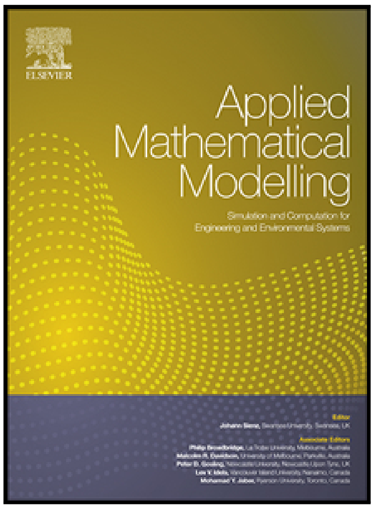
Accepted Manuscript



Acoustic radiation force of attraction, cancellation and repulsion on a circular cylinder near a rigid corner space

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PII: S0307-904X(18)30374-3
DOI: https://doi.org/10.1016/j.apm.2018.07.056
Reference: APM 12409

To appear in: *Applied Mathematical Modelling*

Received date: 5 October 2017
Revised date: 15 June 2018
Accepted date: 31 July 2018

Please cite this article as: F.G. Mitri , Acoustic radiation force of attraction, cancellation and repulsion on a circular cylinder near a rigid corner space, *Applied Mathematical Modelling* (2018), doi: https://doi.org/10.1016/j.apm.2018.07.056

Highlights

-The acoustic radiation force on a cylindrical particle near a corner space is determined
-Progressive waves with an arbitrary incidence angle are considered
-Depending on the distances, incidence angle and particle size, particle neutrality is yielded
-Attraction or repulsion forces can also arise
-Potential applications are in acoustofluidics applications and related areas of research

Acoustic radiation force of attraction, cancellation and repulsion on a circular cylinder near a rigid corner space

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(Submitted October 4, 2017; revised June 13, 2018)

A B S T R A C T

The purpose of this study is to derive exact partial wave series expansions for the longitudinal and transverse radiation force components, for a circular cylinder in the proximity of a rigid corner space, and illuminated by incident plane waves with arbitrary orientation in the polar plane. Based on the multipole expansion method in cylindrical coordinates, the method of images as well as the translational addition theorem, an effective incident field (resulting from the primary waves as well as the multiple scattered fields from the image sources) is determined first, and used subsequently with the scattered field to derive the mathematical expressions for the radiation force components, stemming from the integration of the radiation stress in a non-viscous fluid. Numerical computations illustrate the analysis for rigid and soft cylinders with particular emphasis on the distances from the particle edges to the neighbouring walls, the size of the cylinder and the angle of incidence. Depending on the choice of these parameters, the radiation force components can vanish, rendering complete "invisibility"; i.e., the cylinder becomes unresponsive to the transfer of linear momentum carried by the incident effective field. Moreover, the radiation force components alternate between positive and negative values, suggesting a force of repulsion or attraction. The results find potential applications in acoustofluidics design and optimization as they shed light on the anechoic radiation force effect on a particle nearby a rigid corner. Other applications in noise and vibration control could also benefit from the results of the present investigation along with further related topics.

1. Introduction

The linear momentum carried by acoustical waves and the ensuing forces [1, 2] which arise due to the momentum transfer is a physical phenomenon relevant in a wide range of impactful applications and fundamental concepts [3-9]. Examples include acoustical tweezers [10] and acoustofluidics [11, 12] including cells and drops sorting in suspension [13], biological tissue characterization [14], tissue engineering [15, 16], manmade acoustically-engineered periodic structures of inert materials [17, 18], phononic crystals [19] and metamaterials to name a few examples.

The numerical prediction of such forces allows adequate experimental design and optimal strategies to be applied and analyzed. Along that direction of research, significant investigations considered the single particle case, ranging from disks [20], circular [21-32] and elliptical [33-35] cylinders, spheres [36-54], to more complex aspherical shapes [55-59]. Moreover, thorough analyses considered the multiple particles case [60-63] in unbounded fluids, and further examined the effects of a flat boundary on a single particle [64].

In some practical cases dealing with a microfluidic channel in acoustofluidics applications, an anechoic corner effect [65] can arise, which plays a crucial role in the cancellation of the acoustic radiation forces exerted on a particle located in that region. Thus, the available analytical models [64, 66, 67] for a particle near a single planar boundary becomes inaccurate to predict the acoustic radiation forces when the particle is present nearby the channel corner space. Hence, there is a need to develop a rigorous analytical modeling that allows accurate calculation of the acoustic radiation forces, which lay the foundation for tri-separation of the microspheres [65].

The purpose of this investigation is therefore directed toward developing a formal analytical model with exact solutions for the acoustic radiation forces on a circular rigid or soft particle immersed in a non-viscous liquid in 2D with plane wave illumination at an arbitrary incidence angle in the polar plane, and located nearby a rigid corner space. In this work, the multipole partial-wave series expansion method in cylindrical coordinates is used along with the method of images and the translational addition theorem of cylindrical wave functions to derive exact series expansions for the

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