Mechanisms of DDT in Terrestrial Systems

V.N. Gamezo, A.Y. Poludnenko
Laboratories for Computational Physics and Fluid Dynamics,
Naval Research Laboratory, Washington, DC, USA

Deflagration-to-detonation transition (DDT) is one of the key unsolved problems in the theory of Type Ia supernovae (SNIa), and is still not completely understood for terrestrial chemical systems. It is a complicated multiscale process that usually involves three consecutive stages [1-2]: (1) the flame evolution that creates necessary conditions for detonation initiation, (2) the actual formation of the detonation wave, and (3) the spread of the detonation into large areas of unburned material that ensures the detonation survival.

The first stage of DDT is highly dependent on the geometry and often involves accelerating turbulent flames. For this stage, a terrestrial geometrical configuration that is the most relevant from the point of view of SNIa theory is a large unconfined cloud of a reactive gas mixture with a slow laminar flame speed. A laminar flame ignited in this cloud would become turbulent and accelerate mostly due to the gravity-induced Rayleigh-Taylor (RT) instability, similarly to what is expected during SNIa explosions. Experimental explosions of unconfined premixed gas clouds are described in literature, but there are no reports of DDT observed in these experiments. Numerical simulations that would produce DDT starting from sparks in unconfined gas clouds do not exist neither. Accidental explosions of large gas clouds in open air sometimes produce damage consistent with the development of detonations, but such accidental configurations usually involve obstructions on the ground that promote the flame acceleration. Since obstructions facilitate DDT and are often present in practical configurations, most of the experimental and numerical studies of DDT are carried out for obstructed geometries. There are also studies of DDT in smooth channels where boundary layers play an important role in flame acceleration. The development of the first stage of DDT for all these configurations is very different from mechanisms involved in SNIa where obstructions or boundary layers do not exist. Studies of these configurations, however, allow us to observe the second stage of DDT which involves more universal mechanisms that could be relevant for both terrestrial systems and SNIa.

It is rather paradoxical that while DDT is routinely observed in laboratory experiments, the actual detonation initiation was never observed with enough detail to clearly identify the mechanism of this initiation. This is related to a wide range of length and time scales involved at different stages of DDT, and a stochastic nature of DDT. As a result, it is difficult to predict the time and location where the detonation will appear, and then apply experimental diagnostics at this location with enough resolution. Nevertheless, at least two distinct mechanisms for the detonation initiation at the second stage of DDT were analyzed theoretically an identified in numerical simulations. These include the gradient mechanism [3-4] and the spontaneous runaway of fast flames [5]. Here we analyze existing evidence for these mechanisms in terrestrial systems and discuss their applicability to SNIa explosion models.

References

[1] E.S. Oran, V.N. Gamezo, Combust. Flame 148:4–47 (2007)

[2] V.N. Gamezo, T. Ogawa, E.S. Oran. Combust. Flame 155:302–315 (2008)

[3] Ya.B. Zeldovich, V.B. Librovich, G.M. Makhviladze, G.I. Sivashinsky. Astron. Acta 15:313–32 (1970)

[4] J.H.S. Lee, I.O. Moen, Prog. Energy Combust. Sci. 6:359–389 (1978)

[5] [2] A.Y. Poludnenko, T.A. Gardiner, E.S. Oran. Spontaneous Transition of Turbulent Flames to Detonations in Unconfined Media, Phys. Rev. Lett. 107:054501 (2011)