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Research Article

Sound Scattering and Its Reduction by a Janus Sphere Type

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Sound scattering by a Janus sphere type is considered. The sphere has two surface zones: a soft surface of zero acoustic impedance and a hard surface of infinite acoustic impedance. The zones are arranged such that axisymmetry of the sound field is preserved. The equivalent source method is used to compute the sound field. It is shown that, by varying the sizes of the soft and hard zones on the sphere, a significant reduction can be achieved in the scattered acoustic power and upstream directivity when the sphere is near a free surface and its soft zone faces the incoming wave and vice versa for a hard ground. In both cases the size of the sphere's hard zone is much larger than that of its soft zone. The boundary location between the two zones coincides with the location of a zero pressure line of the incoming standing sound wave, thus masking the sphere within the sound field reflected by the free surface or the hard ground. The reduction in the scattered acoustic power diminishes when the sphere is placed in free space. Variations of the scattered acoustic power and directivity with the sound frequency are also given and discussed.

1. Introduction

Sound scattering is a fundamental problem in acoustics. It affects a wide variety of acoustic analysis and design ranging from issues concerning room acoustics and noise pollution to acoustic detection of objects. In this study we look at the fundamental problem of sound scattering by a sphere and more particularly by a Janus sphere type; that is, a sphere that has two zones that are not necessarily of the same size. One zone is a soft surface of zero acoustic impedance and the other one is a hard surface of an infinite acoustic impedance. Sound scattering by a hard sphere placed in free space and subject to an incident planar monochromatic sound wave was already investigated by Rayleigh [1]. Both the incoming and scattered waves were expressed as Fourier-Legendre series, where the amplitudes of the scattered wave modes' were determined by fulfilling the boundary condition on the sphere for each mode. A similar derivation can be applied for a soft sphere [2]. Both cases of sound scattering by a hard or a soft sphere can be approximated using the sound fields of a monopole and a dipole placed at the centre of the sphere for the low frequency limit.

Reduction of sound scattering is of great interest for a range of reasons from better audio communication of speech and music to reduction of noise pollution or avoiding acoustic detection. Commonly reduction in sound scattering is achieved by coating the object with a material with an acoustic impedance similar to that of the medium where the sphere is placed. A significant improvement can be achieved using a resonant sound absorber that combines layers of absorbent material with Helmholtz resonators such as cavities that lead to a better dissipation of the incoming and scattered sound inside the coating [3]. Recently an approach based on metamaterials has been intensively investigated in order to achieve acoustic invisibility or cloaking. A coordinate transformation for solving the wave equation can be used to find the required material properties to achieve acoustic cloaking, for example Chen and Chan [4]. Such material properties can be also achieved approximately using microstructures combining resonant cavities and channels [5].

Alternatively, active control can be used to reduce sound scattering. For example the object's structural dynamics can be utilised to cause disturbance on the object's surface that will reduce significantly or even eliminate the scattered wave.

This is particularly attractive for shells of thin wall, where more than 10 dB reduction in sound scattering by simple shells such as plates and free surface piercing cylinders was achieved theoretically using a few external pressure points acting on the shell's wall [6, 7]. A combination of active and passive control was pursued by Scandrett et al. [8] who considered a combination of a viscoelastic coating and piezoelectric substance to reduce sound radiation through a plate or sound scattering. It was argued that the use of a viscoelastic layer alone is not much effective in reducing sound radiation or scattering. However, a promising reduction was found numerically through the use of a combined piezoelectric and viscoelastic material that could change its properties using active control.

A combined methodology of active and passive control is also suggested in this study as the background to support the concept of a Janus sphere type that can change the sizes of the soft and hard zones on its surface in order to achieve maximum reduction of sound scattering. Such configuration may reduce sound scattering of long waves as the sphere acts as a compact scatter. Thus a combination of the hard and soft surfaces on the sphere can lead to an overall acoustic impedance that is not far from the impedance of the surrounding medium. Furthermore, when the Janus sphere is close to a free surface, pointing the sphere's soft surface towards the incoming sound wave may mask the sphere's acoustic scattering within the sound field reflected by the free surface. The same approach can be used for when the sphere is near a hard ground but with pointing the sphere's hard surface towards the incoming wave.

Recent developments in smart materials technology and particularly in shape memory alloys (SMA) lay the foundation for this approach of Janus sphere [9]. These alloys can be transformed from a soft martensite state to a hard austenite state using several ways including temperature change due to electric currents and activating a magnetic field. This technique can be used to vary the sizes of the hard and soft surfaces as required. Of course from structural point of view an internal pressure inside the sphere will have to balance the external hydrostatic pressure for the soft surface, but in terms of acoustic pressure fluctuations, the latter will be taken as zero on the soft surface.

Sound scattering by partly coated objects has been investigated, but as far as we are aware not for a Janus sphere type and particularly as a possible tool to reduce sound scattering. For example Partridge [10] used the deformed cylinder method (DCM) to estimate the scattering from axisymmetric bodies partly coated with a viscoelastic layer. He found that the latter had very little effect for underwater sound frequencies below 2 KHz, but a better reduction was found at higher frequencies. Partial coating was also considered by Ferri et al. [11] for cylinders where analytical expansion series were used to model the scattered sound as well as the boundary element method (BEM). They found that fine numerical resolution is required on the surface around the discontinuity in the acoustic impedance in order to calculate accurately the near sound field. However, the numerical resolution could be relaxed for the far sound field calculations.

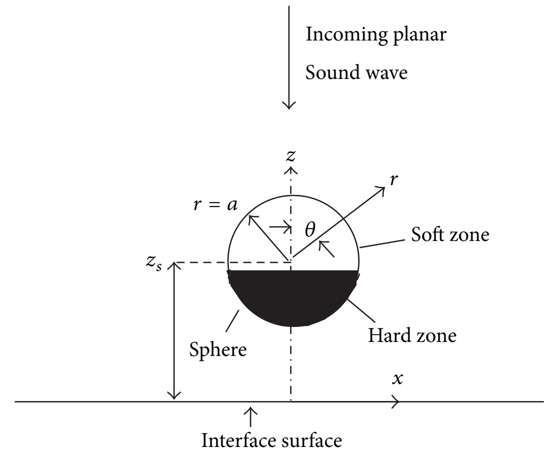


Figure 1: Schematic description of the problem for when the sphere is near a free surface. The hard-soft configuration of the Janus sphere is illustrated.

In the following the computational methodology as based on the equivalent source method is presented. The sphere is assumed to be in free space or near a free surface or near a hard ground. This is followed by presentation of some results for a sphere located in fresh water, pointing to the conditions and sound frequencies where a Janus configuration can achieve significant reduction in sound scattering and also in what zones of the sound field this is achieved. Finally a summary is given.

2. Methodology

Linear acoustics is assumed and the equivalent sound source method is used in order to compute the scattered sound field. The effect of the sphere is modelled using the multipole source approach [12]. This approach is similar to Rayleigh's spherical harmonics expansion method but instead of trying to satisfy the boundary condition on the sphere for every spherical mode or every surface element on the sphere, an orthogonalization operation is used to achieve global fitness to the boundary condition while reducing significantly the number of modes required for the calculation and avoiding an ill-conditioned matrix [2].

The sound pressure field $p(x,z,t)$ can be written for when the sphere is in free space as

$$p(x,z,t) = e^{-i(kz+\omega t)} + \sum_{0}^{N-1} b_n \phi_n(r,\theta) e^{-i\omega t}, \tag{1}$$

$$\phi_n(r,\theta) = h_n(kr) P_n(\cos\theta), \tag{2}$$

where x and z are the rectangular horizontal and vertical axes, respectively, while r and θ are the radial distance and spherical angle as relative to the sphere's centre, see Figure 1. The incoming wave is assumed to be a planar monochromatic wave with a frequency ω propagating opposite to the z direction, where k is the wave number. The assumption of a planar incoming wave means that we assume the wave source is far from the sphere. The second term on the right hand side of (1) represents the scattered sound wave, where the amplitude b_n is to be found. N is the number of modes that will be considered in the computations. h_n is the first spherical Bessel function of the third kind, and P_n is the Legendre polynomial.

If an interface surface in the form of a free surface or a hard ground exists at distance z_s from the sphere's centre as in Figure 1, then the image method can be used to model the effect of the interface surface. In the case of a free surface, that is, of zero acoustic impedance, the sound pressure can be written as

$$\begin{aligned} p(x,z,t) &= \sin(kz)\, e^{-i\omega t} \\ &\quad + \sum_{0}^{N-1} b_n \left[\phi_n(r,\theta) - \phi_n(r',\theta')\right] e^{-i\omega t}. \end{aligned} \tag{3}$$

The free surface is assumed to be located at $z = 0$ as in Figure 1, while r' and θ' are the radial distance and spherical angle as relative to the image sphere's centre that is located at $z = -z_s$. If the interface surface at $z = 0$ is of hard ground, that is, of infinite acoustic impedance, the sound pressure can be written as

$$\begin{aligned} p(x,z,t) &= \cos(kz)\, e^{-i\omega t} \\ &\quad + \sum_{0}^{N-1} b_n \left[\phi_n(r,\theta) + \phi_n(r',\theta')\right] e^{-i\omega t}. \end{aligned} \tag{4}$$

In deriving (3) and (4) it is assumed that the incoming wave propagates normal to the interface surface as in Figure 1. This corresponds to the case where the sender and receiver of the sound wave are located at the same place and thus the sound wave will be sent perpendicular to the interface surface in order to maximise reflection. It also simplifies the solution by keeping the axisymmetry that exists in the free space solution of (1). Extensions to an oblique sound wave propagation are possible [7] and are kept for a future study.

The coefficients b_n of the scattered wave are to be determined by fulfilling the boundary conditions on the sphere's surface. A Janus sphere type has two surface zones: a hard surface and a soft surface. Then on the hard surface the boundary condition is

$$\frac{\partial p}{\partial r} = 0, \tag{5}$$

and on the soft surface the boundary condition is

$$p = 0. \tag{6}$$

The sphere is divided to N_{sph} elements and one can try to force boundary condition (5) or (6) (depending on the surface nature of the element) at the centre of each element in order to determine the coefficients b_n. This is the collocation method where the number of elements is the same as the number of elements; that is, $N_{\text{sph}} = N$. However, experience showed that this could result in an ill-conditioned matrix as found in other problems of sound scattering by cylinders and plates [6, 7].

Instead of the collocation method we will use the moment method where an orthogonalization operation is pursued as relative to the complex conjugate of the multipole source at the centre of the element, that is, $\phi_m^*(r,\theta)$ for the free space case, $\phi_m^*(r,\theta) - \phi_m^*(r',\theta')$ for the free surface case, and $\phi_m^*(r,\theta) + \phi_m^*(r',\theta')$ for the hard ground case, where $*$ means complex conjugate [2]. Using only $\phi_m^*(r,\theta)$ for all three cases did not affect much the results shown in the following section. The pressure as expressed in (1) or (3) or (4) is substituted into boundary condition (5) or (6) at the centre of each element and this is multiplied by a specific $\phi_m^*(r = a,\theta)$ or its equivalents for the free surface or hard ground cases. The result is integrated all over the sphere yielding one equation for N unknowns of b_n. Repeating the same procedure for $m = 0$ to $N - 1$ will yield N equations that can be solved using publicly available LU decomposition algorithms [13]. The Bessel and Legendre functions of (2) can also be calculated using publicly available algorithms [13]. In this way the number of surface elements N_{sph} can be much higher than the number of modes N that are considered in the computations. This was found to be essential particularly when the sphere was of a Janus type.

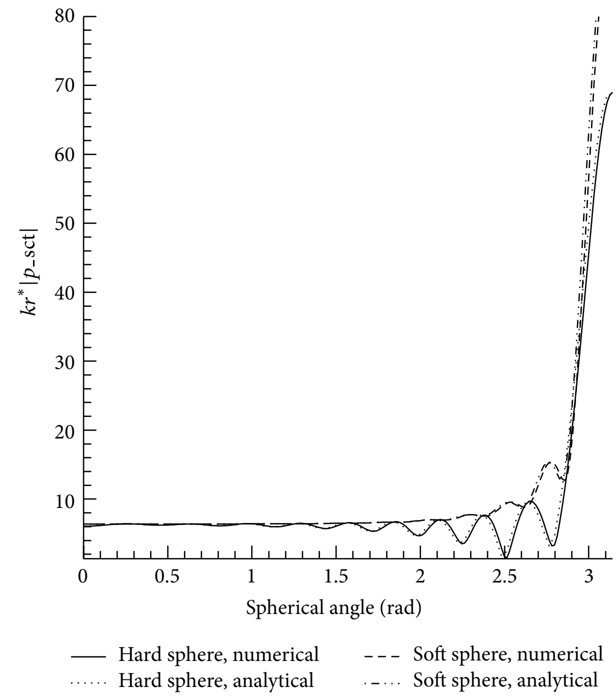


FIGURE 2: Verification of the numerical equivalent source method against the analytical scattered far field directivities of fully hard and soft spheres of 1 m radii in free space and for a wave frequency of 3000 Hz and a speed of sound of 1500 m/s.

3. Results and Analysis

The computations were verified against analytical solutions of sound scattering by a hard sphere and a soft sphere in free space, showing excellent agreement. This is illustrated in the scattered far field directivities plotted in Figure 2 for a wave frequency of 3000 Hz and a speed of sound of 1500 m/s as of fresh water. Adding an interface surface in the form of a free

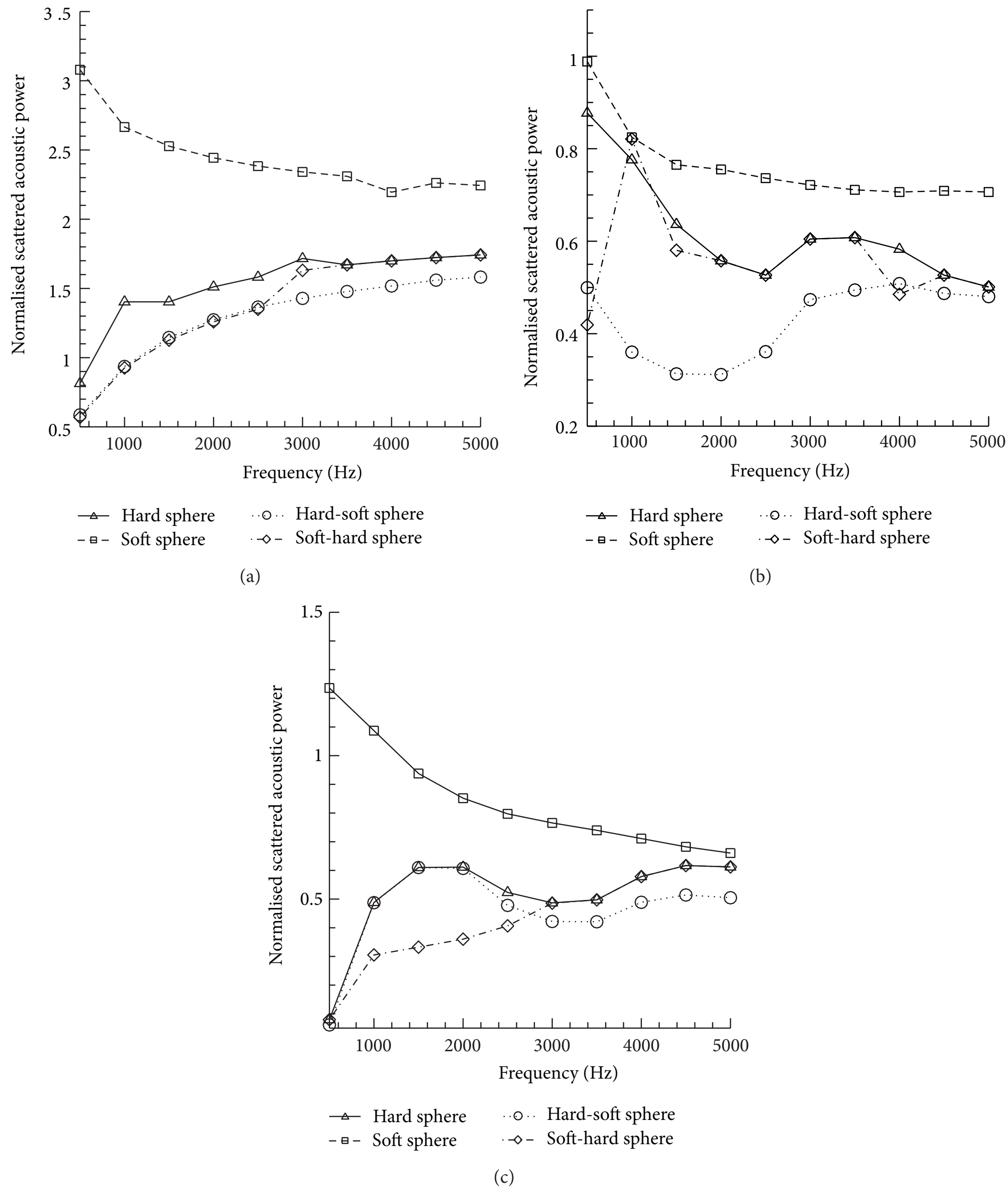


Figure 3: The frequency variation of the scattered acoustic power that is normalized by the incident wave's power per the sphere's cross-sectional area. The sphere's radius is 1 m and is (a) in free space, (b) its centre is 2.1 m away from a free surface, and (c) 2.1 m away from a hard ground. The hard-soft configuration means the soft zone faces the incoming sound wave and the soft-hard configuration means vice versa. The zones' sizes were optimised to minimise the scattered acoustic power.

surface or a hard ground yielded zero pressure or zero vertical velocity at the location of the free surface or hard ground, respectively, as expected. The computed pressure field was verified to fulfil the Helmholtz equation using central finite difference schemes. The computations for the Janus sphere type required a large number of surface elements as relative to the number of spherical modes that were computed. For the range of frequencies from 500 Hz to 5000 Hz as considered in the following results, an ambient speed of sound of 1500 m/s as of fresh water and a sphere of 1 m radius, 40 spherical modes with 400 surface elements of equal area, were found to be sufficient. Increasing the number of modes or the surface elements was found to have a small effect on the following results.

The variation of the scattered acoustic power with the sound frequency is shown in Figure 3 for three spatial cases: the sphere is in free space, the sphere is near a free surface, and the sphere is near a hard ground. The distance of the sphere's centre from the interface surface in the last two configurations is $z_s = 2.1$ m. Each figure shows the power distribution for the hard, soft, hard-soft, and soft-hard sphere configurations. The hard-soft configuration means that the hard zone on the sphere faces away from the incoming sound wave and soft zone faces the incoming wave. The soft-hard configuration means the opposite. The sizes of the hard/soft zones were optimised in order to reduce the scattered acoustic power. The scattered acoustic power is shown in Figure 3 as being normalised by the incident acoustic power per the cross-sectional area of the sphere.

In all three spatial cases the soft sphere causes more disruption to the sound field than the hard sphere in terms of the scattered acoustic power. As the frequency increases the level of the power scattered by the soft sphere generally reduces towards that of the hard sphere, except for the free surface case where the power level scattered by the hard sphere fluctuates. Both the hard-soft and soft-hard configurations show a very similar behaviour for the free-space case of Figure 3(a) with a slight better performance for the hard-soft configuration for frequencies higher than 3000 Hz. Both show a reduction of up to 20% in the scattered acoustic power which is not that considerable. Nevertheless, it confirms the view that was raised in the Introduction section that as the wave frequency decreases, that is, the incident wave length increases, the sphere will act more as a compact scatter and the Janus sphere configuration can yield an overall acoustic impedance closer to that of the surrounding medium.

On the other hand when the free surface is present, the hard-soft sphere configuration shows a clear superior behaviour in terms of reducing the scattered acoustic power by up to 50% as relative to the hard sphere in wave frequencies less than 2000 Hz. The soft-hard sphere does not present such an advantageous behaviour for the free surface case except at 500 Hz. At frequencies higher than 3000 Hz both the hard-soft and soft-hard spheres behave as similar to the free space case. This can be understood as more wave lengths can exist in the gap between the sphere and the free surface as the frequency increases above 3000 Hz, making the effect of the free surface less pronounced.

The behaviour of the hard-soft and soft-hard spheres configurations become the opposite when the free surface is replaced by a hard ground as seen by comparing Figure 3(b) with Figure 3(c) and sound frequencies of less than 2000 Hz. In that case the soft-hard configuration manages to reduce the acoustic power by up to 50% as relative to the hard sphere. At frequencies higher than 3000 Hz the hard-soft sphere produces a mildly better performance in terms of reducing the scattered acoustic power. Again this can be explained by the increase in the ratio between the sphere's gap to the hard ground and the sound wave length, making the effect of the hard ground less pronounced.

Both Figures 3(b) and 3(c) show that the second mechanism to reduce scattering as suggested in the Introduction section can be effective. This means pointing the soft surface of the Janus sphere towards the incoming wave if the sphere is close to a free surface and the hard surface of the Janus sphere towards the incoming wave if the sphere is near a hard ground. However, the water between the sphere and the free surface or the hard ground has finite acoustic impedance. Thus using fully hard or soft spheres will not be effective in reducing sound scattering as the Janus' sphere that can yield an overall acoustic impedance close to the surrounding medium for low wave frequencies.

The vertical location of the boundary separating the hard and soft zones in the sphere is plotted in Figure 4 as a function of the sound frequency for all three investigated spatial cases. That location was optimised in order to reduce the scattered acoustic power and the location is plotted as relative to the location of the sphere's centre, that is, showing zero if the boundary location coincides with the sphere's centre. It is evident that for all three spatial cases and for both the hard-soft and soft-hard configurations the hard zone has to be much larger than the soft zone in order to reduce the scattered acoustic power. The hard-soft sphere configuration that manages to get the highest scattered acoustic power reduction in the free-space and near a free surface shows an increase with the frequency in the proportional size of the soft zone facing the incoming wave. The soft-hard configuration that showed the best reduction in the scattered acoustic power for the case of the sphere near a hard ground also exhibits an increase in the soft zone facing this time the hard ground as the sound frequency increases up to 3000 Hz. Above that frequency the sphere behaves more like as it is in free space and the boundary location's dependence on the frequency completely changes.

The near field contours of the overall pressure amplitudes are shown in Figures 5, 6, and 7 for the investigated cases of a sphere in free space, the sphere near a free surface, and the sphere near a hard ground. The contours corresponding to the hard sphere's sound field are compared against the best configuration of the Janus sphere that achieved maximum reduction in the scattered acoustic power. The sound frequency is 1500 Hz in Figures 5 to 7. The free-space case contours show the wave fronts to curve around the sphere with a large V wake behind it, which can also be seen in sound scattering by other bluff bodies as cylinders [6]. The hard-soft sphere causes some blur in the level of the side line contour levels on the expense of a moderate increase in the level of the contours upstream of the sphere as can be seen in Figure 5.

The overall pressure amplitude contour levels near the free surface in Figure 6 or near the hard ground in Figure 7 show a picture much different than of the free space case. The incoming wave has become a standing wave because of the free surface or the hard ground at $z = 0$. The sphere causes ripples in the wave fronts and there is a clear V shape in front of the hard sphere as seen in Figure 6(a). That V shape greatly diminishes when the hard sphere is replaced by the optimised hard-soft sphere in Figure 6(b). Interestingly the zero pressure line at $z = 3.2$ m coincides with the soft zone on the top of the sphere as seen in Figure 6(b). This points to the need to optimise the zone's location to coincide with the incoming standing wave fronts' locations. The pressure is zero at the free surface of $z = 0$ as expected.

When the free surface is replaced by a hard ground at $z = 0$, a high pressure front develops at $z = 0$ as seen in

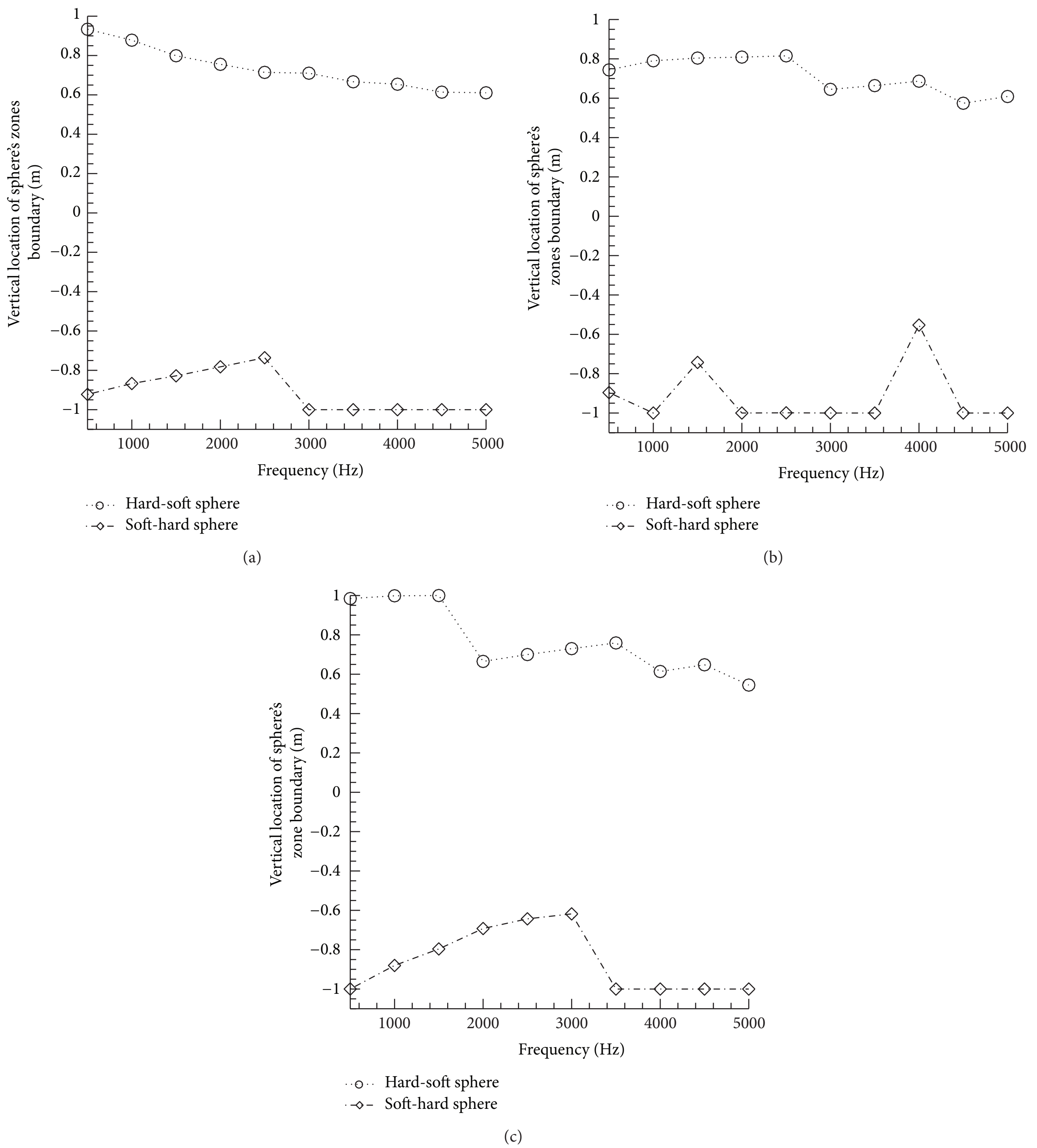
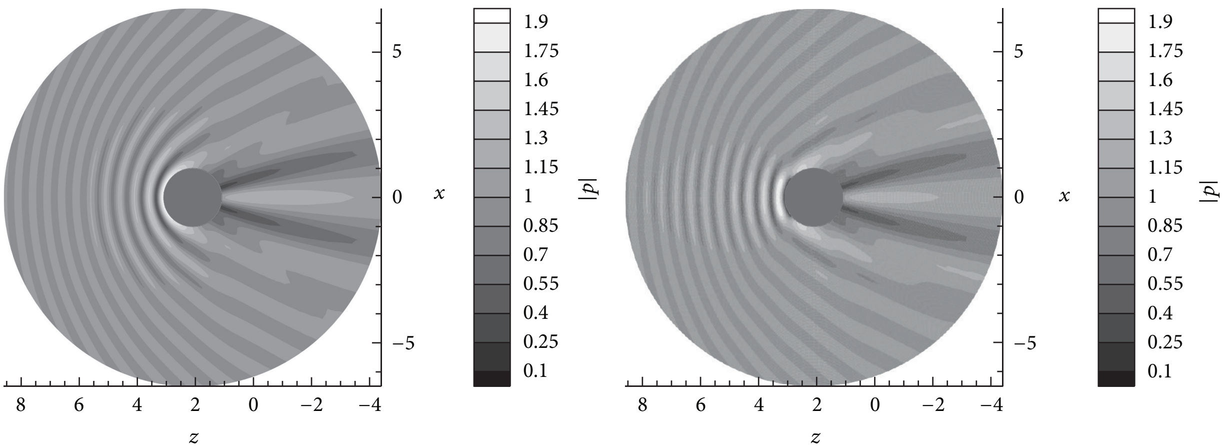


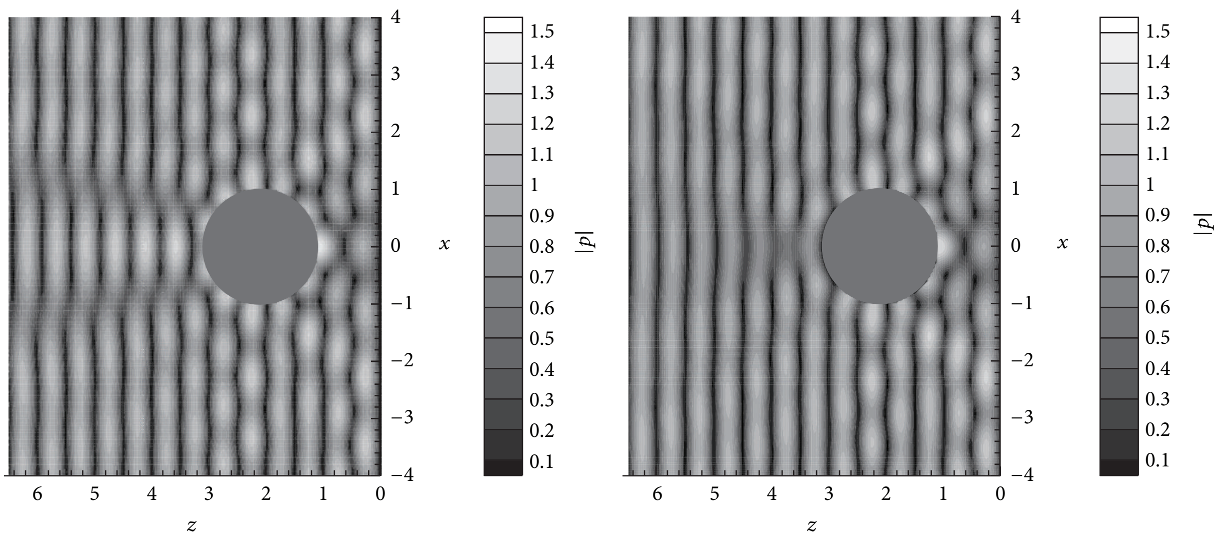
Figure 4: The frequency variation of the vertical location of the boundary between the hard and soft zones of the sphere. Zero location means the boundary is at the sphere's centre. The location of the boundary was optimised to minimise the scattered acoustic power and is plotted for when the sphere is (a) in free space, (b) its centre is 2.1 m away from a free surface, and (c) 2.1 m away from a hard ground. The rest of the conditions are as in Figure 3.

Figure 7. The sphere still causes ripples in the wave fronts with a more pronounced V shape disturbance upstream of the sphere. The soft-hard configuration was found to reduce better the scattered acoustic power for the sphere near a hard ground and at a frequency of 1500 Hz. Thus its overall near pressure amplitude field is shown in Figure 7(b). As in the free surface case, the sphere's soft zone that faces this time the hard ground coincides with a zero pressure line in the near field at about $z = 1.5$ m. The wave front lines are straighter than in the pressure field of the hard sphere seen in Figure 7(a).



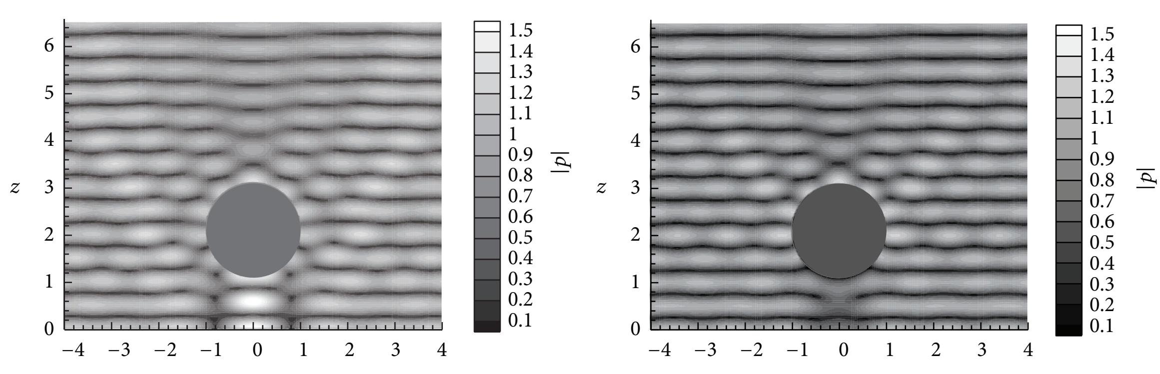
(a) (b)

FIGURE 5: Near field contours of the overall pressure amplitudes computed for (a) the fully hard sphere and (b) the optimised hard-soft Janus sphere. The sphere is in free space and the wave frequency is 1500 Hz.



(a) (b)

FIGURE 6: Near field contours of the overall pressure amplitudes computed for (a) the fully hard sphere and (b) the optimised hard-soft Janus sphere. The sphere is near a free surface located at $z = 0$ and the wave frequency is 1500 Hz.



(a) (b)

FIGURE 7: Near field contours of the overall pressure amplitudes computed for (a) the fully hard sphere and (b) the optimised soft-hard Janus sphere. The sphere is near a hard ground located at $z = 0$ and the wave frequency is 1500 Hz.

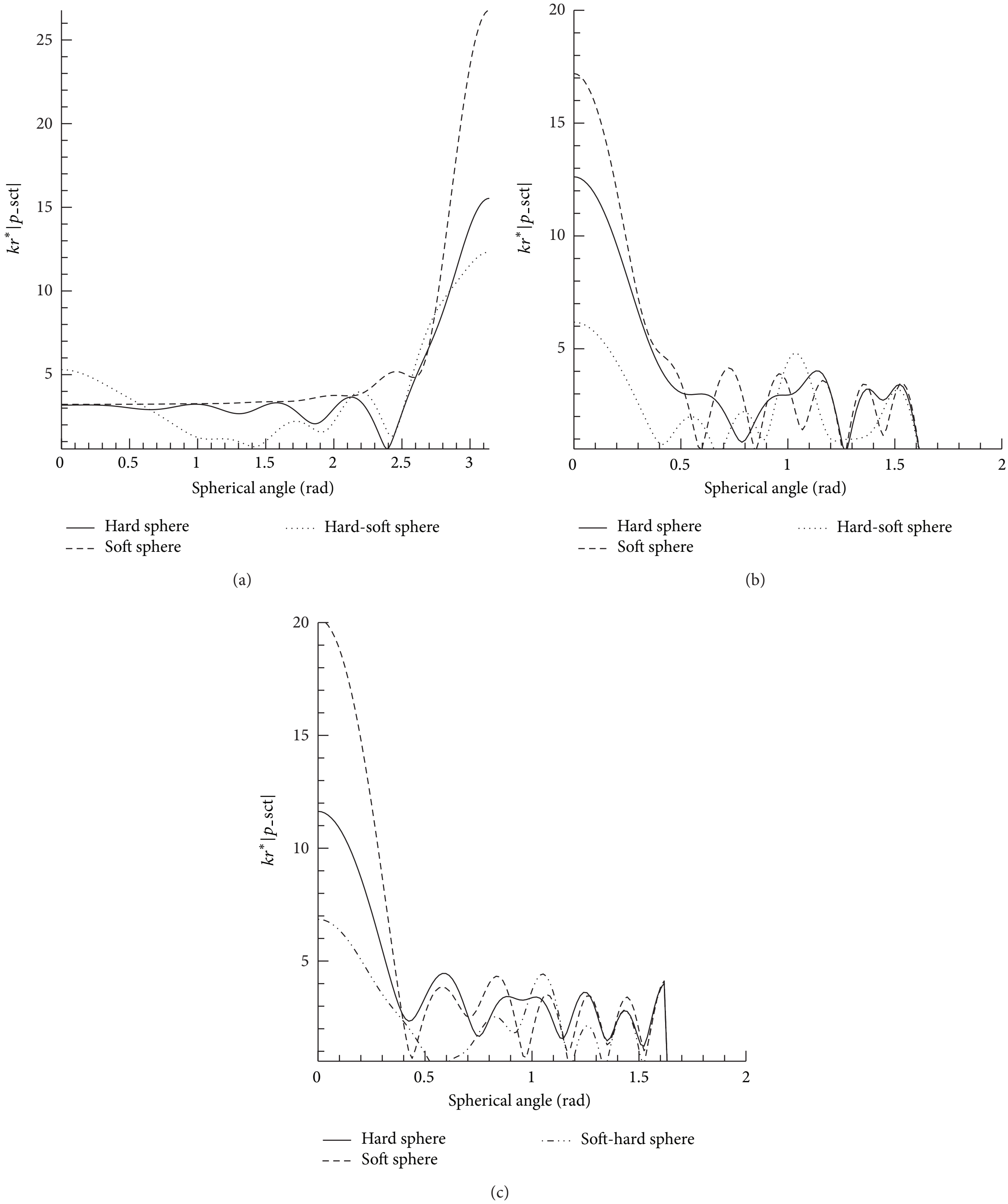


Figure 8: The directivity of the scattered far field pressure is plotted for when the sphere is in (a) free space, (b) its centre is 2.1 m away from a free surface, and (c) 2.1 m away from a hard ground. The wave frequency is 1500 Hz and the rest of the conditions are as in Figure 3.

This is particularly evident in the area between the sphere and the hard ground.

The directivities of the scattered far sound fields are plotted in Figures 8 and 9 for the sound frequencies of 1500 Hz and 3000 Hz, respectively. The configurations of the sphere correspond to the configurations that are illustrated in Figure 3 for the scattered acoustic power's variation with the sound frequency. As in Figure 3 the soft sphere generally shows the highest directivity which is downstream at $\theta = \pi$ rad for the free space cases of Figures 8(a) and 9(a).

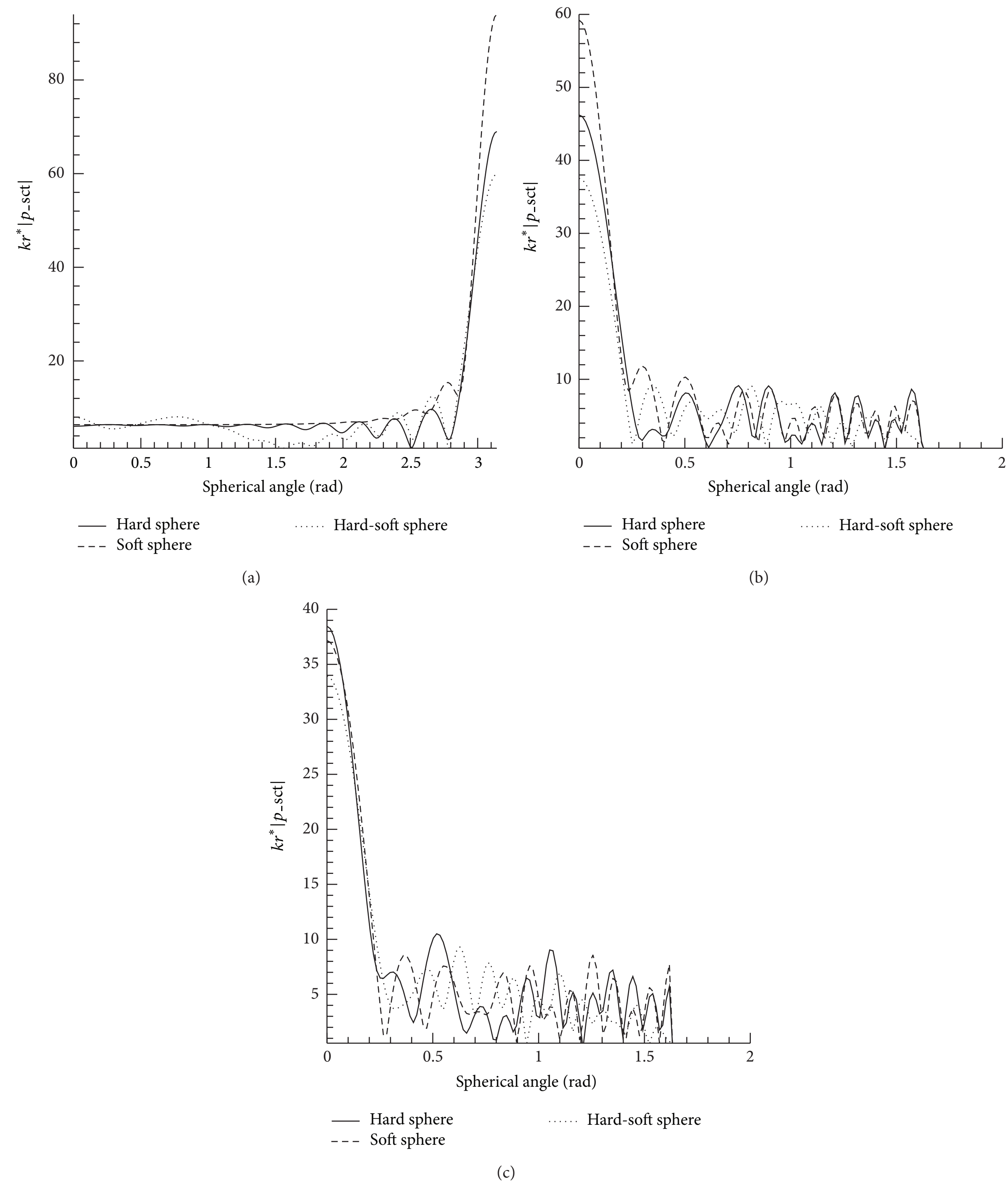


FIGURE 9: The directivity of the scattered far field pressure, which is plotted for when the sphere is in (a) free space, (b) its centre is 2.1 m away from a free surface, and (c) 2.1 m away from a hard ground. The wave frequency is 3000 Hz and the rest of the conditions are as in Figure 3.

This means the highest disturbance in the sound field due to the sphere is at the wake downstream of the sphere. The optimised hard-soft sphere shows a mild reduction in the downstream directivity for the free-space case and some reduction at the sideline directivity around $\theta = \pi/2$ rad. However, the upstream directivity around $\theta = 0$ actually increases due to this Janus sphere type. It corresponds to the higher contour levels seen in the near pressure field of Figure 5(b). This is not a favourable outcome if one seeks reducing the sphere's acoustic detectability as it is likely that the sound receiver is placed far upstream of the sphere as the sound source is.

On the other hand, the hard-soft and soft-hard spheres show significant reduction in the upstream directivity for when the sphere is near the free surface or the hard ground, respectively, as can be seen in Figures 8(b) and 8(c) for the sound frequency of 1500 Hz. This is a favourable outcome if one seeks to use the Janus sphere concept in order to reduce the sphere detectability. However, as the sound frequency increases to 3000 Hz, the reduction in the upstream directivity as relative to the hard sphere ceases to be significant as can be seen in Figures 9(b) and 9(c), showing the frequency limitation of the concept of the Janus sphere type in affecting the sound scattering.

4. Summary

Sound scattering by a Janus sphere type having two surface zones, a hard surface of infinite acoustic impedance and a soft surface of zero acoustic impedance, was investigated assuming linear acoustics. The equivalent source method as based on spherical harmonics was used to carry the computations for a sphere located in free space, near a free surface, and near a hard ground. The sphere was subject to a planar monochromatic incoming sound wave; that is, its sound source was assumed to be in the far field. The effect of the free surface or the hard ground was modelled using the image method where a mirror sphere was placed in an opposite location beyond the free surface or the hard ground. The incoming sound wave was taken as propagating normal to the free surface or the hard ground. This means that in the case of acoustic detection the sound source and receiver are located at the same place and thus the sound wave will propagate normal to the interface surface to maximise reflection back.

Low sound frequencies of 500 Hz to 5000 Hz were investigated for an ambient speed of sound of 1500 m/s as of fresh water. The sphere's radius was of 1 m. It was found that the number of surface elements had to be much larger than the number of spherical modes in order to avoid spurious results, particularly for the Janus sphere type. Solution verifications were pursued against known solutions of the full hard and soft spheres in free space and by checking the solutions to fulfil the Helmholtz equation and produce the expected results near the free surface and the hard ground.

The Janus sphere type was found to be effective in reducing the scattered acoustic power by up to 50% as compared to the power scattered by the hard sphere near a free surface or a hard ground. That reduction was achieved using a hard-soft sphere near a free surface where the soft zone faced the incoming wave and using a soft-hard sphere near a hard ground where the hard zone faced the incoming wave. Thus the acoustic scattering of the Janus sphere was masked within that of the interface surface. In both cases the sizes of the hard and soft zones had to be optimised in order to achieve the reduction in the sound scattering, which led to the hard zone to be much larger than the soft zone. The soft zone's boundary with the hard zone coincided with a line of zero pressure of the standing wave caused by the free surface or the hard ground. This further points to the masking effect of the Janus sphere within the sound field reflected by the free surface or the hard ground. The sphere's centre was located 2.1 m away from the interface surface and thus at frequencies higher than 3000 Hz; the effect of that surface diminished as well as the reduction in the sound scattering that resembled more the mild reduction was achieved for the free space case. Higher reduction in sound scattering was recorded for the Janus sphere in free space as the frequency decreased. This was attributed to the sphere becoming more a compact scatterer and thus an optimised configuration of the hard and soft surfaces could yield an overall acoustic impedance closer to that of the surrounding medium.

Most of the sound-scattering reduction for when the sphere was near the interface surface was achieved in the far field's upstream directivity. This is a favourable outcome if this method of a Janus sphere is to be considered to reduce acoustic detectability. On the other hand most of the mild sound-scattering reduction of up to 20% for when the sphere was in free space was achieved in the far field's downstream directivity, while actually yielding a mild increase in the upstream directivity. Therefore the Janus sphere cannot be considered as effective for reducing acoustic detectability in free space unlike near a free surface or near a hard ground, but it can be considered for reducing mildly the acoustic wake behind that sphere. In that case the hard-soft sphere configuration should be used, where the soft zone faces the incoming sound wave. In all cases, optimisation of the zones' sizes is required as the sound frequency is varied. Thus material technology such as shape memory alloys is needed in order to implement the proposed approach of reducing sound scattering.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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