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Determining the leeway drift characteristics of tropical Pacific island craft

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ABSTRACT

An accurate understanding of the leeway drift characteristics of drifting objects is required to effectively forecast the drift of persons, vessels or objects lost at sea, and to generate efficient search areas to maximise the probability of successfully locating those missing. Presently, the most effective method for calculating the leeway drift characteristics of an object or vessel is to empirically derive the leeway coefficients of that object through field studies. The main goal of the studies is to measure how the object drifts in relation to the surface currents, due to the wind and wave action upon it. This paper outlines the determination of downwind and crosswind leeway coefficients for three small craft common to Pacific island communities for which no accurate leeway coefficients exist. These craft were: a 19 foot (5.8 m) fibreglass skiff (known locally as pangas, fibres, or banana boats); a 20 foot (5.97 m) fibreglass outrigger canoe; and a 2-person sit down personal water craft (PWC). Due to the vast distances between pacific islands and the remoteness of these locations it can be several days until a search can be mounted to rescue those lost at sea, hence it is paramount that an accurate description of the drift of these tropical pacific craft is available for use in search and rescue (SAR) drift models, to define appropriate search areas. This study successfully derived the leeway coefficients required for each of these three craft. The leeway speed of the outrigger canoe and PWC, both with one person on board (POB) equivalent loading, were calculated to be 2.40% and 4.24% of the wind speed respectively. The leeway speed of the skiff was found to range between 7.71% and 4.40% of the wind speed for equivalent loading between 1 POB and 13 POB.

The results of these field tests have subsequently been implemented into search and rescue models by several SAR organisations worldwide. These results show that the findings herein have the potential to both increase the likelihood of finding persons adrift at sea alive, as well as reducing search costs through more effective drift prediction and efficient search area formulation.

1. Introduction

Several key elements are required to successfully predict the drift of a person or object at sea; these include search and rescue (SAR) drift forecast models, input wind and current forecast data and the drift object's leeway drift coefficients. Maritime search and rescue (SAR) drift forecast models are used to numerically model the drift of an object at sea; however these models are only as effective as the input data provided. Both accurate external forcing data (winds and currents) and a well-defined representation of how the object may drift due to the external forces upon it are essential model inputs. The forces acting upon a drift object include those from wind, waves and currents. Prior studies have shown that the drift of an object due to wave action (forcing) only becomes significant once the drift objects have a length scale greater than that of the wavelength [1], and as the drift objects investigated herein have a length less than the wavelength, effects due to wave forcing may be disregarded. Wind and current forcing may be provided through a number of means, including near real time observations and more commonly, numerical forecast models. As the object drifts with the currents, it is exposed to the effects of the wind and waves. The combined effect upon the drift of an object due to wind and waves is described as the "leeway" of the object.

The leeway of an object varies from object to object and therefore a new set of leeway coefficients is required for each drift object to accurately determine their leeway drift characteristics. Without the correct leeway coefficients, it is impossible to accurately forecast how that object may drift. Leeway field tests are currently the most

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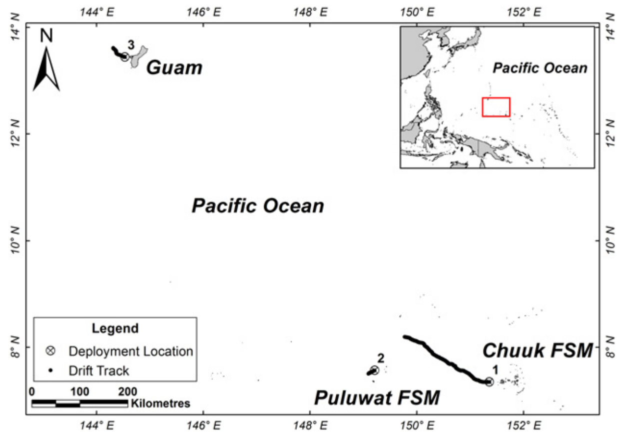

Fig. 1. Location map showing the tracks of the leeway drift objects at the three locations studied; Chuuk (FSM), Puluwat (FSM) and Guam.

common and most accurate method for determining the leeway coefficients of a drift object. A standard approach to the leeway field tests is outlined by Breivik et al. [2]. The leeway study was carried out at three locations within the tropical North Pacific Ocean during the months of May and June 2012 (refer to Fig. 1). The initial 5-day drift of the skiffs (and multiple single-day drifts of the PWC and outrigger canoe) commenced approximately 15 km off the western coast of Chuuk Lagoon in the Federated States of Micronesia (FSM). The next study location (one single-day drift of all craft) took place approximately 20 km to the north of Puluwat Atoll (westernmost land features of Chuuk State, FSM). The final study (single-day, all craft) took place approximately 10 km to the west of Apra Harbour, Guam. All drifts were undertaken in deep water where the dominant current forcing was attributable to the westward flowing North Equatorial Current (NEC).

The total drift of an object at sea can be summarised by the three equations below (adapted from Hackett et al. [3]). Eq. (1) shows that the total drift is a summation of the drift due to currents (relative to the earth) plus the drift due to leeway (slip relative to the ambient currents). The drift due to currents is a result of the combination of surface currents (derived from Ekman drift, baroclinic motion, tidal currents and inertial currents), as well as drift due to wave induced currents or Stokes drift (Eq. (2)). Leeway drift is the sum of the drift due to the winds acting on the object plus the drift due to the wave forces acting on the object (Eq. (3)).

$$D_T = D_C + D_L \tag{1}$$

where D_T = total object drift; D_C = drift due to current forces (relative to the earth); D_L = drift due to leeway (relative to the currents).

And

$$D_C = D_{Sc} + D_{Sd} \tag{2}$$

where D_C = drift due to currents; D_{Sc} = drift due to surface currents; D_{Sd} = drift due to Stokes drift.

And

$$D_L = D_{Wi} + D_{Wa} \tag{3}$$

where D_L = drift due to leeway; D_{Wi} = drift due to wind forces; D_{Wa} = drift due to wave forces.

The effect of Stokes drift may be present for the drift of an object on the water surface, in two forms. The first is Stokes drift due to wind generated waves, and the second is the Stokes drift due to swell. The wind generated wave-induced Stokes drift predominately acts in a downwind direction (the same direction as the wind); however the swell-induced Stokes drift acts in the direction of the swell, which is not necessarily the same direction as the wind generated waves, and hence may not be in the downwind direction. As it was not possible to determine the swell direction in this study and due to the minimal swell encountered, any Stokes drift was assumed to be a result of wind generated waves only, and act in the downwind direction. The swell-induced Stokes drift may become an important factor in higher energetic areas with larger swell sizes. Once the drift due to surface currents has been subtracted from the total drift, the empirically derived leeway drift of the object cannot distinguish between the downwind leeway drift effects and the downwind Stokes drift effects on the drift of the object, and therefore the effects that Stokes drift may have on the drift of the object are included in the regression of the leeway of the object. As a result of this, Breivik et al. [2] recommend that for small craft it is most practical to express leeway as a function of the wind only.

Breivik and Allen [4] suggest that the drift due to wave forces may be ignored for small craft whose length is less than that of the wavelength, as the drift due to wave forcing may only become significant once the object's length is similar to the wavelength (e.g. large vessels).

In summary, as the lengths of the craft used in this study were significantly less than the wavelength, the effects of wave forces were assumed to be negligible, and as the wind generated wave-induced Stokes drift was accounted for in the leeway coefficients derived for the objects, the total drift of the objects was calculated as a sum of the drift due to the surface currents and the drift due to the wind.

The definition of leeway has evolved over time, with each iteration becoming more rigorous and less ambiguous. The most recent definition of leeway is listed by Breivik et al. [1,2] where it is defined as:

> "*Leeway is the motion of the object induced by wind (10 m reference height) and waves relative to the ambient current (between 0.3 and 1.0 m depth)*".

This definition allows the SAR responder to use standard 10 m reference height model forecast winds and the surface layer of current forecast models or currents measured by HF radar.

There are two methods of describing the leeway of a drifting object. Both methods refer to the speed of the drift of the object when compared to the 10 m reference height wind speed. The first method refers to the object's leeway speed and divergence angle referenced to the down wind direction and speed. The second method decomposes the leeway speed and divergence angle into downwind leeway (DWL) and crosswind leeway (CWL) vectors. The former method, utilising leeway speed and divergence angle, has historically been used for manual drift planning, however Allen [5] noted that when using numerical model solutions for drift planning, the leeway divergence angle can cause the solution to become unstable at low wind speeds when wind direction fluctuates. As a result, the latter method using DWL and CWL is the preferred method for numerical SAR models as it does not suffer the same shortfall and remains numerically stable, even at low wind speeds.

The leeway coefficients can be calculated through either a constrained or non-constrained linear regression with the 10 m wind speed. The constrained through zero regression implies that the leeway will be zero when there is no wind, whilst the non-constrained linear regression implies that there may still be some residual leeway drift of the object by forcing other than winds when winds are zero. Utilising the constrained through zero regression provides the most stable numerical solution for modelling search object trajectories, whereas numerical models utilising the unconstrained regression may incur difficulties if zero wind speeds are encountered (due to having no wind direction in which to apply the leeway component). This is generally not a problem as zero wind speeds rarely occur; however there are several approaches which can be utilised by numerical models to circumvent this potential issue, which include: (a) carrying forward the wind direction from the previous model time step to calculate the residual trajectory when there is zero wind speed; (b)