Experimental Analysis of Near-Field Acoustic Scattering by Rigid Spheroidal Objects

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Numerous theoretical models have been developed to predict acoustic scattering by objects of various shapes, but experimental verification of these models has been scarce and limited to objects of simple geometry. Therefore, a special anechoic chamber was designed and built to study the steady-state near-field acoustic scattering by rigid spheroids. Five spheroidal objects were fabricated out of a starch powder held together by a cellulose binder ($\rho = 1039 \pm 1\%$ kg/m^3 at 20°C). The objects created are a sphere, a 2:1 prolate spheroid, a 2:1 oblate spheroid, a 5:1 prolate spheroid, and a 5:1 oblate spheroid, all having a major-axis length of about 12.9 cm. Spheroidal size parameters (h) in the range of about 10 to 20 were studied. A super-tweeter was selected as the sound source in the acoustic scattering experiments, and a 3 mm condenser microphone was used to scan the scattered sound in front and behind the five objects. The resultant experimental acoustic pressure profiles were compared to the theoretical predictions. A major contribution of this study are the experimental relative phase angle profiles which, along with the pressure profiles, offer more information about the acoustic scattering trends of rigid spheroids.

Nomenclature

a – sphere radius and spheroidal half major-axis length
b – spheroidal half minor-axis length
f – frequency
f_s – semi-focal length of the spheroid
h – spheroidal size parameter
p_{am} – mean acoustic pressure amplitude
p_{ar} – relative acoustic pressure amplitude
S_c – corrected sensitivity

Greek Symbols

α – sphere size parameter
θ_{dir} – angle of incidence
λ – wavelength
Φ_r – relative phase angle

1. INTRODUCTION

Acoustic scattering by spheroidal objects has been a topic of interest over the past few decades, and continues to be an active area of research. A prolate spheroid can range in shape from a sphere to a long slender rod, while an oblate spheroid can range in shape from a sphere to a flat disk. The importance of studying the acoustic scattering by spheroidal objects lies in the fact that many physical objects can at least be approximated by one of the aforementioned geometries. The current findings summarised in this article can be used to model many important underwater targets such as marine animals, suspended sands, submarines, and sediment inhomogeneities.

Initial studies of acoustic scattering focused on the sphere, the simplest of the spheroids.[1-6] In 1934, the first of those studies calculated theoretically the radiation pressure force exerted on a rigid sphere in plane progressive and standing wave fields.[1] Experimental work was also performed to verify some of the theoretical findings.[4,7] Work on the sphere has continued over the last two decades where numerous studies of the acoustic radiation pressure on rigid and solid elastic spheres have been published.[8-10]

The scattering of sound from a prolate spheroid was first investigated in 1951.[11] The earlier works focused mainly on far-field scattering[12] or the determination of the acoustic pressure at the surface of the spheroid.[13] Furthermore, many of these studies do not provide general solutions and have limitations and restrictions requiring end-on incidence[14,15] or a high frequency/high aspect ratio asymptotic limit,[16] or produce results that are reliable only for low aspect ratio prolate spheroids.[17] More recently, the vector intensity field scattered by a large aspect ratio rigid prolate spheroid was investigated; however, the study was purely theoretical and offered no experimental verification.[18]

The rigid oblate spheroid scattering problem did not receive as much attention as the prolate spheroid. One of the few studies for the oblate geometry was published by NASA (National Aeronautics and Space Administration) in 1976.[19] The objective of the investigation was to determine the frequency limit below which sound scattering by a microphone body is sufficiently small to permit accurate pressure gradient measurements.

The work presented in this paper differs from earlier efforts in that 1) the emphasis is on determination of the near