Spreading of Cryogen on Water

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Introduction

Gaseous fuels such as CH_4 and H_2 are liquified in order to be more effectively stored and transported. An accidental spill of a liquified gaseous fuel (LGF) such as LNG or LH_2 will result in an expanding liquid pool which, because of evaporation, is surrounded by a cloud of flammable gaseous fuel. In the case of LNG, an accidental spill may be followed by a rapid phase transition explosion (RPT).

In order to assess risk involved in transport of LGFs, a modelling framework for spreading of cryogens on water based on the shallow water equations was developed. There was, however, several problems with this model, and it has been my job to improve on it. My work involved both empirical considerations as well as analytical treatment of the one and two layered shallow water equations in both 1 dimension and in 2 dimensions with cylindrical symmetry.

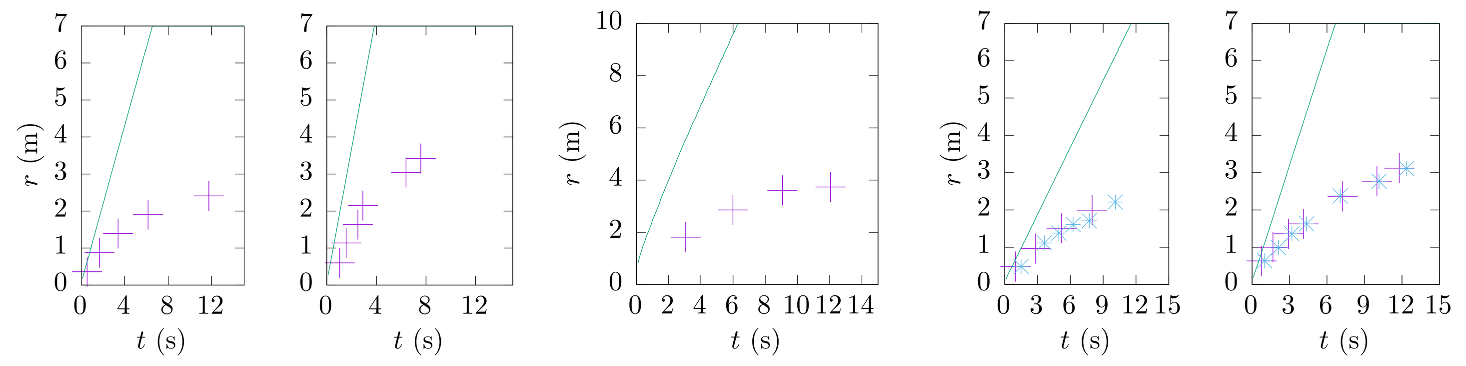
Numerical simulations using the final model agreed well with experimental results found in the literature.

The Challenge

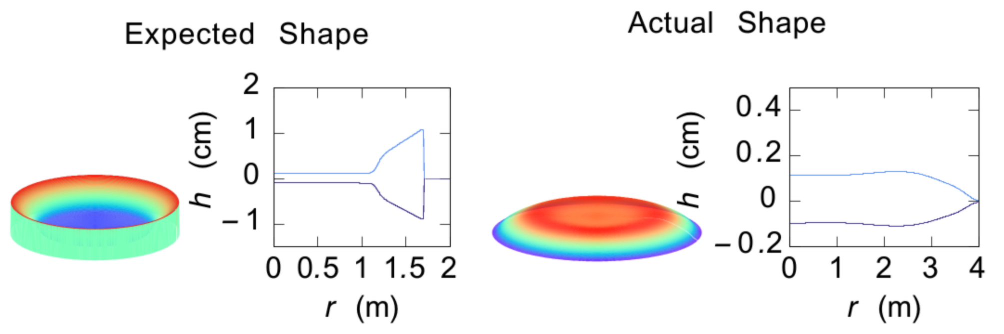
The modified shallow water equations,

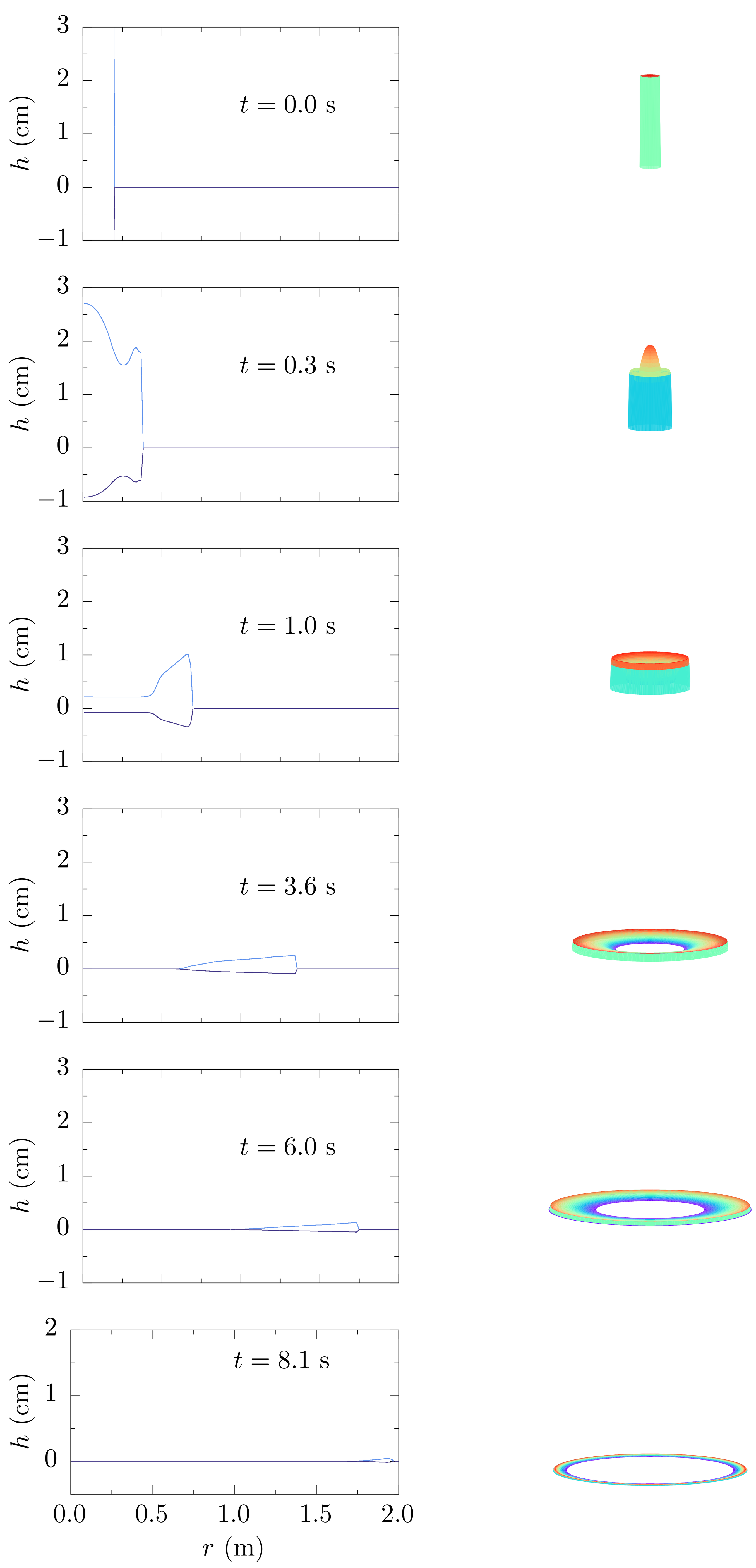
$$\frac{\partial}{\partial t}\begin{bmatrix} M \\ Mw_r \end{bmatrix} + \frac{\partial}{\partial r}\begin{bmatrix} Mw_r \\ Mw_r{}^2 + \frac{1}{2}\delta\rho g h^2 \end{bmatrix} = -\frac{1}{r}\begin{bmatrix} Mw_r \\ Mw_r{}^2 \end{bmatrix}, \qquad (1)$$

gives unsatisfactory results when considering spreading from a dam break on water. Both when comparing spreading rates to experiment,



and when considering the shape.



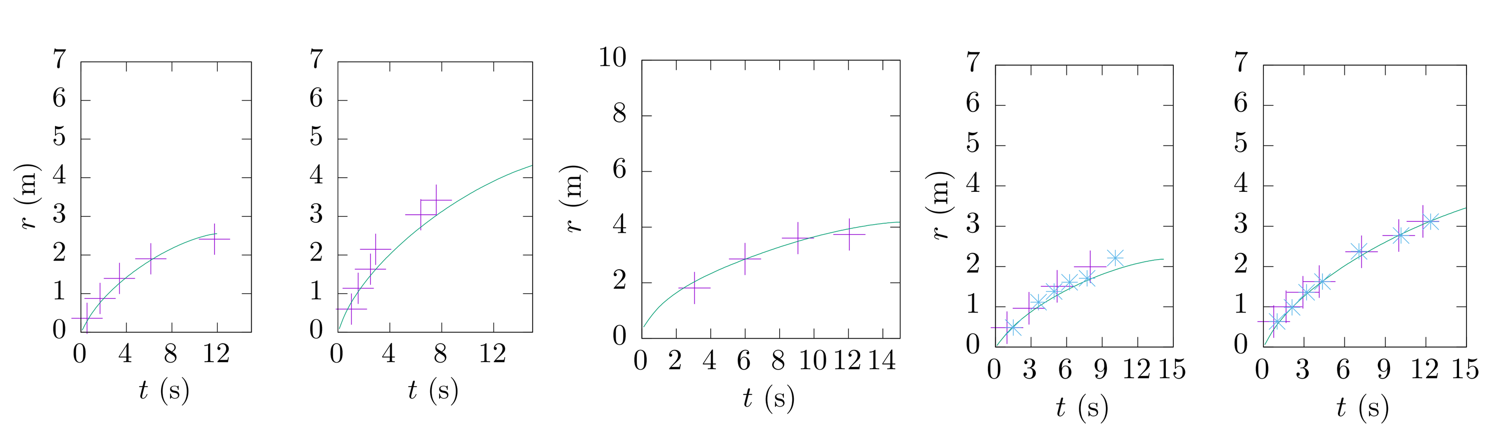


My Work

The equilibrium approximation used to get (1) eliminates the possibility of a shock wave in the dam break problem.

- I solved the dam break problem analytically to show this.
- I went back to the two layer SWE and developed a a special condition for the front, $Fr_{LE} := w_{LE}/(\delta g h_{LE})^{1/2}$ = constant, restoring the shock wave.
    - I compared this to empirical models found in the literature.
- I incorporated the effects of evaporation in the model.
- I implemented my model in the numerical framework.
- I compared spreading rates from numerical simulations with experiments and found good agreement.

Results



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