BENTHIC INTERFACE STUDIES WITH LANDERS: NEW APPROACHES TO DESIGN AND IMPLICATIONS

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Introduction

The physical and chemical properties and the behaviour of the benthic interface can not generally be predicted from first principles so must be determined empirically. The physical characteristics of the interface are such that *in-situ* determinations provide the most realistic parameter values which describe the full heterogeneity of the interfacial environment. This is especially the case where the interface properties are dominated by biological mediators or where the nature of the parameters of interest is such that they are influenced by temporal changes in stress distributions. Part of the problem is the lack of suitable tools that have minimal impact on the sediment interface/pore-water matrix and also provide appropriate measurements at the time and space scales that are most relevant to consideration of sediment-water interface questions. Aspects of these problems illustrated here are:

- Lander interface interactions and artefacts
- Impact of lander structures on flow fields and sediment using computational fluid dynamic (CFD) studies
- The CEFAS/Blackdown Sedflux lander designed to be a flexible tool for looking at the sediment water interface

Lander interface interactions

Although landers provide the best opportunity for process measurements, as lander technology moves towards autonomy and longer term measurement capability, current approaches to lander design need to improve if the results gathered are not to be contaminated by experimental artefacts created by the proximity of the lander to the sediment-water interface or its interaction with the sediment/pore-water system(Figure 1).

Materials respond differently to applied stresses. Some materials, such as water, respond immediately. Others, such as mud, respond much more slowly requiring the stress to be sustained. Because of the constraints to movement imposed by sediment porosity and permeability, pore-water can respond immediately to localised loads (i.e. lander weight) (Ref 2) but may respond slowly to local pressure gradients. This variability in response to stress can be described by a dimensionless number known as the Deborah Number (D_e), (Ref 1) relating the response time of the system to the period of the stress.

Where:

$D_e << 1$ = *material behaves as a viscous fluid*

$D_e >> 1$ = *material behaves as an elastic solid.*

Figure 1: Lander interface interactions (when on bed) CEFAS Minipod Lander - for measuring near-bed flows and suspended sediment behaviour)

Flowfield round lander produces dynamic asymmetric pressure field which can lead to pore-water migration (> few hrs)

Static loading and dynamic cyclical loading (turbulence, waves, tides, spring/neap cycles, storms) lead to pore pressure excess, pore-water migration and consolidation.

Landers bridge the interface between materials which exist in a D_e regime of less than one (the overlying fluid) and other materials (the substrate and its pore-water) for which D_e may vary from close to one to very much greater than one.

Any lander is subjected to stresses (for example tidal flows) whose amplitude varies on a range of time-scales from seconds to months. These stresses are applied to the substrate/pore-water system through the lander contact with the sediment framework and result in local changes in pore pressure. The local pressure field due to the interaction of the lander with the flow can generate persistent local pressure gradients which may induce pore-water advection.

Differing stress spectra lead to responses which are difficult to predict. Sustained, lander induced gradients in local pressure fields needs to be considered in relation to long term studies (greater than a few hours to days) of pore-water geochemistry and flux determinations.

Consideration of the various tasks required of landers juxtaposes practical considerations such as probe length or positional accuracy/repeatability with the dynamic inputs of lander arrival and the hydrodynamic impact of its continued presence. Practical engineering constraints may bring bulky lander components closer to the benthic interface than is compatible with minimising the hydrodynamic footprint of the lander. It is evident that at times lander elements may need to be near the bed whereas ideally they are best kept further away to avoid longer term impacts relating to pore-water dynamics. This has led to the concept of the Variable Proximity Lander in which the lander changes its gross vertical position relative to the interface according to the activities being undertaken. This introduces a requirement for new control strategies and facilities.

Many of these issues can be analysed using various simulation techniques for flows external to the substrate as well as multiphase simulations for the coupling of the external flow and pressure fields to the interstitial waters. Computational fluid dynamics (CFD) is one of these simulation techniques and some results of this technique are presented here.

Computational Fluid Dynamics (CFD) Applications

Computational Fluid Dynamics (CFD) is a method by which the fundamental equations for fluid flow are solved in a computer model using an iterative solution of the 3D form of the Navier -Stokes equations for fluid flow.

Initial applications of CFD to lander design characterisation are as follows

- Fully 3D simulation of a 200mm diameter cylinder and 50x50mm bar (at 30mm above a horizontal bed)
- Fully 3D simulation of a simplified (typical) "lander" assembly

These simulations are intended to give a feel for the possibilities available within the practical application of CFD techniques.

In all cases, the bed is approximated to be relatively smooth (roughness length less than 20mm) and an ambient flow (representing the tidal flow in the bottom 0.5m of the water column) as 0.3 ms^{-1}. The flow field is allowed to develop a log-profile close to the bed in these simple tests, however any known (measured) flow profile can be applied to the CFD model boundary condition.

The velocity scale of 0.000 to 0.500 ms^{-1} is common to all the subsequent velocity plots and is coloured as shown in Figure 2.

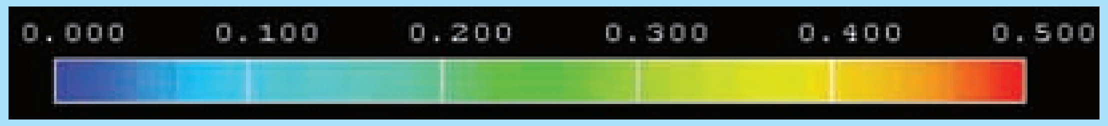

Figure 2: Velocity scale for plots

3D Simulation - Cylinder and 50 x 50 mm bar Figures 3a to 3e

This simulation shows the flow variation (accelerations), which can be expected in the region around a simple 200mm diameter cylinder and 50 x 50mm bar placed close to the bed. This is typical of a simplified arrangement of a instrument pod with an upstream support member, which could form part of a lander assembly.

Figure 3a: 3D representation of the Cylinder and Bar

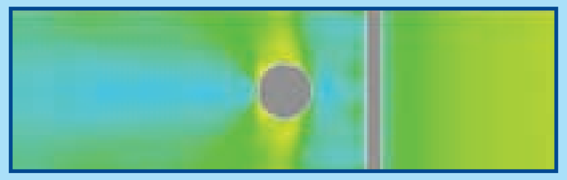

Figure 3b: Plan view of flow field 30mm above bed

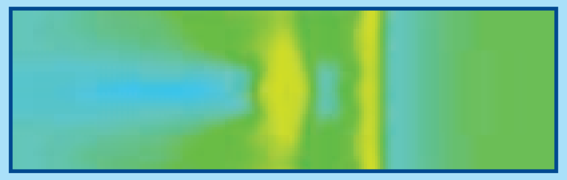

Figure 3c: Plan view of flow field 10mm above bed

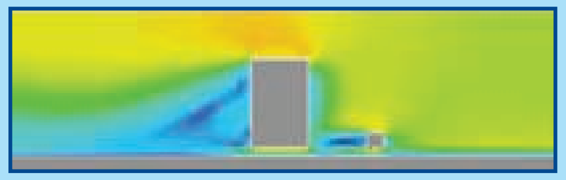

Figure 3d: Sectional view of flow field along centre-line of domain

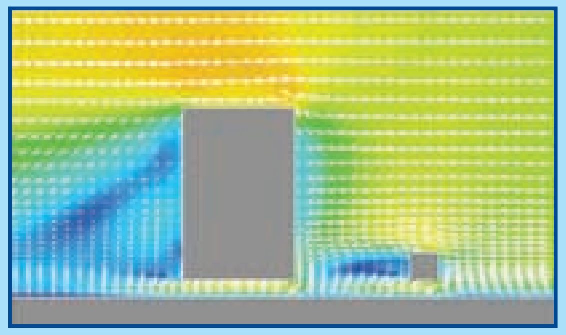

Figure 3e: Close-up sectional view of flow field with velocity vectors

Figures 3a-3e show the results from a 3D simulation as plan and sectional views through the flow domain. The CFD code predicts the flow over, around and under the obstacles in the domain and suggests areas where (when the obstacles are in close proximity to the bed) there could be some significant influence on the substrate from the measurement pods and support bar.

3D Simulation - Simplified Lander Assembly (based on Figure 4) and results Figures 5a to 5e

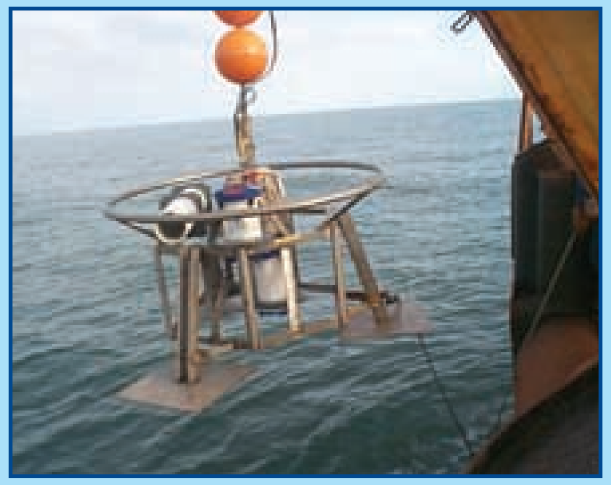

Figure 4: Simplified Lander Assembly (CEFAS ADCP frame)

Figures 5a-5e show the results of a more complex 3D model of the lander in a series of analyses. The simplified development of the instrument pods, support legs and stiffening members on the lander are clearly visible in the 3D graphical views.

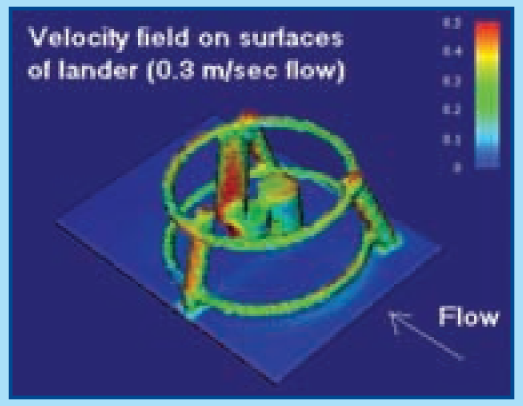

Figure 5a: Velocity Field on 3D model of lander

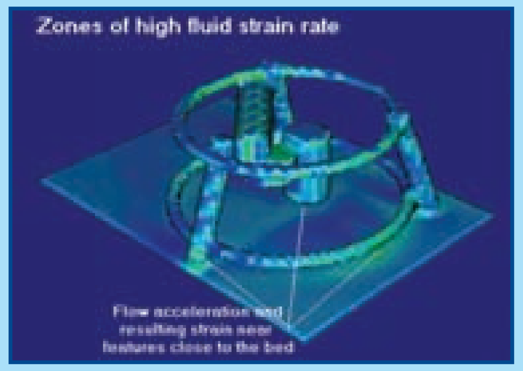

Figure 5b: Fluid strain rate on/near obstacles forming model of lander

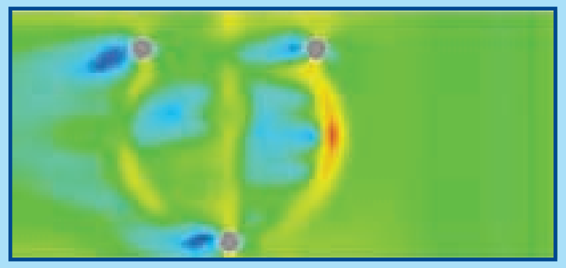

Figure 5c: Plan Velocity Field near bed below lander

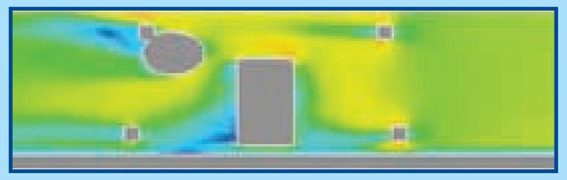

Figure 5d: Sectional Velocity Field near centre-line of lander

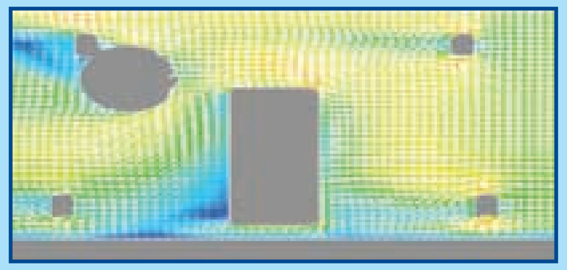

Figure 5e: Close-up on sectional Velocity Field with vectors

By draping over the lander geometry any computed flow parameter (in this case Velocity or Strain Rate) areas where flow accelerations can be expected and where re-design would perhaps be beneficial can be identified. (Figures 5a and 5b). High local strain rates result in aggregate break-up which may affect both local geochemical processes and instrument calibrations.

Looking at the model results in more detail in plan (Figure 5c and 5d) and sectional views (Figure 5e) reveals flow features developed as flow is forced around, over and under the obstacles of the lander. Wake regions, re-circulations and regions of flow acceleration can be shown and their relative increases estimated. Sustained flow and pressure gradients along the section can induce pore-water movements.

Particularly in the context of long term lander deployments this type of analysis of lander/interface/substrate interactions forms the basis of lander design and is also formative in considering control methodologies and deployment strategies.

Sedflux lander

The CEFAS/Blackdown Sedflux lander is a prototype system designed to investigate some of the measurement problems related to studies of the sediment water interface.

Incorporating a 3 axis, high accuracy positioning system it allows precise (resolution 0.05mm, repeatability 0.1mm) placement and insertion of electrodes or other probes into the sediment in a closely controlled manner for the *in-situ* study of biogeochemical processes in the upper 200mm of the sediment. Control of probe deployment can be visual, via keyboard or joystick or can be executed autonomously. At present operation can include the repetition of the deployment pattern after a specified elapse time or in response to an 'event'.

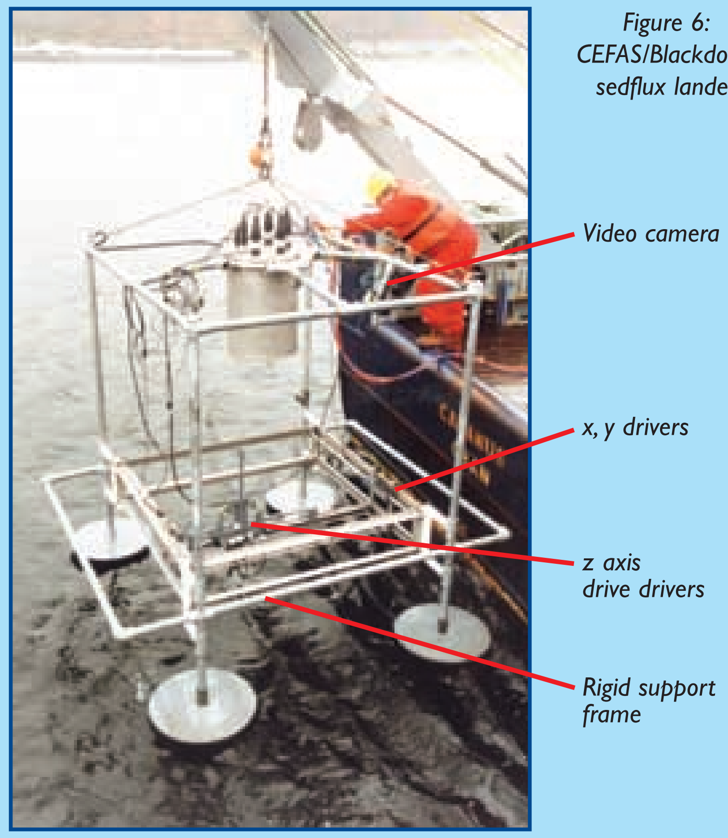

Figure 6: CEFAS/Blackdown sedflux lander

Because the properties and character of the sea bed can be very patchy, autonomous data collection controlled by time or threshold algorithms is sometimes unable to provide an adequate description of what is going on. For these reasons a new concept of visual or image based control of the temporal and spatial patterns of sensor activity has been developed. The Benthic Activity Sensor and Instrumentation Control System (BASICS) allows dynamic, image controlled, event driven, guidance of lander operations.

Upgrading of this prototype to a fully operational and autonomous instrument is being undertaken by CEFAS. This development will link closely to initiatives looking at lander/sensor impact and design and coincide with projects underway looking at the impact of disturbance on contaminant and nutrient sediment processes.

Conclusions

- The Cefas/Blackdown Sedflux lander is a prototype tool designed to provide appropriate measurements at the time and space scales that are most relevant to consideration of sediment-water interface questions.
- Landers can have immediate and longer term impacts on ambient flow fields, sediment entrainment and pore-water movements.
- The hydrodynamic interaction of the lander with the boundary and substrate can be evaluated by application of Computational Fluid Dynamics (CFD) techniques.
- These techniques can aid the optimisation of lander design and the development of deployment and operational strategies

Acknowledgements:

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