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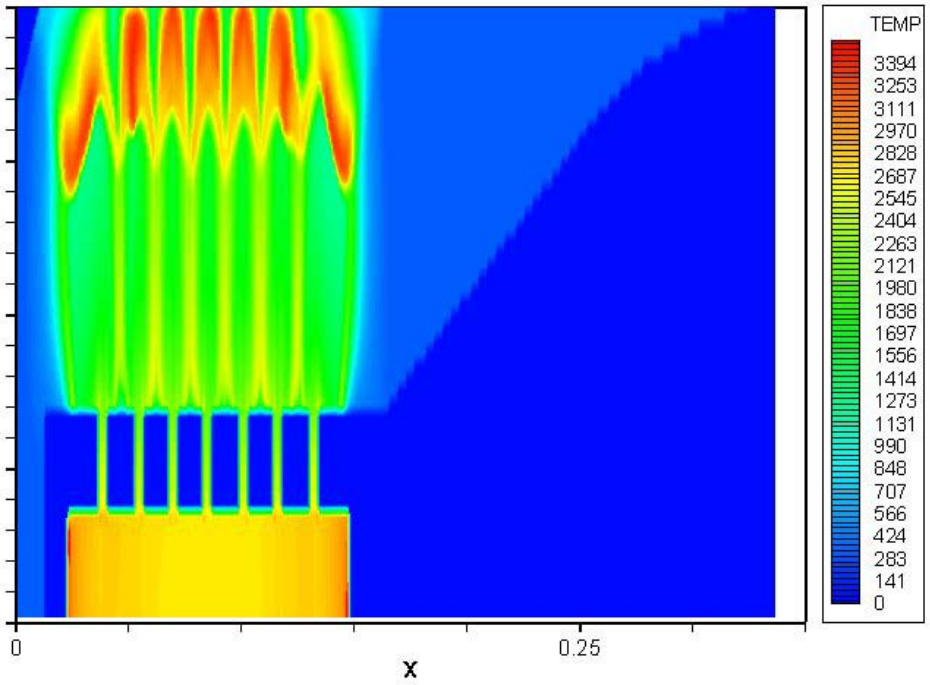

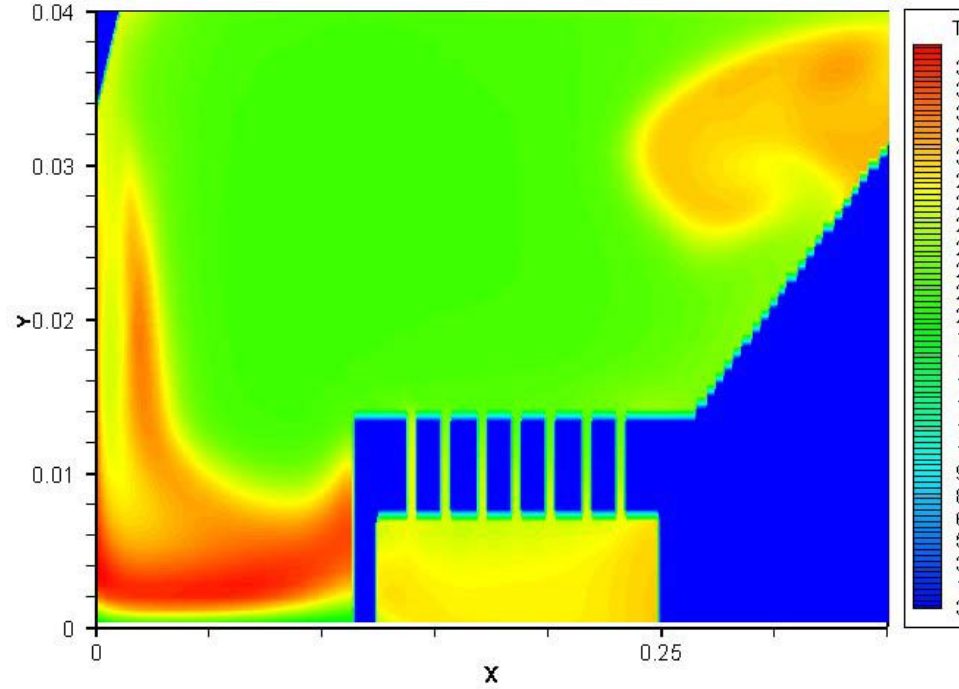

Two-dimensional Modelling of Mortar Internal Ballistics

Clive Woodley, David Finbow, Vladimir Titarev & Eleuterio Toro

International Symposium on Ballistics, November 2005

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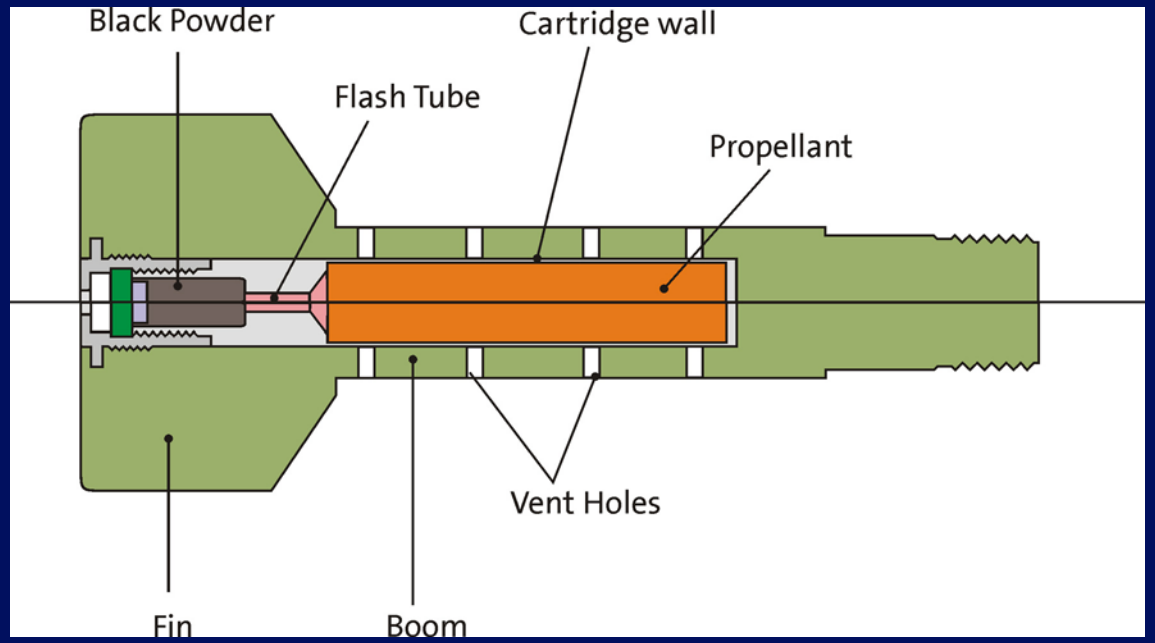
4 Conclusions & further work

Section 1

Introduction

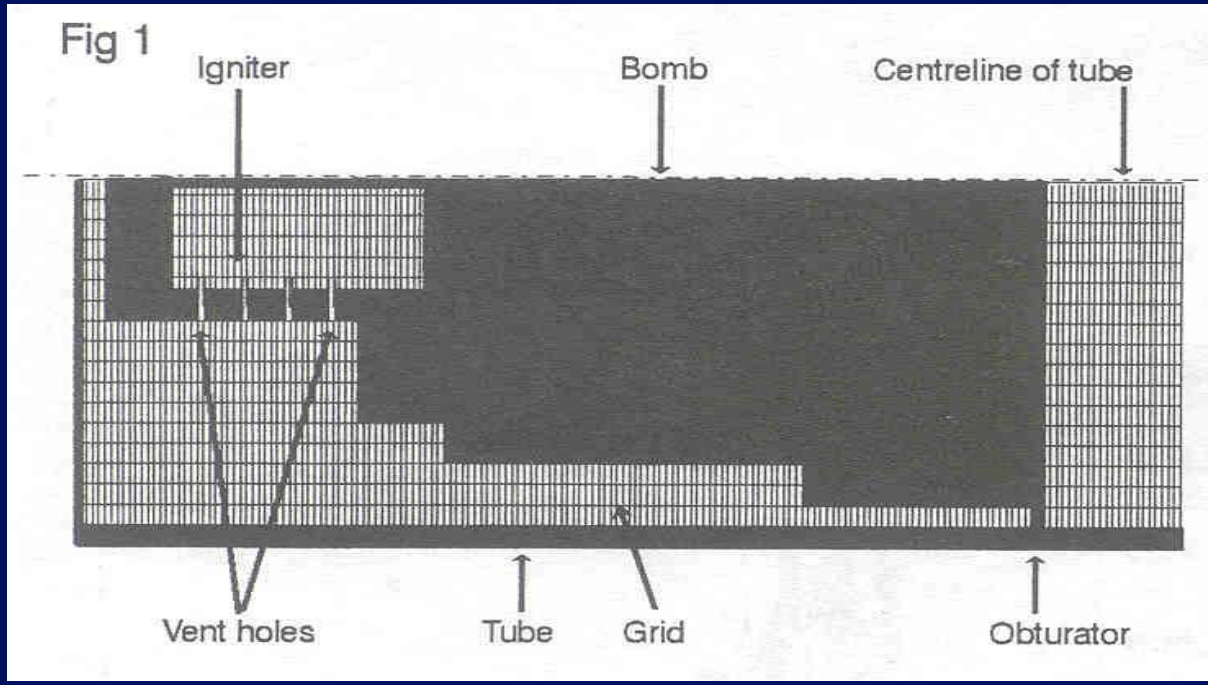
Background

- 51mm & 81mm mortars exhibited pressure oscillations
- Bent fins
- Split/broken tail units



Previous UK work

- Mostly 0D and 1D
- 2D work in mid 90s
  - Code not robust
  - Data hardwired
- New code needed



Section 2

Equations & numerics

Equations – gas phase

$$\frac{\partial}{\partial t}(\rho\varepsilon)+\frac{\partial}{\partial z}(\rho\varepsilon u)+\frac{\partial}{\partial r}(\rho\varepsilon v)=-\frac{\varepsilon\rho v}{r}+\dot{m}_{ig}+\sum_{k=1}^{n}\dot{m}^{k}$$

$$\frac{\partial}{\partial t}(\rho\varepsilon u)+\frac{\partial}{\partial z}[\varepsilon(\rho u^{2}+p)]+\frac{\partial}{\partial r}(\rho\varepsilon uv)=-\frac{\varepsilon\rho uv}{r}+p\frac{\partial\varepsilon}{\partial z}+\sum_{k=1}^{n}(\dot{m}^{k}u^{k})$$

$$\frac{\partial}{\partial t}(\rho\varepsilon v)+\frac{\partial}{\partial z}(\varepsilon\rho uv)+\frac{\partial}{\partial r}[\varepsilon(\rho v^{2}+p)]=-\frac{\varepsilon\rho v^{2}}{r}+p\frac{\partial\varepsilon}{\partial r}+\sum_{k=1}^{n}(\dot{m}^{k}v^{k})$$

$$\frac{\partial}{\partial t}(\rho\varepsilon E)+\frac{\partial}{\partial z}[\varepsilon\rho u(E+p/\rho)]+\frac{\partial}{\partial r}[\rho\varepsilon v(E+p/\rho)]=-\frac{\varepsilon\rho v}{r}(E+p/\rho)+\dot{m}_{ig}Q_{ig}+$$

$$\sum_{k=1}^{n}[\dot{m}^{k}(Q_{p}^{k}+\kappa^{k})-p\left(\frac{\partial(\varepsilon^{k}u^{k})}{\partial z}+\frac{\partial(\varepsilon^{k}v^{k})}{\partial r}\right)]$$

Equations – solid phase

$$\frac{\partial}{\partial t}(\rho^k \varepsilon^k) + \frac{\partial}{\partial z}(\rho^k \varepsilon^k u^k) + \frac{\partial}{\partial r}(\rho^k \varepsilon^k v^k) = -\dot{m}^k - \frac{\varepsilon^k \rho^k u^k}{r}$$

$$\frac{\partial}{\partial t}(\rho^k \varepsilon^k u^k) + \frac{\partial}{\partial z}[\varepsilon^k(\rho^k (u^k)^2 + p + p_{is}^k)] + \frac{\partial}{\partial r}(\rho^k \varepsilon^k u^k v^k) = p\frac{\partial \varepsilon^k}{\partial z}$$

$$-\frac{\varepsilon^k \rho^k u^k v^k}{r} - \dot{m}^k u^k$$

$$\frac{\partial}{\partial t}(\rho^k \varepsilon^k v^k) + \frac{\partial}{\partial z}(\varepsilon^k \rho^k u^k v^k) + \frac{\partial}{\partial r}[\varepsilon^k(\rho^k (v^k)^2 + p + p_{is}^k) = p\frac{\partial \varepsilon^k}{\partial r} - \frac{\varepsilon^k \rho^k (v^k)^2}{r} - \dot{m}^k v^k$$

$$\frac{\partial}{\partial t}(N^k) + \frac{\partial}{\partial z}(N^k u^k) + \frac{\partial}{\partial r}(N^k v^k) = -\frac{v^k N^k}{r}$$

Equations – closure & conservative form

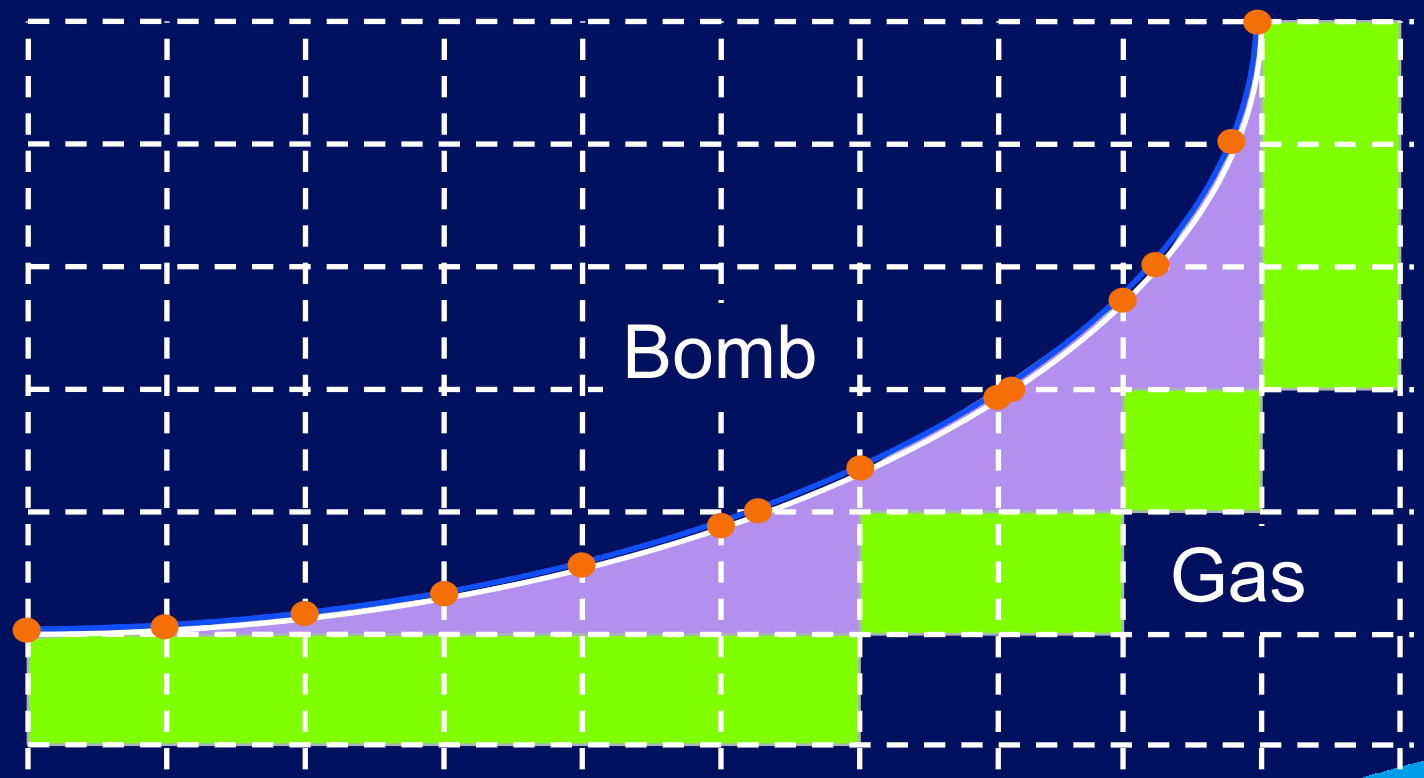
$$\varepsilon + \sum_{k=1}^{n} \varepsilon^{k} = 1$$

$$p(1/\rho - \eta) = RT / W$$

$$\partial_t Q + \partial_z F(Q) + \partial_r G(Q) = S(Q)$$

Numerical algorithm

- Cartesian cut cell mesh generator
- Numerical solver



Numerical solver

- Two step time splitting procedure

$$Q_{ij}^{*} = Q_{ij}^{n} - \frac{\Delta t}{V_{ij}} \sum_{s=1}^{N} A_s T_s^{-1} F^{HLLC}\left(T_s Q_L, T_s Q_R\right)$$

Step 1

Phase splitting

Gas phase

Solid phases

$$Q_{ij}^{n+1} = Q_{ij}^{*} + \Delta t \sum_{k=1}^{3} S_k\left(Q_{ij}^{*}\right)$$

Step 2

Remesh

Section 3

Testing & results

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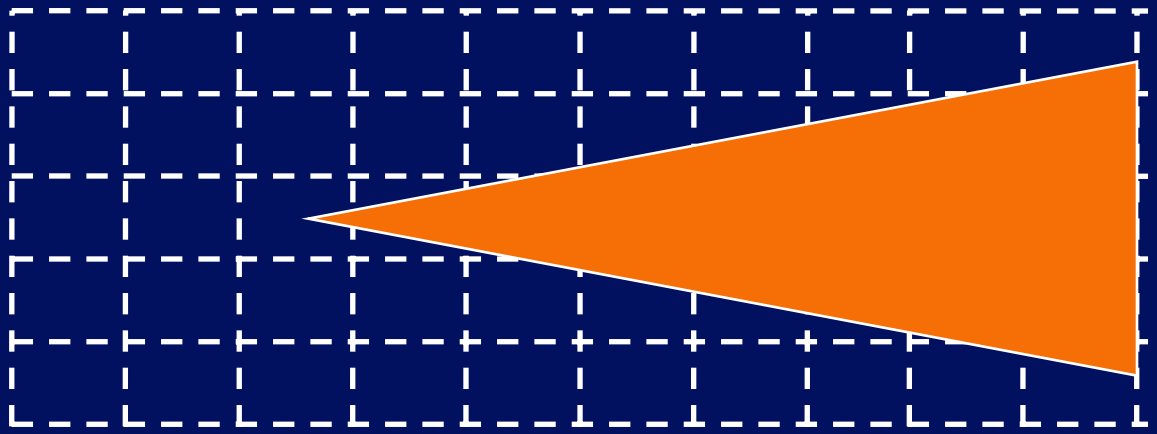
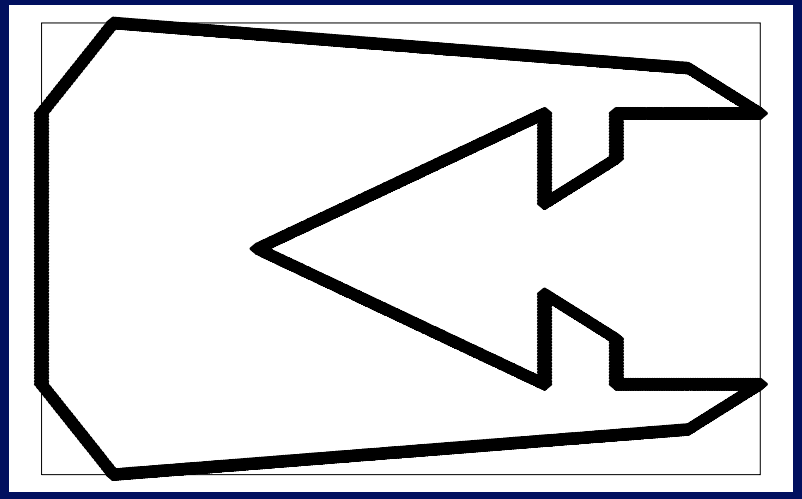
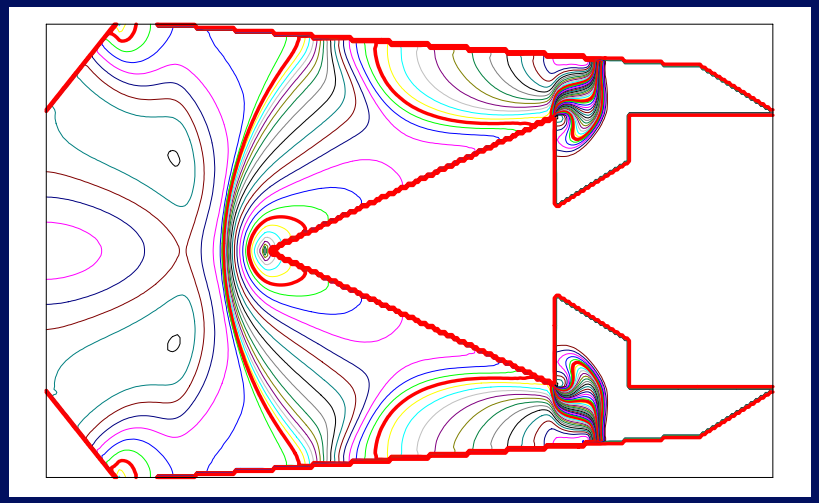
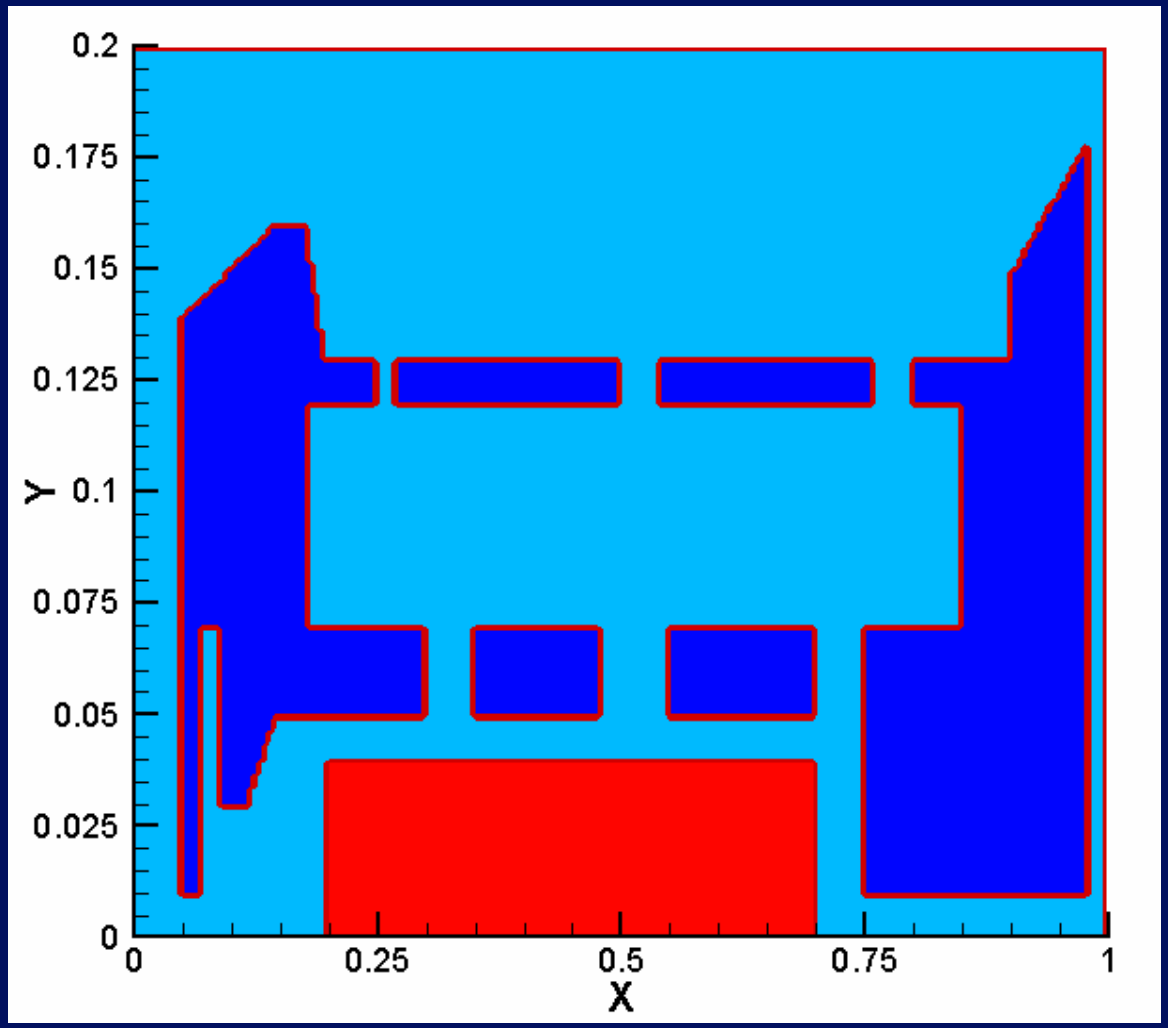
Testing on complex geometries



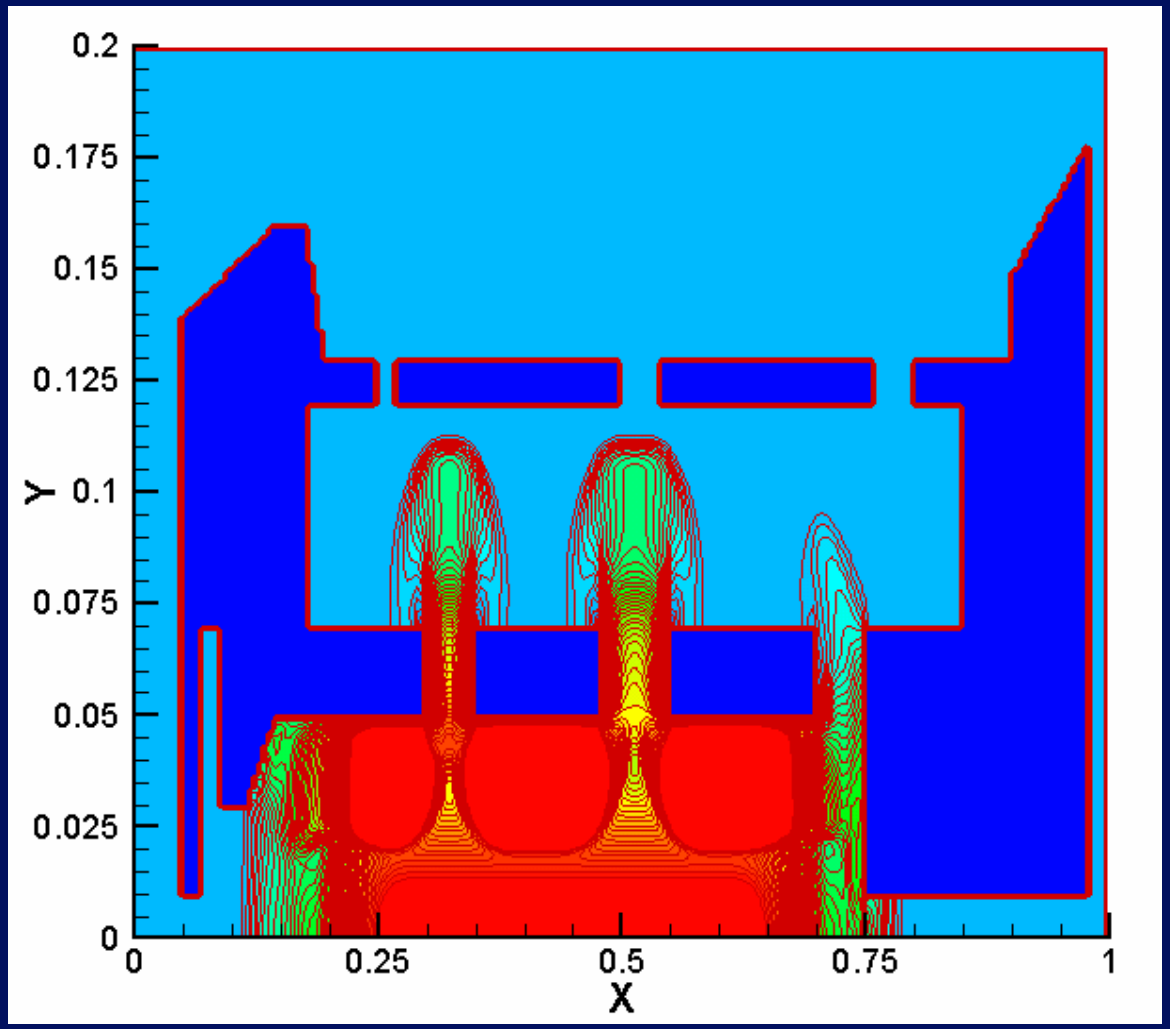




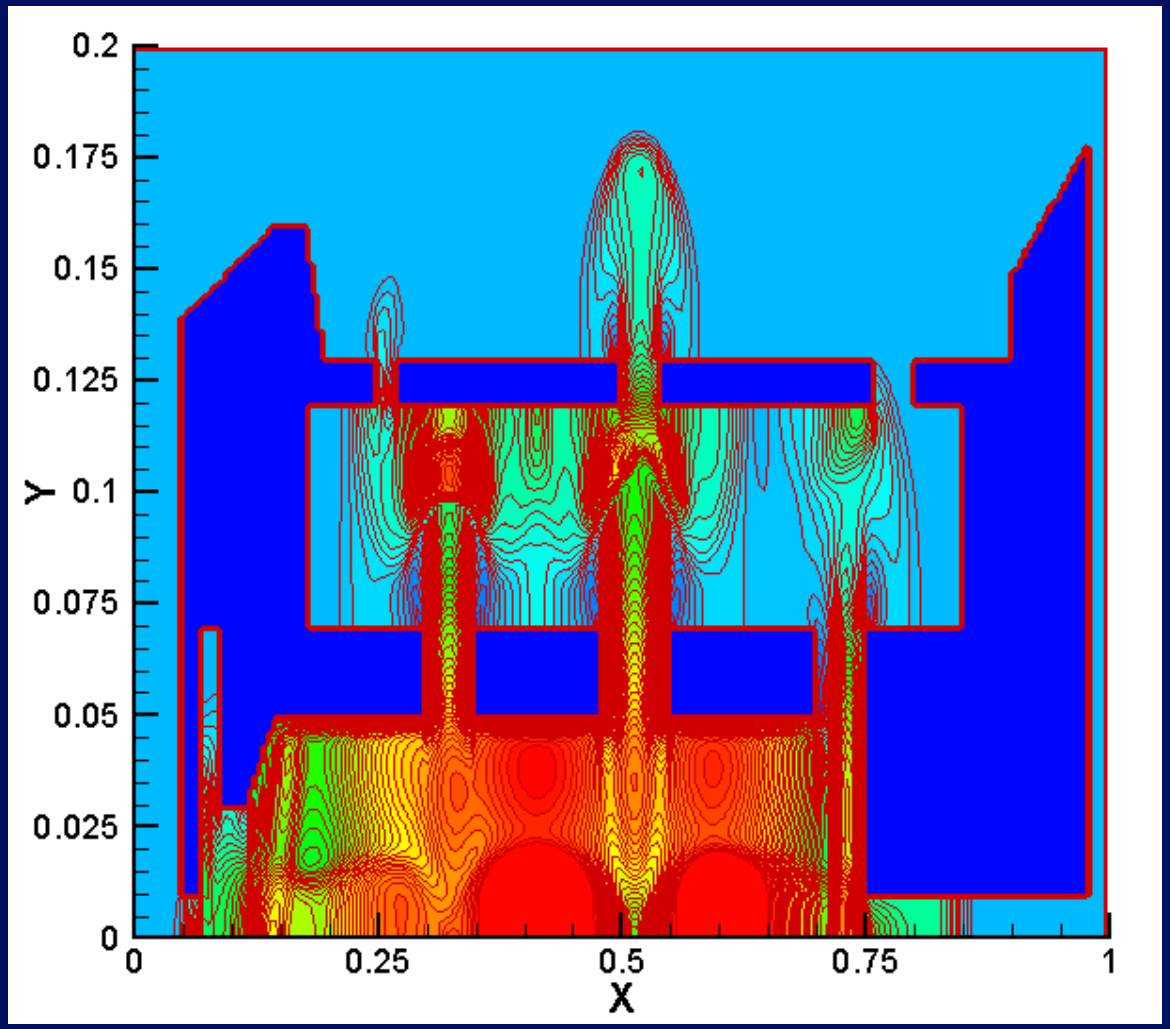
Testing on Mortar-like configuration



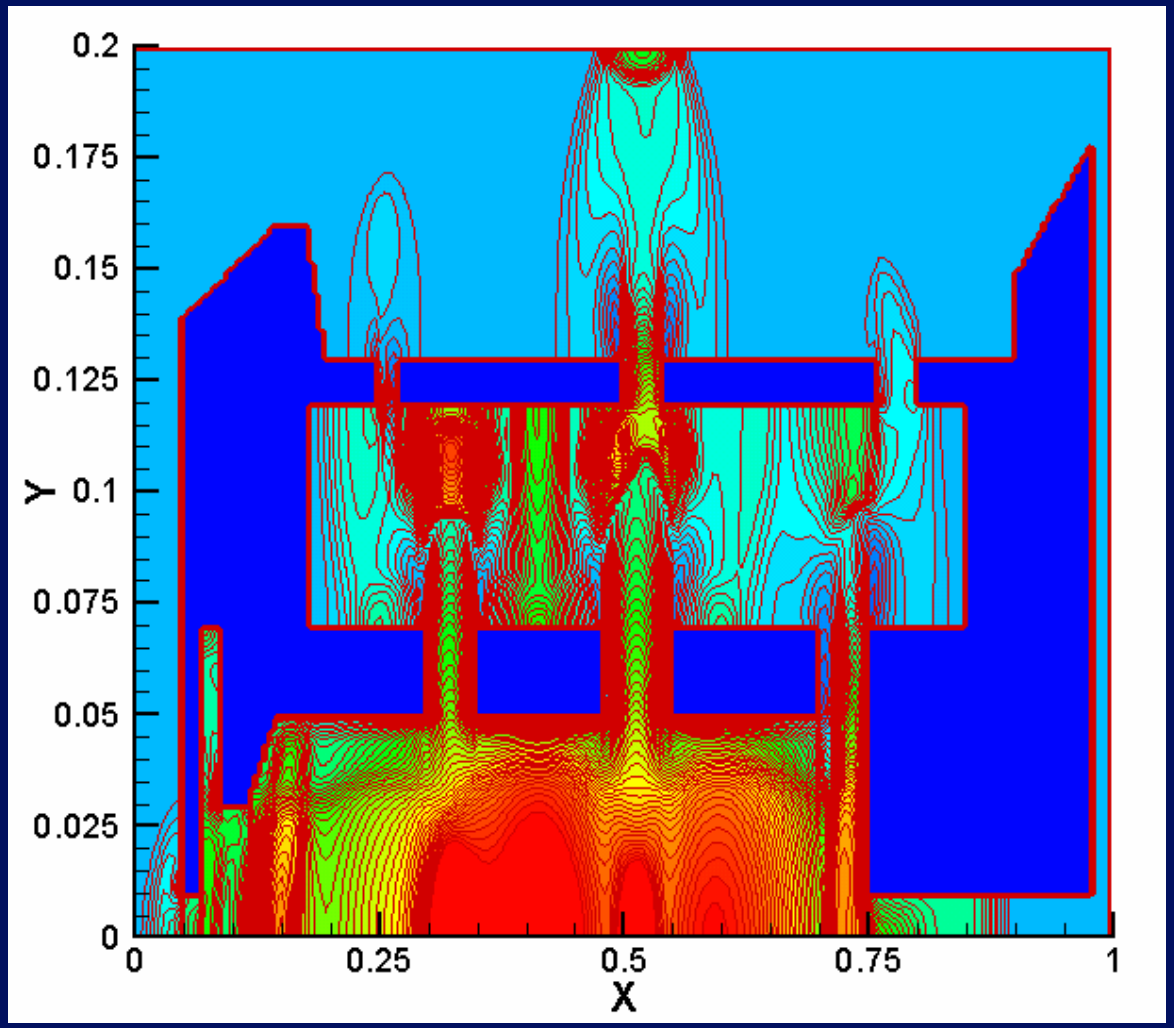
Testing on Mortar-like configuration



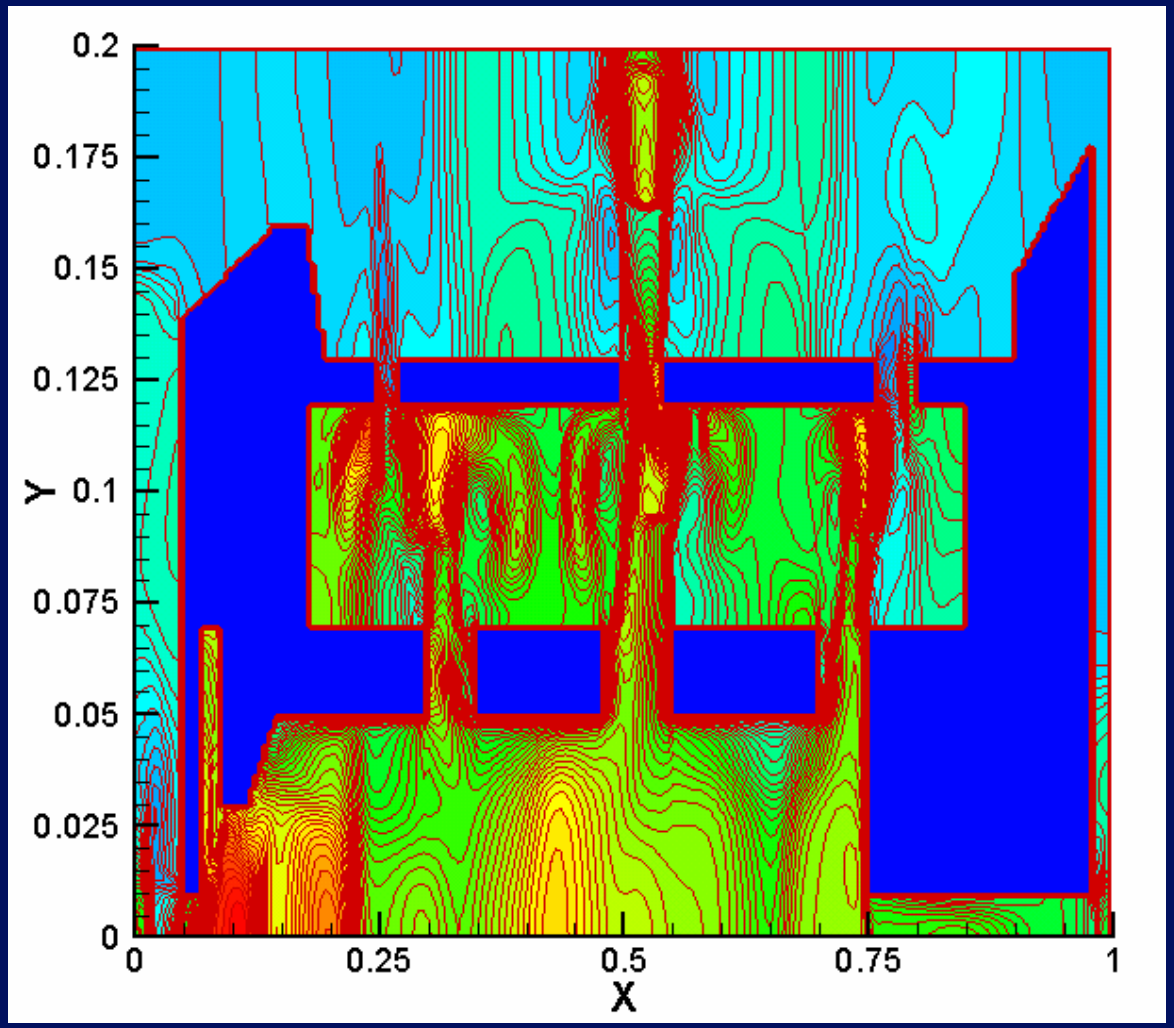
Testing on Mortar-like configuration



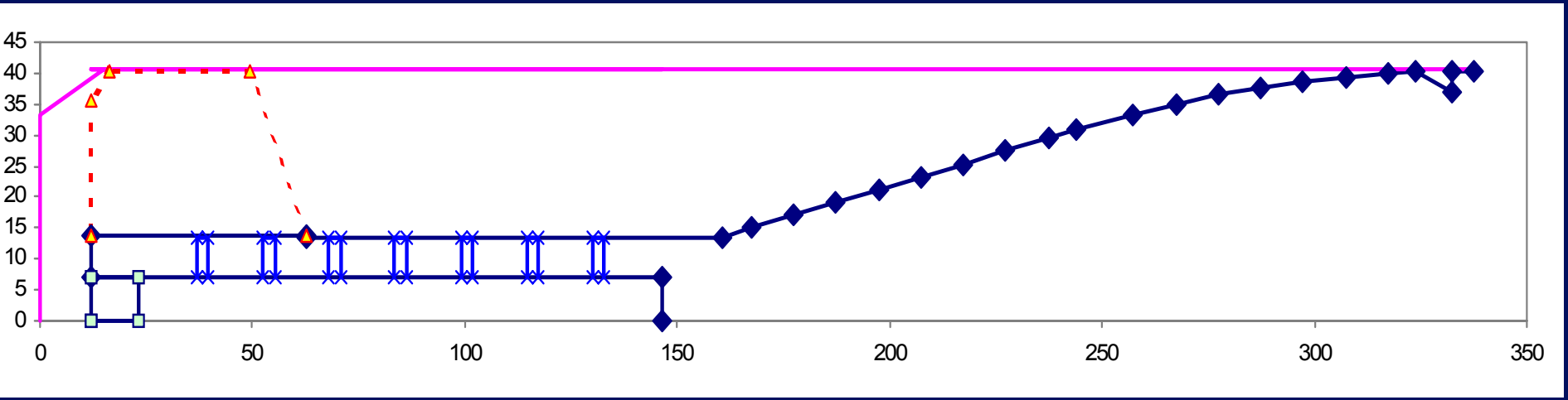
Testing on Mortar-like configuration



Testing on Mortar-like configuration



81mm mortar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40
35
30
25
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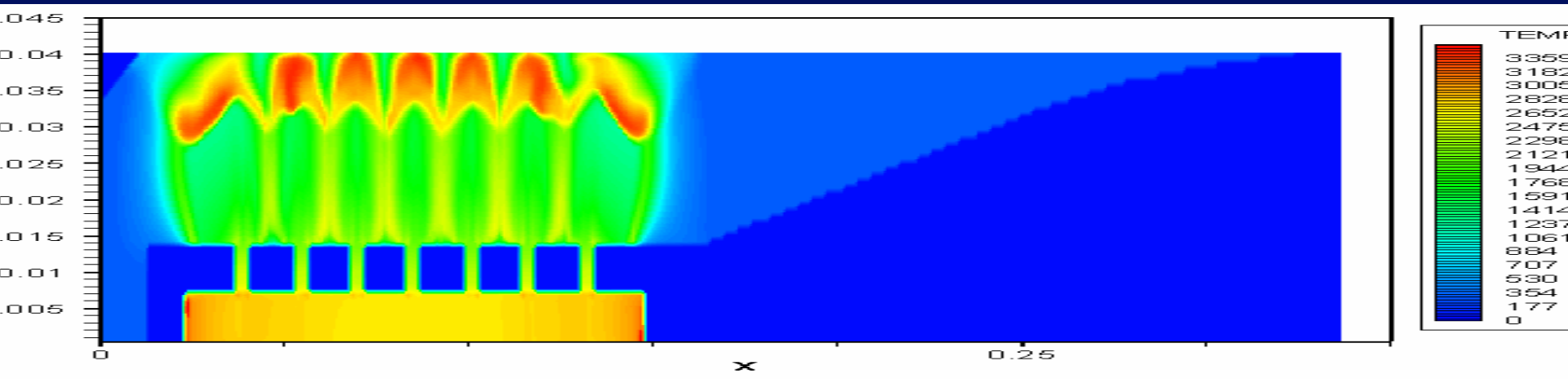
15
10
5
0
0
50
100
150
200
250
300
350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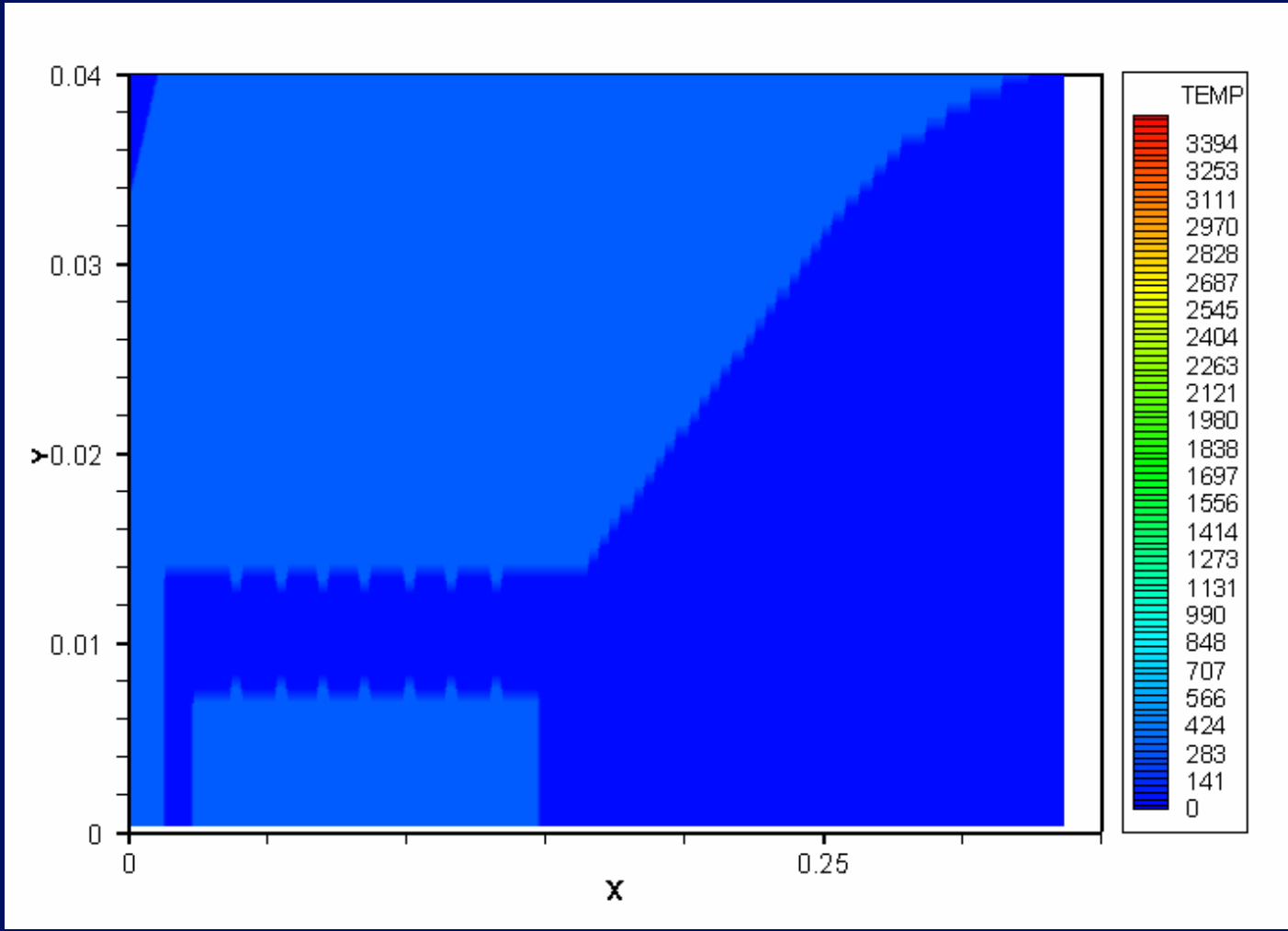
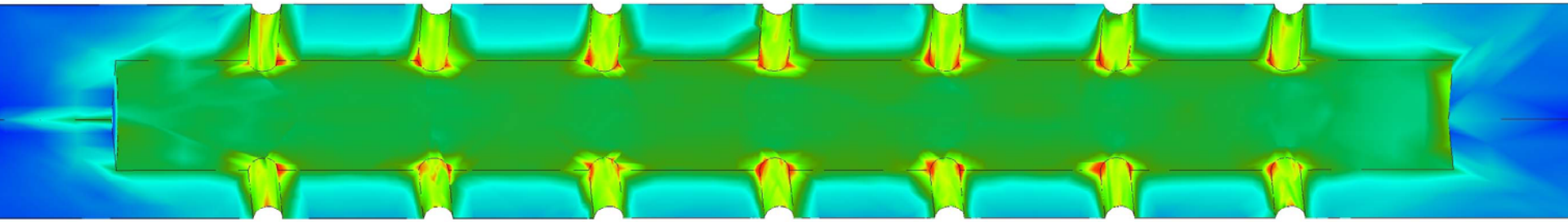
0.03
0.02
0.01
0
0.25
x
TEMP
3359
3182
3005
2828
2652
2475
2298
2121
1944
1768
1591
1414
1237
1061
884
707
530
354
177
0

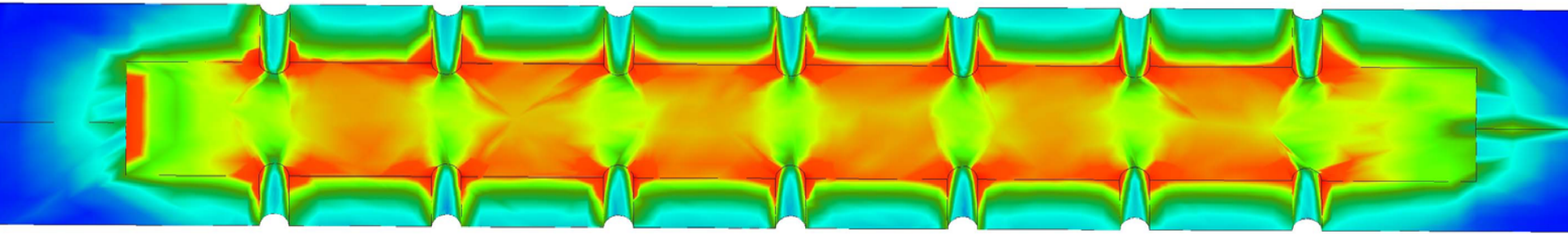
81mm mortar animation



FE analysis on tail unit



Stress distribution at 1ms



Stress distribution for 80MPa internal pressure

Section 4

Conclusions & further work

Conclusions & furtherwork

- 2D mortar code developed & capable of modelling representative mortar geometries
  - Rigorously tested for complex geometries
- Output linked to FE analysis software to allow the calculation of stress distributions
- Software can also be used for any gun/projectile system in which the projectile intrudes significantly into the combustion chamber

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