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Education

Aug. 2012 – Dec. 2016 (Exp) The University of California, Berkeley
Ph.D. in Mechanical Engineering (Ocean Engineering Major Field). GPA: 4.0.
Minors: Fluid Mechanics, Mathematics.
Ph.D. Thesis: *High-performance Discrete Vortex Algorithms for Unsteady Flows Near Boundaries With and Without Free-Surface Effects.*

Aug. 2011 – May 2012 The University of California, Berkeley
M.S. in Mechanical Engineering. GPA: 4.0.

Aug. 2009 – May 2011 The University of California, Berkeley
B.S. in Mechanical Engineering.* GPA: 4.0.
*Mechanical Engineering Departmental Citation Award Recipient, 2011.

Sept. 2007 – Jun. 2009 East Los Angeles College, Monterey Park GPA: 3.96.

Current Research Topics

- Numerical algorithm for viscous-fluid flow near multiple moving bodies submerged in infinite fluid using Discrete Vortex Method.
- Numerical analysis and optimization of a Savonius vertical-axis wind turbine.
- Modeling hydrodynamics of 3-D ships in waves and in roll motion.

Publications and Conference Presentations

Archival Journals (Peer-Reviewed)

- Wang, L. and Yeung, R. W., 2016, "On the performance of a micro-scale Bach-type turbine predicted by discrete vortex simulations," *Applied Energy* (***in Press***).
- Wang, L., Son, D., and Yeung, R. W., 2016, "Effect of mooring-line stiffness on the performance of a dual coaxial-cylinder wave-energy converter," *Applied Ocean Research*, vol. 59, pp. 577–588. DOI:10.1016:j.apor.2016.07.014
- Wang, L. and Yeung, R. W., 2016, "Investigation of full and partial ground effects on a flapping foil hovering above a finite-sized platform," *Physics of Fluids*, **28**(7):071902. DOI:10.1063/1.4954656
- Wang, L. and Yeung, R. W., 2015, "Nonlinear and unsteady waves generated by a traveling pressure distribution and the associated waveless shapes," *Journal of Engineering Mathematics*, **91**(1):1-16. DOI:10.1007/s10665-014-9738-x
- Wang, L., 2014, "Nonlinear waves generated by a moving pressure patch in arbitrary water depth and the implied zero-wave-resistance (ZWR) conditions," *Transactions, Society of Naval Architects & Marine Engineers (SNAME)*, **122**:334-350.

- Wang, L., Chen, X., Wang, L., Sun, S., Tong, L., Yue, X., Yin, S., and Zheng, L., 2011, "Contribution from urban heating to China's 2020 goal of emission reduction," *Environmental Science & Technology*, **45**(11):4676-4681. DOI:10.1021/es102898p

Conference Publications

- Yeung, R. W., Jiang, Y., and Wang, L., 2016, "Validations of a discrete-vortex method (SS-FSRVM) for modeling nonlinear coupled vertical-plane and lateral-plane motions in head waves," in *Proceedings* of the 31st Symposium on Naval Hydrodynamics, Monterey, CA, Sept. 2016. i+17 pp.
- Wang, L., Son, D., and Yeung, R. W., 2016, "On the performance of a dual-cylinder wave-energy converter: single versus two degrees of freedom," in *Proceedings* of the 35th ASME International Conference on Ocean, Offshore, and Arctic Engineering, Pusan, Korea, Paper #OMAE2016-54422.
- Wang, L., 2014, "Nonlinear waves generated by a moving pressure patch in arbitrary water depth and the implied zero-wave-resistance (ZWR) conditions," presented at the SNAME Northern California Section Meeting, March 19, 2014, i + 19 pp.

Other Presentations

The University of California, Berkeley

- "Discrete vortex method for unsteady viscous flow," presented at the Marine Mechanics Laboratory Prospective Graduate Student Open House, January 2016, Berkeley, CA.
- "On the effect of two-body motion of coaxial cylinders on wave energy extraction," presented as part of the E201 Ocean Engineering Seminar Series, April 2015, Berkeley, CA.
- "Nonlinear waves generated by a moving pressure distribution and the design of a near-zero-wave two-dimensional planing shape," presented at the Marine Mechanics Laboratory Research Meeting, October 2013, Berkeley, CA.

Research Positions Held

The University of California, Berkeley
Graduate Student Researcher Advisor: Prof. Ronald W. Yeung Summer 2014
Development and optimization of high-resolution CFD software based on Discrete Vortex Method for general two-dimensional flow with viscosity.

Graduate Student Researcher Advisor: Prof. Ronald W. Yeung Spring 2015
Extensive validation of the Discrete-Vortex-Method CFD software through replicating classical solutions of flow past fixed bodies and vortex-induced vibration.

Graduate Student Researcher Advisor: Prof. Ronald W. Yeung Fall 2015 / Spring & Summer 2016
Investigation of flow around a flapping airfoil and flow past a rotating Savonius vertical-axis flow turbine. Vortex method for nonlinear ship motion in waves.

Teaching Experiences

The University of California, Berkeley – Graduate Student Instructor
Graduate Student Instructor for ME 165 Instructor: Prof. Ronald W. Yeung Fa2015 / Sp2014
Ocean-Environment Mechanics

Graduate Student Instructor for ME 106 Instructor: Prof. Ronald W. Yeung Sp2015

Fluid Mechanics

Graduate Student Instructor for ME 102A* Instructor: Dr. George Anwar Fa2014 / Fa2013
Introduction to Mechanical Systems for Mechatronics

* For satisfying Ph.D. student teaching requirements.

The University of California, Berkeley – Substitute Lectures
ME 165 *Ocean-Environment Mechanics* Fall 2015
Oct. 20th, 2015 *80-min lecture on unsteady and oscillatory flow with Morison's Equation.*
Nov. 5th, 2015 *80-min lecture on marine propeller geometry and blade element theory.*

ME 106 *Fluid Mechanics* Spring 2015
Feb. 6th, 2015 *50-min lecture on Euler's Equation of Motion and the Bernoulli Equation.*
Apr. 13th, 2015 *50-min lecture on dimensional analysis, similitude, and model testing.*
Apr. 15th, 2015 *50-min lecture on viscous flow in pipes.*

Other Work Experiences

The Society of Naval Architects & Marine Engineers (SNAME)
Cal-SNAME Student Section President Sept. 2013 – Aug. 2014
Cal-SNAME Student Section Treasurer Sept. 2012 – Aug. 2013

American Bureau of Shipping, Houston, Texas
Corporate Technology Summer Intern Summer 2012
Longitudinal strength calculation for tankers and estimation of ship hydrostatic deformation under various loading conditions. Clarification of safety regulations for clients.

Awards and Honors

- UC Berkeley - *Outstanding Graduate Student Instructor (GSI) Award*, 2015-2016.
- SNAME *Graduate Paper Honor Prize* for paper "Nonlinear waves generated by a moving pressure patch in arbitrary water depth and the implied zero-wave-resistance (ZWR) conditions" presented at the SNAME Northern California Section Meeting on Mar. 19, 2014.
- UC Berkeley – ABS Ocean Technology Graduate Fellowship, 2012-2013.
- UC Berkeley - Mechanical Engineering *Departmental Citation Award* (Highest Honors in Mechanical Engineering), May 2011.

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Nonlinear and unsteady waves generated by a traveling pressure distribution and the associated waveless shapes

Lu Wang · Ronald W. Yeung

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Abstract The wave elevation and flow near a moving pressure distribution of characteristic intensity p_0 and length $2a$ are investigated using a fully nonlinear and unsteady mixed Eulerian–Lagrangian method. Special attention is paid to the zero-wave-resistance (ZWR) conditions and the associated waveless free-surface profiles. Large-time solutions for free-surface elevation are in good agreement with linear steady-state solutions for small applied pressure parameter $p_0/(\rho g a)$, with ρg being the weight density of the fluid. The ZWR phenomenon predicted by the linear wave theory at certain critical speeds is recovered from these nonlinear solutions. As $p_0/(\rho g a)$ increases, large-time nonlinear solutions indicate that trailing waves of near-zero amplitude can still be achieved at certain adjusted critical speeds. The time evolution of the trailing waves is presented and discussed.

Keywords Nonlinear waves · Planing-hull shapes · Pressure distribution · Time-dependent gravity waves · Wave resistance

1 Introduction

The minimization of wave-making resistance has been a subject of intense study in the field of ocean vehicle research. This problem is related to the improvement of fuel efficiencies of marine vessels. Zero- or minimum-wave conditions for various kinds of objects moving on or below the free surface have been proposed and studied. One interesting problem is the wave generation by a constant pressure distribution applied over the free surface of a steady stream. Lamb [1, chap. 9] studied the linearized, steady-state version of this problem in two dimensions for a uniform pressure distribution of finite length. It was noted that the free-surface elevation at a distance downstream becomes zero for pressure distributions of certain lengths. Schwartz [2] and Vanden-Broeck and Tuck [3] solved the fully nonlinear version of this problem and discovered that exceedingly small trailing-wave amplitude could be achieved at certain Froude numbers. Forbes [4] investigated the nonlinear and steady wave field over a two-dimensional, semielliptical obstacle fixed to the bottom of a horizontal stream. The obstacle was found to experience exceedingly small wave drag for a series of special ellipse lengths when the ellipse height- and depth-based Froude numbers are fixed. In this case, the disturbance of the free surface becomes localized, and downstream waves practically

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PHYSICS OF FLUIDS **28**, 071902 (2016)

Investigation of full and partial ground effects on a flapping foil hovering above a finite-sized platform

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The full and partial ground effects on the lift generation of a flapping airfoil in normal hovering mode are investigated numerically using the discrete vortex method in two dimensions. To achieve full ground effect, the airfoil of chord c is made to hover above the center of a finite-sized platform of length $10c$. We have observed the force-enhancement, force-reduction, and force-recovery regimes at low, medium, and high ground clearances in line with the existing literature. This paper puts special focus on partial ground effect when the airfoil is hovering near the edge of the platform. Lift-modifying mechanisms not previously observed under full ground effect have been discovered. When stroke reversal occurs near the edge of the platform, a relatively stationary strong vortex may form above the platform edge. This strong vortex can either increase or decrease the instantaneous lift force on the airfoil depending on the position of the airfoil relative to the platform edge. Also, the platform edge may lead to the formation of an additional vortex pair which increases the instantaneous lift force as the airfoil sweeps past the edge under suitable conditions. Lastly, the platform edge can lead to the formation of a reverse von Kármán vortex street that extends well below the stroke plane under suitable geometric arrangements. *Published by AIP Publishing.* [http://dx.doi.org/10.1063/1.4954656]

I. INTRODUCTION

Unlike most large man-made aerial vehicles that fly on fixed wings, insects, avian species, and aquatic animals often rely on flapping wings/fins for lift/thrust generation. Flapping wings provide improved maneuverability at low speeds and may be more efficient than fixed wings at very small scale (low Reynolds number) with optimized wing motion.[1] There are mainly three distinct mechanisms that are responsible for the high lift force generated by the flapping motion: delayed stall, rotational circulation, and wake capture.[2] The delayed stall phenomenon occurs when the wing moves through air at large angles of attack. A leading edge vortex forms which creates a suction effect on the low pressure side of the wing. The rotational circulation has a strong effect on the lift force when the wing rotates to reverse its direction. The wake capture effect accounts for the interaction between the wing and its wake shed during the previous stroke. Depending on the timing of the rotation relative to stroke reversal, wing-wake interaction may increase lift generation, allowing the wing to effectively recapture energy from the shed wake.

Numerical or experimental investigations are needed to study the lift/thrust generating mechanisms of a flapping wing because the flow around the wing is highly dynamic with strong boundary-layer separation. The complicated motion of the body boundary presents unique challenges for computational investigation especially in terms of mesh generation. As a result, mesh-free techniques such as the discrete vortex method (DVM)[3] and smoothed particle hydrodynamics (SPH)[4] or methods based on non-body conformal grids such as the immersed boundary-lattice Boltzmann method (IB-LBM) are often preferred.[5–7] However, conventional methods based on body fitted grids

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Effect of mooring-line stiffness on the performance of a dual coaxial-cylinder Wave-Energy Converter

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ABSTRACT

A point-absorber-type Wave-Energy Converter (WEC) consisting of a floating vertical inner cylinder and an annular outer cylinder that slides along the inner one is considered. The two cylinders heave differently under wave excitation, and wave energy can be harnessed from the relative heave motion between the two cylinders using a Permanent Magnet Linear Generator (PMLG) as the Power Take-Off unit. A mooring cable is attached to the bottom of the inner cylinder. This paper aims to examine the effect of the stiffness of the mooring cable on the performance of the coaxial-cylinder WEC system. The two limiting cases of no mooring cable (freely floating inner and outer cylinders) and an infinitely stiff mooring cable (fixed inner cylinder) were also considered. To perform the analysis, hydrodynamic and interference coefficients of the two heaving cylinders were computed semi-analytically using the method of matched eigenfunction expansions. Experimentally determined viscous corrections on damping were also included in the model in order to have more realistic predictions. The performance of the system in terms of motion responses and capture width were predicted and discussed for both regular and irregular waves. The results of the analysis indicate that both the freely floating design and the design with rigidly moored inner cylinder are viable. The two limiting cases show similar optimal performances, albeit with very different optimal generator damping. However, an ill-chosen mooring-cable stiffness may cause the inner and the outer cylinders to have the same resonance frequency, eliminating the relative heave motion and leading to almost no energy extraction. This situation needs to be avoided when designing the mooring system for a coaxial-cylinder WEC.

1. Introduction

The radiation problem of a truncated cylinder in finite water depth has been a popular research topic for decades in ocean and offshore engineering. Yeung [1] solved the hydrodynamic coefficients such as added mass and wave damping of a truncated cylinder moving with three Degrees of Freedom (DOF). The solution of the radiation problem was computed with high efficiency using the method of matched eigenfunction expansions. The fluid domain was separated into the region under the cylinder and the exterior fluid region. The velocity potential as well as its normal derivative was matched at the interface between the two regions. This semi-analytical approach can be extended to solve problems involving more complicated body geometries and arrangements: a cylinder in shallow water [2], a cylindrical body with a moon pool [3–5], two concentric cylindrical shells [6], two concentric cylinders with a moon pool in-between [7], and even arbitrarily shaped body of revolution [8]. Recently, Chau and Yeung [9] computed the hydrodynamic coefficients of two heaving coaxial cylinders: an inner cylinder and an outer annular cylinder with no gap in-between. This work is highly pertinent to the design of the dual (coaxial-)cylinder Wave-Energy Converter (WEC). This point-absorber-type WEC extracts energy from the relative heave motion between the inner cylinder and the outer annular cylinder that slides along the inner one. With viscous corrections, the results of [9] can be used to efficiently predict the performance of the coaxial-cylinder WEC system as shown in [10–12].

A variety of point-absorber-type WEC designs utilize the coaxial-cylinder arrangement, albeit with very different geometric proportions. Some designs only allow the outer annular cylinder to heave under the excitation of surface waves while the inner cylinder is kept relatively stationary with a heave plate [13] or a high-stiffness mooring cable [10,14]. We refer to this type of designs as the one DOF case. Other designs allow both cylinders

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2014 Annual Meeting Activities
2014 Annual Meeting
Report of the Executive Director
Report of the Treasurer
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Award Winning Papers

The 2014 Elmer L. Hann Award is presented for the best paper given at the 2013 Ship Production Symposium

The 2014 Vice Admiral E.L. Cochrane Award is presented for the best peer-reviewed paper published by the Society from conferences, symposia, "Featured Papers," and non-archival papers presented at the Annual Meeting

The 2014 Vice Admiral E.L. Cochrane Award Honorable Mention

**This paper was published in the Journal of Ship Production and Design Volume 29, Number 4, November 2013, pp. 162-182. The paper can be read in it's entirety there.*

The 2014 SNAME Offshore Technology Conference Best Paper Award is presented for the best paper given at the 2014 Offshore Technology Conference

The 2014 Graduate Paper Honor Prize

The 2014 Graduate Paper Award -

The 2014 Undergraduate Paper Honor Prize -

The 2014 Undergraduate Paper Award –

Significant Papers

NONLINEAR WAVES GENERATED BY A MOVING PRESSURE PATCH IN ARBITRARY WATER DEPTH AND THE IMPLIED ZERO-WAVE-RESISTANCE (ZWR) CONDITIONS

Lu Wang*

Abstract

In the interest of reducing trailing wave formation of a hovercraft or planning surface, we investigate the wavy flow generated by a moving pressure distribution of length $2a$ using a fully nonlinear mixed Eulerian-Lagrangian method. The pressure distribution is assumed to accelerate smoothly from rest to a constant cruising speed. The time-evolution of the downstream wave field is examined with a focus on the zero-wave-resistance (ZWR) phenomenon. For both finite and infinite water depths and a small pressure parameter $P \equiv p_0/\rho g a$, with p_0 being the applied pressure and g the gravitational constant, we recover, using current nonlinear simulation, the linear ZWR behavior at certain critical speeds as reported by Yeung *et al.* (*2011, 26IWWWFB*) and Matte (*2011, UC Berkeley Master's thesis*). As P increases, the new large-time nonlinear solutions indicate that near-zero trailing wave can still be achieved but at slightly shifted critical speeds. The shifting of the ZWR points are determined for several water depths and values of P that are of practical interests.

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On the performance of a micro-scale Bach-type turbine as predicted by discrete-vortex simulations

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HIGHLIGHTS

- Flow past a micro Bach-type turbine is solved using a viscous Discrete-Vortex Method.
- Performance of Bach-type turbines is not significantly degraded at small scales.
- In laminar flow, performance of Bach-type turbines can be boosted with wake capture.
- Velocity fluctuation and decreased performance observed for free rotation in water.
- Micro-scale Bach-type turbines can potentially power wireless sensor nodes.

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ABSTRACT

The flow past a Bach-type vertical-axis wind or current turbine is simulated using a viscous Discrete-Vortex Method at a Reynolds number of 1500. The main purpose of the study is to evaluate the suitability of Bach-type turbines for use as micro-scale energy harvesters that can be applied to power, for example, sensor nodes of a wireless sensor network. The maximum power coefficient of the turbine operating at a prescribed constant tip-speed ratio is found to be 0.18, which is comparable to the performance of the same turbine at much higher Reynolds numbers, thus indicating only minimal performance penalty for miniaturization. The speed of the turbine has a strong influence on the evolution of vortical flow structures. A new wake-capturing mechanism that boosts the performance of the turbine is discovered from the simulations for a certain range of tip-speed ratios where the vortex shed by the advancing blade helps drive the returning blade. In addition to prescribed rotation, free rotation of a steel Bach-type turbine in water is also investigated. Significant fluctuation in angular velocity over one period of rotation is observed. This speed fluctuation is found to be detrimental to energy extraction, reducing the maximum power coefficient to approximately 0.16. The estimated power generating capacity of a micro-scale turbine indicates that it can significantly extend the life expectancy of a wireless sensor node or even maintain the node in a low-power state indefinitely.

1. Introduction and background applications

Currently, on-shore utility-scale wind power generation is dominated by horizontal-axis wind turbines (HAWT). Large commercial HAWTs incorporate active orientation (yaw) control [1] and collective or independent blade pitch control [1,2] to ensure the turbine is constantly facing the wind and operating at near-optimal load. As an alternative to HAWTs, vertical-axis wind turbines (VAWT) are also being developed and improved. Although less popular for on-shore applications, VAWTs have a number of advantages over HAWTs. First of all, VAWTs can work with any wind direction, and a yaw-control mechanism is not needed, leading to simpler and cheaper constructions. Further, VAWTs have a smaller footprint and can be arranged in close-packed arrays. In fact, it has been found that it is possible to increase power extraction efficiency of VAWTs through constructive aerodynamic interactions between a pair of counter-rotating VAWTs [3].

VAWTs can be divided into two different types: lift-based Darrieus VAWTs and drag-based Savonius-type [4] or Bach-type [5] VAWTs. Compared to drag-based VAWTs, Darrieus VAWTs operate at a higher tip-speed ratio (λ) and are generally more efficient [6]; thus, Darrieus VAWTs are usually preferred for large-scale wind energy applications. However, Darrieus VAWTs have a low starting torque and are sometimes used in conjunction with a Savonius-type VAWT to improve their self-starting capability [7]. On the

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Validation of a Discrete-Vortex Method (SS-FSRVM) for Modeling Nonlinear Coupled Vertical-Plane and Lateral Ship Motions in Head Waves

Ronald W. Yeung*, Yichen Jiang†, and Lu Wang
(University of California at Berkeley, USA)

ABSTRACT

This paper addresses several essential developments of the Slender-Ship Free-Surface Random Vortex Method (SS-FSRVM) for modeling viscous-fluid flows about a ship advancing in head-seas, with consideration of nonlinear coupling effects of the vertical-plane (pitch and heave) motions and possibly large roll motions. Successful development of the SS-FSRVM computational model was previously restricted to either forward motion in calm water, or excitation in strictly beam waves. This highly efficient method based on discrete-vortex elements was shown to be capable of predicting prescribed roll-motion hydrodynamic coefficients (Seah & Yeung, 2008). First, we present a formulation that allows motion excitation in head seas, yet utilizing the efficient computational feature in the sectional frames, a hallmark of the SS-FSRVM work. The restriction of this generalization requires the parameter: wave-steepness/Froude number be $O(\varepsilon)$, which can be met by most operational conditions. The solution procedure to predict heave and pitch responses in head seas for a Wigley-type hull was demonstrated by comparing with the existing experimental data of Journee, 1992. A C11-class container-ship model hull was used to test the nonlinear heave-pitch and roll coupling in head seas. At certain expected synchronization conditions, moderate seas were indeed found to induce parametric rolling. A hybrid model of "phantom bilge keels (PK)" was seen to reduce such excessive large roll motion. To facilitate the eventual removal of the PK modeling by a fluid-flow modeling of physical keels, SS-FSRVM was tested for free decay of roll motion of a naval frigate hull (INSEAN-C2430). Published DPIV measurements of Aloisio & Felice (2006) were used to validate the predicted flow details. These three-step validations confirm SS-FSRVM's readiness to predict the coupling of vertical and lateral plane motions.

1 INTRODUCTION

The prediction of ship motion in waves relies on an ability to model the continuous interaction between the ship's rigid-body dynamical response and the surrounding fluid motion. The coupling of motions in the vertical plane (heave and pitch) with those in the transverse plane (roll and sway) is normally not strong, but there are known situations where nonlinear coupling effects occur, particularly when the motion is large and the sea states are strong. In particular, cross-coupling between vertical and transverse motions can occur in a nonlinear way and parametric roll resonance may result. Roll motion experiences relatively small damping, and if roll resonance should be excited, even just by a small perturbation, undesirable consequences can result. There was the well-known incident of a post-Panamx C11 containsership in the literature (France, 2003). The incident called attention to the problem of parametric excitation in head seas and have been studied by many researchers (see, for instances, Shin *et al.*, 2004, Neves *et al.*, 2007, Umeda *et al.*, 2008 and Uzunoglu *et al.*, 2015).

To predict the parametric rolling phenomenon, three essential components are believed to be needed: (1) time-dependent nonlinear roll restoring moment based on the instantaneous wetted surface; (2) nonlinear coupled equations of motion in the time domain; (3) viscous roll damping modeling. In principle, computational fluid dynamics (CFD), e.g. Miller *et al.* (2008) and Sadat-Hosseini *et al.* (2010), have advanced to a stage that high-fidelity prediction is within the designers reach. Nonetheless, meshing of millions of cells, computational time of thousands of CPU hours (without resorting to multi-processors) impede the designer from gaining a thorough grasp of the effects of various physical parameters on the

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