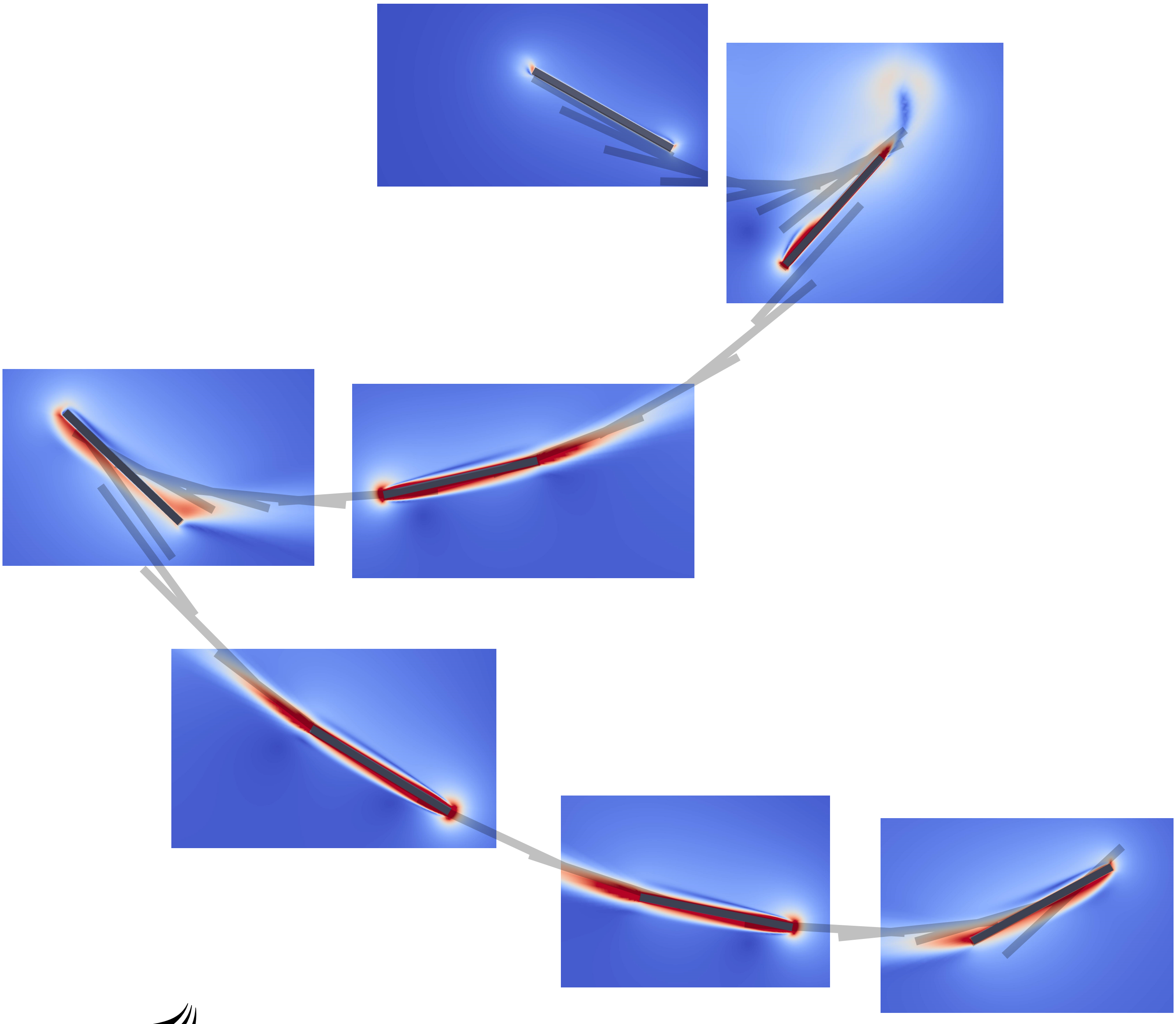
Executive Summary

Extending the Existing Modelling Framework for Non-Spherical Particles to Include Flat Plates in Free Fall



Master's Thesis, June 2014

Thermal Energy and Process Engineering
Aalborg University

AALBORG UNIVERSITY
STUDENT REPORT

Modelling of Non-spherical Particles

Accurate modelling of the motion of non-spherical particles is important for a wide range of industrial applications. Yet, the modelling of such particles rely on assumptions of the particles being close to spherical and thus neither the orientation nor the exact shape are taken into account. Due to predominant secondary side-to-side way motion of highly non-spherical particles, the assumption of sphericity is insufficient. One type of particle where both the orientation and exact shape cannot be neglected is a flat plate, where the non-sphericity results in different falling regimes depending on the exact plate. ***Figure 1*** illustrates different falling regimes for flat plates ranging from steady falling motion to periodic oscillating motion to tumbling motion[1].

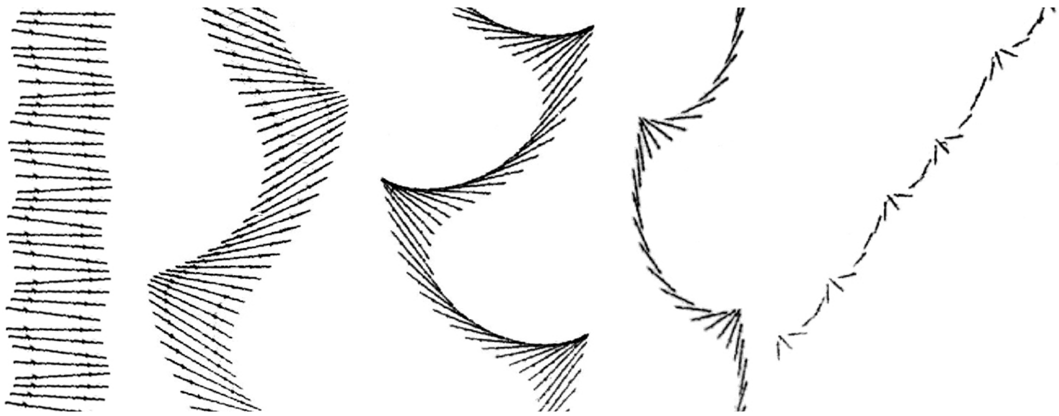


Figure 1. Different falling regimes for freely falling plate[1]. Note that the steady falling regime has been added to the original figure.

Based on the commonly used assumption of spherical particles, the motion regimes in ***Figure 1*** can not be reproduced. In the present work, a modelling framework has been proposed based on validated CFD simulations and experimental work using digital video camera recordings. The ultimate aim of this model has been to predict exact plate trajectories and the transition between the different motion regimes.

Development of New Correlations

A freely falling plate is simulated using the 6DOF solver in ANSYS Fluent. The results of the simulation are validated by comparing the obtained trajectory to trajectories of flat plates falling in a glass container. Based on the validated CFD simulation (see front page), the maximum center of pressure offset for aerodynamic forces for the flat plate is found to be approximately 1.5 % of the plate length rather than the commonly accepted 25 % for airfoils. The result is a modified formulation for the center of pressure of the aerodynamic forces.

[1]**Belmonte et al., 1998**. Andre Belmonte, Hagai Eisenberg, and Elisha Moses. *From Flutter to Tumble: Inertial Drag and Froude Similarity in Falling Paper*. Physical Review Letters, 81, 345-348, 1998

A PhD thesis[2], concluded that rotational lift plays a dominant role in the description of flat plates in free fall, but did not investigate these effects in details. To include these details in the present study, a set of CFD simulations have been carried out, leading to new lift- and drag coefficient correlations by taking the change in angle of attack $\mathrm{d}\alpha/\mathrm{d}t$ into account. The correlations for rotational drag- and lift coefficients found in this work are illustrated in ***Figure 2*** and ***Figure 3*** respectively.

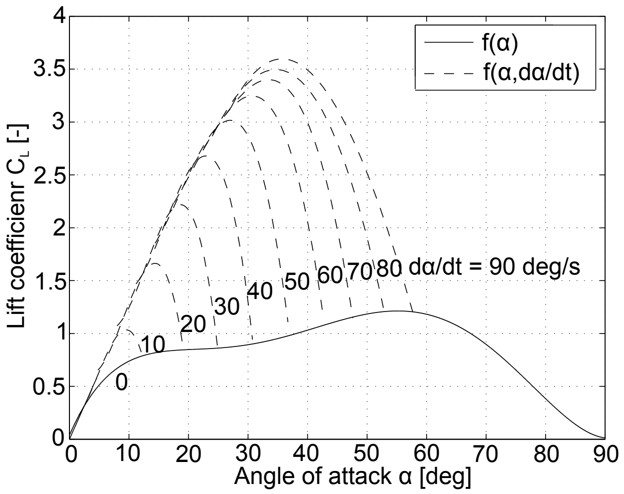


Figure 2. Rotational lift correlations developed based on CFD simulations.

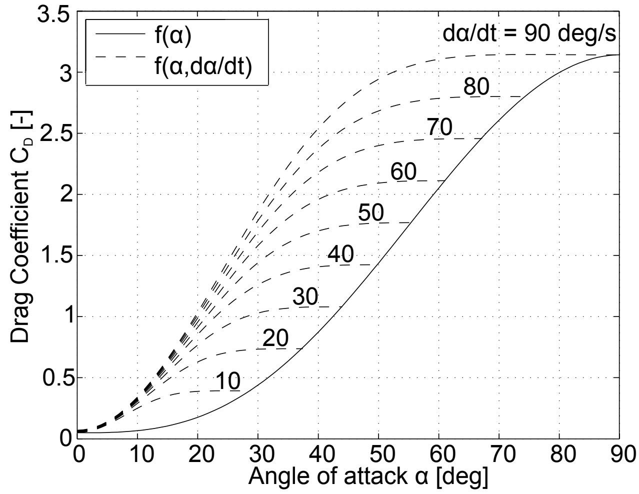


Figure 3. Rotational drag correlations developed based on CFD simulations.

These two correlations along with the modified center of pressure correlation have dramatically improved the model.

Validity and General Applicability of Model

The free fall is investigated by both CFD simulations, a quasi two-dimensional experiment, and the model. The model generally proved successful to describe the free fall trajectory of a flat aluminium plate with a length of 40.0 mm and aspect ratio of 1/20 falling in water. A comparison between the model, CFD simulations, and quasi two-dimensional experiment is shown in ***Figure 4***.

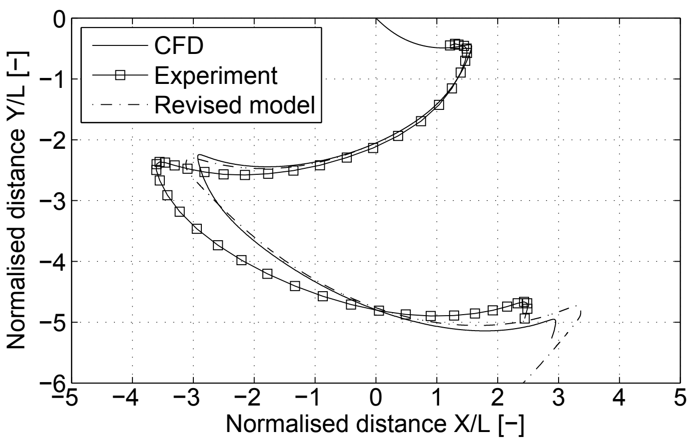


Figure 4. Trajectories obtained from CFD simulation, experiment, and revised model.

[2]**Pesavento, 2006.** Umberto Pesavento. *Unsteady Aerodynamics of Falling Plates*. Cornell University, 2006. PhD thesis

To investigate the capability of the model to predict the free fall trajectory for flat plates in general, the results have been compared to a regime map presented in literature[3]. This comparison is presented in ***Figure 5***.

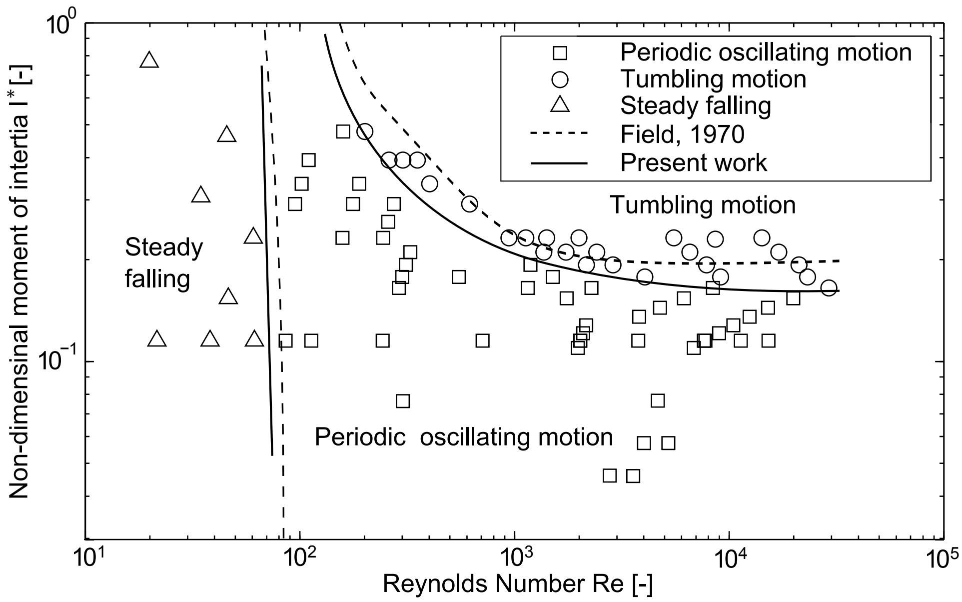


Figure 5. Motion regime plot suggested by the revised model presented throughout this work compared to literature[3].

The motion regime map in ***Figure 5*** indicates that the model is capable of predicting the motion for a wide range of plates falling with different Reynolds numbers and having different dimensionless moments of inertia.

Conclusions

An extension of the existing modelling framework for non-spherical particles to include flat plates in free fall has been proposed. New correlations for rotational lift and drag coefficients as well as center of pressure location have proved to be of major importance. A way to simulate a plate in free fall has been suggested and the results are validated by experimental work. Thereby, the present work has led to a significant improvement of existing modelling framework for flat plates in free fall.

Future work includes extensive experimental work to investigate and validate the general applicability of the model. Furthermore, effort should be put into implementing the proposed modelling framework in a CFD software.

Anna Lyhne Jensen *Jakob Hærvig*

[3]**Smith, 1970**. Edmund H Smith. *Autorotating Wings: An Experimental Investigation*. The University of Michigan, Department of Aerospace Engineering, July 1970