Research Paper

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Development of Fluidics for Driving and Steering Unit of Orchard Sprinkler Boat*

— Drag Coefficient of the Boat and Fluidics Thrust —

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Abstract

Small boat with no screw or rudder has been used for showering the canopies of orchards in Thailand. During the showering operation, the boat moves forward by a reaction force of two flat nozzles used for showering. This study discusses the drag coefficient of the boat and the feasibility of using fluidics as a driving and steering unit of the boat in place of conventional flat nozzles. A one-fifth scale model of the boat and a fluidics were built to determine its drag coefficient, the thrust imparted by the fluidics and boat traveling speed. The drag coefficient of the model was found to be inversely proportional to the Froude number and effective in predicting the traveling speed of a boat.

[Keywords] fluidics, Coanda effect, boat, nozzle, thrust, model test, drag, drag coefficient

I Introduction

1. Background

The Kingdom of Thailand has developed its irrigation network and fluvial system by excavating numerous canals in The Central Plains for more than 120 years. The canals fed by the Chaophraya River are used to irrigate paddy fields (Asawai, 1987). In recent years, most of the paddy fields have been converted to orchard farming areas, which continue to increase annually, because conventional littoral orchards were damaged by seawater, and the farmers found orchard farming more profitable than rice culture. A general view of such orchard farming is shown in Fig. 1. The level of underground water in this area is high; consequently, farmers need to convert their flat paddy fields into high banks on which to plant trees, by excavating numerous small parallel channels where underground and irrigation water collects. The banks of an average height and width of 1.2 m and 3.8 m, respectively, are spaced at intervals of 7.0 m to one another. The water in the channels is stagnant, without currents and approximately 0.4 m deep. A typical orchard has 16 to 20 banks, each 400 to 800 m long, where citrus, guava, papaya trees, oil palms, and such are planted.

Despite the presence of water in the channels adjacent to these banks, farmers have to shower water on the tree canopies because of the shallow tree roots and the high diurnal temperatures. Agricultural substances generally used for the trees result in chemical residues in the channels. Generally, the farmers use a small boat, as shown in Fig. 2, to shower the tree canopies, usually twice a day, at a water flow rate of approximately 12×10^{-3} m^3/s.

Fig. 1 An orchard on the banks and a sprinkler boat

The small boat, hereby referred to as "sprinkler boat", is equipped with a showering and driving device comprising a centrifugal pump and two fan-shaped flat nozzles mounted on

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a Y-shaped water-discharging pipe. The boat is not equipped with conventional thrusting devices such as screws. The angle of the flat nozzles to the horizon and to the centerline of the boat is 45 degrees. The height of the flat nozzles from the outlet of the centrifugal pump is 600 mm. The pump, connected directly to a 3.0 to 5.0 kW-gasoline engine, draws water through a strainer installed at the bottom of the boat. The sprinkler boat, usually made of welded stainless steel plates, is approximately 1.8 m long and 0.8 m wide. While showering water, the farmer has to be on board to steer the boat which is propelled forward by only the thrust imparted by the water jet from the flat nozzles that direct the water to the tree canopies. For large-scale orchard farming, the showering may take more than two hours. (Marnadee and Horio, 2002).

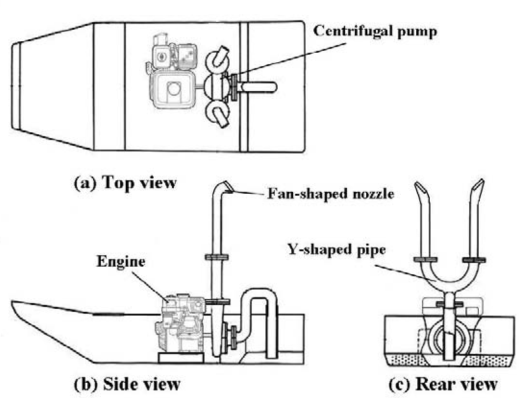

Fig. 2 Schema of typical sprinkler boat

2. Objective

The objective of this study is to develop an unmanned driving and steering device for the boat to save human labor and, in particular, to protect the farmer during the showering operation from exposure to agricultural chemical residues contained in the channels. A fluidics, a fluid element that operates fluid jets without the use of moving mechanical parts, is fabricated and installed at the bottom of the boat both as a driving and a steering device. Due to its simple construction, fluidics is almost maintenance-free and operable under severe environmental conditions. In this study, the test on a model was conducted to determine total drag on and the drag coefficient of the boat during its forward travel. Moreover, the model boat equipped with a fluidics was used to determine the thrust imparted by the fluidics and to measure the traveling speed of the boat.

II Theoretical Considerations

1. Fluid resistance

A boat is a body moving in two different fluids: water (the submerged portion below the waterline) and air (the portion above the waterline). Consequently, while moving forward, the boat experiences drag from both fluids. In this study, the aerial drag is disregarded, and the boat is considered a semi-submerged body moving in water; consequently, the drag on the boat is calculated by the following equation:

$$D = C_D \cdot \frac{1}{2} \rho v^2 S \qquad (1)$$

where D is the total drag; ρ the density of water; v the mean velocity of the boat relative to the water; and S the total area of the stationary boat below the waterline. C_D, a dimensionless constant of proportionality called “apparent drag coefficient”, is measured for a given set of geometric and hydraulic conditions. Generally, the drag on the boat consists mainly of frictional drag and wave-making drag from the water, which make up the main proportion of total drag that is calculated by the product of dynamic pressure and the area of the boat below the waterline (Kunikiyo, 2006). Nonetheless, the total drag on the boat comprises complicated drags and is related to the total submerged area of the boat (Yamagata, 1984). In evaluating the resistance on the boat, generally its total submerged area, more than the projected submerged area, is used as one of the parameters. (Kodama, 2001; Hayashita *et al.*, 2002). The application of typical values for the steady motion of a submerged body in infinitely large volumes of fluid, as stated in most textbooks on fluid mechanics (e.g., Yunus and John, 2006) may not be quantitatively valid in this case for several reasons: a free surface interacting with both the flow and the boat, the influence from Karman’s vortex and the roughness of the boat skin. Moreover, the configuration of the boat used here is unique in that the aspect ratio (length-to-width ratio) is kept small to facilitate turning at the end of each bank, thus necessitating the determination of the apparent drag coefficient experimentally. From Eq. (1), when drag D is measured directly, the apparent drag coefficient of the boat is calculated by the following equation:

$$C_D = \frac{2D}{\rho v^2 S} \qquad (2)$$

2. Thrust generated by fluidics

The configuration of the fluidics installed on the boat and used in this experiment is shown in Fig. 4. The working fluid (in this case, water) is impelled into the inlet port and accelerated at the main nozzle of the fluidics. Both control ports on either side are open to the atmosphere. While the boat so equipped is stationary, the forward thrust associated with the water jet discharged from the nozzle of the fluidics is determined by

$$T = \rho a u^2 \qquad (3)$$

where T is the thrust; a and u denote cross-sectional area of the nozzle of fluidics and the velocity of main jet,