic interface: research, development and application, *The Aeronautical Journal*, Vol.116, No. 1185, pp 1155 - 1184, 2012.

[4] Yoo C.S., Lee C. H., Park B. J., Cho A., Kang Y. S. Wake Modeling and Simulation of Tilt Rotor UAV Shipboard Landing, *Proc. of the International Conference on Control, Automation and Systems*, Gyeonggi-do, 2014

[5] Doucet J. A., Shipborne Helicopter Harpoon/Grid Rapid Securing System, *Standardization Agreement*, 1981

Copyright Statement