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A theory for the hydrodynamic origin of whale flukeprints

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ABSTRACT

Whale flukeprints are an often observed, but poorly understood, phenomenon. Used by whale researchers to locate whales, flukeprints refer to a strikingly smooth oval-shaped water patch which forms behind a swimming or diving whale on the surface of the ocean and persists up to several minutes. In this paper we provide a description of hydrodynamic theory and related experiments explaining the creation and evolution of these "whale footprints." The theory explains that the motion of the fluke provides a mechanism for shedding of vortex rings which subsequently creates a breakwater that damps the short wavelength capillary waves. The theory also suggests that the role of natural surfactants are of secondary importance in the early formation of these prints.

1. Introduction

Flukeprints are a visible pattern that appears on the surface of the ocean when a whale is swimming at a shallow depth or beginning a terminal dive. Whale-watchers can easily observe these striking oval-shaped prints on the surface of the ocean. The outer edge of the print is accentuated by small ridges, where wave-breaking may occur. The interior of the print is smooth compared to the surface outside the print, since very few capillary (wind-driven) waves are visible as in Fig. 1. The print grows radially and may remain visible for as long as several minutes, depending on ocean and wind conditions. A popular name for this phenomenon is "whale footprint" since the prints can be used to track whales over long distances as they migrate. While smaller swimming animals such as dolphins and manatees create surface prints, whales create the largest prints with the longest duration.

There is no extensive research on the phenomenon of whale prints. A study conducted concurrently with this one uses aerial photographs to determine that the water temperature in the prints is lower than that of the surrounding water, indicating that the water in the print has been brought from below the surface [1]. At the same time, the glossy, slick-like appearance of the print and the fluid ridge at its edge is reminiscent of small oil slicks. This has fueled popular theories that surfactants (surface tension-reducing substances) create the prints [2–4]. In the case of slicks made by surfactants, gradients in surfactant concentration (changes in the concentration of surfactant on the surface of a liquid) cause a surface stress. The surface is pulled to regions of higher tension, and small disturbances are stretched out. This "calming of the waters" by surfactants such as oil or soap has been observed since ancient times [5]. In addition, the calm water in the far wake of navy sea ships has been shown to have lower surface tension than water outside the wake, which has been attributed to natural ocean surfactants brought to the surface in the wake [6–8]. Other literature attributes hydrodynamic forces, such as vortices, as the origin of flukeprints [9,10].

Marine biologists note that there are several reasons that surfactants might be present in flukeprints. One hypothesis concerns the whale's oily skin, which could act as a surfactant. Whales shed their oily skin at approximately 50 times the rate of humans [11]. The skin is usually exfoliated during social activities such as lobtailing and breaching [12], and skin fragments can subsequently be found near the whale's flukeprints. Although researchers collect skin samples from flukeprints, the material is sparse and not always evident. Therefore, the volume of skin sloughed may be too small to cause a significant surfactant effect. Another possibility is that algae, remains of feeding and other particulate matter brought to the surface may act as surfactants [13]. While any of these effects could be present to enhance the formation or duration of the flukeprint, we will argue below that the evidence is not compelling as the primary origin of the prints.

To summarize, two primary mechanisms have been proposed for the formation of flukeprints, a general "upwelling" of water off the fluke and a surfactant-based explanation. In this paper we propose that the dominant mechanism is the motion of the water induced by the movement of the fluke. We will demonstrate that in order to understand flukeprints, new fluid mechanics are not required. However, several aspects of existing theory must be

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