Issues for the Creation of the *DRTF* – A Large-Scale Facility for Study of Detonations and Explosions

[1]E.S. Oran, [2]R.K. Zipf, Jr., [1]S.I. Jackson, [3]V.N. Gamezo, [4]J.K. Thomas, [1]E.L. Petersen
[1]Texas A&M University, College Station, TX, USA
[2]NIOSH (Retired), Pittsburgh, PA, USA
[3]US Naval Research Laboratory, Washington DC, USA
[4]Baker Engineering and Risk Consultants, Inc. (BakerRisk), San Antonio, TX, USA

1 Introduction

In the past 15 years, large-scale numerical simulations of the deflagration-to-detonation transition (DDT) have provided very graphic visualizations of the how DDT can occur in an exothermic gas under confined, partially confined or even unconfined conditions (see, e.g., [1], for a review). These visualizations and the accompanying analyses describe explosion events in scenarios ranging from coal mines to vapor clouds to nuclear power plants to a variety of astrophysical phenomena. Many of the predictions by simulations could be verified in experiments or supported by experimentally deduced trends, either quantitatively or quantitatively, and they have been used frequently either to explain observed phenomena in real systems or design more controlled ways of creating or avoiding a detonation. As computational capabilities have increased, these computations were extended to describe physical processes occurring in domains larger than could be tested and verified in a laboratory. That is, the existence of interesting and important reactive-flow phenomena seen in large-scale numerical simulations have not been verified by experiments.

The development of the Detonation Tube Research Facility, or DRTF, now under construction at the Rellis Campus of Texas A&M University (TAMU), is based on the principle that the more we understand about the the dynamics of explosive events and the controlling flow physics, as well as reactions occurring in energetic materials generally, the better we can develop ways to avoid, mitigate, enhance, or even control these processes. As described below, the DRTF might be thought of as a larger successor of the Gas Explosions Test Facility (GETF) that was built and used at Lake Lynn Laboratory from 2008 to 2012 (see, e.g., [2,3]). Now, however, we have the possibilities of much improved optical diagnostics.

2 The Concept of the DRTF

Figure 1 is an early schematic (*circa* 2020) of the DRTF now under construction. During the course of developing this design, the length of the tube and the physical site were changed several times. Nevertheless, the major parts of the facility and general sizes are very similar to what was originally conceived, and the figure is generally correct. The DRTF consists of three major elements: the detonation tube, the

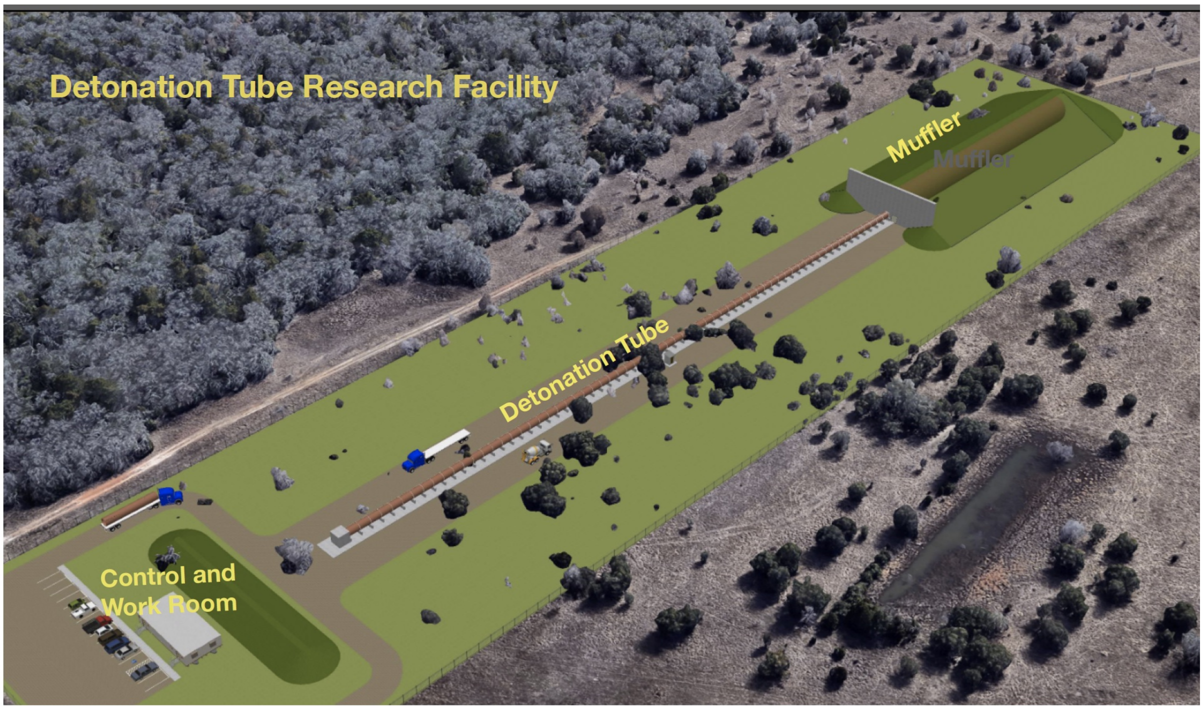

Figure 1: Artists conception of the DRTF. (Drawing created *circa* 2020, curtesy of Ben Sasse, Texas A&M University.)

muffler at the open end of the detonation tube, and the control and work room behind and separated from the closed end of the detonation tube.

The cylindrical detonation tube will be 150 m long by 2 m in diameter. It is made of 3/4-inch thick steel in order to withstand strong explosions from deflagrations, detonations, and the high pressures that occur during the transition from deflagration to detonation. The tube itself is equipped with an evolving suite of pressure and optical sensors. Several optical ports will be positioned along the length of the tube for optical diagnostics. The tube design also allows the possibility of inserting or removing baffles to control a transition to detonation.

The tube design for the DRTF is very similar to its predecessor, the GETF, that had a 73 m long tube with 1.05 m internal diameter and 3/8-inch thick wall. Besides the tube sizes, the DRTF differs by the gas mixing system, the planned optical diagnostic, and the “muffler” that has been added at the exit end of the tube to ensure TAMU safety and noise requirements.

3 Something New: A Muffler for Noise Reduction and Emission Safety

The muffler at the open end of the tube (see Figure 1) consists of a large steel, tubular structure made of 8-mm thick steel. It is planned to be 90 m long and 9 m wide, and so approximately six times the volume of the detonation tube. The structure is covered with earth. The cylindrical shape of the muffler takes advantage of hoop stress to resist the explosion forces within the muffler.

A detonation wave exiting from the tube into the lager-diameter muffler filled with air could produce a Mach 5 shock that would diffract and quickly decay into weaker shocks. These weaker shocks would travel and bounce off walls inside the muffler chamber for milliseconds, that is, until the shock waves die out and the pressure equilibrates. Meantime, vents at various locations along the top of the muffler will allow gases to escape.

The muffler contains the hot, high-pressure gases exiting the detonation tube. In some DDT experiments, a detonation may not form and hot shocked, partially reacted gases will exit the tube. The shock waves are then weaker, but a flammable mixture may form and ignite in the muffler. This requires additional precautions when experiments are performed with rich mixtures.

The detonation tube alone, with no sound mitigation, produces unacceptably loud noise levels that could occur for miles downstream of an open tube. Research performed to evaluate the extent of this problem was done early in the design process, and the remedy was the creation of the muffler. Estimates of noise generation by an open detonation tube can be found in [4,5]. Without a muffler, extremely high decibel levels (over 150 db) caused by a detonation exiting the detonation tube would occur for several miles in the forward direction. With the muffler, the noise level will be almost negligible. Even assuming the most intense explosion, the resulting noise will be no louder than a passing train. This is illustrated in Figure 2.

Figure 2: Extent of noise levels (in dbs) caused by detonation exiting the DRTF. Left: Unmitigated. Right: With muffler. For comparisons, 140 db is the pain threshold, 80 db is the level 30 m from a freight train, and 60 db is a conversation at 1 m.

4.1 Unresolved Issues and Perplexities from Prior Experiments and Simulations

On one hand, the GETF allowed us to conduct detonation experiments on scales larger than were previously possible. On the other hand, the ability to perform the DDT simulations was extended to even larger scales, even to those comparable to mine tunnels. The observations resulting from these large-scale experiments and simulations revealed a number of fundamental questions or inconsistencies, two of which we briefly discuss here.

DDT Scaling for Large-Diameter Channels

Natural gas in coal mines can leak through porous walls into enclosed portions of the mine that are no longer used or ventilated. In those regions, even an accidental spark can ignite a flame that may transition to detonation. The fundamental problem is if, when, and where the detonation can occur. This information can then be used to help to determine the strength of barriers need to protect other mining areas. To evaluate this, a series of numerical simulations of flame acceleration and DDT in obstacle-laden channels was performed, with the objective of finding a scaling law that could be used. The quantity of interst here is L_{DDT}, the distance the deflagration travels before a detonation forms as a function of channel characteristic size d. Figure 3 shows the results of such a series of numerical simulations computations to determine L_{DDT} for a channel containing a stoichiometric mixture of natural gas and air with a series of equally spaced obstacles in the channel (blockage ratio 0.3) and channel sizes ranging from 0.17 to 3.0 m (see, e.g., [6]).

Examination of this figure leads to the question: *Why does the curve tube turn downwards down at large diameters?* The answer is only speculation at this point. One suggestion is that the curvature is related to the role and type of turbulence that evolves in the system before it detonates. Other suggestions are related to other fundamental differences between two-dimensional and three-dimensional, which are related to the complexity of possible shock interactions as well as properties of nonequilibriium non-Kolmogorov. turbulence. This is a trend requiring verification by measurement, as well as extended, more resolved computations.

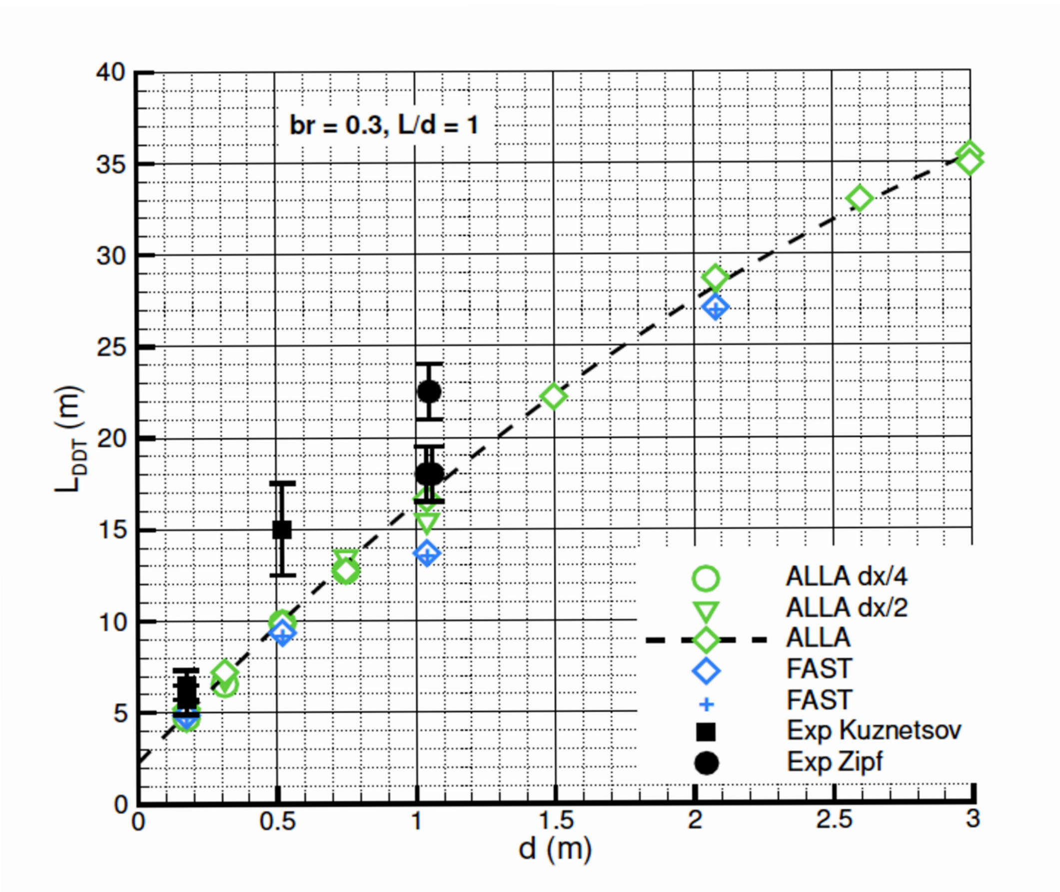

Figure 3: A collection of computed and measured distances to DDT as a function of channel height d for stoichiometric methane-air mixture. References and more details are given in [6].

Extension of the Absolute Detonability Limits

Another result from GETF concerned detonability limits. Both the lean and rich limits of detonability become leaner and richer, respectively, with increasing system size. The physical reasons for this are related to two propertIes of gas-phase detonations. First, the detonation cell structure is required to maintain a propagating detonation, and second, the detonation cell size increases with the equivalence ratio greater and less than stoichiometric.

Figure 4 is a summary of the detonation limits as a function of system size, compiled from series of measurements done between 1959 at the earliest and the most recent GETF measurements in 2012. From the GETF data for the 1 m tube, the lean detonability limit is precariously close to the flammability limit for stoichiometric methane-air mixtures. The question then is this: Can the lean detonability limit reach the flammability limits, or can it even become lower? It is possible to argue both ways on this question. One of the earlier experiments with DTRF will be to find ways to examine this question, either using methane, methane-hydrogen mixtures, or another gaseous fuel.

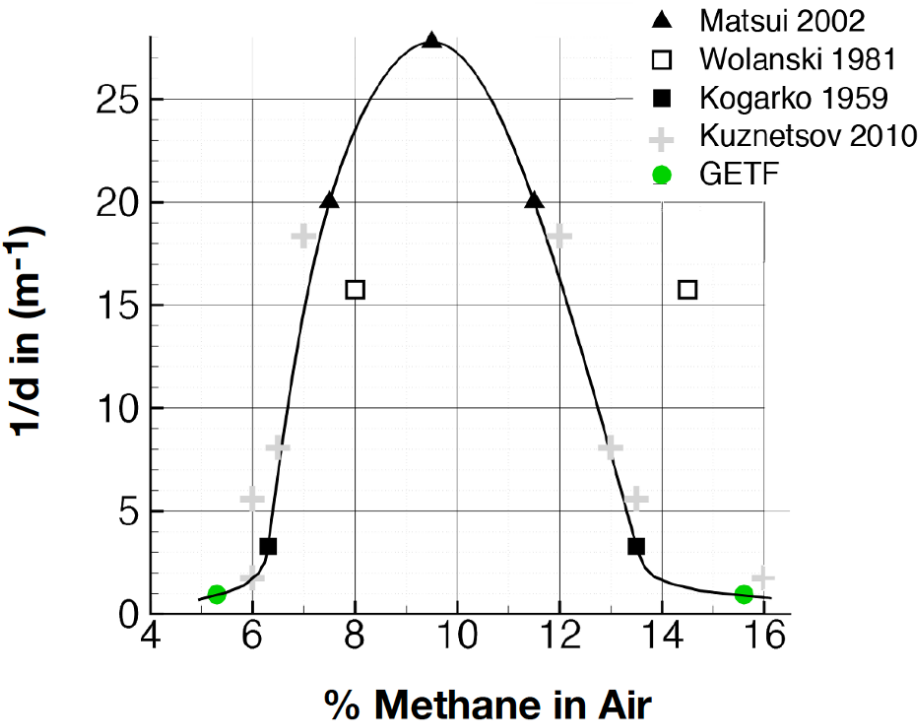

Figure 4: CAPTION.

5 Discussion

Design, construction, and operation of the Detonation Tube Research Facility is itself an experiment. The size of the detonation tube goes beyond what is commonly available in university research laboratories. The concept of the muffler for the open detonation tube, needed because the DRTF must be in the proximity of other facilities, is itself new. We know that scaling a system up or down is not always straightforward, so that new ideas are needed to ensure safety and functionality. Compromises are inevitable.

The discussion above focused on extensions to natural gas and air mixtures that were done at GETF. Other experiments are now being considered, such as similar experiments with natural gas mixed with hydrogen, the effects of particulates on deflagration and detonation, and the evaluation of deflagration velocities in other mixtures and types of fuels.

By the time this presentation is given, the basic strccture of the construction of the DRTF should be at least half completed. Likely there will have been a number of design and construction issues that require some care and decisions. In addition, the facility will have determined and prioritized the first set of tests to ensure proper operation. Thus, in this presentation, we will describe issues that arose in planning, the state of the construction, and the first set of actual experiments to be performed.

5 Acknowlegments

This project was funded by the O'Donnell Foundation Professorship and by the Texas GURI/CRI (Governor's University Research Initiative and the Chancellor's Research Initiative) at Texas A&M University. The authors would also like to acknowledge the efforts of Rodney Bowersox, Ivett Leyva for their support in trying times, James Thomas, Logan Kunka, Nathan Gaddis, and Ashwath Sethu Venkataran for their efforts to evaluate the noise levels and test methods of sound mitigation, and Ben Sasse for his continuous support and patience with the project.

5 References

[1] Mechanisms and Occurrence of Detonations in Vapor Cloud Explosions, E.S. Oran, G. Chamberlain, A.Pekalski, Progress in Energy and Combustion Science, 77, 100804, 2020.

[2] Detonability of Natural Gas-Air Mixtures, V.N. Gamezo, R.K. Zipf, Jr., M.J. Sapko, W.P. Marchewka, K.M. Mohamed, E.S. Oran, D.A. Kessler, E.S.. Weiss, J.D. Addis, F.A. Karnack, D.D. Sellers, Combustion and Flame, 159, 870–881, 2012

[3] Deflagration-to-Detonation Transition in Natural Gas-Air Mixtures, R.K. Zipf, Jr., V.N. Gamezo, K.M. Mohamed, E.S. Oran, D.A. Kessler, Combustion and Flame, 161, 2165-2176, 2014.

[4] An Experimental Study of Shock Transmission from a Detonation Tube, J.C. Thomas, F.A. Rodriguez, D.S. Teitge, L.N. Kunka, G.N. Gaddis, Z.K. Browne, C.B. Ahumada, E.T. Balci, S.I. Jackson, E.L. Petersen, E.S. Oran, to appear, Shock Waves, 2021.

[5] A Scaling Law for Shock Transmissions from Detonation Tubes, J.C. Thomas, E.T. Balci, G.N. Gaddis, S.I Jackson, E.L. Petersen, E.S. Oran, submitted to Physical Review Fluids, 2022.

[6] Towards Scaling Laws for DDT in Obstructed Channels, E.S. Oran, V.N. Gamezo, Progress in Scale Modeling, 1, Article 4, 2020. https://uknowledge.uky.edu/psmij/vol1/iss1/4

[7] Large-Scale Experiments and Absolute Detonability of Methane/Air Mixtures, E.S. Oran, V.N. Gamezo, R.K. Zipf, Jr., Combustion Science and Technology, 185, 324-341, 2015.