Near-wall hydrodynamic interactions between a settling sphere and a wall

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Abstract. The near-wall dynamics of a sphere is experimentally resolved at microscale using a specially designed interferometry-related device. The millimeter size sphere, settling in a viscous oil towards a horizontal wall, is used as a reflector. The accuracy on the sphere displacement is smaller than 0.2 µm. Since its first implementation, this technique has been used to investigate various issues related to near-wall hydrodynamics. This presentation focuses on two recent developments of this device. In the first case of a sphere entering the near-wall region with a Reynolds number of order unity, it is shown how the dynamics of the sphere is modified by small inertia effects. In the second case, if a textured wall with microscopic periodic grooves is used, the velocity of the sphere increases, as compared to the velocity near a "smooth" wall. This velocity enhancement is measured accurately and correlated to the texture geometry. The results are useful for specifying effective boundary conditions at microscale, with possible applications in the field of microfluidics.

1. Introduction

The flows of suspensions are of wide interest in industrial applications and natural phenomena. The case of particles interacting with walls is very important for specifying the boundary conditions in particulate two-phase flows. Recently, these boundary-related problems have received a renewed attention with the development of microfluidic devices. However, their complete understanding is still lacking. This paper illustrates how the near-wall dynamics of a sphere can be experimentally resolved using an interferometer device (Fig. 1), in which a millimeter size sphere, settling in viscous oil towards a horizontal wall, is used as a reflector. The accuracy on the displacement of the sphere is smaller than 0.2 µm. Since its early implementation [1, 2], this technique has been used to tackle various issues related to hydrodynamic interactions with walls [3, 4]. Here, the focus is on the region near to the wall, with sphere-to-wall distance, h, restricted to a small fraction of the sphere radius, a: typically h ≤ 0.02a. In that region, the drag on a sphere moving with velocity \( V(h) \) towards the wall has been calculated exactly, in the absence of fluid inertia, as a function of dimensionless gap h/a, and reads [5]:

\[
F_C = 6\pi \mu a V \left( \frac{a}{h} + \frac{1}{5} \ln \left[ \frac{a}{h} \right] + 0.9713 \right)
\]

where \( \mu \) is the fluid dynamic viscosity. Eq. (1) reflects the rapid increase in drag as the distance between sphere and wall decreases. It is only valid for \( h \leq 0.3a \). For smaller gaps (\( h \leq 0.01a \),...
Figure 1. Sketch of the experimental set-up: sphere in the close vicinity of a surface (left), here a model striped surface, the distance $h$ is measured from the contact with the top of the stripes. Interferometric device (right), mirror M5 is removed in case of the approach of a smooth (glass) wall. Bottom: recorded signal for a sphere approaching a smooth wall (left) and a striped wall (right) at small Reynolds number. The time unit and origin of times are arbitrary. The approach to the wall occurs from left to right of the signal-time panel.

Eq. (1) reduces to the lubrication drag force (Taylor’s formula):

$$F_T = \frac{6\pi\mu a^2 V}{h}$$

In settling experiments, in the absence of particle inertia, the drag force on the sphere is a constant equal to gravity forces, that is in turn also equal to the Stokes drag $F_{St} = 6\pi\mu a V_{St}$, where $V_{St}$ is the Stokes velocity (terminal sphere velocity in an unbounded fluid). Therefore, the velocity $V_C(h)$ under the action of a constant buoyancy force given by Eq.(1), is expected to read:

$$\frac{V_C(h)}{V_{St}} = 1/(\frac{a}{h} + \frac{1}{5} \ln \left[\frac{a}{h}\right] + 0.9713)$$

with a leading term equal to $h/a$. Eq.(3) is experimentally verified in the reference case of a (smooth) sphere approaching a quasi smooth-wall at small Reynolds number (Fig. 2). Note that the dimensionless velocity coincides with $h/a$ only in the very near-wall region ($h/a \leq 0.01$),
Figure 2. Dimensionless velocity versus dimensionless sphere-to-wall distance, obtained in case of a sphere approaching a smooth wall at small Reynolds number. Crosses: experimental points for a quasi-smooth wall (glass), Line: prediction from Eq.(3).

i.e the range of validity of Eq.(2).

In the following, two deviations to this reference situation will be examined. In the first case, the approach of the sphere to a (smooth) wall occurs at a Reynolds number of order unity, i.e. sphere and fluid have non-negligible inertia. In the second case, a sphere (with negligible inertia) approaches a well-defined textured surface. The fluid inertia is negligible. The texture under study consists of periodic rectangular grooves, the wavelength of which is small compared to the sphere radius.

2. Materials and procedures

2.1. Fluids and particles

The sphere settles by gravity in a fluid contained in a cylindrical vessel, with a 50 or 80 mm diameter, and a 40 mm height, towards the horizontal wall of interest. The lateral walls are made with altuglass, and the top and bottom plane walls are made of glass of optical quality. The fluids are PDMS (silicone) oils of different viscosities, of the 47V Rhodorsyl series (by Rhône-Poulenc). The physical properties at 25°C, are: density $\rho = 978 \text{ kg m}^{-3}$, and kinematic viscosity $0.1 \text{ m}^2\text{s}^{-1}$ (resp. $10^{-3} \text{ m}^2\text{s}^{-1}$) for experiments at small Reynolds number (resp. at Reynolds number of order unity). Experiments are conducted at ambient room temperature. Physical properties of the oil (viscosity, refraction index) vary slowly with temperature. The oils have a Newtonian behaviour for the shear rates under study, even in the near-wall region. The particles are spherical steel balls with density $\rho_p = 7.8 \times 10^3 \text{ kg m}^{-3}$ and diameters ranging from 5.55 mm to 14 mm. The arithmetic roughness $R_a$ of the particles, as given by manufacturer, is 0.013 $\mu\text{m}$.

2.2. Interferometry

An interferometric technique [2, 6, 7] is used to measure the displacement of the sphere at distances from the wall smaller than 1 mm. In the configuration with transparent vessel bottom, two laser beams are reflected by the top and bottom of the moving sphere. Interference fringes (circular rings) are formed, that move according to the sphere displacement. The recorded signal is the light intensity at the centre of the interference pattern. In this configuration, a signal variation from a maximum (bright fringe) to another maximum (bright fringe) is due to a displacement of the sphere equal to $\lambda/4n$, where $\lambda$ is the wavelength of the laser, and $n$ the
refraction index of the suspending fluid. Here, with a silicon oil \((n = 1.404)\) and a He-Ne laser beam \((\lambda = 632.8\text{nm})\), we have \(\lambda/4n = 0.112\mu\text{m}\). The velocity \(V(h)\) of the sphere is obtained by multiplying \(\lambda/4n\) by the frequency of the signal. For the experiments with textured surfaces, however, the experimental set-up is the same as described in [6] : only one of the laser beam is reflected by the top of the moving sphere, whereas the second beam is reflected by a (fixed) mirror at the outside of the bottom container wall. Here, the interfringe becomes equal to \(\lambda/2n\). In order to follow the faster sphere motion occurring at \(Re \cong 1\), the data acquisition system and treatment procedure were updated (for more details, see [7]). Currently, the maximum velocity that can be detected is \(100\text{mm/s}\). The signal, after opto-electronic conversion and amplification, is recorded with a high frequency electronic oscilloscope (DPO4032 from Tektronics), transferred to a PC and processed by a Matlab code for detecting its extreme values as a function of time. The spatial resolution is therefore equal to 0.112 \(\mu\text{m}\) (resp. 0.224 \(\mu\text{m}\)), for the interferences formed with two (resp. one) beam on the sphere. Fig. 1 depicts the signal evolution for a sphere arriving at a quasi-smooth wall (optical glass). The deceleration of the sphere corresponds to an increase in the period of the signal, until contact occurs. The contact position with the bottom wall \((h = 0)\) is defined at the time when the period of the signal becomes very large indicating a vanishing velocity. Note that the signal-to-noise ratio deteriorates at vanishing frequency, because the low frequency limit of the oscilloscope is reached. Finally, the velocity \(V(h)\) of the sphere is obtained for each value of the sphere-to-wall distance, \(h\), that is reconstructed from the contact position (top of the roughness or textures, respectively). The measured frequency is averaged over 7 to 8 periods, except just before the contact, where no averaging is applied in order to capture the rapid velocity variations occurring in that region.

![Figure 3.](image-url)  
**Figure 3.** Scanning electron micrograph of a micro-patterned NOA surface obtained by soft lithography (dimension of the grooves : \(e = 45\mu\text{m}, \ L = 100\mu\text{m}, \ \phi = 0.5\))

### 2.3. Soft lithography

Various surfaces with controlled texture geometry were fabricated in a clean room. In a first step, geometric shapes are transferred from a mask to a silicone (Si/SiO2) wafer coated with a photo-reticulable (SU8, MicroChem) resin, by exposure to UV, developing and hard-baking. The thickness of the film is controlled by spin coating. The size of the structures obtained in this first step are checked by mechanical profilometry. In a second step, a replica molding of the SU8 structures is obtained by soft lithography, using a thermo-reticulable PDMS (Sylgard 184). A last step is a replica of the PDMS molding by soft imprint of a photo-curable polymer,
a thiolene based resin (NOA 81, Norland optical adhesives) on glass microscope slides (to be fixed at the bottom of the vessel). This resin has a good resistance to compression, a good adhesion to glass [8]. The wetting of NOA surfaces by silicon oil is proved by deposition of a millimetric drop of oil: after complete imbibition of the textures by the oil, the contact angle reaches an equilibrium value lower than $30^\circ$. Thus, the surface can be considered as lyophilic: it is expected that the oil completely fills the grooves of the textures, without air-bubbles being trapped at the solid-oil interface.

3. Sphere-wall hydrodynamic interactions with small particle inertia

3.1. Position of the problem

Let us consider a sphere of mass $m_p$, with a density $\rho_p$ of same order as the fluid density $\rho$, settling in this fluid with a velocity such that the sphere enters the near-wall region with non-negligible inertia. Particle inertia is characterized by a Stokes number, ratio of particle inertial forces to viscous forces. Here, an impact Stokes number is defined as: $St_i = m_p V_i / (6\pi \mu a^2)$. It is based on an impact velocity, $V_i$, the terminal velocity of a sphere in an unbounded fluid at $Re \ll 1$. This terminal velocity can be estimated by using Oseen’s correction to Stokes drag $(1 + 3 Re/16)$. The corresponding impact Reynolds number, $Re_i = (2a)\rho V_i / \mu$, is then related to the impact Stokes number by: $St_i = (\rho_p / \rho) / 9 / Re_i$. This yields, for the present experimental conditions, $St_i \approx 0.9 Re_i$, so that $St_i$ is very close to $Re_i$. The range of impact Stokes and Reynolds number used in this study are $0.5 \leq St_i \leq 4.6$ and $0.6 \leq Re_i \leq 5.2$, respectively.

Note that, with these impact conditions, collision of the particle with the wall occurs without bouncing, as the critical value of Stokes number for bouncing is situated around $St_i \approx 10$ ([9]).

![Figure 4](image_url)

**Figure 4.** (a) Dimensionless velocity versus dimensionless sphere-to-wall distance, obtained in case of a sphere approaching a smooth wall at Reynolds number of order unity. Solid line: experiments at $Re_i=2.8$ (with a sphere of 10.50mm diameter settling towards a glass wall in a silicone oil of kinematic viscosity $10^{-3}m^2s^{-1}$). The arrow indicates the recovering of linear behaviour at the critical distance $h_0/a$. Dashed line: Numerical solution of Eq.(4).

(b) Critical dimensionless sphere-to-wall distance versus Stokes number. Symbols: measurements (Stokes number based on $V_0$ (squares) and on $V_i$ (circles)). Solid line: Equation $Y = 0.036/X$. Dashed line: Equation $X = ln(0.1/Y)$.

3.2. Experimental results

A typical velocity-distance curve obtained at $Re_i = 2.8$ is shown on Fig. 4(a). Two distinct regimes for the dynamics of the sphere are obtained in the near-wall region (note that the spatial
scale is the same as in Fig. 2). At the entrance of the near-wall region, the dynamics is governed by inertia, and the velocity-distance curve is non-linear, reflecting the rapid deceleration of the sphere under the action of viscous forces. But at a smaller distance from the wall, the velocity has decreased sufficiently so that inertia becomes negligible and a linear regime is recovered just prior to contact, with a velocity proportional to $h/a$. A linear regression yields a characteristic velocity, $V_0$. The distance to the wall where the linear regime is recovered is denoted $h_0$. In practice, the value of $h_0$ is obtained at the distance where the relative difference between $V(h)/V_0$ and $h/a$ becomes larger than 0.03. In the case of Fig. 4(a), the following values are obtained: $V_0 = 51 \text{cm/s}$ and $h_0 = 40 \mu\text{m}$. Increasing the impact Reynolds number, and hence the characteristic velocity $V_0$, the spatial extension of the linear regime reduces. The smallest value of $h_0$ that could be measured with the experimental device is $h_0 = 10 \mu\text{m}$, and was obtained for $St_i = 4.6$, the largest impact Stokes number used in this study.

3.3. Discussion
A simple mechanical model has been developed in [7] to describe the motion of the sphere in the near-wall region, taking into account its inertia. Added mass is neglected, as it is not relevant for Reynolds numbers of order unity, except for times smaller than the time of diffusion of vorticity, which is not the case here. The difficult part in that model is that currently, no theoretical expression exists for the drag on the sphere that would account for small inertia effects of the fluid. So, an ad-hoc drag force is used, that fits to the linear regime found experimentally, in which the velocity is proportional to a characteristic velocity $V_0$. This drag is obtained from Eq.(2) corrected by the ratio $V_{St}/V_0$. Therefore, with $V(h) > 0$ pointing towards the wall, the dimensionless equation of motion reads:

$$-St_0 \frac{d^2 \varepsilon}{d\tau^2} = \frac{1}{\varepsilon} \frac{d\varepsilon}{d\tau} + 1$$  \hspace{1cm} (4)

where $\varepsilon = h/a$, $\tau$ is time divided by $a/V_0$ (so that $V(h)/V_0 = -d\varepsilon/d\tau$), and $St_0$ is a particle Stokes number based on the velocity $V_0$:

$$St_0 = \frac{\rho_p V_0^2}{(\rho_p - \rho)ga}$$  \hspace{1cm} (5)

Neglecting gravity with respect to inertia, Eq.(4) yields an exponential decreasing of velocity with distance, the same as described in earlier works dealing with elasto-hydrodynamic collision ([10, 11]):

$$\frac{V(\varepsilon)}{V_i} = \frac{V_1}{V_i} + \frac{1}{St_i} \ln \frac{\varepsilon}{\varepsilon_1}$$  \hspace{1cm} (6)

where $V_1$ is a value of $V(h)$ at the normalized distance $\varepsilon_1$. Note that in Eq.(6), impact parameters $V_i$ and $St_i$ are used.

Remarkably, a linear variation of the velocity with distance can be obtained from Eq.(4), but at a critical distance to the wall, $\varepsilon_0$, that is sufficiently small, so that inertia becomes negligible compared to gravity. Therefore, $\varepsilon_0$ verifies the condition: $\varepsilon_0 \ll 1/St_0$. Solving Eq.(4) numerically, with experimental initial conditions at the entrance of the near-wall region, gives an excellent agreement with the experimental curve, as illustrated in Fig. 4(a), not only for the linear part of the curve, as expected from the ad-hoc drag force, but also for the non-linear part, with a correct description of the sharp transition between the two regions. This indicates that the postulate made for the drag modified for fluid inertia, is correct in the entire near-wall region. On Fig. 4(b), the values of the Stokes number, $St_0$, are reported as a function of the spatial
extension of linear region, $h_0/a$, obtained from experimental velocity curves. The results can be nicely fitted by the equation $St_0 = 0.036/\varepsilon_0$, indicating that the condition for $\varepsilon_0$ predicted by the model is correct. On the same graph, the variations of the impact Stokes number, $St_i$, are plotted also as a function of $h_0/a$, and fitted by the equation $St_i = \ln(0.1/\varepsilon_0)$. The use of this logarithmic fit comes from the force balance (inertia vs lubrication drag) that holds for $1/St_0 \ll \varepsilon \ll 1$, yielding Eq.(6). The critical distance can indeed be roughly estimated as the distance $\varepsilon$ for which $V(\varepsilon)$ vanishes in Eq.(6). The equation $St_i = \ln(0.1/\varepsilon_0)$, that gives the best agreement with the data, corresponds to a velocity $V_i$ equal to $V_i$ at $\varepsilon_1 = 0.1$ (this impact velocity $V_i$ resulting from the balance between drag force and buoyancy forces for $\varepsilon \gg 1$). This fit is essentially a guide for the eyes, showing that extrapolation to smaller critical distances than measured in this work, would yield an impact Stokes number that is close to the value 10, the critical value for bouncing transition [9].

4. Hydrodynamic interactions between a sphere and a textured wall

4.1. Position of the problem

Eq. (2) predicts an infinite drag force in the limit $h \to 0$. In practice, this model breaks down for various reasons [12, 13]. In particular, real surfaces are never perfectly smooth, so that the presence of roughness at the microscopic scale, modifies the drainage of the fluid squeezed between the sphere and the plane. Thus, rough surfaces make contact in a finite time. This physical importance of roughness has motivated several theoretical and experimental studies [14]. Measurement of the far-field motion of a sphere towards a periodic corrugated wall showed an increase of velocity as compared to the case of a smooth wall [6]. Recently, a decrease in hydrodynamic resistance compared to Taylor’s formula was observed in the case of an aqueous film squeezed between randomly rough surfaces using an AFM-related device [15]. In the present work, experiments are performed in the case of a smooth sphere settling towards an anisotropic textured surfaces, with the textures having the form of periodic longitudinal grooves (stripes), such as depicted in Fig. 3. Geometrical parameters of the grooves (spacing $\delta$, and wavelength $L$), are systematically varied, in order to cover a broad range of $\phi = \delta/L$, the area fraction of the liquid-liquid interface at the top of the grooves. The groove height $e$ is of the order of 50 $\mu$m.

4.2. Experimental results

In Fig. 5(a), dimensionless velocities measured for spheres having different diameters, in the vicinity of the same textured surface (with following groove dimensions: $e = 42$ $\mu$m, $L = 200$ $\mu$m, and $\phi = 0.5$), are plotted as a function of dimensionless sphere-to-wall distance $h/a$. The experimental velocity is made dimensionless using the Stokes velocity $V_{St}$, obtained for each experiments by fitting experimental curves in the far-field to Eq.(3). Note that this procedure yields a value of $V_{St}$ which does not need an independent measure of the fluid viscosity. The Stokes velocity obtained for the diameters 5, 7 and 8 mm is: 0.83, 1.77 and 2.32 mm/s, respectively. The case of a smooth wall is also plotted as a reference curve. The dimensionless velocity measured near the textured wall deviates from the reference curve, and is significantly above it. This increase of sphere velocity near the textured wall can be explained by the fact that the fluid, squeezed between the sphere and the wall, is able to escape through the grooves of the textures. The velocity curves in Fig. 5a, show also that the sphere decelerates abruptly on a short distance (a few number of $\lambda/2n$) before stopping by making a contact with the top of the textures (see also Fig. 1).

In the coordinate systems of Fig.5(a), different curves are obtained for each sphere radius, with a larger mobility for the smallest radius. This indicates that here, the Stokes velocity and the sphere radius are not the relevant scales in the near-wall region, because the textures
Figure 5. (a) Dimensionless velocity vs $h/a$, measured (continuous lines) for spheres of different diameters approaching the same striped wall ($e = 45 \ \mu m$, $L = 200 \ \mu m$, $\phi = 0.5$) ; from top to bottom : $2a = 5, 7$ and $8 \ \text{mm}$. Dashed line : prediction for a smooth wall (Eq. 3).
(b) Correction to drag obtained from the same measurements (squares) as in (a), and predicted (dashed line) by the shift model (Eq. 9) with $s = 9 \ \mu m$.

introduce other characteristic lengths. In view of this, we evaluate the ratio :

$$f^*(h) = \frac{V_C(a,h)}{V(a,h)}$$

where, for a given sphere radius, $V_C(a,h)$ is the velocity at the distance $h$ from a smooth wall (from Eq.3), and $V(a,h)$ the velocity measured at the same distance but from a textured wall. This ratio is plotted on Fig. 5(b), as a function of the distance normalized by $L$, the wavelength of the textures (here, $L = 200 \ \mu m$ in all 3 experiments), in semi-Log scale. Then, all measurements obtained at different sphere diameters collapse into a single curve. As a consequence, the function $f^*(h)$ is, for a given texture geometry, only sensitive to the sphere-to-wall distance. Note that $f^*(h)$ coincides (in the absence of inertia) with the correction to drag force near a smooth wall, $F_C(a,h)$, that is introduced by the textures. In other words, $f^*(h) = F(a,h)/F_C(a,h)$, and would be obtained by measuring the drag $F(a,h)$ on a sphere moving at constant driven velocity towards the textured wall [15]. In the following, $f^*(h)$ will be interpreted in terms of correction to drag force. It is seen on Fig. 5(b) that $f^*(h)$ is close to unity at large distances, i.e the drag force is the same as for a smooth wall, however it decreases significantly as $h$ becomes of the order of $L$ and smaller. Finally, it vanishes at contact.

In Fig. 6, various groove sizes are used, with approximately the same height $e = 42 - 45 \ \mu m$, but different $L$ and different $\phi$. It can be seen that for a given $L$, the liquid area fraction $\phi$ is a key parameter controlling not only the shapes of the $f^*(h)$ curves, but also the intensity of drag reduction : at a given distance, drag reduction (smaller value of $f^*$) is promoted by a larger liquid area fraction. In Fig. 6(c) shows an example of two textures having the same $\phi$ but different $L$. The re-scaling of the distance $h$ by the texture wavelength $L$ gives here a remarkable collapsing of the two $f^*$ curves.

4.3. Discussion
It is well known (for a review see [6] and references therein) that a shear flow along a periodically corrugated wall is equivalent to a shear-flow near an equivalent smooth plane, that is shifted down from the top of the corrugations. These equivalent smooth plane and associated "shift
Figure 6. Correction to drag vs $h/L$, measured for different striped walls of nearly same height ($e = 42 \pm 45 \ \mu m$). Continuous lines : measurements. Dashed lines : shift model (Eq.9) with values of $s$ indicated in each case.

(a) Same $L = 150 \ \mu m$, $\phi = 0.33$ (left, $s = 4.2 \ \mu m$) and $\phi = 0.66$ (right, $s = 15 \ \mu m$)
(b) Same $L = 250 \ \mu m$, $\phi = 0.1$ (left, $s = 0.5 \ \mu m$) and $\phi = 0.9$ (right, $s = 28.5 \ \mu m$)
(c) Same $\phi = 0.5$, $L = 200$ and $100 \ \mu m$ ($s = 9 \ \mu m$ and $s = 5 \ \mu m$, respectively).

length” result from averaging the flow on a scale larger than the corrugations. They are effective properties of the flow, and in that sense are distinct from the concept of hydrophobic slippage, a local property giving rise to the so-called ”slip length”. In the case of the film drainage between a sphere and a plane with periodic corrugations, the flow is the sum of two shear flows in the directions parallel and perpendicular to the corrugations. As a consequence, the following shift in drag force has been proved theoretically [6] :

$$F(h) = F_C(h + s)$$ (8)

where $s$ is the shift length, i.e. the distance from the top of the textures at which this equivalent smooth plane is shifted from the real surface. Moreover, $s$ has been shown to be the average of effective shift lengths in the directions parallel an perpendicular to the corrugations, respectively. These ideas were confirmed recently, and generalized to any type of texture geometry [16], using the formalism of tensorial slip [17], with a shift length obtained as the average of the eigenvalues of the slip tensor [16]. Using Eq. 8 together with Eq. 1 yields , at the leading order, the following correction to drag :

$$f^*(h) = \frac{F_C(h + s)}{F_C(h)} \approx \frac{h}{h + s}$$ (9)
The ratio of measured velocity to Stokes velocity, then reads:

\[
\frac{V(h)}{V_{St}} \approx \frac{h + s}{a} \approx \frac{h}{a} + \frac{s}{h} \sim \frac{h + s}{a} \tag{10}
\]

Using spheres with different radii, Eq.(10) predicts that plotting the velocity ratio versus \( h/a \) yields parallel straight lines, with \( s/a \) corresponding to the horizontal shift along the \( h/a \) axis, the smallest radius giving the largest shift. As the curves are of slope 1, they also have an intercept \( s/a \) with the \( h = 0 \) axis, in agreement with the experimental results of Fig. 5(a). Now, the value of the shift length, \( s \), depends on each texture geometry, and is obtained by fitting \( f^* \) to Eq.(9), searching the best agreement with the experimental curve in the far-field (\( h >> L \)). These fits are depicted as dashed lines in Fig. 5 and Fig. 6, showing good agreement with experiments at all distances, except very small (\( h \leq 0.01L \)). The values of \( s \) obtained by this procedure are significant compared to the groove height, remaining however smaller than it, as expected. As an example, the maximum value obtained in this study is \( s = 28.5 \mu m \), for the following groove dimensions \( e = 42 \mu m, L = 250 \mu m, \) and \( \phi = 0.9 \). At a fixed \( L \), \( s \) is increasing with increasing \( \phi \). The collapsing of the two \( f^* \) curves obtained for a same \( \phi \) but two different \( L \), indicates that \( s \) is essentially proportional to \( L \) for this value of \( \phi \).

The present results are currently complemented by varying systematically the size of the grooves, in order to correlate the value of the shift length \( s \), to the parameters (surface coverage \( \phi \), wavelength \( L \), depth \( e \) ) of the texture. Preliminary results show that \( s \) is proportional to \( e \) at fixed \( \phi \) and \( L \). A comparison with theoretical predictions for the shift length is under progress.

5. Conclusion and perspectives

This paper shows the capabilities of the interferometric device to bring new insights in the near-wall dynamics of a sphere, in two situations of current interest. The results obtained can be used for a better description of effective hydrodynamic boundary conditions, that are of special relevance for systems with size reduced to micro-scales. They also open the way to further investigations. First, concerning the textured surfaces with microgrooves, a theoretical examination of hydrodynamic interactions at distances much smaller than the groove wavelength, is required. Then, using various texture geometries (e.g. pillars), would enlarge the range of experimental results for effective boundary conditions. On another hand, studying the combined effect of sphere inertia, and wall (or sphere) textures, and increasing the particle Stokes number, would possibly bring new informations on the transition towards bouncing. Finally, using non-Newtonian fluids, the modifications brought by their non-linear flow properties to the dynamic of the sphere, could be detected, and compared to recent analytical and numerical studies on the flow of non-Newtonian fluids squeezed between a sphere and a wall [18].

Acknowledgments

I thank my collaborators François Feuillebois, Samir Yahiaoui, Cyril Lamriben, and Thibault Chastel, for their highly valuable participation at various stages of this work. I am grateful to Nicolas Lecoq for technical support and helpful remarks. The support of the "PICS 4696" cooperation agreement between CNRS (France) and PAN (Poland) is gratefully acknowledged.

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