Numerical Simulation of the Ramac Benchmark Test.

J. E. Leblanc[1], M. Nusca[2], X. Wang[3], F. Seiler[4], M. Sugihara[1], and T. Fujiwara[1]

1. Department of Aerospace Engineering, Nagoya University,
Chikusa-ku, Nagoya, Japan 464-8603
joseph@momo.nuae.nagoya-u.ac.jp, toshi@momo.nuae.nagoya-u.ac.jp
2. Ballistics and Weapons Concepts Division, AMSRL-WM-BE, Army Research Lab.
Aberdeen Proving Ground, MD, 21005-5066, nusca@arl.mil
3. School of Mechanical and Production Engineering, Center for Advanced Numerical Engineering Simulations
Nanyang Technological University, Singapore 639798, mxjwang@ntu.edu.sg
4. French-German Research Institute of Saint-Louis (ISL), 5 Rue du General Cassagnou
F-68301 Saint-Louis, CEDEX, France, isl@concorde.cedocar.fr

Abstract

Numerical simulations of the same ramac geometry and initial conditions by different numerical and physical models highlight the variety of solutions possible. A comparison between codes is achieved.

Background and definition

Since the beginning of research on the Ram Accelerator problem, a large body of experimental data and numerical simulations have been accumulated. It was suggested that a coordinated effort for a particular experiment and numerical simulation replicated identically by all laboratories could be of use and interest. This project was labeled the Ramac Benchmark Test. This is by definition a numerical simulation based on a successful experiment, but not an attempt to recreate an experiment. The simplifications were specified to allow comparisons between codes, and they limit the scope of a more realistic simulation, but given the variety of computer codes, the limited budget and time available to dedicate to this project, the simpler conditions were preferred to the realistic ones. Given the complexity of this simulation, it can be expected that the outcome can be quite different for each simulation. With that forewarning, the authors volunteered their computer resources and time to perform the simulation following closely the guidelines established, and a comparison of the results will be possible.

The Benchmark is a standard, simple, two-dimensional axisymmetric ramac configuration, avoiding the major complications of fins and three-dimensional effects. It is based on the rail-guided ramac developed at the Institute of Saint-Louis (ISL) [2]. The purpose of the Benchmark is to have a standard configuration which can be used to calibrate a numerical code before attempting a more elaborate simulation.

Selected configuration

The geometry and initial conditions were defined based on a suggestion by Dr. Seiler from the ISL to use the 30 mm rail-guided experiment with hydrogen fuel diluted with carbon dioxide. The ISL is providing experimental data of the superdetonative shots. The shape, shown in Fig. 1, is a two-dimensional, axisymmetric cone-cylinder-cone without fins, of maximum diameter of 30 mm, and total length of 160 mm, centered in a tube of 44 mm bore diameter. This leaves a gap of 7 mm at the throat. The following initial conditions have been proposed for the simulation: Mixture: $2H_2 + O_2 + 5CO_2$, Pressure: 20 bars, Temperature: 300 K, Injection velocity: 1800 m/s

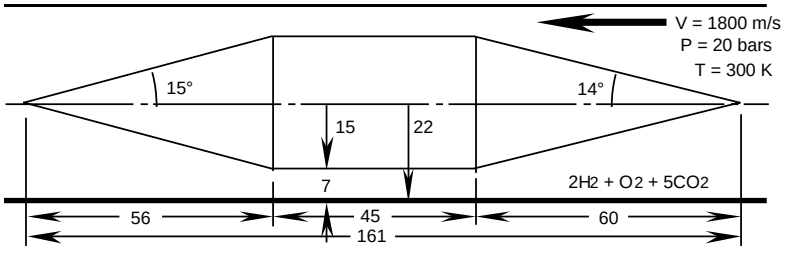

Figure 1. Geometry and initial conditions of the proposed Ramac Benchmark Test.

The options of governing equations, numerical scheme, grid system, and boundary conditions were left open for each author. The physical models were somewhat restricted; the guidelines suggest that heat transfer, turbulence and diffusion models can be included, if available. The ideal gas equation of state was specified, to avoid discrepancies with various real equations of states, although a comparison between equation of states is desired.

The chemistry was limited to hydrogen and oxygen reactions, using any existing model, but it was specified that carbon dioxide be used strictly as a diluent. The reaction with CO_2, will be neglected for this simulation to avoid discrepancies in the simulation from codes with and without a model of CO_2 combustion. It should be kept in mind that the Benchmark is not a reproduction of an experiment, but a selected model for the purpose of comparing and calibrating our numerical codes, it is only based on a set of experimental conditions.

Results

The comparison is done in three parts: non-reactive simulation between codes, chemically reactive simulation between codes, and a final comparison between codes and experiment.

Figure 2 shows the result of the chemically reactive simulation obtained by Nusca. He used a Navier-Stokes code with a detailed model of hydrogen combustion. Autoignition occurred at the wall and body and the combustion was steady. The pressure levels on the wall are similar to the experimental results shown in Figure 5 ($P/P_o = 60$).

Figure 3 shows the results obtained by Wang for the non-reactive simulation (top) and the chemically reactive simulation (bottom). He used a Navier-Stokes code, with a chemical kinetics model of H_2/O_2/diluent combustion with 8 reactions and 7 species, and the ideal gas equation of state. Autoignition occurred at the rear point (x = 170 mm) and moved forward. Eventually this simulation experienced an “unstart” when the combustion moved to the front cone. The pressure level on the throat section is similar to the experimental level ($P/P_o = 60$), although the pattern is different.

Figure 4 shows the results obtained by Leblanc for the non-reactive simulation (top) and the chemically reactive simulation (bottom). I used an Euler code, with a chemical kinetics model of H_2/O_2/diluent combustion with 19 reactions and 8 species, and the ideal gas equation of state. There was no autoignition anywhere, even though the pressure and temperature levels were as high as in Fig. 3. Even after igniting the mixture, it could not support combustion, so the amount of diluent was reduced to three moles CO_2 to make it more energetic. Still it had no autoignition, but after ignition it supported a steady combustion. The pressure level on the wall is low by a factor of four, compared to the experimental result. The reason for this low pressure is not apparent, but it does not seem due to the ideal gas equation of state because Wang used the same e.o.s. and obtained high pressures.

The following general remarks can be made about these results.

• The non-reactive part of the simulation produces a steady-state flowfield which is similar for all simulations; Figs. 3 and 4 have similar pressure patterns. The chemically reactive part depends much more on the physical models used.

• An Euler code simulation is not capable of producing self-ignition, the combustion had to be initiated.

• The Navier-Stokes simulation had self-ignition , perhaps due to the boundary layer, which allows the flow to remain longer than the induction time period before being convected away.

• One Navier Stokes simulation had a steady state solution, while the other was unsteady.

These results show the variety of solutions possible form an similar set of initial conditions, but with various level of physical models and numerical schemes. It does not invalidate the numerical simulation, but illuminates the strengths and limitations inherent.

References

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[2] Seiler F., Patz, G., Smeets, G., Srulijes, J., Presentation of the rail tube version II of ISL’s RAMAC 30. In: Takayama, K. and Sasoh, A. (eds.) *Ram Accelerators*, Springer-Verlag, Heidelberg, pp. 79-87.

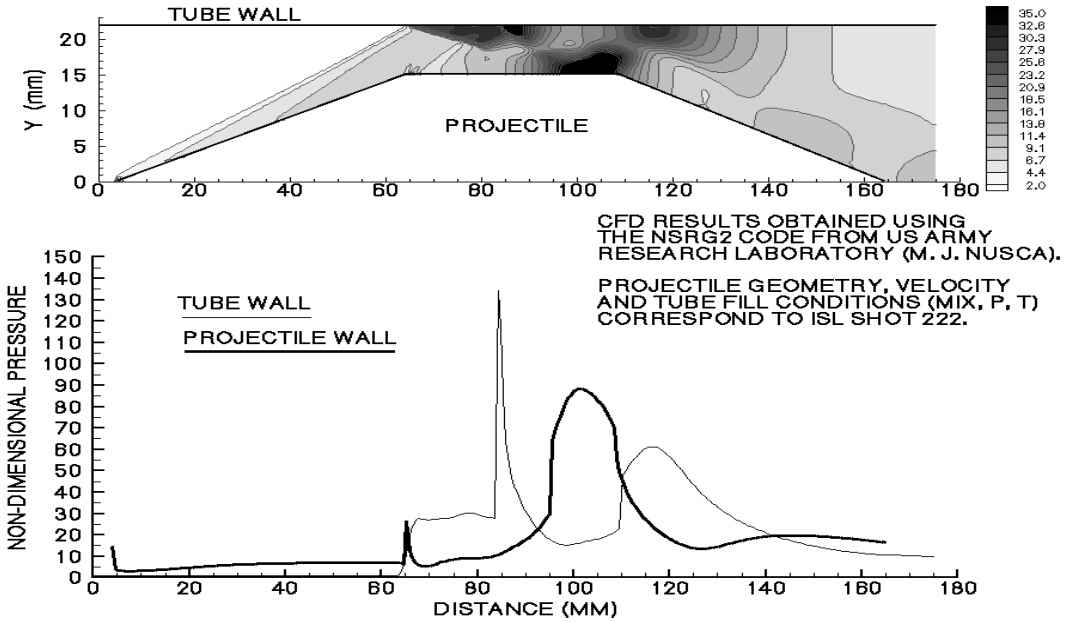

Figure 2. Results of Navier-Stokes simulation by Nusca.

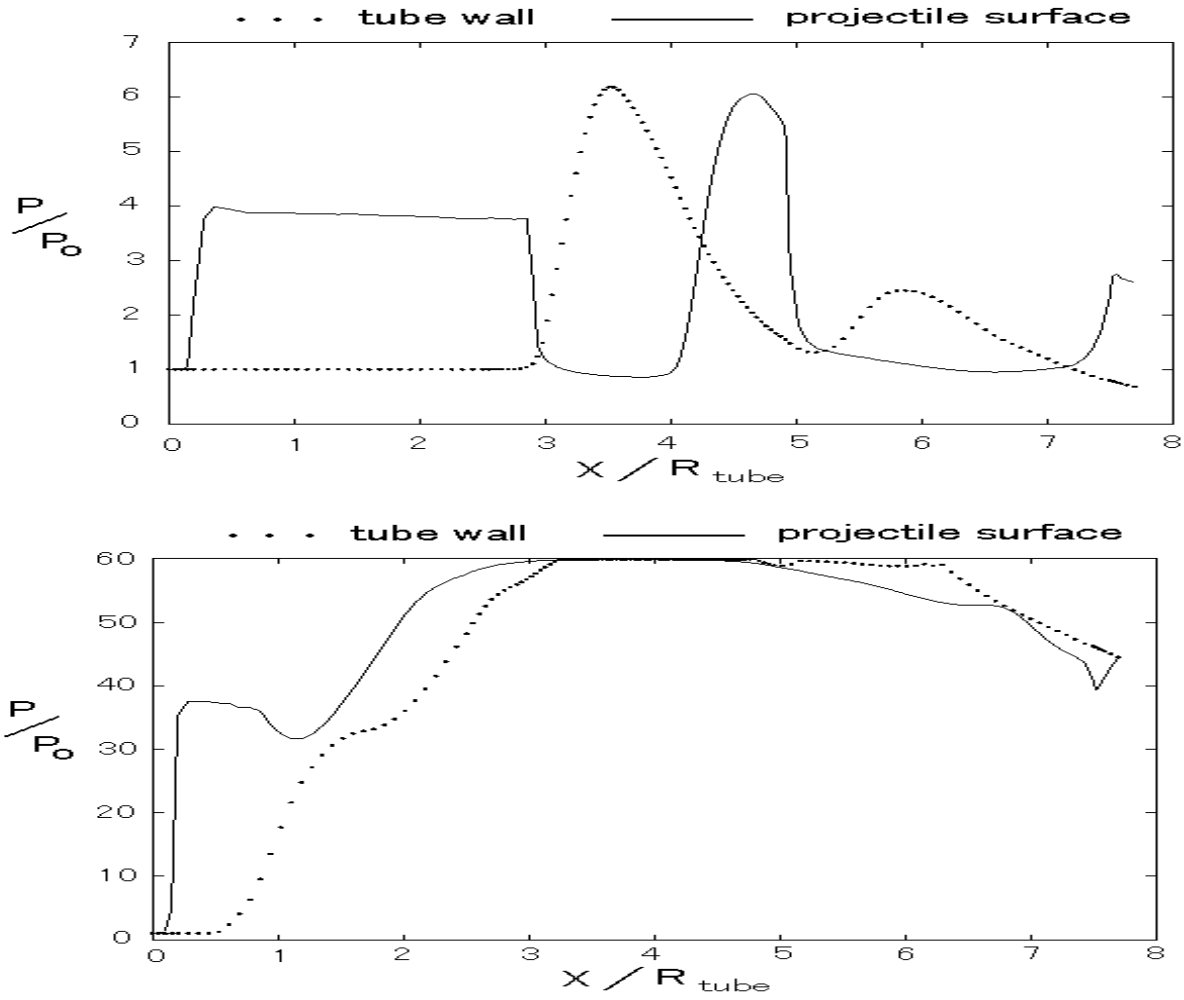

Figure 3. Results of Navier-Stokes simulation by Wang. Non-reactive case on top, chemically reactive case on bottom.

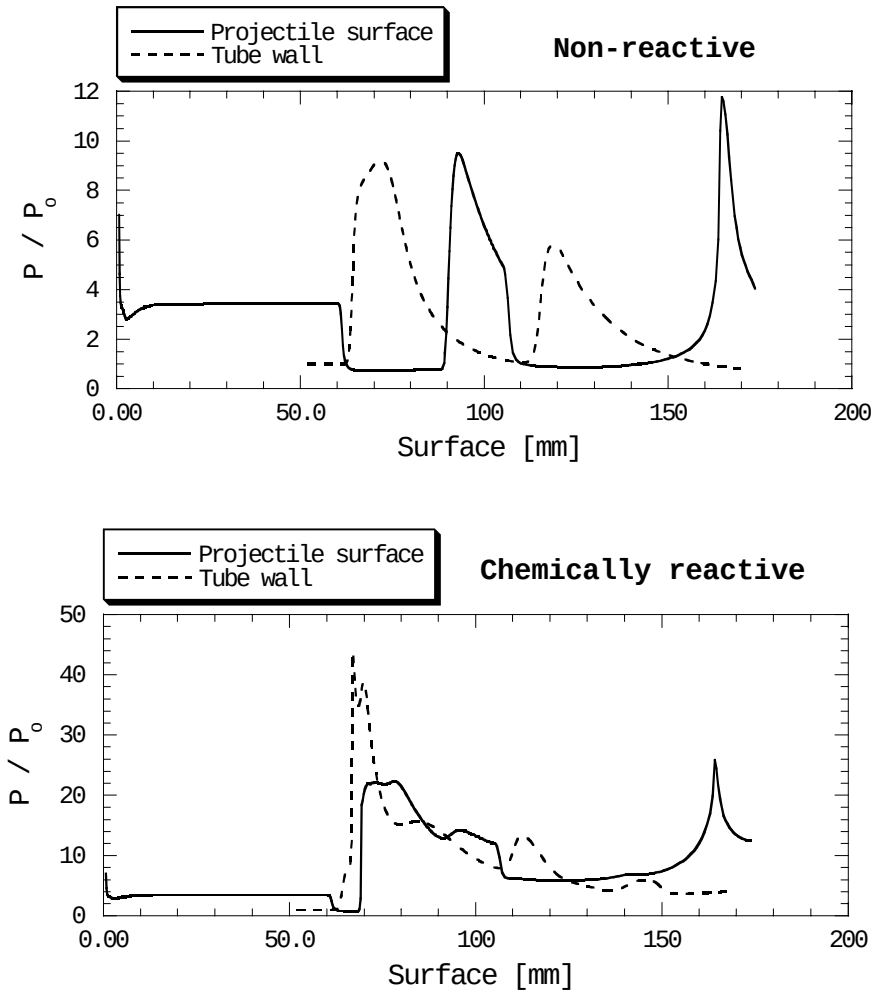

Figure 4. Results of Euler simulation by Leblanc and Sugihara. Non-reactive case on top, chemically reactive case on bottom.

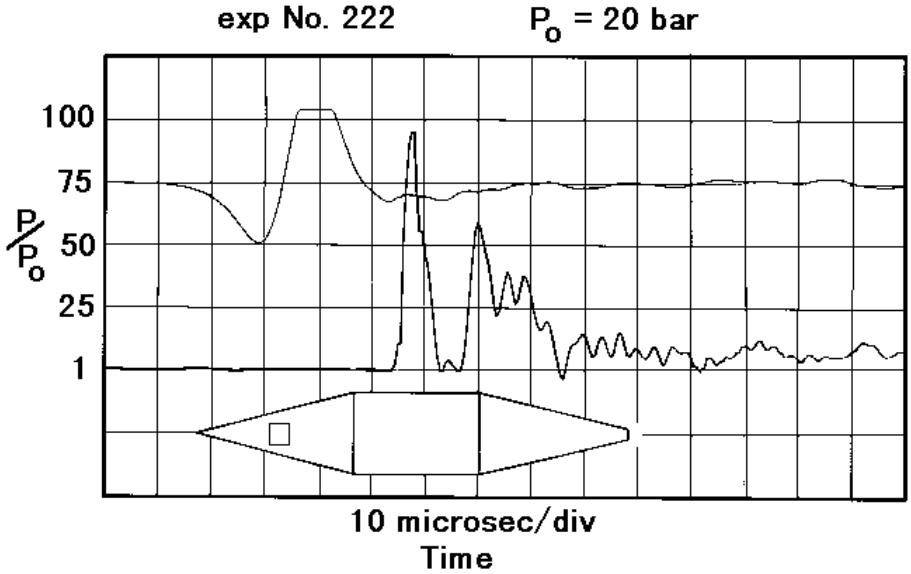

Figure 5. Experimental data for shot No. 222 provided by Seiler, and used for the basis of defining the benchmark geometry and initial conditions.