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THE MULTI-PHYSICS, USER-FRIENDLY GAS-DYNAMICS CODE VISUAL TSUNAMI 2.0

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ABSTRACT

Since the early 1990s, the series of simulation code known as TSUNAMI has been the main tool employed to explore gas dynamics phenomena in thick-liquid protected inertial fusion target chambers. The applicability and user-friendliness of the code was recently extended through a set of MATLAB pre- and post-processing tools and graphical user interfaces [1]. Geometry, initial, and boundary conditions can be specified from within AutoCAD through a set of in-house AutoLISP graphical user interfaces. A novel MATLAB core was recently developed and tested, and is now routinely used with the user-friendly pre- and post-processors [2]. An overview of Visual Tsunami 2.0, the latest version of the code, is presented here.

Key Words: gas dynamics, Visual Tsunami, inertial fusion

1. INTRODUCTION

"TSUNAMI" refers to a series of ablation and gas dynamics codes developed and maintained since the early 1990s at the University of California at Berkeley (UCB) in collaboration with the Lawrence Berkeley National Laboratory, Lawrence Livermore National Laboratory and the University of California at Los Angeles. The different versions of the code were employed to model a variety of inertial fusion energy (IFE) and inertial confinement fusion (ICF) systems; the history of the code is summarized in Refs. [1-3]. Recent utilizations of TSUNAMI 2.8 include an updated prediction of mass and energy fluxes of a HYLIFE-II-like chamber [4], the first modeling of the gas dynamics inside a heavy-ion beam tube [5], and, in the framework of the neutralized-ballistic Robust Point Design study [6,7], the first "integrated" simulation of a HYLIFE-II-like chamber [8], encompassing the whole domain of early-time gas dynamics, namely from the target implosion location to the site of the magnetic shutters introduced in Ref. [5]. TSUNAMI was also employed to model a variant of the Robust Point Design chamber, suitable for the assisted-pinch transport scheme [9,7,10].

A new series of codes---named "Visual Tsunami"---was born out of a desire to use the conveniences of modern, object-oriented, modular programs and software. Visual Tsunami is strongly inspired by the experience gained using TSUNAMI 2.8. The adjective "Visual" stems from the input and output graphical user interfaces (GUIs) that have been recently developed

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and improved the user-friendliness of the code significantly. Tsunami is no longer an acronym and should be read as a name, with only the first letter capitalized. The code is versatile enough to be used outside of the ICF/IFE community. Visual Tsunami 1.0 was first presented in Ref. [1], while Visual Tsunami 2.0 was introduced in Ref. [2]. The architecture of the code is shown in Fig 1. and its main parts are briefly presented in the following sections. Only the models that are benchmarked and used routinely---hence have shown to be accurate, versatile, robust, and reasonably quick---are mentioned in this short write-up.

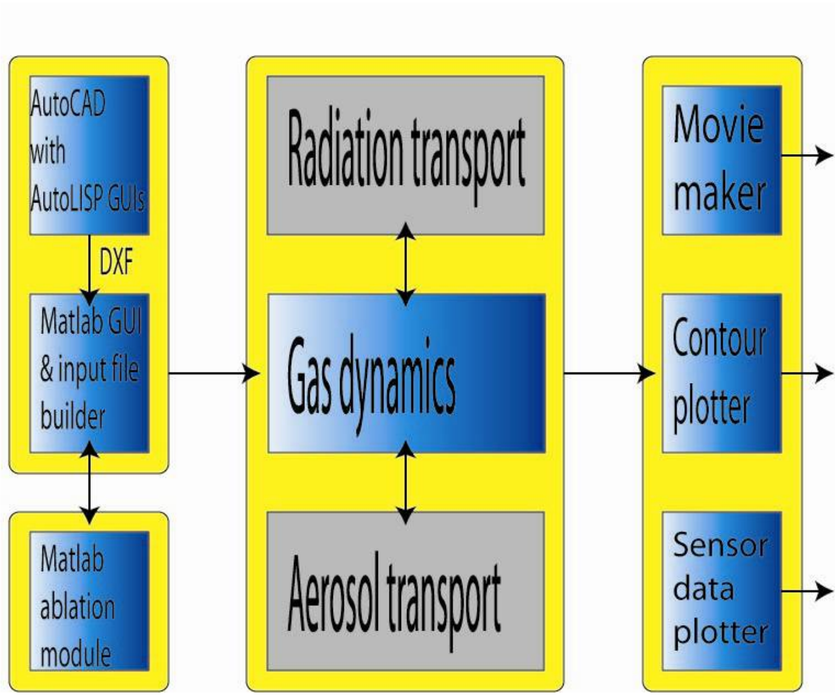

Figure 1. Architecture of Visual Tsunami 2.0: pre-processor tools (left), MATLAB core (center), and MATLAB post-processor [2]. The implementation of radiation and aerosol transport models is left for future work.

2. PRE- AND POST-PROCESSORS

2.1. Input File Builder

TSUNAMI has typically been used to model gas dynamics phenomena in complex geometries. In 2001, in order to ease the setting up of the initial and boundary conditions, the lead author developed a modular 2-D mesh generator and template input file program in Fortran 95 [11]. The mesher was conveniently reusable from one simulation to the other and the formatting of the input files was taken care of by the builder entirely and automatically. Such a builder limited the amount of time and programming required to set up a new simulation, reduced the likelihood of making an input error, and represented a significant advance in user-friendliness.

Visual Tsunami makes use of current commercial computer-assisted design (CAD) software. Autodesk's AutoCAD was chosen for its wide use and its ability to be tailored. A set of GUIs was designed and written by Wang and the present lead author [1] in AutoLISP, AutoCAD's historical programming language, and is used to define most material properties, initial and boundary conditions in two dimensions. The AutoLISP GUIs could easily be expanded to incorporate more parameters, as needed. All the information is exported as a DXF file, one of the de-facto CAD file interchange standards. Additionally, a GUI was developed in MATLAB for the mesher, the core of the input file builder.

X-rays interact with liquid or solid surfaces over time scales that are usually short compared to the resulting gas dynamics of interest. Ablation may therefore be considered instantaneous and treated as an initial condition to the gas dynamics simulations. Visual Tsunami can call an in-house ablation program to define such initial conditions, whenever relevant. Recent improvements [2] to the traditional TSUNAMI model include a time-dependent x-ray pulse capability, treatment of thermal heat conduction and re-radiation, and use of tabulated hot opacities in addition to the cold cross-sections usually employed. The target-facing cell interfaces were defined manually in TSUNAMI. The AutoCAD GUIs were designed so that the target-facing surfaces could easily be specified, once they have been determined by the user. A further simplification was recently introduced. A two-dimensional ray-tracer was developed in 2005. It flags the target-facing cell interfaces without any user intervention.

2.2. Output File Processor

In the spring of 2001, the lead author developed an extensive set of MATLAB output processing tools for two-dimensional TSUNAMI simulations. These consisted of a movie maker and contour and sensor data plotters. The output processor was recently revised for inclusion into Visual Tsunami; the speed of the movie maker was increased more than an order of magnitude [11]. A set of MATLAB GUIs was developed by Wang and the present lead author [1] to streamline data reduction, make the code more versatile, and reduce the user's programming effort and likelihood of error input. Visual Tsunami 2.0 makes use of a variant of this fast and user-friendly post-processor.

3. CORE PHYSICAL AND NUMERICAL MODELS

Visual Tsunami 2.0 solves the Euler equations for compressible flow in one, two or three dimensions in Cartesian coordinates and in two-dimensional axisymmetric cylindrical coordinates. The equations are solved using a finite volume scheme that follows Godunov's approach; the flow field is determined by a succession of calls to a Riemann solver, at each time step and at each cell interface. Godunov's second method is implemented along with an exact solver to the exact Riemann problem. The ideal gas Riemann problem is reduced to a single equation in one unknown, the pressure in the middle region between the left and right waves. This equation is solved iteratively through a Newton-Raphson method. An elaborated initial estimate for the unknown pressure allows for a quick convergence in just a few iterations. Open outflow and immobile reflective boundaries can be specified. Open outflow can be used to reduce the computational domain or to mock a perfectly condensing surface. Reflective boundaries are used on symmetry axes and at immobile, perfectly rigid, non-condensing gas/solid and gas/liquid interfaces. Details are presented in Ref. [2].

The MATLAB core is highly vectorized and was designed to be easily parallelizable. Visual Tsunami 2.0 is meant to be a tool to explore new algorithms and form the backbone into which future expansions of the code will be implemented. (Previous major upgrades to the code required a complete rewriting of the core.)

4. CONCLUSIONS

Visual Tsunami 2.0 constitutes the latest version of the UCB code TSUNAMI. The gas dynamics core physical and mathematical model---Euler's equations for compressible flows---has been retained from previous versions of TSUNAMI, as well as a finite volume approach. However, the details of the numerical schemes in the Visual Tsunami series and their actual implementations are significantly different. A set of graphical user interfaces makes pre- and post-processing fast, intuitive, and straightforward. In particular, the input file builder is now graphics-based. The geometry, the initial and the boundary conditions can be specified in 2-D through AutoCAD, tailored with a set of AutoLISP GUIs.

Visual Tsunami 2.0 was successfully applied to gas dynamics modeling in thick-liquid protected Z-pinch target chambers and to model Lawrence Livermore's series of condensation debris experiments. Details of the models and benchmarking of the code are presented in Ref. [2], where a description of the Z-pinch and condensation debris experiment simulations can be found as well.

REFERENCES

1. C.S. Debonnel, T.X. Wang, *et al.*, "Visual Tsunami: a versatile, user-friendly, multidimensional ablation and hydrodynamics design code," *Fusion Science and Technology*, **47(4)**, pp. 1165-1169 (2005)
2. C.S. Debonnel, *Gas transport and control in thick-liquid inertial fusion power plants*, PhD thesis, University of California, Berkeley, USA (2006)
3. A.R. Raffray, W. Meier, *et al.*, "IFE thick liquid wall chamber dynamics: governing mechanisms and modeling and experimental capabilities," *Fusion Science and Technology*, **49**, pp. 1-27 (2006)
4. C.S. Debonnel, G.T. Fukuda, *et al.*, "Control of the heavy-ion beam line gas pressure and density in the HYLIFE thick-liquid chamber" *Fusion Science and Engineering*, **63-64**, pp. 647-652 (2002)
5. C.S. Debonnel, D.R. Welch, *et al.*, "Gas transport and density control in the HYLIFE heavy-ion beam line," *Fusion Science and Technology*, **43(3)**, pp. 408-413 (2003)
6. S.S. Yu, W.R. Meier, *et al.*, "An updated point design for heavy ion fusion," *Fusion Science and Technology*, **44(2)**, pp. 266-273 (2003)
7. S.S. Yu, R.P. Abbott, *et al.*, "Heavy ion fusion (HIF) driver point designs," *Nuclear Instruments and Methods in Physics Research A*, **544**, pp. 294-299 (2005)
8. C.S. Debonnel, S.S. Yu, P.F. Peterson, "X-ray ablation and debris venting for the heavy-ion point design," *Fusion Science and Technology*, **44(2)**, pp. 274-278 (2003)
9. C.S. Debonnel, S.S. Yu, P.F. Peterson, "Progress towards thick liquid fusion chambers for assisted-pinch and solenoid focusings," *Nuclear Instruments and Methods in Physics Research A*, **544**, pp. 342-346 (2005)

10. S.S. Yu, J.J. Barnard, *et al.*, “Towards a modular point design for heavy ion fusion,” *Fusion Science and Technology*, **47(3)**, pp. 621-625 (2005)
11. P.M. Bardet, C.S. Debonnel, *et al.*, “Dynamics of liquid-protected fusion chambers,” *Fusion Science and Technology*, **47**, pp. 626-632 (2005)