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INITIAL 1-D SINGLE PHASE LIQUID TRANSIENT VERIFICATION OF COBRA-TF

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ABSTRACT

Abstract . . .

Key Words: List no more than five key words

CONTENTS

LIST OF FIGURES

1 INTRODUCTION

[1]

For the past several decades, the primary focus in nuclear engineering within the United States has been focused on light water reactors (LWR). Commercially, all nuclear reactors are either boiling water reactors (BWR) or pressurized water reactors (PWR). Correct computation of the thermal hydraulics within the reactor core leads to effi- cient design and accuracy in the safety analysis. A popular subchannel code for modelling the hydrodynamics with in the reactor core is COBRA-TF. This FORTRAN based code solves 8 conservation equations for liquid, entrained droplet, and vapor phases in 3-D dimmensions [2]. The conservation equations analytically reduce into a pressure matrix in a semi-implicit method with rod temperatures solved for explicitly. Because the physics are integrated into the numerical solution, the equations must be linear and the solution method semi-implicit. With a residual formulation, greater flexibility and control over the numerical solution is possible. COBRA-TF was originally written in FORTRAN 77, but over the years has been partially updated to newer versions of Fortran.

2 COBRA-TF

2.1 Background

The finite volume structure in COBRA-TF in figure 1 is for a one-dimmensional channel in the axial direction with n number of cells. The first and last cells at 0 and n + 1 are ghost cells and act as the boundary conditions for the problem. Pressure, enthalpy, and density are averaged over the cell volume and are located at the center of the cell. Mass flow rate and velocity are located at the faces in between cells. The cells are represented with an index i, and the faces with indexes of $i + \frac{1}{2}$ or $i - \frac{1}{2}$. This project will initially focus on this 1-D configuration. Usually the code is 3-D, with channels connecting to each other in two more dimmensions.

2.2 1-D Single Phase Liquid Conservation Equations

2.3 Residual Formulation and Jacobian Construction

3 CODE VERIFICATION

Introduction here ...

What is it, what are its objectives ...

What distinguishes it from Solution Verification???

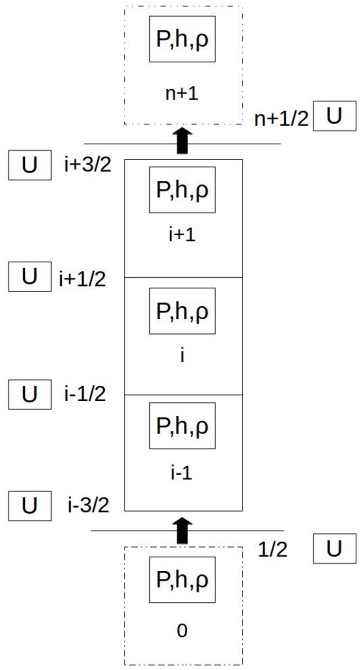

Figure 1. The finite volume structure for COBRA-TF

3.1 Software Quality Assurance

Git, unit tests, code documentation, doxygen, etc.

3.2 Verification Criteria

Code verification criteria can be defined to have the following levels of rigor [1] (cite the original source???)

- expert judgement
- error quantification
- consistencey / convergence
- order of accuracy

Error quantification, convergence, and order of accuracy will all be used. Order of accuracy is the most difficult to satisfy and the most sensitive to coding mistakes.

3.3 Method of Exact Solutions

What it is ...

How it applies here

Explanations of the expected results ...

4 SOLUTION VERIFICATION

4.1 Sources of Numerical Error

Round off error, iterative convergence error.

Discretization error?? (Check with)

5 SINE WAVE ADVECTION PROBLEM

Needs a figure and a table of parameters. Geometry and reference conditions should be for a PWR.

The problem is to transiently vary the inlet enthalpy h and inlet mass flow rate $\dot{m}$ using a smooth trigonometric function so as to keep velocity constant throughout the solution. Using a cosine, the analytical solution for a variable Y at time index j and space index i, where Y_1 is the initial value, Y_2 is the minimum value of the wave, and P is the period of the wave. The time step size dt, axial mesh size dx, and velocity V_o are assumed constant. If $V_o * j * dt > i * x$, then this equation doesn't apply and the value should just equal the initial value Y_1.

$$Y(i,j) = \frac{1}{2}\left((Y_1 + Y_2) + (Y_1 - Y_2)cos\left(\frac{2\pi}{P}\left(j * dt + \frac{i * dx}{V_o}\right)\right)\right) \tag{1}$$

This analytical solution can be applied to mass flow rate $\dot{m}$, density ρ, liquid enthalpy h, and liquid temperature T. Since velocity and pressure are cosntant, mass flow rate will be proportional to density, and enthlapy will be proportional to temperature.

5.1 Input Verification

For the inlet condition, a transient data table was generated for enthalpy and mass flow rate and applied at the inlet node. The comparison between the data table and the output in CTF are shown for enthalpy and mass flow rate in figures 2 and 3 respectively. The CTF output was read from hdf5 data files at each point in time, wich omitted the actual ghost cell where these values were applied.

The CTF values are located at the nearest node to the inlet, and therefore will be slightly out of phase to the exact values in the figure. This difference is more notable for smaller mesh sizes.

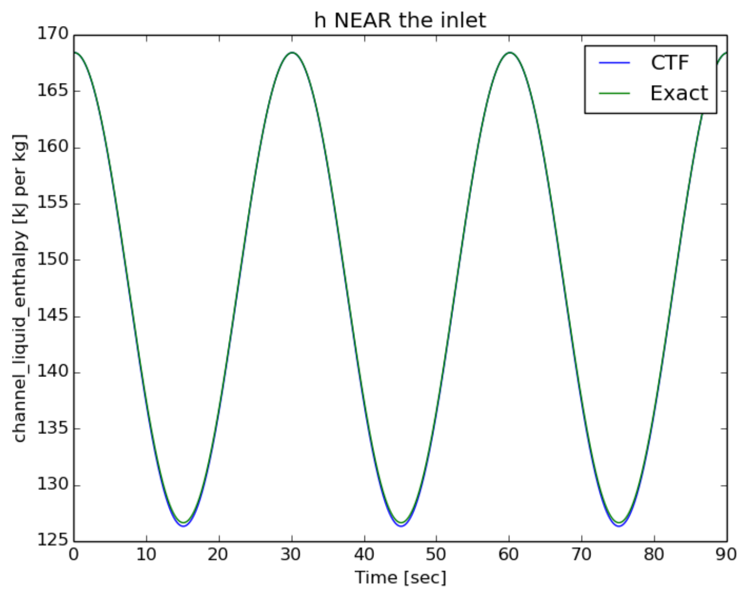

Figure 2. Enthalpy near the inlet and the analytical solution

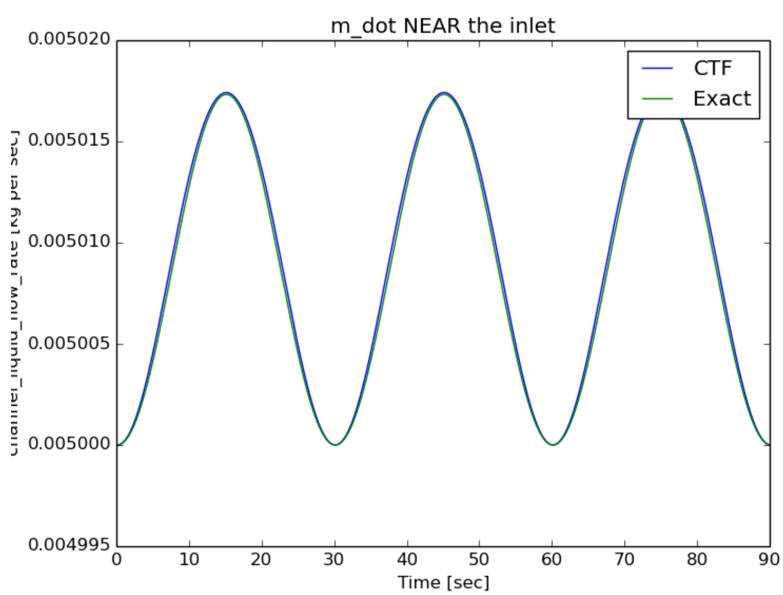

Figure 3. Mass Flow rate near the inlet and the analytical solution

6 VERIFICATION OF ALL SOLUTION METHODS

Both COBRA-TF and residual version semi-implicit method, residual fully implicit method with and without linear EOS.

6.1 Code Verification

This compares the exact solution to the COBRA-TF Solution Methods

6.1.1 Error Quantification

Show qualatative plot and demonstrate that the error is quantified for a single time step and space discretization

A figure and a table of l1 normalized error

6.2 Convergence of Error

Show how error behaves for different time and space sizes

6.3 Order of Accuracy

7 PARAMETER STUDY

Tables and figures of varying the results.

7.1 Changes in $\triangle$T

This changes the amplitude of the displacement

7.2 Changes in Frequencey

This changes the frequencey of the displacement

7.3 Changes in Mass Flow Rate

8 COMPUTATIONAL TIME

The computational time of the two methods for different computational sizes. Compare the semi-implicit and fully implicit methods at 0.5 , 1.0, and 2.0 CFL.

9 CONCLUSIONS

Present your summary and conclusions here.

10 ACKNOWLEDGMENTS

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11 REFERENCES

[1] C. J. Roy, "Review of Code and Solution Verification Procedures for Computational Simulation," *J. Comput. Phys.*, **205**, *1*, pp. 131–156 (2005).

[2] R. K. Salko, "CTF Theory Manual," The Pennsylvania State University (2014).