

Evaluating control algorithms for wave energy converters in an OpenFOAM wave tank

Josh Davidson



**Maynooth
University**
National University
of Ireland Maynooth

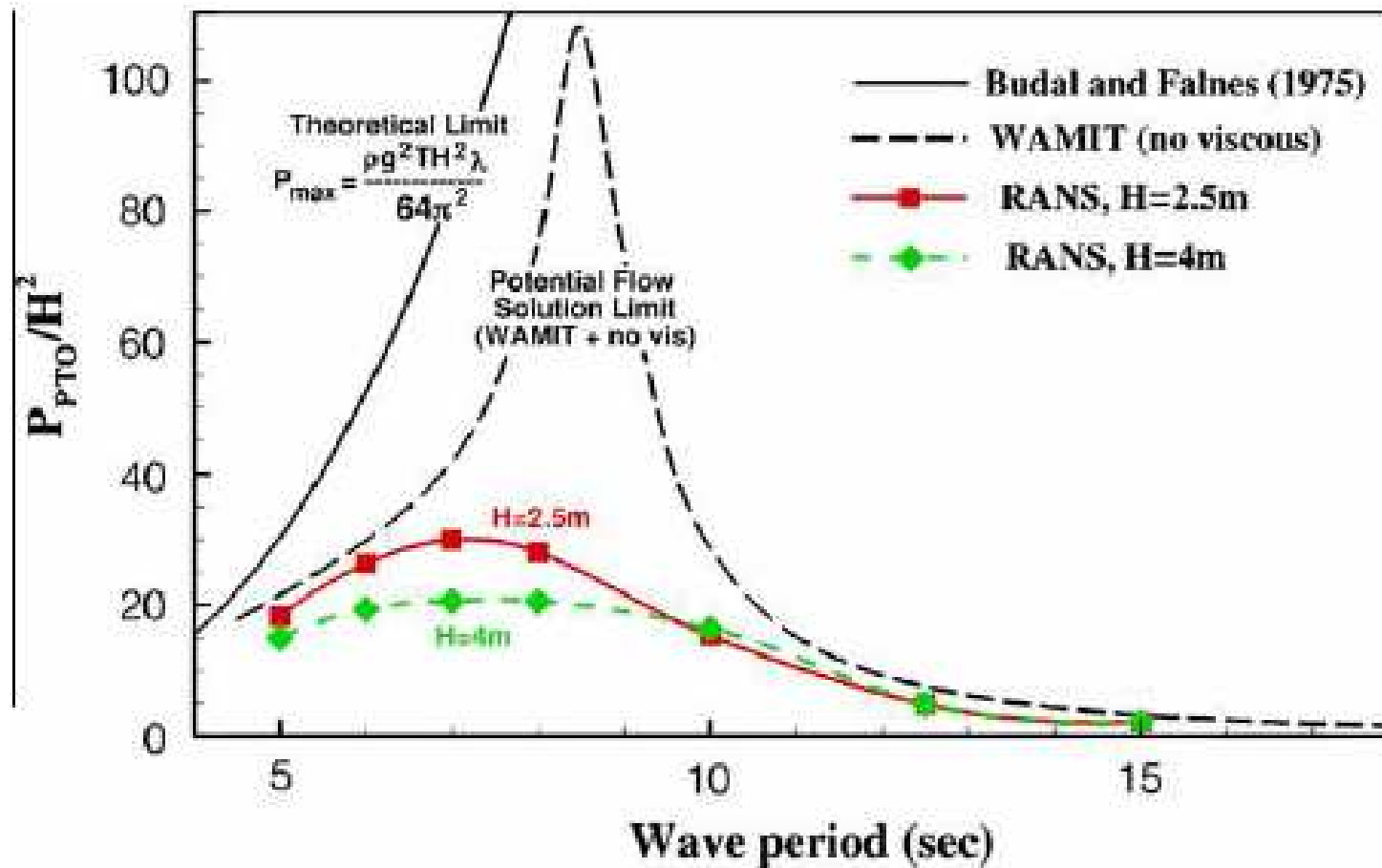
Outline

- Background
- Motivation
- OpenFOAM NWT for wave energy experiments
 - Previous uses
 - Current focus
- Controlling WECs
- Problems / my questions for you

Wave energy

- Essential development trajectory towards an economically competitive wave energy converter (WEC) is through early device experimentation and refinement, using numerical tools
- Historically, numerical analysis for WECs has been performed using velocity potential methods, which contain many linearising assumptions that are often violated for the case of wave energy
- The use of OpenFOAM for wave energy experiments has been reported in many publications in recent years, and shows promise as useful numerical tool for WEC development.

WEC simulation: CFD vs Linear hydrodynamics



* Yu and Li, Reynolds-Averaged Navier-Stokes simulation of the heave performance of a two-body floating point-absorber wave energy system, *Computers and Fluids*, 2013

OpenFOAM NWT for wave energy experiments

The OpenFOAM NWT has the following features which are useful for wave energy experiments:

- Import any WEC geometry without incurring costs involved for building prototypes.
- Any tank depth / width can be used and changed as desired.
- Can test at full scale, eliminating scaling effects.
- Wave creation and absorption
- Actuate or constrain motion in six DoF, without mechanical restraints adding parasitic effects to device dynamics (e.g. friction).
- Passively probe variables everywhere with zero measurement noise.
- Hydrodynamic force measurement.
- Viscous effects, wave breaking, green water effects, slamming loads, etc. neglected by velocity potential methods are included.

OpenFOAM NWT for wave energy experiments

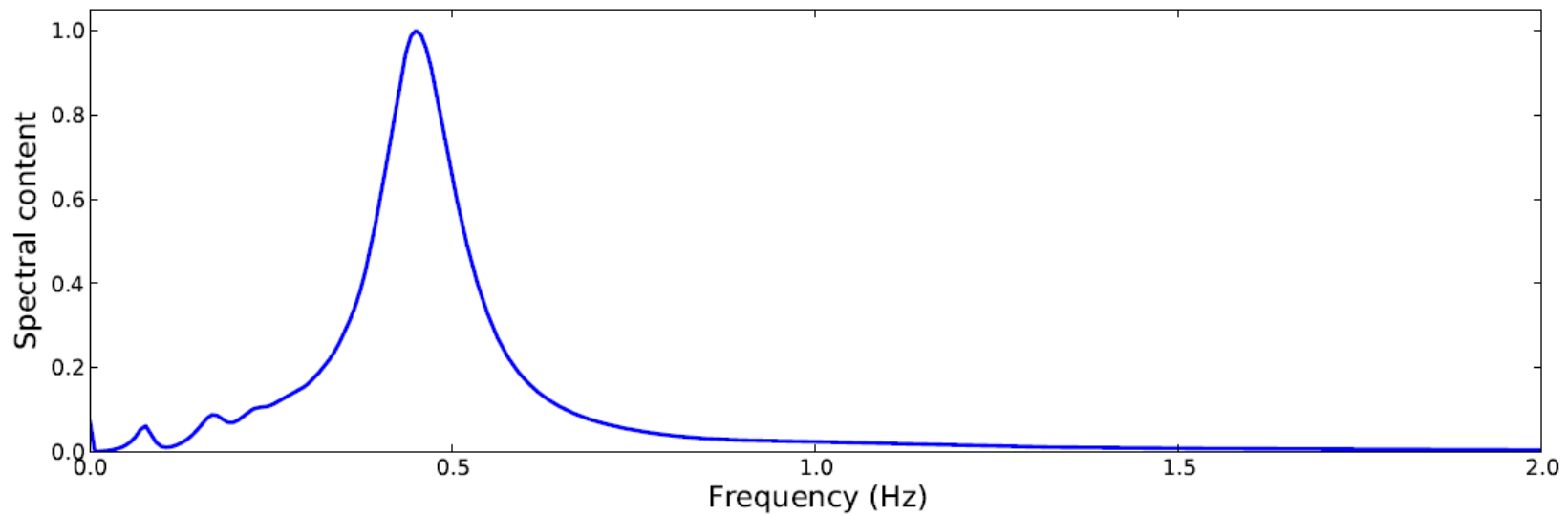
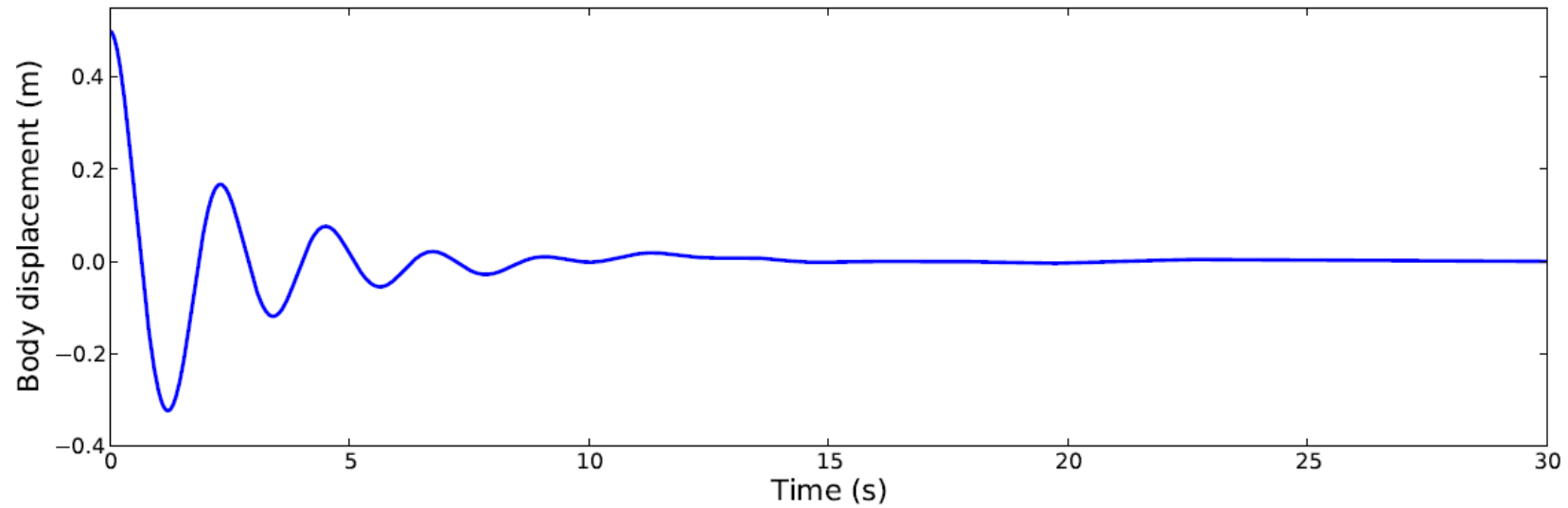
Applications

- Provide data to identify nonlinear parametric hydrodynamic models
 - System identification
 - NARX models, neural network etc
 - Ringwood, Davidson and Giorgi, “Identifying models using recorded data”, in *Numerical modelling of wave energy converters – State of the art techniques for single devices and arrays*, Elsevier, 2016
- Evaluate control algorithms
- Others...

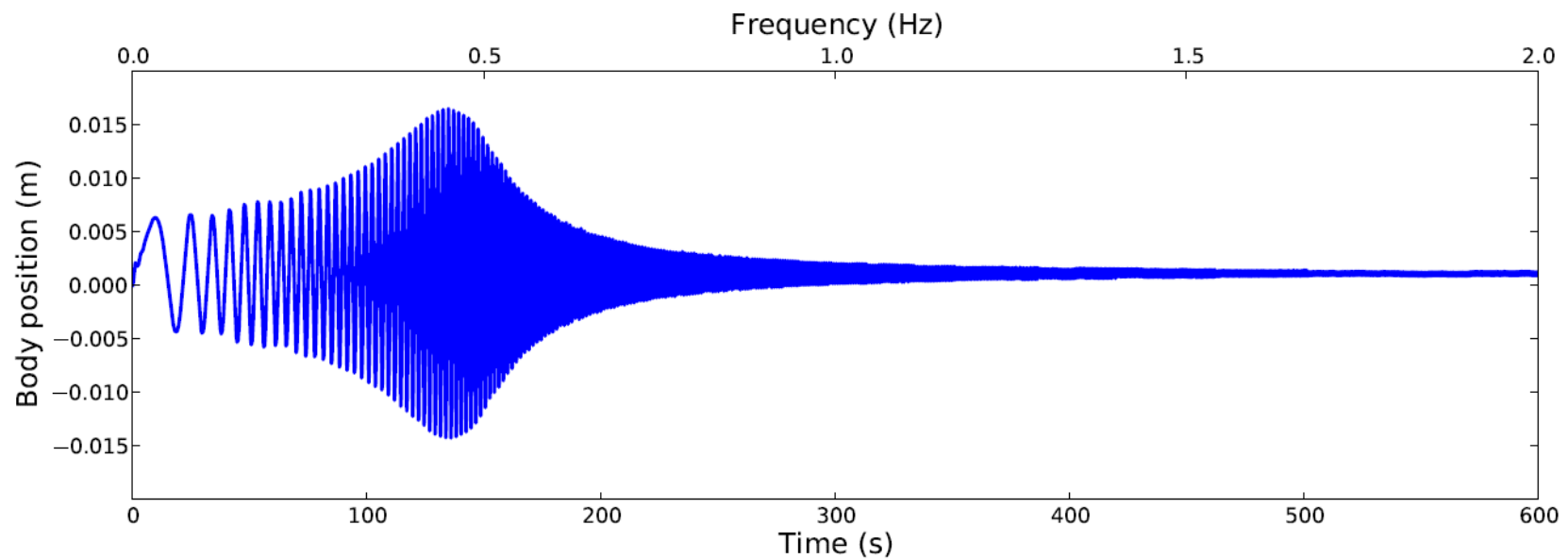
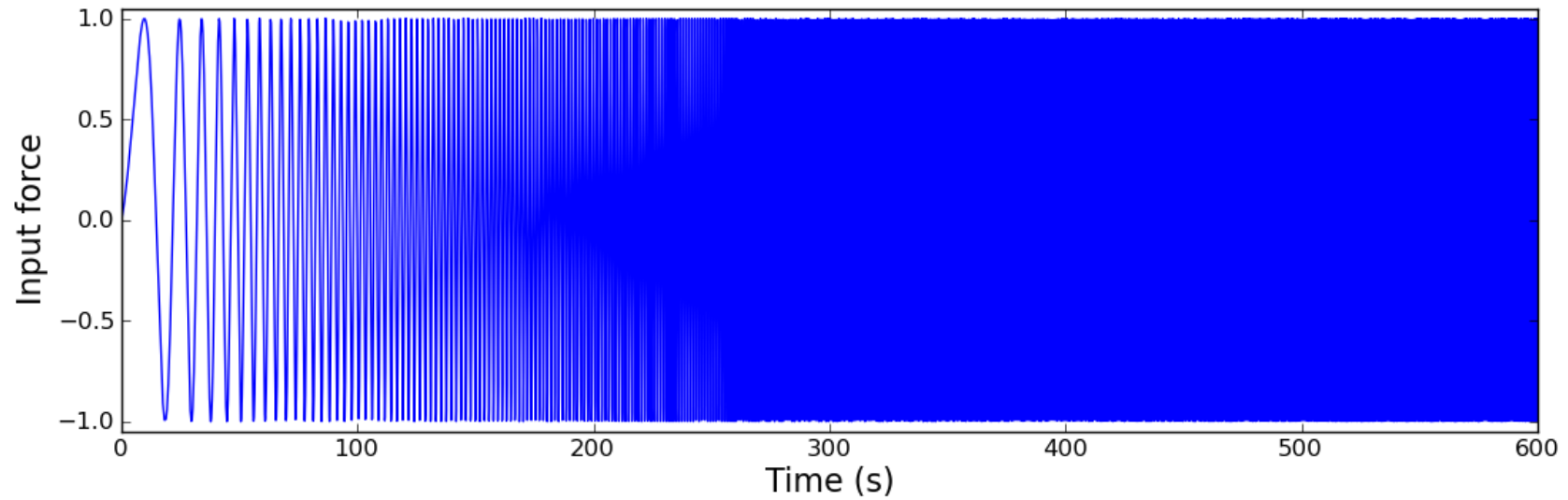
Implementation

Davidson et al , “Implementation of an OpenFOAM numerical wave tank for wave energy experiments”, in Proc 11th European Wave and Tidal Energy Conference (EWTEC) 2015

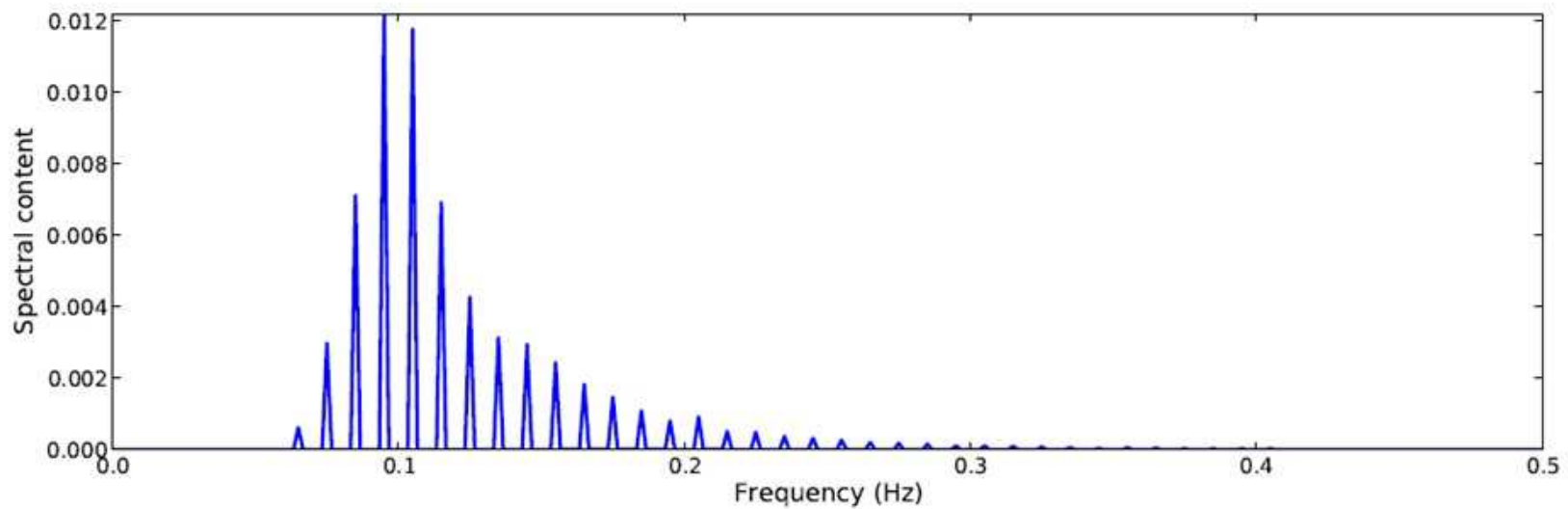
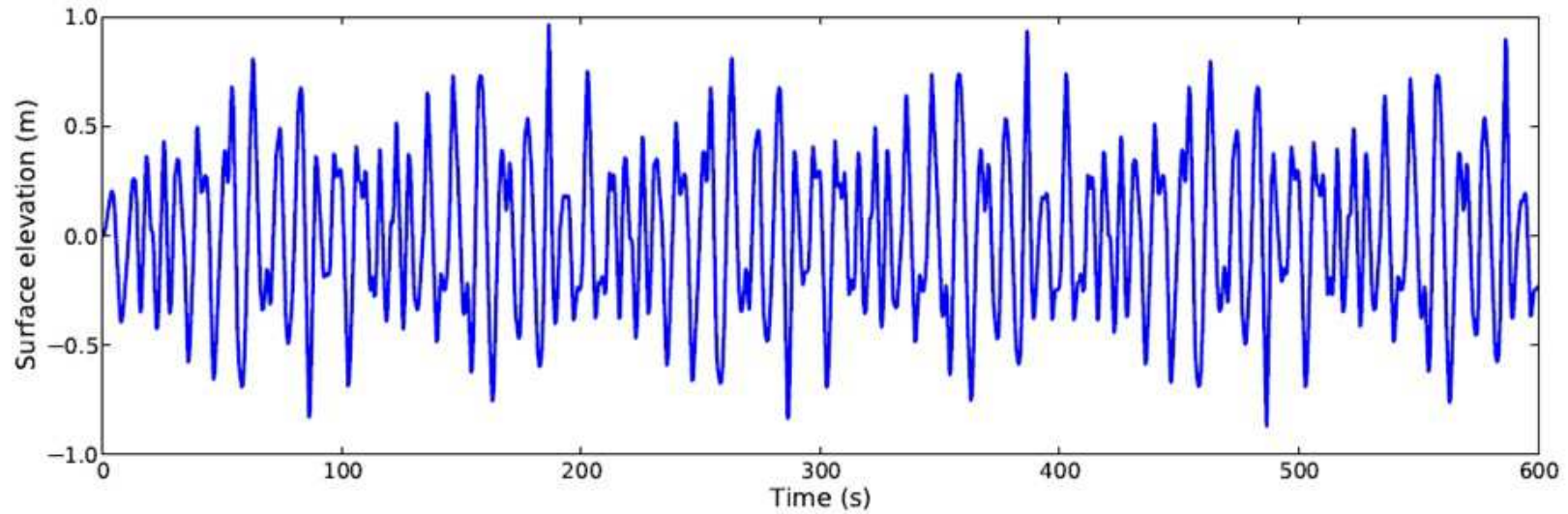
Examples – Free decay



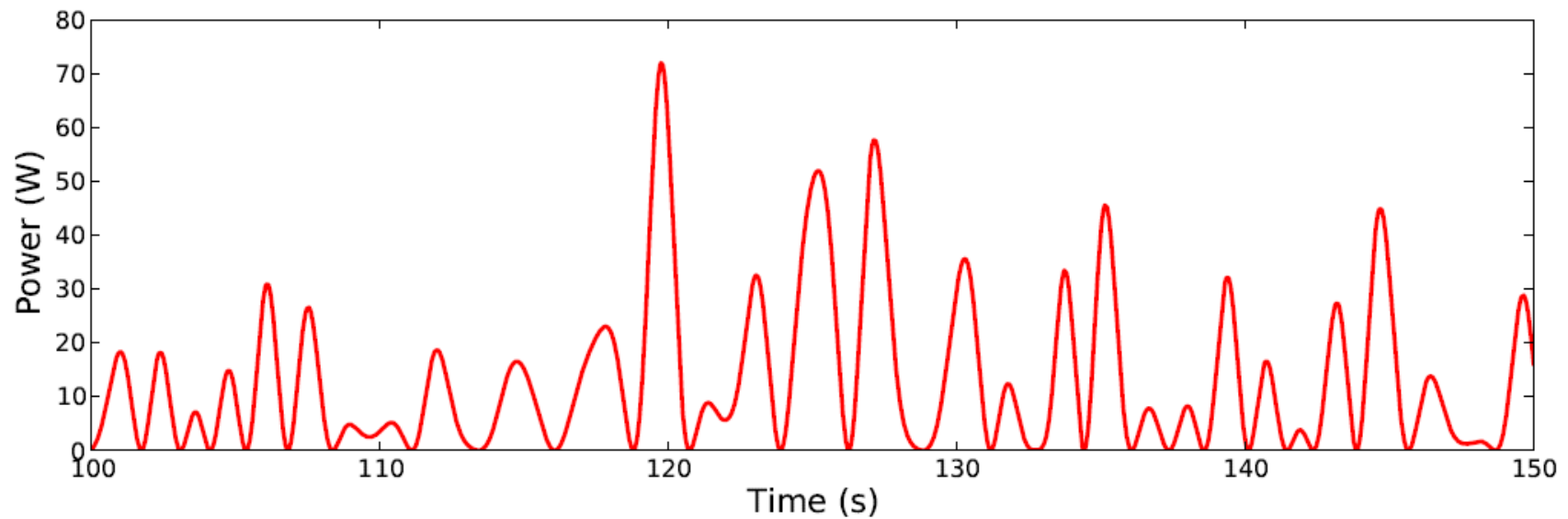
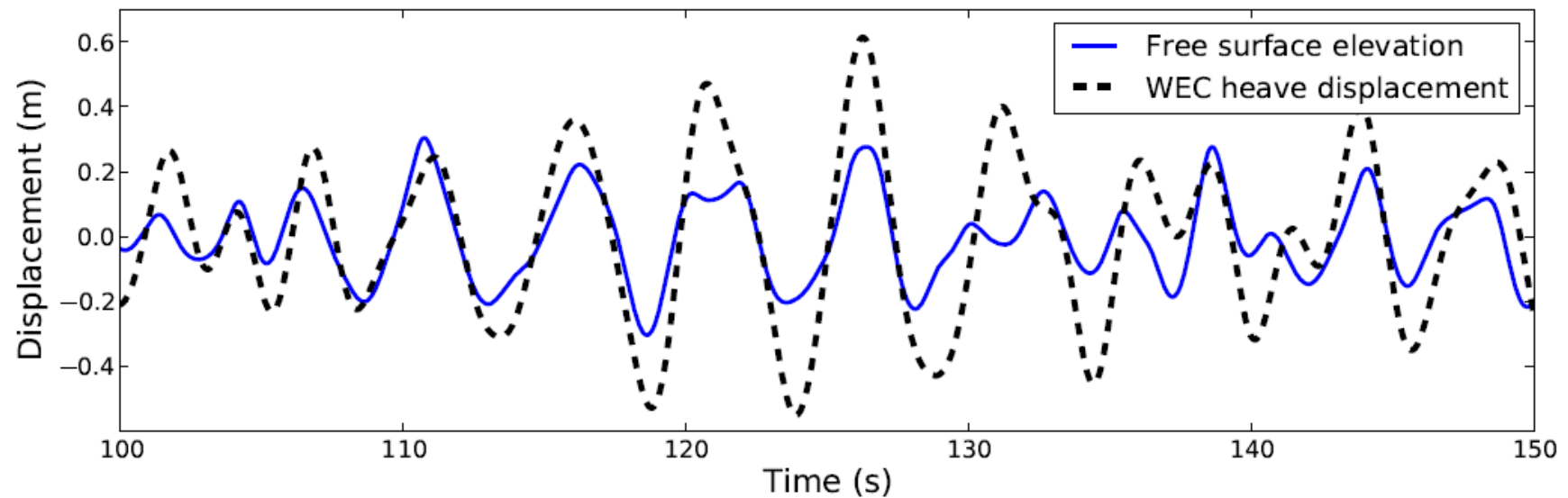
Examples – Input force



Examples – Wave creation



Examples – WEC Operation



Wave Energy Conversion

- Captured wave energy is maximised when the excitation force from the waves and the velocity of WEC are in phase, *and*
- The optimal amount of damping is provided by the power take off / generator

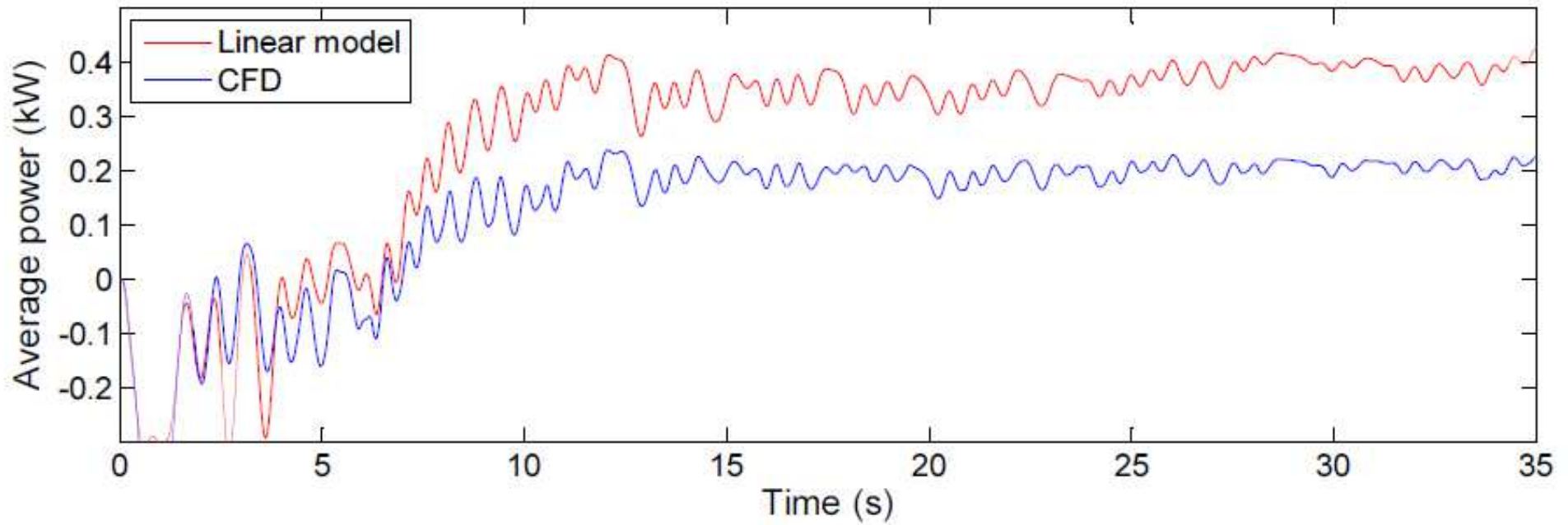
Power take-off (PTO)

- PTO converts mechanical energy into electrical energy
 - Applies a resistive force to WEC motion
 - $\text{Power} = \text{Force} \times \text{velocity}$
- Simplest PTO is a linear damper
 - $\text{Force} = \text{constant} \times \text{velocity}$
 - $\text{Power} = \text{constant} \times \text{velocity squared}$
- Absorbed power is maximum when WEC is in resonance with input waves
 - Advanced PTO
 - Reactive power
 - Sometimes the PTO should deliver power to the WEC to keep it in phase with the input waves, in order to capture more power back overall

PTO control

- Apply PTO force which maximises converter power for a given wave series
- Use a model and optimisation routine, to calculate the PTO force signal that maximises the absorbed power output over a future time horizon
- Traditionally, the model used in the control optimisation has been the same model used for the simulation to evaluate the performance of the controller
 - Therefore the controller always works perfectly
 - Control and simulation model based on linear hydrodynamics
 - This is where the fully nonlinear OpenFOAM simulation is valuable to give a realistic assessment of the controller's performance
- Implementaion:
 - At each time step, use a MATLAB pipe to calculate the optimum PTO force to apply to the body (using a modified *restraints* function in the *sixDoFRigidBodyMotion* solver)

Example result



Problems

- Me
- Large mesh motions -> simulation crashes
 - Efficient dynamic meshing strategies
- Turbulence modelling
 - Calculating Reynolds numbers for oscillating flows?
 - Oscillating two-phase flow
- Time step for whole domain, determined by the highest Courant number in a single cell
 - Small mesh around body and free surface
 - Is it possible to take smaller time steps just for the cells that need it and iterate in between longer time steps for the numerous cells away from the body and free surface?
- Efficient wave creation / absorption strategies