

Studies on the extraction of laminar flame speed and Markstein length from outwardly propagating spherical flames

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Spherical flame method (constant P)

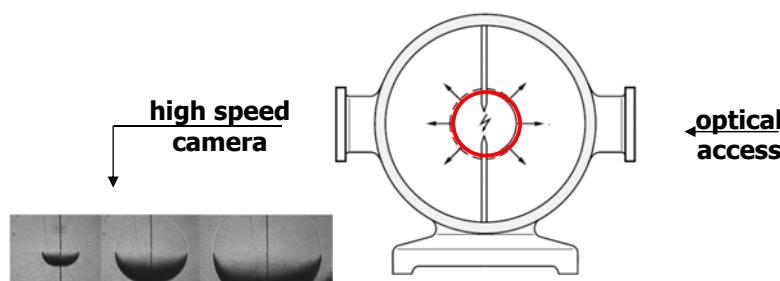
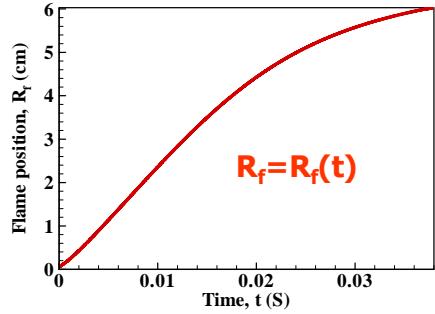
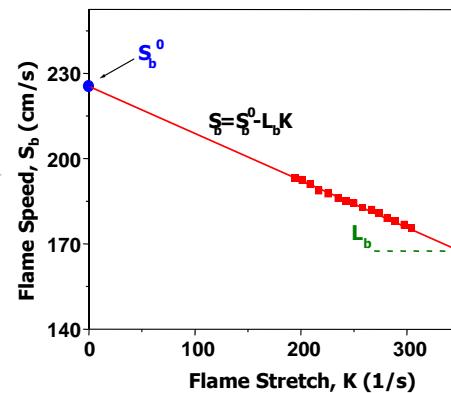


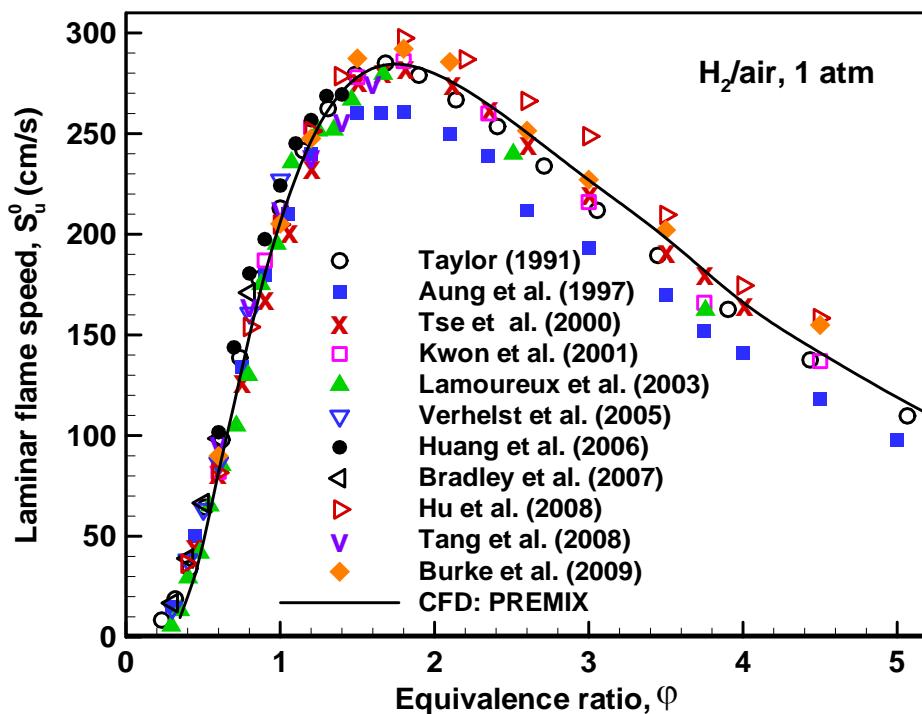
Fig. from N. Peters (1992)



$$S_b = \frac{dR_f}{dt} - U_b$$
$$K = \frac{2}{R_f} \frac{dR_f}{dt}$$

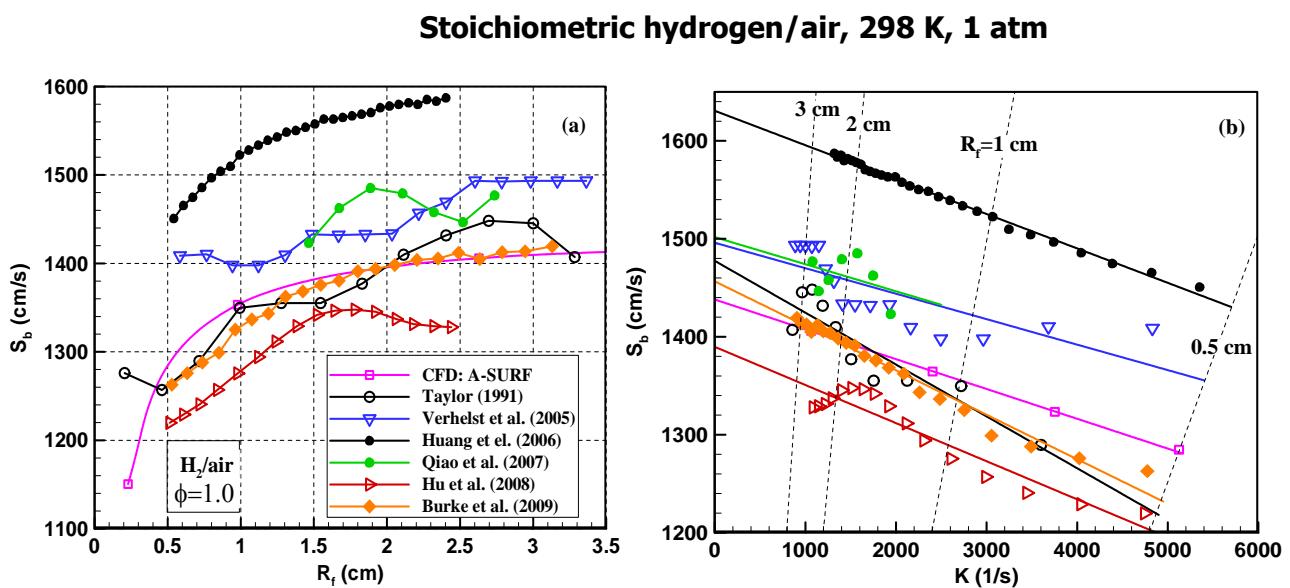


Can the speed be accurately measured ?



3

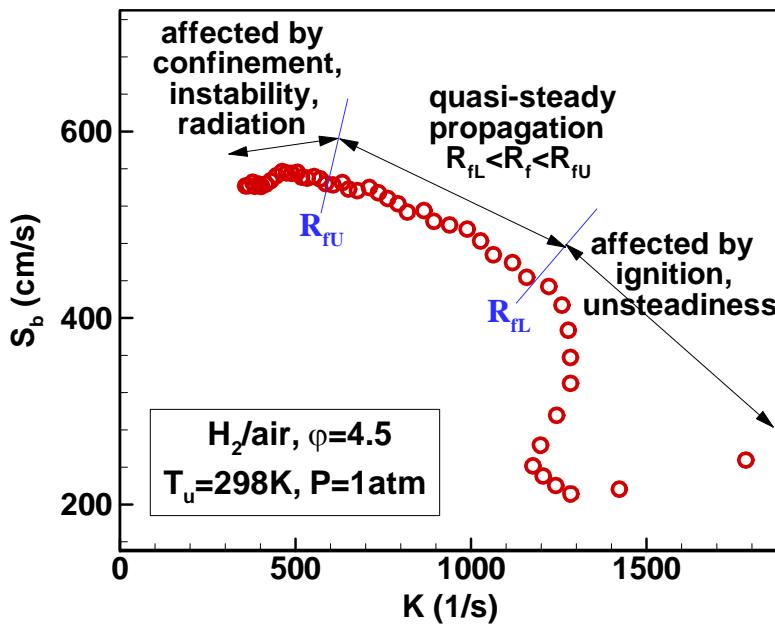
Can the speed be accurately measured ?



What is the cause ?

4

Possible causes



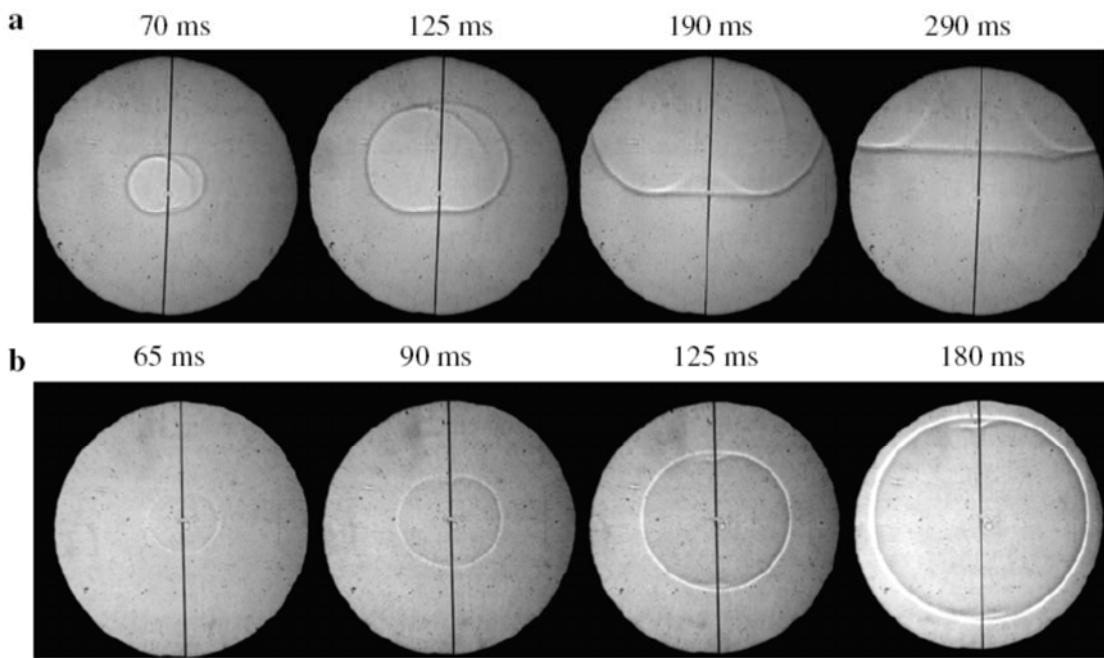
- Buoyancy
- Ignition
- Confinement
- Radiation
- Instability
- Extrapolation method
- ...

5



Effects of buoyancy

Qiao et al. 2009 PCI

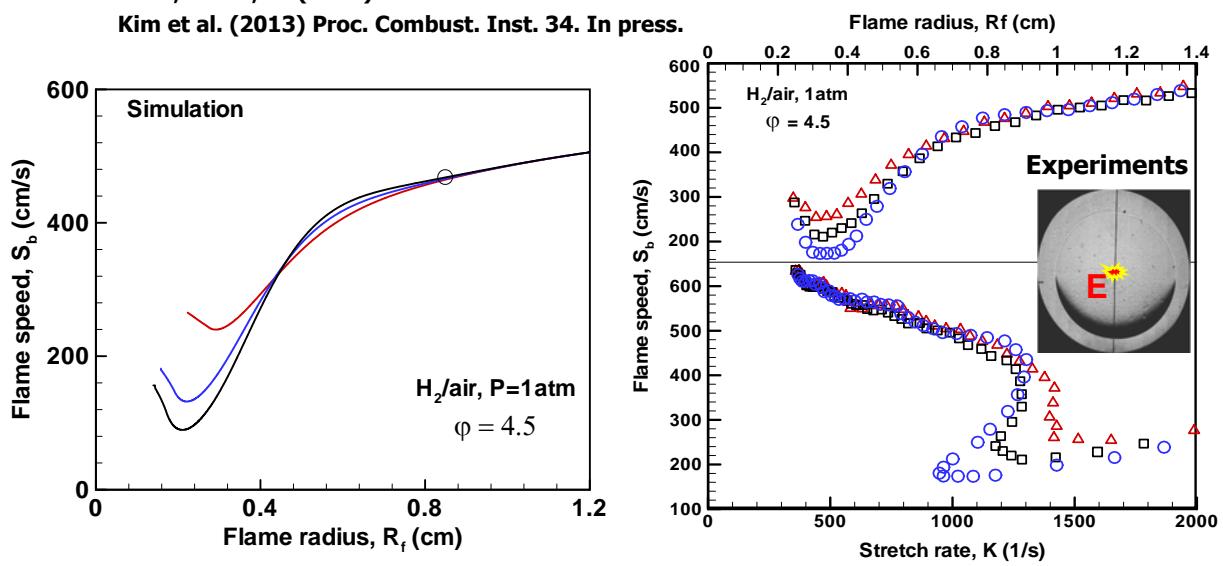


For fast burning mixtures ($S_u > 15$ cm/s), burning velocities were identical at one-g and zero-g [Ronney & Wachman, 1985 CNF].

Effects of ignition & unsteady transitions

Chen, Burke, Ju (2009) Proc. Combust. Inst. 32: 1253.

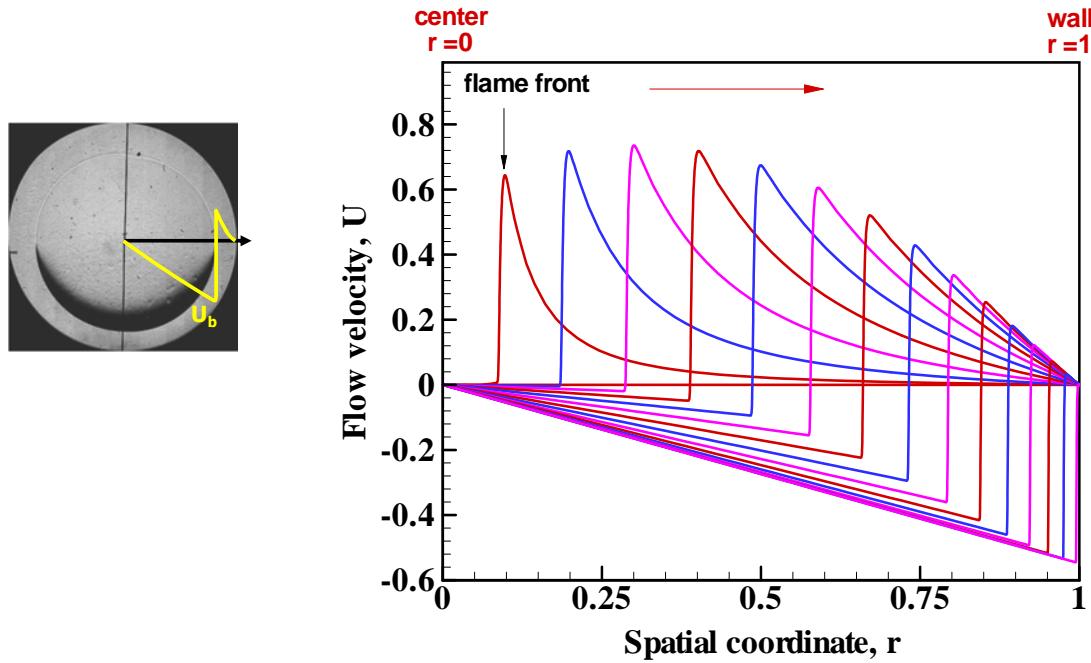
Kim et al. (2013) Proc. Combust. Inst. 34. In press.



- There is a critical radius above which the ignition effect could be neglected and this critical radius depends on Lewis number.
- At large Le, a flame speed reverse phenomenon is found, which narrows the experimental data range for extrapolation.

Compression induced flow

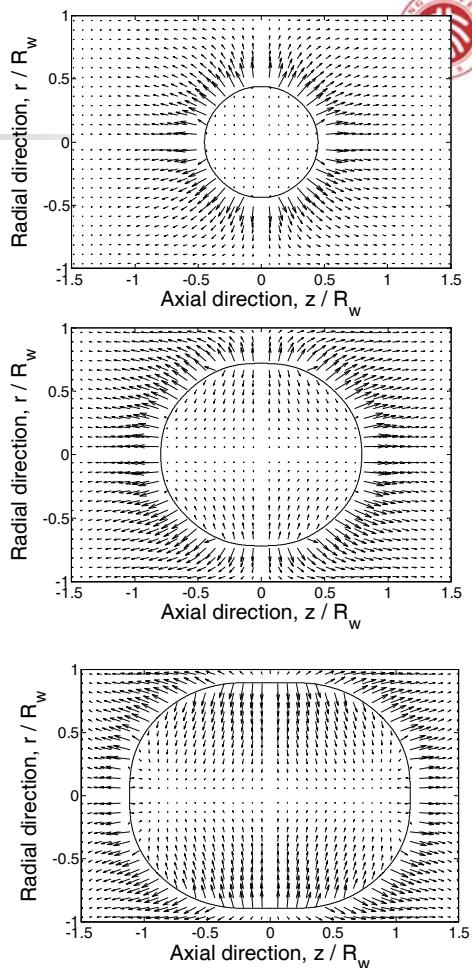
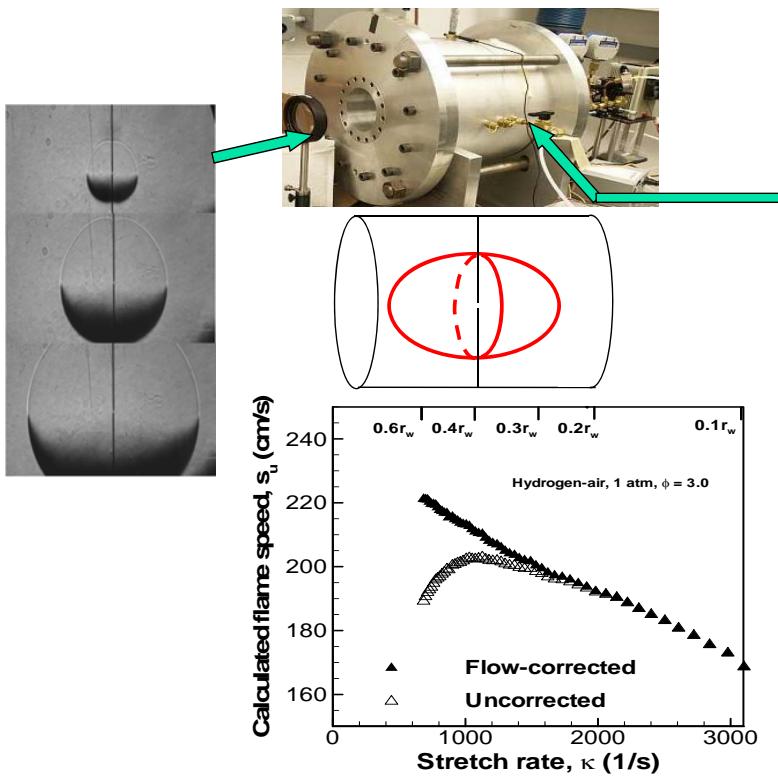
Chen, Burke, Ju (2009) Combust. Theory Model. 13: 343.



- The burned gas is NOT static ($u_b \neq 0$) when $R_f/R_w > 20\%$.

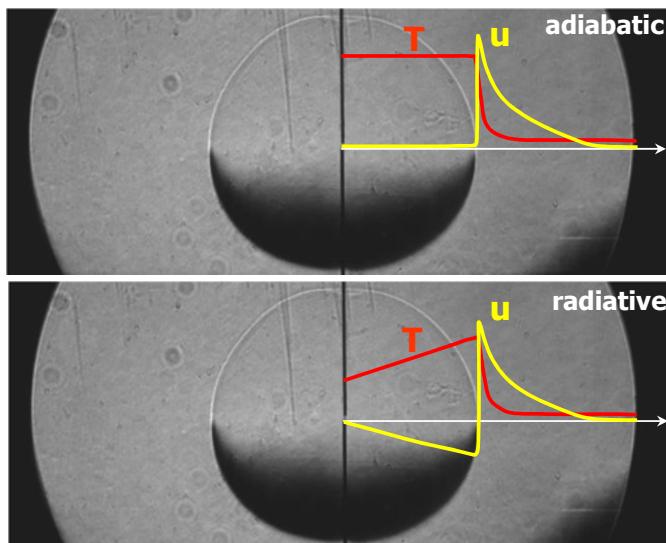
Cylindrical confinement

Burke, Chen, Ju (2009) Combust. Flame 156: 771.



Effects of radiation

Chen, Z. (2010) Combust. Flame 157: 2267.



- **Thermal Effect:** to decrease the flame temperature and thus the flame propagation speed.
- **Flow Effect:** to induce inward flow and slow flame propagation.
- **Important only for near-flammability-limit mixture.**

Different extrapolation models

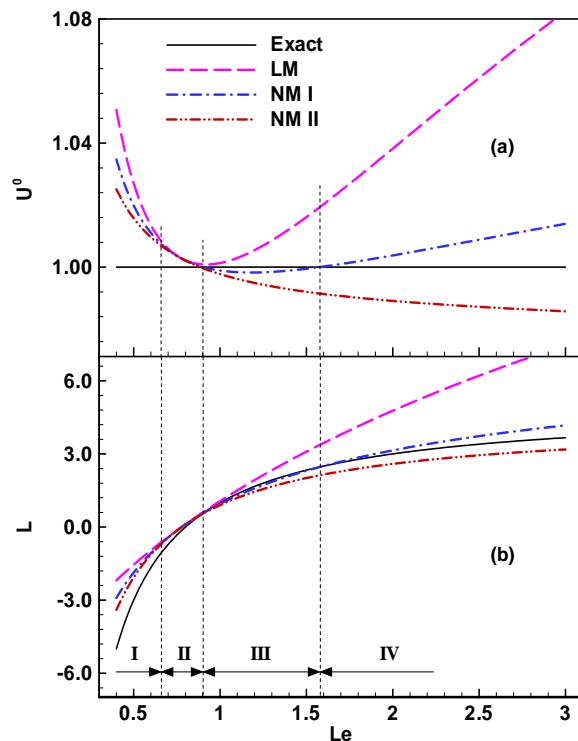
Chen, Z. (2011) Combust. Flame 158: 291.

$$\text{LM: } \frac{S_b}{S_b^o} = 1 - \frac{L_b}{S_b^o} K$$

$$\text{NM I: } \frac{S_b}{S_b^o} = 1 - \frac{2L_b}{R_f}$$

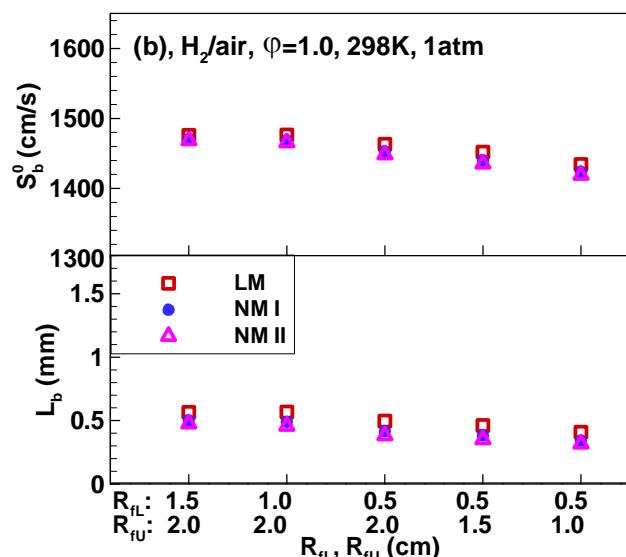
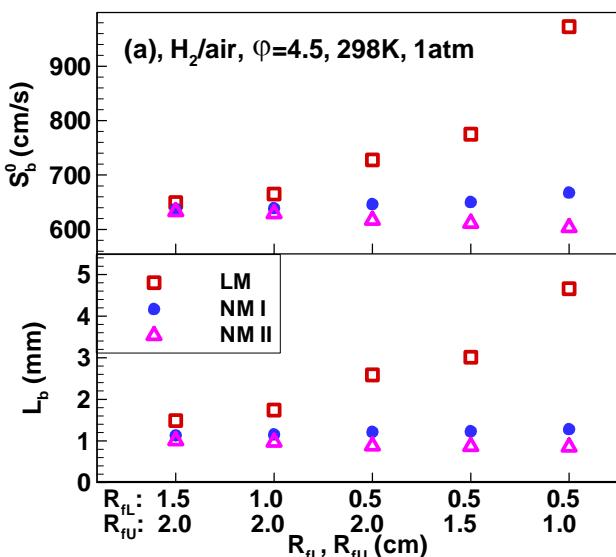
$$\text{NM II: } \ln(S_b) = \ln(S_b^o) - \frac{2L_b S_b^0}{R_f S_b}$$

- Error of these models is in the same order of $O(1/R_f^2)$.
- All are linear models.



11

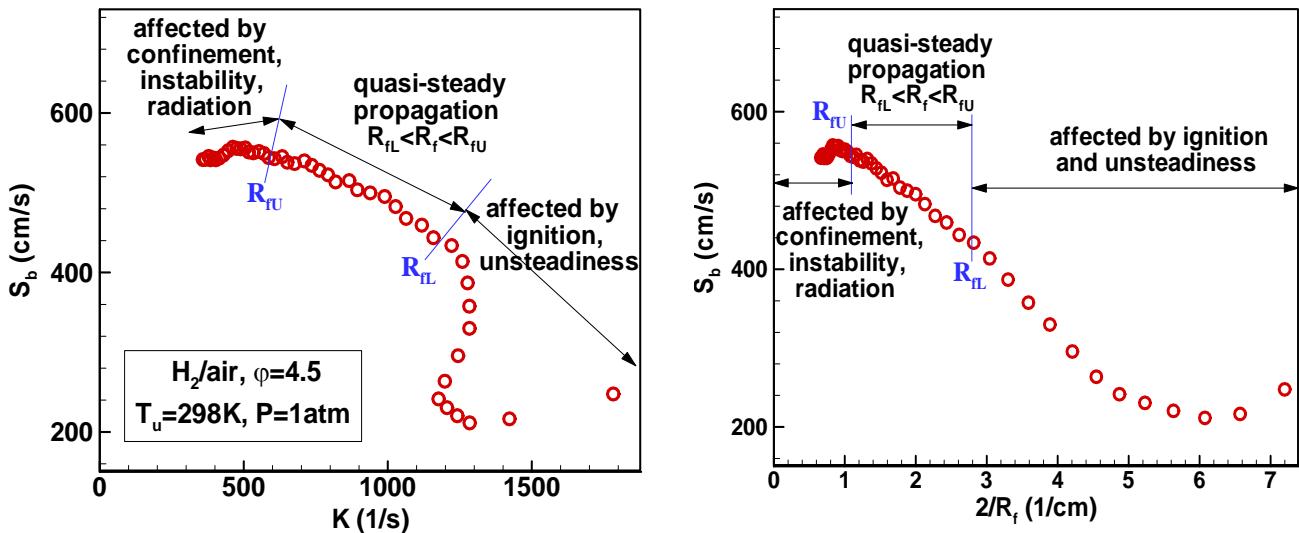
Different models and flame radius ranges



- At large Le , extracted results are the sensitive to the extrapolation model and flame radius range.
- Linear extrapolation of the stretched flame speed based on flame curvature is least sensitive to flame radius range.

12

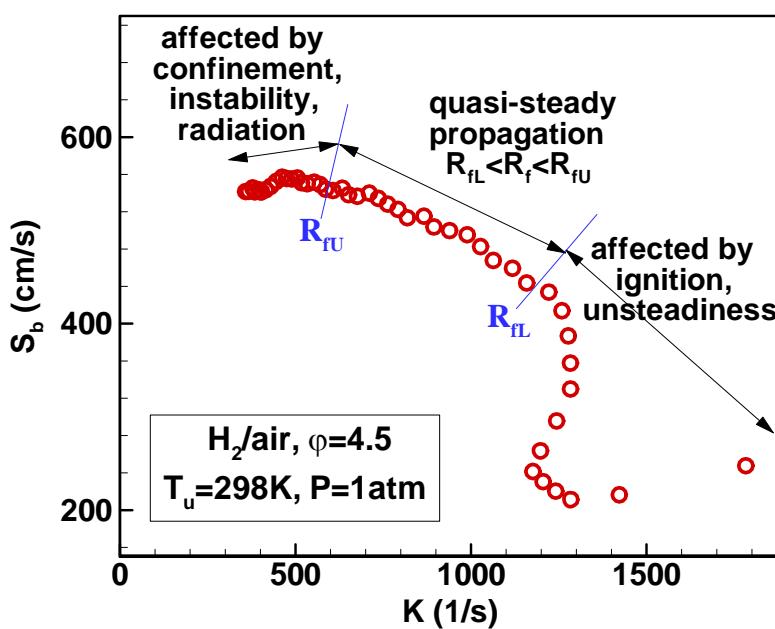
Different models and flame radius ranges



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13

Summary



- Buoyancy
- Radiation
- Ignition & unsteadiness
- Compression
- Cylindrical confinement
- Extrapolation model
- Flame radius range
- ...

14



Related publications

Full paper available online at:

<http://www.coe.pku.edu.cn/subpaget.asp?id=247>

- Z. Chen*, X. Qin, B. Xu, Y. Ju, F. Liu, "Studies of radiation absorption on flame speed and flammability limit of CO₂ diluted methane flames at elevated pressures," *Proceedings of the Combustion Institute*, 31 (2007) 2693-2700.
- Z. Chen*, M.P. Burke, Y. Ju, "Effects of Lewis number and ignition energy on the determination of laminar flame speed using propagating spherical flames," *Proceedings of the Combustion Institute*, 32 (2009) 1253-1260.
- M.P. Burke, Z. Chen, Y. Ju*, F.L. Dryer, "Effect of cylindrical confinement on the determination of laminar flame speeds using propagating spherical flames," *Combustion and Flame*, 156 (2009) 771-779.
- Z. Chen*, M.P. Burke, Y. Ju, "Effects of compression and stretch on the determination of laminar flame speeds using propagating spherical flames," *Combustion Theory and Modelling*, 13 (2009) 343-364.
- Z. Chen*, "Effects of hydrogen addition on the propagation of spherical methane/air flames: a computational study," *International Journal of Hydrogen Energy*, 34 (2009) 6558-6567.
- Z. Chen*, "Effects of radiation and compression on propagating spherical flames of methane/air mixtures near the lean flammability limit," *Combustion and Flame*, 157 (2010) 2267-2276.
- Z. Chen*, "On the extraction of laminar flame speed and Markstein length from outwardly propagating spherical flames," *Combustion and Flame*, 158 (2011) 291-300.

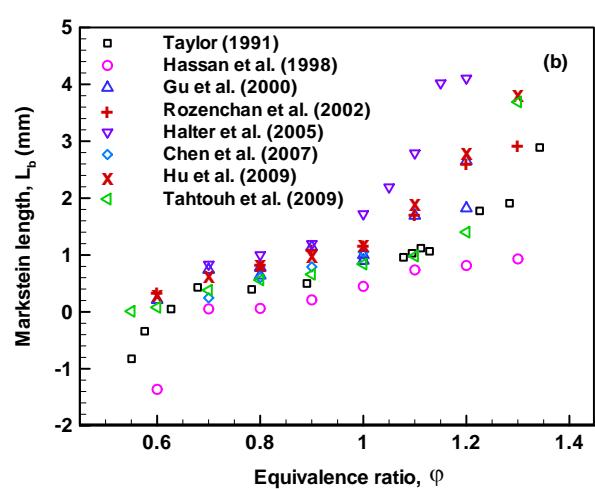
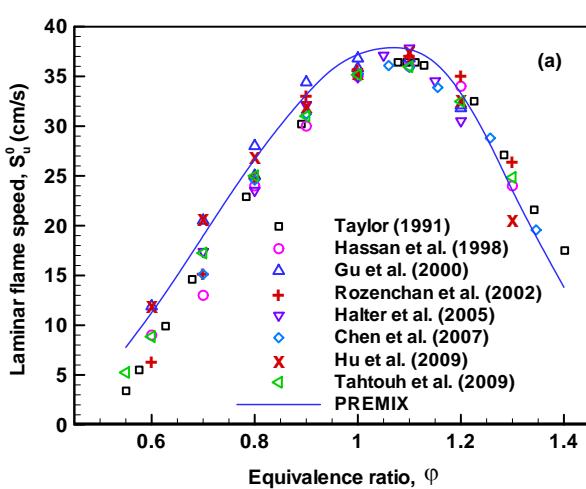
15

Thank you !

Questions & suggestions ?

Markstein length

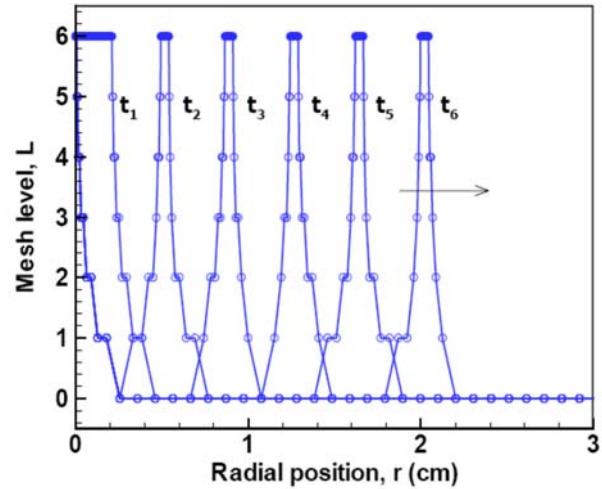
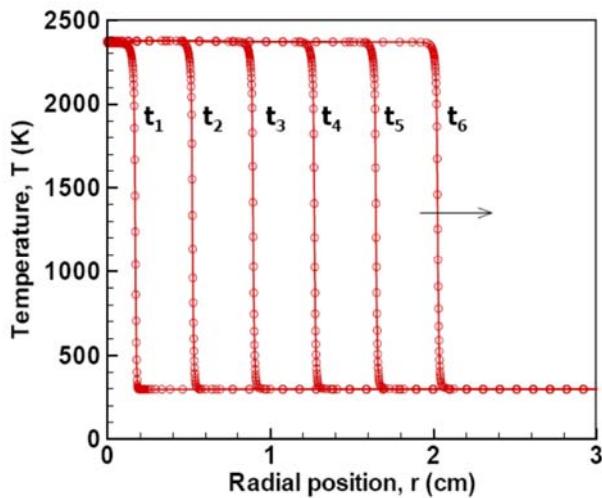
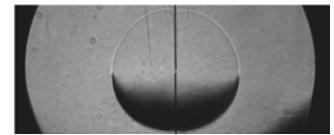
Methane/air, 298 K, 1 atm



1D simulation of expanding spherical flame

A-SURF (Adaptive Simulation of Unsteady Reactive Flow)

- Unsteady, compressible N-S equations for multi-species reactive flow
- Finite volume method; Adaptive mesh refinement

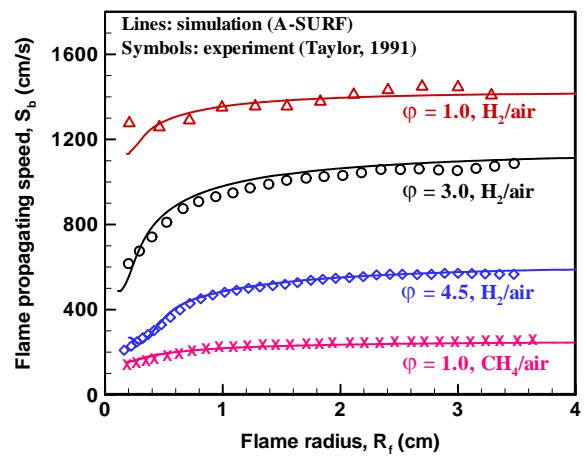
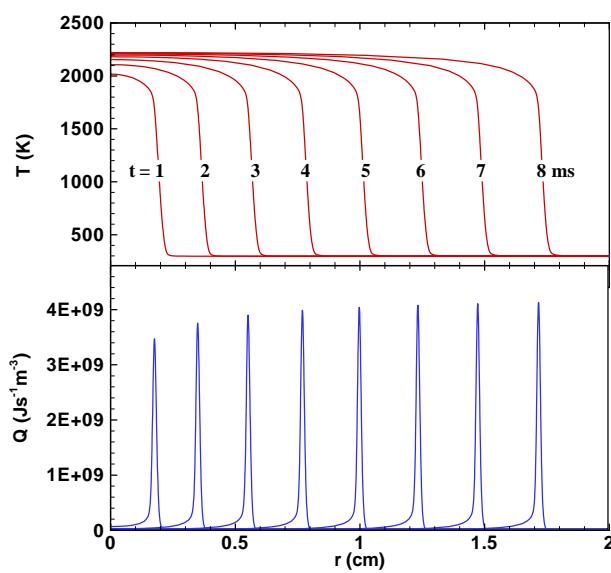
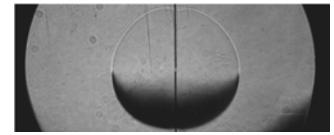


19

1D simulation of expanding spherical flame

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20