Fluid flows containing both gas and liquid phases simultaneously are observed in nature as well as in a wide range of engineering applications, specifically those related to sustainable energy conversion systems. In some cases, basic analysis of conservation laws is sufficient while many cases require detailed analysis of fluid flow. These cases can effectively be tackled with numerical simulations for assessing system design or its performance. Even though commercial and other open source computational fluid dynamics (CFD) software are capable of dealing with various flow conditions, they frequently come with limitations and restrictions imposed on their usage and numerical methods. The fundamental limitations are related to (i) grid management, (ii) equation sets, (iii) numerical methods, and (iv) boundary and initial conditions.

The primary objective of this project is to establish a CFD code that will promote both research and education in problems involving moving boundaries, specifically immiscible multiphase flows. Achieving this objective requires following capabilities:

- Grid generation and their self-management through automated refinement;
- Differential and algebraic operators on these grids;
- Flexible and readable data structure to nourish continuous development;
- One- and two-way interaction between grids to enable moving boundary simulations.

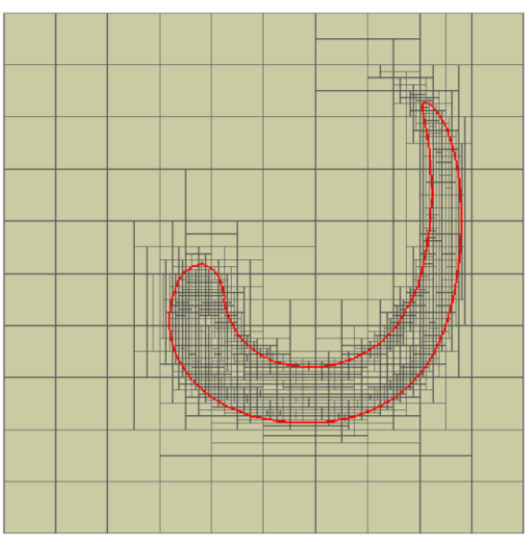
Implementing these capabilities, this project produced an open source object oriented autonomous grid management library for multi-physics simulations, named *girdap*. The library can be used to define multiple grid objects, which are capable of performing local anisotropic grid refinement (h-adaptation) as well as relocating their vertices (r-adaptation) based on their solution field. Grid objects are generated using edges in 1D, quadrilateral and triangular cells in 2D, and hexagonal cells in 3D. In addition, grid objects can interact with each other (including triangulated surfaces and one-dimensional strings) through interpolators which allow extension for tackling moving boundary problems using immersed boundary method. The data structure is carefully chosen so that it is even possible to mix different cells in a single mesh. Library is not only able to enhance research on simulations involving multiple phases but also equipped with a potential to tackle with problems involving solid-fluid interactions.

Object oriented library brings better readability and flexibility allowing custom set of equations, custom transport variables, and even their location arrangement. These are automatically supported by a compatible set of differential operators so that the conservation laws can be solved with ease. Among these operators, a novel advection scheme is devised for convection-dominated flow simulations on grids featuring hanging nodes as a result of *h*-adaptation. This new technique allows researchers to explore level-set type methods. In addition to divergence operator, Laplacian, gradient and time advancing operators are also defined as objects so that these operators can easily be used to represent a set of partial differential equations to provide flexibility.

Each added capability is verified and validated through benchmark problems. Its 1D form is successfully applied for renewable energy related applications, where numerical modeling of heat exchangers involving phase change in organic Rankine cycles, parabolic trough collectors are needed. These simplified cases nourished development of a new advection scheme. The extensions for multi-dimensions are verified considering grid adaptation algorithm using various error estimates for time dependent solutions. Interaction between grids is verified using a test case, "*large deformation of an interface under vortex flow field*", which also is used to verify the characteristics of developed advection scheme. Figure attached illustrates the capability of anisotropic grid adaptation in Cartesian grid systems. The capability of *r*-adaptation is verified for handling complex geometry as shown in the figure.

The current project targets promotion of research and education globally by providing flexible and easily managed accurate CFD libraries as an open source. The source code is made freely available through project's web page (http://blog.metu.edu.tr/uzgoren/research/projects/cart3dadapt/) and project's site at GitHub (https://github.com/uzgoren/girdap). In addition, the unpublished project results are disseminated in social networks (https://www.facebook.com/eray.uzgoren), and posts has reached about 1000 people, who belong to both scientific and non-scientific communities.

This project allowed the researcher to establish a research agenda not only in multiphase flows but also in renewable energy area. The researcher has supervised 10 MSc (2 co-supervised) students and helped 8 of them to complete their thesis. He has been teaching computational fluid dynamics course at the undergraduate level and hold small workshops on numerical modeling to an audience consisted of undergraduate and graduate students. The researcher obtained his tenure and promoted to Associate Professor at the Host institution.



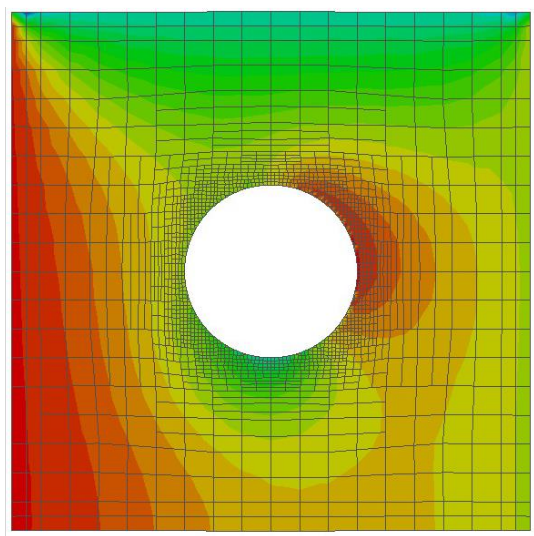


Figure 1. Examples of (a) interface deformation in a decaying vortex using h-refinement and (b) temperature distribution around a cylinder using hr-refinement.