Combustion Animation

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CSE 888 - Au07

Papers

- Wrinkled Flames and Cellular Patterns.
  - Hong, J-M., Shimar, T., and Fedkiw, R.
  - SIGGRAPH 07
- Combustion-based Technique for Fire Animation and Visualization
  - Min, K. and Metaxas, D.
  - Visual Computer, Aug. 2007

Wrinkled Flames & Cellular Patterns

- Detonation Shock Dynamics
  - First Order
    - Nguyen et al. 2002

$$D = a - b\kappa$$

  - Second Order
    - Also produces smooth flames

$$D_t + \mathbf{w} \cdot \nabla D = \dot{D}$$

$$\dot{D} = -\alpha\kappa + \beta(D - D_{CJ})$$

Third Order DSD

- Produces cellular patterns in flames

$$D_t + \mathbf{w} \cdot \nabla D = \dot{D}$$

$$\dot{D}_t + \mathbf{w} \cdot \nabla \dot{D} = \ddot{D}(\dot{D}, D, \dot{\kappa}, \kappa)$$

$$\ddot{D} = -c_1 \alpha^2 (D - D_{CJ}) - c_2 \alpha \dot{D} - c_3 \alpha^2 L_{CJ} - c_4 \dot{\kappa}$$

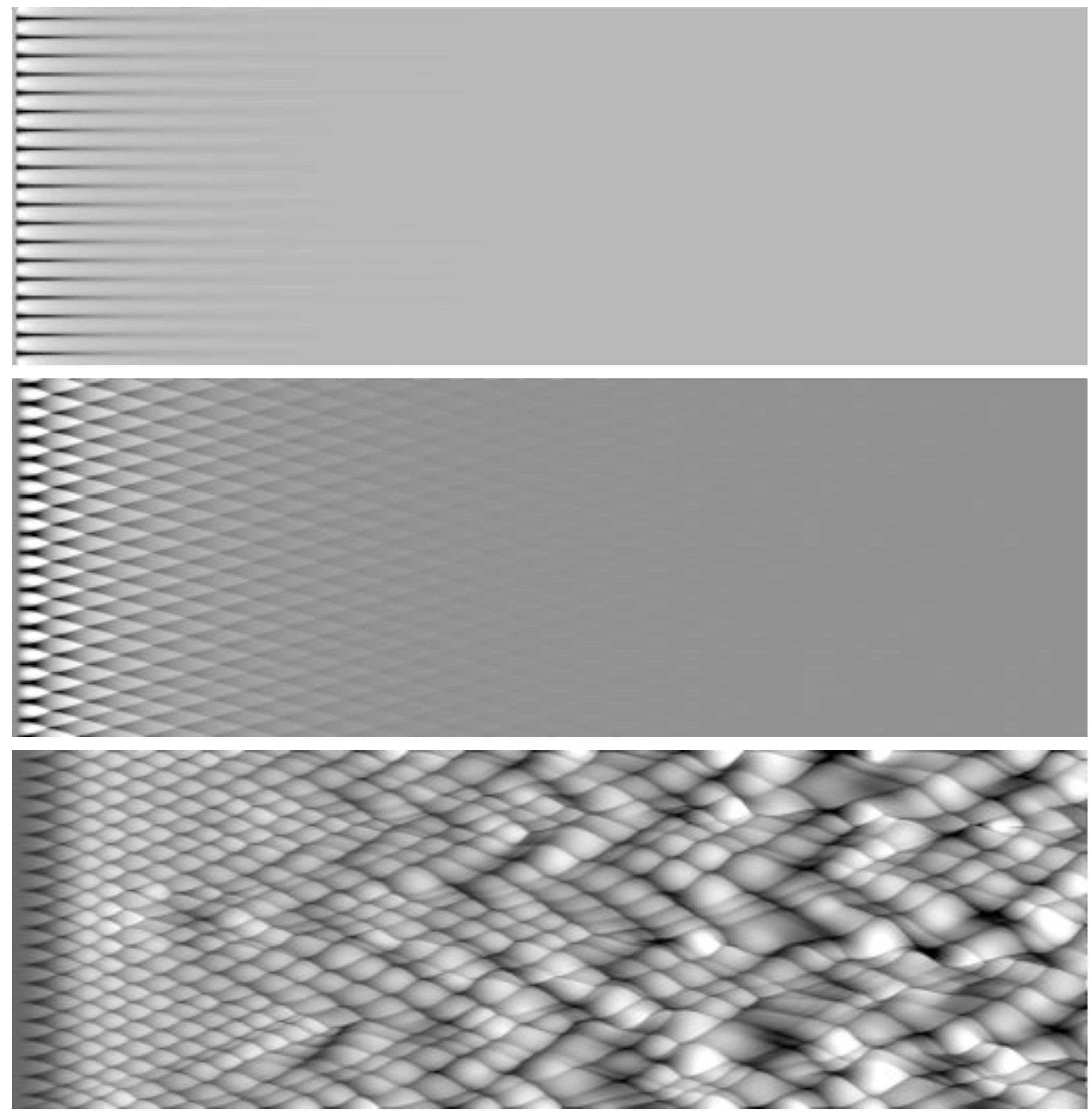
$$\alpha = e^{\mu \theta (D - D_{CJ})}, \qquad L_{CJ} = \ln|1 + c_5 \theta \kappa / \alpha|$$

DSD Comparision

First Order

Second Order

Third Order



Third Order DSD Constants

- c1, c2, c3, c4, c5, μ : constants that depend on material properties
- θ : activation energy

$$\ddot{D} = -c_1 \alpha^2 (D - D_{CJ}) - c_2 \alpha \dot{D} - c_3 \alpha^2 L_{CJ} - c_4 \dot{\kappa}$$

$$\alpha = e^{\mu \theta (D - D_{CJ})}, \qquad L_{CJ} = \ln |1 + c_5 \theta \kappa / \alpha|$$

Modeling Fuel

- Navier-Stokes Equations
  - Inviscid, Incompressible Flow

$$\mathbf{u}_t + (\mathbf{u} \cdot \nabla)\mathbf{u} + \nabla p / \rho = \mathbf{f}$$

$$\nabla \cdot \mathbf{u} = 0$$

Fuel Continued

- Conserve mass, momentum and energy across reaction interface

$$[\rho(u_n - w_n)] = 0$$

$$[\rho(u_n - w_n)^2 + p] = 0$$

$$[e + (u_n - w_n)^2/2 + p/\rho] = 0$$

Results

	Number of frames	Total time	Mean time per frame	DSD time per frame	CFL number	Grid resolution
Figure 1	521	68 hr	469 sec	5 %	2	$300 \times 250 \times 250$
Figure 6	300	24 hr	291 sec	6 %	2	$200 \times 300 \times 200$
Figure 7	225	50 hr	800 sec	6 %	1.5	$250 \times 250 \times 250$

Combustion-based Technique for Fire Animation

- Voxel-based combustion simulation
- Photon mapping using fire temperature

Fluid Equations

- Navier-Stokes again
  - This time with viscosity

$$\frac{\partial \boldsymbol{u}}{\partial t} = -(\boldsymbol{u} \cdot \nabla)\boldsymbol{u} - \frac{1}{\rho}\nabla p + \nu \nabla^2 \boldsymbol{u} + \boldsymbol{f}$$

- Density

$$\frac{\partial \rho}{\partial t} = -(\boldsymbol{u} \cdot \nabla)\rho$$

- Temperature

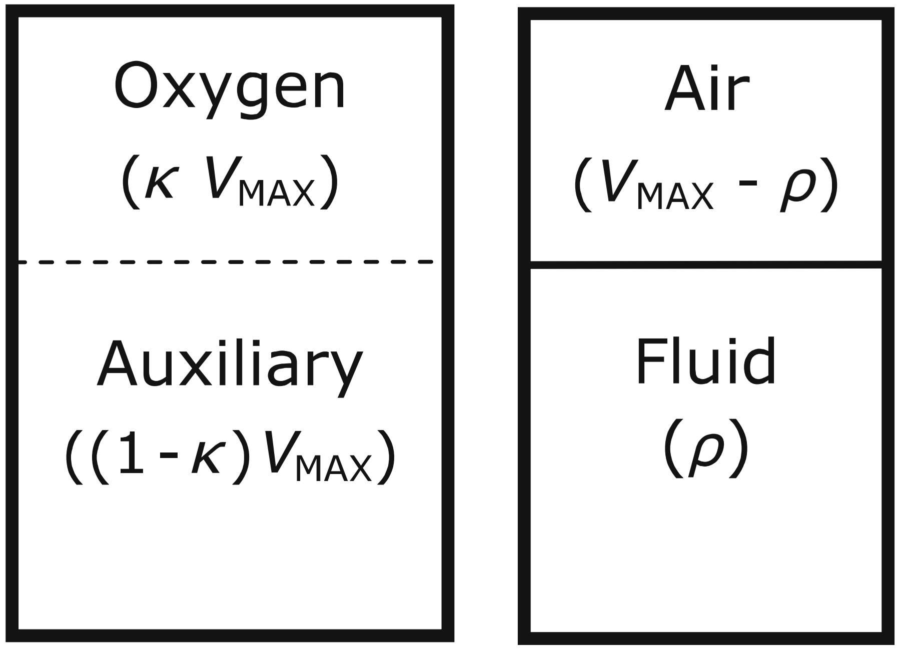
$$\frac{\partial T}{\partial t} = -(\boldsymbol{u} \cdot \nabla)T - c_T \left(\frac{T - T_{\mathrm{air}}}{T_{\max} - T_{\mathrm{air}}} \right)^4 + \frac{\mathrm{d}H}{\mathrm{d}t}$$

Fuel Model

- Potential Heat
- Combustion Speed
- Oxygen Requirement
- Threshold Temperatures
    - Pyrolysis
    - Ignition

Voxel Configuration

- Initially, voxels contain only air or fluid
- Fluid may consist of several different fuels
- Air consists of Oxygen and auxiliary gasses



Combustion Model

- Estimate oxygen availability & requirement
- Compute heat generated by each fuel
- Compute total heat of voxel

Oxygen Estimation

- Available

$$O_a^x(v) = O(v)\frac{\varphi^x(v)}{\Phi}, \quad \text{where } \Phi = \sum_{n=1}^{N} \varphi^n(v)$$

- Required

$$O_r^x(v) = O_r^x \varphi^x(v)$$

Heat Generation

- Estimate fuel combusted
  - If more than enough oxygen is available, combustion speed determines amount

$$\phi^x(v) \leftarrow \gamma^x \times \varphi^x(v)$$

  - Otherwise, oxygen availability limits combustion

$$\phi^x(v) \leftarrow \frac{O_a^x(v)}{O_r^x(v)}\gamma^x \times \varphi^x(v)$$

Heat Generation Continued

- Heat generated by each fuel is the product of amount of fuel combusted, potential heat, and density over the simulation timestep

$$H^x(v) = h^x \times \phi_v^x \times \rho_v \times \delta t,$$

Results