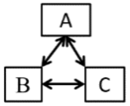
Unified Turbulent Flame Formulation for Predictive Modelling of Combustion and Explosions in Gaseous and Dust Environments

V'yacheslav (Slava) Akkerman

Center for Alternative Fuels, Engines & Emissions (CAFEE), *Department of Mechanical & Aerospace Engineering* (MAE)
Benjamin M. Statler College of Engineering & Mineral Resources (CEMR), *West Virginia University* (WVU)
Annex 273 ESB, Morgantown, WV 26506-6106 || Office: 304.293.0802 || Cell: 650.815.9021 || Vyacheslav.Akkerman@mail.wvu.edu

General Objectives

❑ **Develop an integrative computational, analytical and phenomenological platform for gas and dust explosions in complex geometries such as those in coal mines and other industries with serious hazards to life and property. The Platform is based on the following blocks**



A. *Unified formulation for premixed turbulent flame speed*

Phase 1: Establish a novel model for gaseous premixed turbulent flame

Phase 2: Develop a computational platform, with the model of Phase 1

B. *Effect of dust on the explosivity limits and flame propagation*

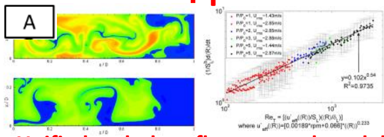
Phase 3: Extend the analyses to particle-gas-air environments, laminar and turbulent

Phase 4: Extend the studies to partially-premixed combustion, laminar and turbulent

C. *Laminar formulation for sporadic flame (deflagration) acceleration and subsequent deflagration-to-detonation transition (DDT) in tunnels*

Phase 5: Incorporate the developed platform into the laminar DDT formulation

Technical Approaches



Unified turbulent flame speed model is being developed to incorporate

A1. Effect of thermal expansion on the flame-flow feedback

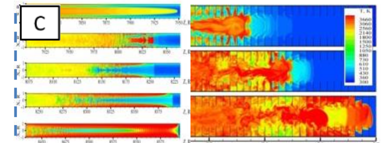
A2. Ambiguity between measured turbulence and that experienced by a local flame segment

A3. Centrifugal effect of burning along the turbulent vortex axes

A4. Turbulence coupling to the combustion instabilities

B **(Work in Progress)**

The role of dust in explosion and DDT initiation to be quantified. Namely, it will be determined how mean size and concentration of the impurity influences the thermal-chemical flame properties and evolution



Conceptually-laminar, analytical and numerical platform for flame acceleration and DDT in smooth (left) & obstructed (right) tunnels

C1. Three distinctive acceleration mechanisms are revealed

C2. Various acceleration stages are detected and investigated

C3. Flame evolution is quantified

C4. DDT locus is predicted

C5. ***Heat losses to be determined***

Motivation and Broader Impacts

❑ **Gas/dust explosion is a hazard to personnel and equipment; mining has one of the highest injury rate**

- Compare fatalities: Year 1912. Titanic: 1,514 vs US Coal Mines: 2,360
- Two orders of magnitude reduction in the mining fatality in 1912-2012. Still…
- > 250 combustible dust incidents in US in 1980-2005 (119 deaths, 718 injuries)
- Major West Virginia coal dust incidents: Fairmont, 1907 (361); Eccles, 1914 (183); Benwood, 1924 (119); Bartley, 1940 (91); Farmington, 1968 (78); Upper Branch, 2010 (29)

❑ **Current industrial bench scale test methods and corresponding analytical/empirical/numerical analysis are not adequate in assessing hazards associated with dust-air combustion**

- Industrial safety standards are not able to keep up with various types of dusts
- Most of exiting computational explosion models (COBRA, EXSIM, FLACS, FLARE, REAGAS) utilize empirical correlations, being thereby linked to a particular case

❑ **Qualitatively new consideration and techniques, from the first scientific principles, are highly required to redesign the industrial test apparatus**

- If successfully developed and deployed, this will allow the transfer of fundamental scientific information into the real-life applications.

Summary, Progress, Proposed Activity & Estimated Budget

❑ The integrative research, consisting of blocks A–C with Phases 1–5, is being developed.

❑ Block A: Analytical component for A1–A4 is practically completed, with a slight revisiting required, while the computational implementation needs additional efforts. The estimated budget to complete block A is k$ 100-150*

❑ Block B: This is an almost new research, with minor pilot studies performed so far. The estimated budget to complete block B is k$ 150-250*

❑ Block C: My colleagues and I have worked on block C for a decade now, and I am happy to report that the laminar formulation is practically completed now. The only serious task remained in block C is C5. It is nevertheless noted that, while C5 is of interest for the multitude of academic problems and is critical for micro-channels, it plays a minor role in the mining safety issues. The estimated budget to perform task C5 is k$ 50-100*

* It is noted that the budget above is estimated in a rough manner as it depends on the accuracy and detailization of the work required