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Interactive comment on "Inertial drag and lift forces for coarse grains on rough alluvial beds" *by* Georgios Maniatis et al.

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Comment: This manuscript is intended to quantify the dynamics of entrained sediment particles by using advanced inertial force monitoring systems. I believe this work has good contributions to this long-standing problem and it is worth being published. Overall, the materials are properly organized and relevant concepts explained concisely. I see no significant problems for its publication, but there are several minor suggestions for the authors to consider in their revision. Below, I listed my comments and suggestions as I read through the manuscript.

Reply: We want to thank the reviewer for the thorough review and the supportive comments. We set out to address all the suggestions as will hopefully become clear from our following responses.

Comment: L50-54: Regarding the Lagrangian approach, Ballio et al. (2018, “Lagrangian and Eulerian description of bed load transport”) provide a unified framework to describe sediment particle motion under different frames of reference and quantification methods. The authors may want to refer to this work and highlight their particular contributions to the topic.

Reply: This is an important aspect of our work (see also Maniatis 2016 thesis). Ballio et al. (2018) defined this problem for 1D motions. We also find the consideration of the intermittency of sediment motion from the setup of their model to be very useful. For the scale of particles and motions discussed by Ballio et al. (2018) their approach is the best available to extract Lagrangian metrics from the Eulerian domain (and vice versa). Our approach is directly relevant to this work, but it is also heavily based on the type of measurement we derive. We monitor constantly the Eulerian-Lagrangian orientation changes which gives us the chance to formalise the Lagrangian Eulerian transformations in 3D (with the quaternion multiplication). There are obvious benefits from this approach because it can be applied to all the kinematics (e.g. in theory the trajectory of the particles is fully resolved and the ensemble of trajectories, the Lagrangian, can reconstruct the sediment flux) and there is no reason for even the minimal considerations described in Ballio et al. 2018 (e.g. our operational window is in theory infinite and fixed). But we need to repeat that the measurements are not perfect and the size of particles we can use at the moment to verify that is quite large. We will include a paragraph in the discussion in order to reflect on all the above.

Comment: L58: The issue of over-prediction of transport rates was also extendedly discussed by Bunte et al. (2004, “Measurement of coarse gravel and cobble transport using portable bedload traps”) and Singh et al. (2009, “Experimental evidence for statistical scaling and intermittency in sediment transport rates”), and other related papers. The reference can be updated with these contributions.

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Reply: We accept the comment. We wanted to focus specifically on the role of particle inertia with that sentence, but referring to those articles will make the presentation more complete.

Comment: Sec. 2 (Frames of reference, rotations and IMU measurements) provides details of mathematical expressions for the conversion/transformation among different frames of reference. But Fig. 1 needs some more clarity on the specifics of these frames, e.g. (x,y,z) (rx,ry,rz),(ix,iy,iz).

This is requested by all three Reviewers. Figure 1 will be significantly revised to reflect better both the frames of reference and the experimental design.

Comment: Based on their formulation, Eq. (9) only concerns the threshold condition in the tractive mode towards downstream, and Eq. (10) the upward movement. Yet, when approaching the strictly critical condition, particle rolling, which has even lower resistance, can be the most predominant entrainment mode. The authors can consider adding an extra formula describing the rolling threshold for providing a more complete framework.

Reply: We accept the comment and we will revise accordingly. As we describe in our reply to Reviewer 2, the rolling condition in the Newton Euler model we present is defined by the sum of torques around the centre of the mass of the particle exceeding 0 (Equation 6). This sum is measured by differentiating the angular velocities derived by the gyroscope. At the same time, we know that this rotational component is negligible (in terms of force magnitude applied on the centre of mass of the particle) because it needs to be multiplied by the moment of inertia (Icm in the paper). Icm is a generally small number even for relatively large particles (for our sphere it is 0.00085 kg. m2). Finally, it is important to clarify that this rotational component is a spinning component (defined around the centre of the mass of the particle) and not an orbital component (defined around the centre of mass of a supporting particle as it is common in the literature of sediment hydraulics). Overall to address this comment we will: a) Revise

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sections 3 and 4 in order to include a formula for the rolling threshold

b) Demonstrate how much smaller the rotational component is compared to the linear component by adding the norm of tangential force in Figure 1 (for both the sphere and the ellipsoid) and

c) Add an appendix showing the same time series (derived the norm of angular velocities) at a scale that is more visible.

Comment: L234. Has the 1.5 mm uniform sand glued to surface or also movable?

Reply: No, the bed was washed before the experiments and the sand was static. Will add that in the experimental description.

Comment: Fig.2 (b) describes the change of drag forces during the noted five entrainment events. The pattern shown here, however, somewhat contradicts the impulse model mentioned later in the manuscript (e.g. L278-279). If all these five events follow exactly the impulse criterion, the events of higher magnitude should persist for a shorter duration, and vice versa, to maintain at the same impulse level. In other words, these events, very likely, represent different degrees of particle mobility and not the most extreme cases of entrainment (minimal critical impulse). I think this aspect is worth mentioning in the discussion.

Reply: The exceedance of the threshold doesn't lead always lead to entrainment. In Figure 2b, there are five events where the linear force threshold was exceeded, but entrainment (1 particle diameter dislodgement) took place only during one of them. We need to clarify that even further in the manuscript and this point has also been raised by both Reviewers 1 and 2. In this context the Reviewer is absolutely correct, the exceedances represent both pre-entrainment and entrainment vibrations and the critical impulse can only be approximated statistically as shown in Figure 4.

Comment: Sec. 5.0.2. The calculation of entrainment probability is not clear to me. Is it described as the ratio of entrainment duration to the total observation time, or the

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ratio of entrainment events to the total exceedance events observed? I assume it is the latter definition. Adding an equation will help to clarify this point.

Reply: The latter is the case (entrainment / exceedance events) but instead of using the ratio we perform a logistic regression (as also used in Maniatis et al., 2017).

Comment: L300. The scaling effects are usually attributed to the intermittency of particle motion dictated by turbulent flow structures. Yet, this sentence seems to suggest the role of physical scale between the laboratory flume and field stream. A clarification will be helpful (see discussion in Singh et al., 2009).

Reply: We intended to refer to the differences in turbulence (non-fully developed flow in the lab, developed (but still shallow) flow in the field). We will adapt material from Maniatis (2016) to explain that the flume experiments were specifically designed to address the case of particle diameter/ depth ration close to 1 and that the flow was not fully developed and clarify that we refer here to differences in coherent structures between the flume and the field.

Comment: Fig. 4(a) can be improved by using different shading colors for FD and FL, respectively.

Reply: We accept this comment and revise accordingly. Comment: L310-317. The differences in magnitude of critical drag and lift forces between this work and literature data are attributed to the particle sizes, or corresponding mass, used differently. To resolve this issue, a dimensionless quantity, e.g. FD/particle weight, FL/particle weight, can be considered for both the present work and previous reports.

Reply: This point is also raised by Reviewer 2. We are happy to de-dimensionalise using the submerged weight.

Comment: L325-332. The description of the negative lift forces can be more precise in relating to the threshold of motion conditions. Specifically, when the negative lift force appears, the probability of particle lifting reduces, and also, the resistance to the tractive movement increases via the enhanced intersurface friction.

Reply: We thank the reviewer for this observation, we are very happy to include it in the discussion despite the fact that we don't account for the surface forces in the thresholds we present in the results.

Comment: L353-357. The description of the entrainment mode of rolling can be placed in the earlier section (see the previous comment) to avoid confusion.

Reply: The comment is accepted and is going to be resolved in a previous section as suggested.

References Maniatis, G.: Eulerian-Lagrangian definition of coarse bed-load transport: theory and verification with low-cost inertial measurement units, Ph.D. thesis, University of Glasgow, 2016. Maniatis, G., Hoey, T. B., Hassan, M. A., Sventek, J., Hodge, R., Drysdale, T., and Valyrakis, M.: Calculating the explicit probability ofentrainment based on inertial acceleration measurements, Journal of Hydraulic Engineering, 143, 2017.

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