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Determining the drag coefficient of a cylinder perpendicular to water flow by numerical simulation and field measurement

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ABSTRACT

This study aimed to improve the estimation of the cylinder drag coefficient, and its accuracy for fishing gears. Five surveys on tuna longline fishing grounds were conducted between 2005 and 2010. Collected data include three dimensional current velocities in different water layers and hook depth. Hook depths were calculated by drag coefficients of the cylinder with a perpendicular flow (C_{N90}) of 1.04 to 1.40 (interval of 0.02), and compared with measured depths. The coefficient of variation (*CV*) was calculated for 70% of the hooks at their measured depths. Additionally, a *t*-test was conducted comparing depths predicted by the model against measured depths of the remaining sites, totaling 30%. The results showed that the hydrodynamic forces on longline gear have a C_{N90} between 1.08 and 1.16, and the drag coefficient decreased with increasing Reynolds number (*Re*, $Re < 10^3$). These results suggest that numerical modeling and at-sea measurement can be used to determine the drag coefficient (C_{N90}) of cylinders such as ropes and lines, and that a drag coefficient of 1.08 to 1.16 are reasonable values for cylinder components of longlines.

1. Introduction

The principle of fluid mechanics has been widely used to study hydrodynamic forces of fishing gear in flowing water. Fishing gear designed on the basis of the fluid mechanics principle can not only guarantee the least resistance, but also ensure a minimum of gear distortion. In addition, codend selectivity is most likely affected by the hydrodynamic, behavioral, and mechanical characteristics of netting and twine (Walsh et al., 2002). The geometry, or dynamic behavior, of the codend is closely related to hydrodynamic drag, tension, and energy efficiency (O'Neill et al., 2003; Priour, 2009; Kim, 2013). Fishing efficiency and gear selectivity can be improved with a better understanding of the hydrodynamic behavior of fishing gear (Lee et al., 2005). Therefore, hydrodynamic analysis is an important component of fishing gear design. Many fishing gears made of netting and ropes can be considered as a cylinder, or an aggregation of cylinders. In recent years, finite element analysis has been widely adopted in the mechanical calculations of fishing gear. Additionally, the cylinder drag coefficient has often been used in the hydrodynamic calculation of fishing gears (She, 1994; Takagi et al., 2002; Suzuki et al., 2003; Takagi et al., 2004; Yuan, 2008; Song, 2008; Song et al., 2011).

The drag coefficient of a cylinder is mainly affected by liquid viscosity, object size, velocity and a corresponding Reynolds number (*Re*). Many methods have been used to determine the drag coefficient of a cylinder, including fishing gear model tests (Hoerner, 1965; Fridman, 1986; Lam et al., 2003) and numerical simulation (Juncu, 2007; Faruquee et al., 2007; Lam et al., 2008; Mahír and Alta, 2008). Hoerner (1965) and Fridman (1986) used the model experimental method to study the drag and lift coefficient of a cylinder. These studies determined the variation rule of a cylinder's drag and lift coefficient, and the pressure distribution around the cylinder. Lam et al. (2003) measured hydrodynamic characteristics of a four-cylinder square structure in a wind tunnel at critical *Re*. The authors adjusted the distances among the four cylinders and the angles of attack, measuring the variation of drag coefficient and other parameters using the rule of fluid mechanics, a numerical method employing the Navier–Stokes (NS) equations and/or the continuity equation of flow to analyze the hydrodynamic characteristics of the cylinder. Lam et al.

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(2008) applied the immersed-boundary method to describe the hydrodynamic forces of the cylinder and surrounding fluid in low *Re* ($50 \le Re \le 160$). Juncu (2007) used the NS equations to analyze the hydrodynamic characteristics of two cylinders in tandem arrangements, and suggested that there was interference between the two different cylinders in the same condition and the differences widened with the increasing *Re*. Faruquee et al. (2007) used both the continuous and NS equations to study the effects of axis ratio on the elliptical cylinder hydrodynamic characteristics. By adjusting the length of the axis ratio and other parameters, the variations of elliptical cylinder drag and lift coefficient were obtained. Mahír and Alta (2008) used FLUENT software (being capable of handling unsteady NS and energy equations using a finite volume method in two and three dimensional geometries) to analyze the energy transfer of two cylinders in tandem arrangements and in an unsteady flow. The variation of cylinder drag coefficient in low *Re* (less than 200) was found.

In this study, finite element analysis was used to develop a three dimensional numerical longline model (Yuan, 2008; Song, 2008; Song et al., 2011) on the basis of longline trial data from 2005 to 2010. The collected data include: gear parameters, three dimensional current velocity in different water layers, and hook depth. By adjusting the values of drag coefficient of flow perpendicular to a cylinder (C_{N90}), multiple sets of longline hook depth data were obtained. Calculated hook depths were compared with TDR measured depths to determine the values of C_{N90}. This study may serve as a reference for the measurement of C_{N90} in the future and for the improvement of drag calculation accuracy for longlines, trawls, purse-seines, and other fishing gears or their components.

2. Materials and methods

2.1. Fishing vessels and fishing grounds

Data were collected from operations on tuna longliners: Huayuanyu No. 18 (2005), Yuyuanyu No. 168 (2006), Xinshiji No. 86 (2008), Shenliancheng No. 719 (2009), and Shenliancheng No. 901 (2010). Vessel parameters, survey duration, number of sites, and areas are described in Table 1, Fig. 1.

2.2. Fishing gear and operations

The same fishing gear was used in 2005 and 2006. Configurations of float, float line, mainline, and hook from 2005 to 2010 fishing trials are shown in Table 2. The first section of branch line was made of polypropylene, and in 2005 and 2006, *t* was 1 m, and had a 3 mm diameter. In 2008, the branch line was 2 m and had a 4 mm diameter. 2009's was 1.5 m, with a 3 mm diameter. In 2010, was 1.5 m and had a 3.5 mm diameter. The second section was made of nylon monofilament and in 2005 and 2006 was 16 m with a 1.8 mm diameter. In 2008, it was 23 m with a 2.5 mm diameter. In 2009 and 2010 it was 18 m long with a 1.8 mm diameter. The third section was stainless steel wire, and in 2005 and 2006, 0.5 m and a 1.2 mm diameter. In 2008, the third section was made of nylon monofilament, 17 m with a 1.8 mm diameter. For 2009 and 2010, the third section was again stainless steel wire, 0.5 m, and had a 1.2 mm diameter. The operational characteristics from 2005 to 2010 fishing trials are shown in Table 3. The configurations and designs of fishing gear were indicated in Song (2008) and Song et al. (2011).

2.3. Data collection

Hook depths were measured and recorded by Temperature Depth Recorder (TDR 2050, RBR Co., Ottawa, Canada). The parts of the gear measured by TDRs were different from year to year or set to set. While deploying the longline, TDRs were attached to connecting points between the mainline and the branch line for various branch lines. In the end, the depth of every hook position was measured by these TDRs (Song et al., 2012). The depth measurement error of TDRs was within $\pm 0.05\%$ in depths of 10–740 m. The three dimensional (3D) current (East/North/Up) at different depths (50 m each, Song et al., 2012) was measured by Acoustic Doppler Current Profilers (ADCP, Aquadopp, NORTECK Co., Vangkroken, Norway), with measurement error within ± 0.005 m/s. For accuracy concerns from the various instruments and requirements of the study, the depth data were rounded to one decimal place, and 3D current data to three decimal places.

The following data were also collected: deployment position and time, duration of retrieving lines, number of hooks, vessel speed, time interval between two hooks, number of hooks between two floats (Table 3).

2.4. Numerical mechanical model of longline fishing gear

Sea trial data obtained from 2005 to 2010, including the fishing gear parameters (diameter of mainline, total weight of branch line and bait in water, density of mainline, elastic modulus of mainline, and length of float rope, etc.), operation parameters (vessel speed, line shooter speed, time interval between two hooks, angle of attack, etc.) and 3D current data. The data were input into the three dimensional numerical longline model (3DNLM), developed by the principles of static mechanical and finite element analysis

Table 1
The vessels' parameters, survey duration, number of sites, and areas.

Vessel's name	Vessels' parameters						Duration	Number of sites	Area
	Gross tonnage (t)	Net tonnage (t)	Length over all (m)	Width (m)	Registered depth (m)	Engine power (kW)			
Huayuanyu No. 18	150.0	45.0	29.98	6.05	2.70	220.00	2005.09.15–12.12	48	0°28′N–9°02′N 62°01′E–70°14′E
Yuyuanyu No. 168	125.0	44.0	25.68	6.00	2.98	318.90	2006.10.01–11.30	36	3°07′S–4°07′N 62°12′E–71°15′E
Xinshiji No. 86	497.0	228.0	56.40	8.70	3.75	882.00	2008.09.22–2009.01.02	24	10°33′S–02°40′S 61°00′E–68°40′E
Shenliancheng No. 719	97.0	34.0	32.28	5.70	2.60	220.00	2009.10.04–12.25	40	1°01′S–5°01′N 169°52′E–176°42′E
Shenliancheng No. 901	102.0	30.0	26.80	5.20	2.20	400.00	2010.11.20–2011.01.20	40	00°42′N– 03°34′N 169°00′E–175°00′E