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Pressure effects in an enclosed volume due to EFP impact

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Problem

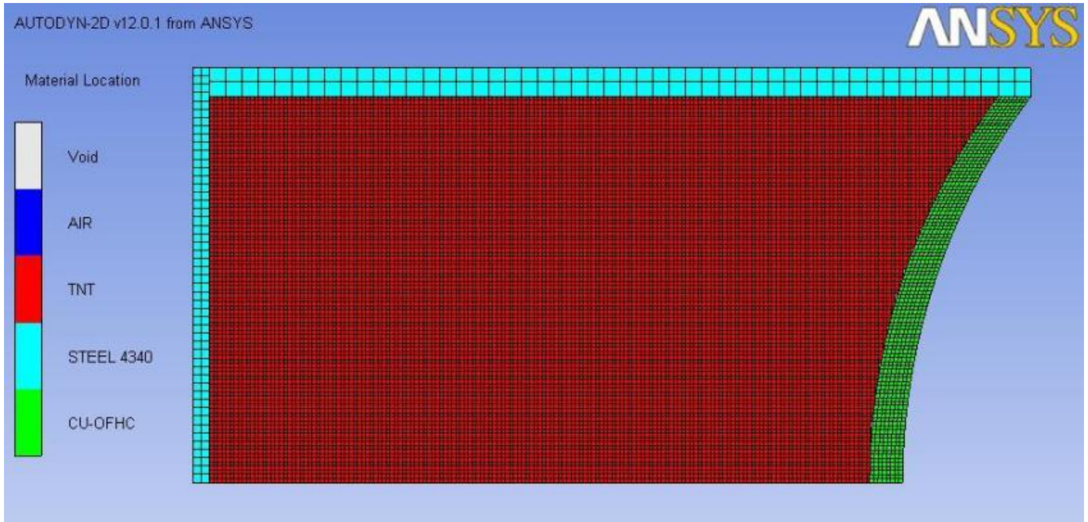
- Is it possible for a build up of dangerous/lethal high-pressure regions inside a vehicle hit by an EFP?

Problem definition

- If complete perforation is assumed, three mechanisms studied:
  - Shock from penetrator.
  - Shock from detonation.
  - Pressure induced by plate vibrations.
- Effects such as chemical reactions, ref. *Heine & Wickert, ESW 2008*, is not considered
- Purely numerical study

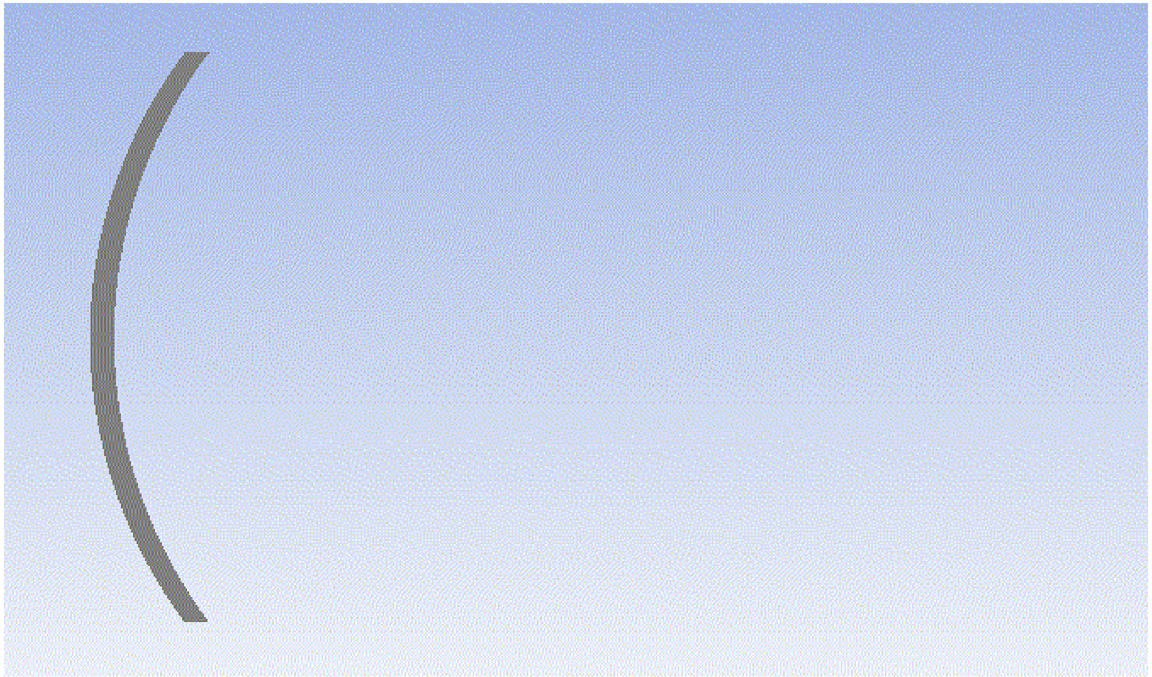
Setup

- A generic EFP was modeled in ANSYS AUTODYN



- Charge mass 1 kg TNT
- Liner mass 250 g Cu

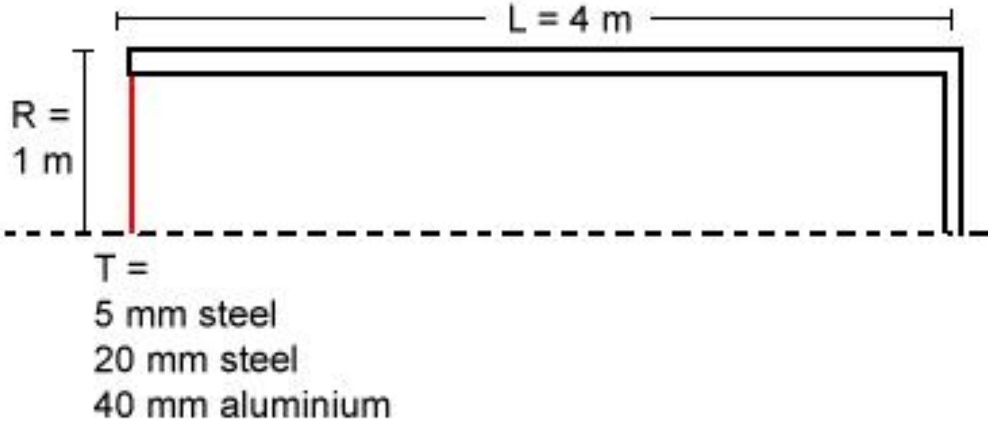
Slug



- V ~ 1300 m/s
- Reaches stable configuration after ~ 0,75 ms.

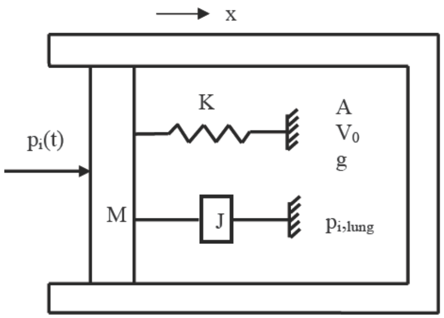
Target

- To simplify the problem, a stand-in target for a vehicle was chosen.



- Slug perforated all target thicknesses.
- Worst case scenario, 5 mm steel, was studied in more detail

Injury Criterion



Name	Explanation
A	Effective area
M	Effective mass
V_0	Lung gas volume at x=0
J	Damping factor
K	Spring constant
p_0	Ambient pressure
$p_i(t)$	External (blast) loading pressure
$p_{i,lung}(t)$	Lung pressure
g	Polytropic exponent for gas in lungs
x	Chest wall displacement

- Axelsson

$$m\frac{d^2x}{dt^2} + C\frac{dx}{dt} + Kx = A\left(p(t) + P_0 - \left(\frac{V}{V - Ax}\right)^{\gamma} P_0\right)$$

$$ASII = (0{,}124 + 0{,}117V_{MAX})^{2{,}63}$$

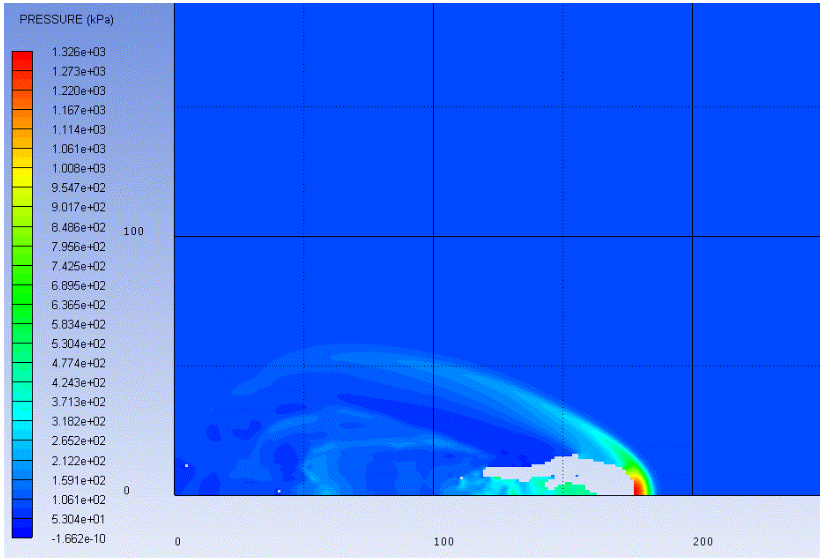
Table 3.4: Injury Levels with Corresponding ASII and CWVP, and Estimated AIS Levels

Injury Level	ASII (-)	V (m/s)	AIS Range
Negative (no injury)	0.0 – 0.2	0.0 – 3.6	0
Trace to slight	0.2 – 1.0	3.6 – 7.5	1 to 4
Slight to moderate	0.3 – 1.9	4.3 – 9.8	2 to 4
Moderate to extensive	1.0 – 7.1	7.5 – 16.9	3 to 5
> 50% lethality	> 3.6	> 12.8	Up to 6

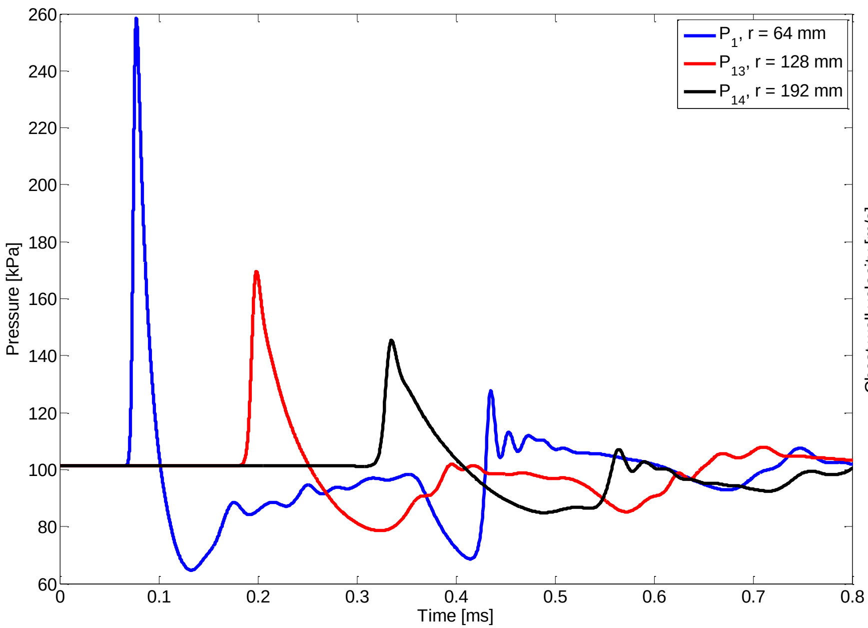
- Single point approximation used

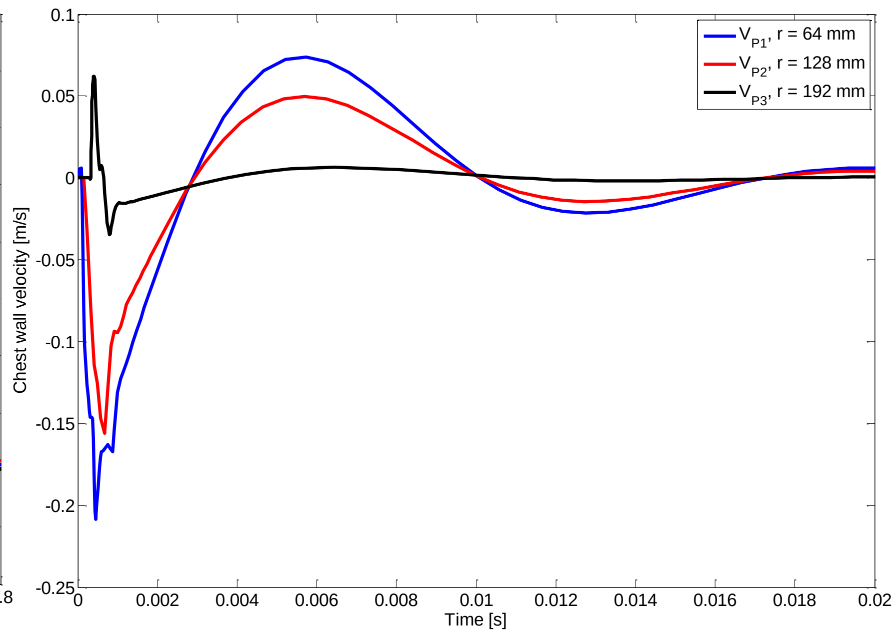
Penetrator Shock

- Impact of the target was simulated using Lagrange parts, slug then remapped to Euler grid to speed up simulation
- After penetration, slug velocity was about 1100 m/s.
- Slug travelled the length of the volume, while pressure was logged at various gauge points.



Pressure and Chest Wall Velocity



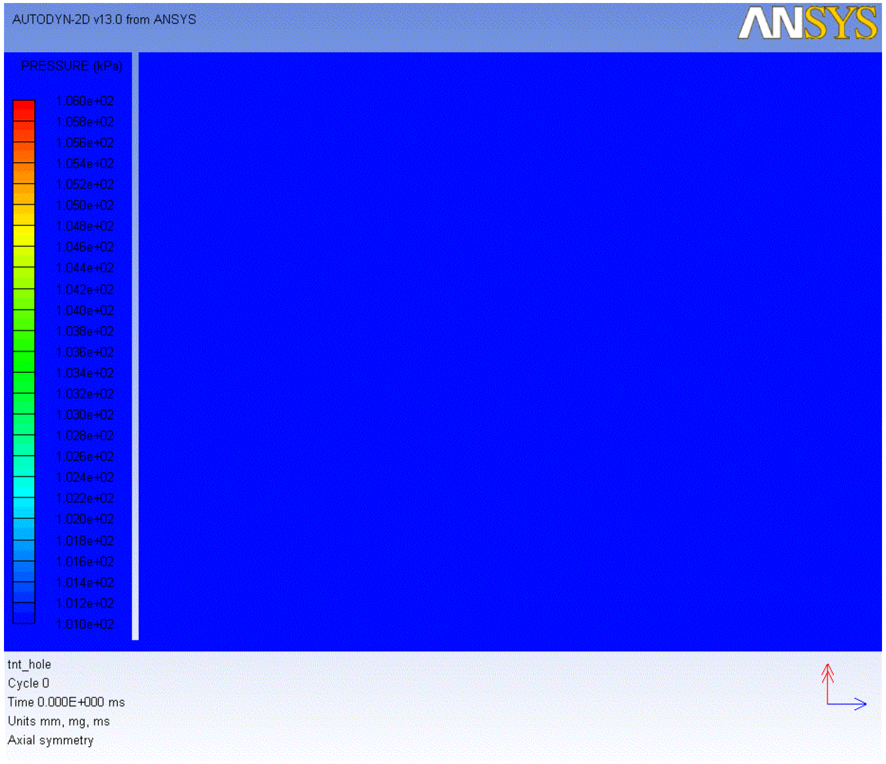


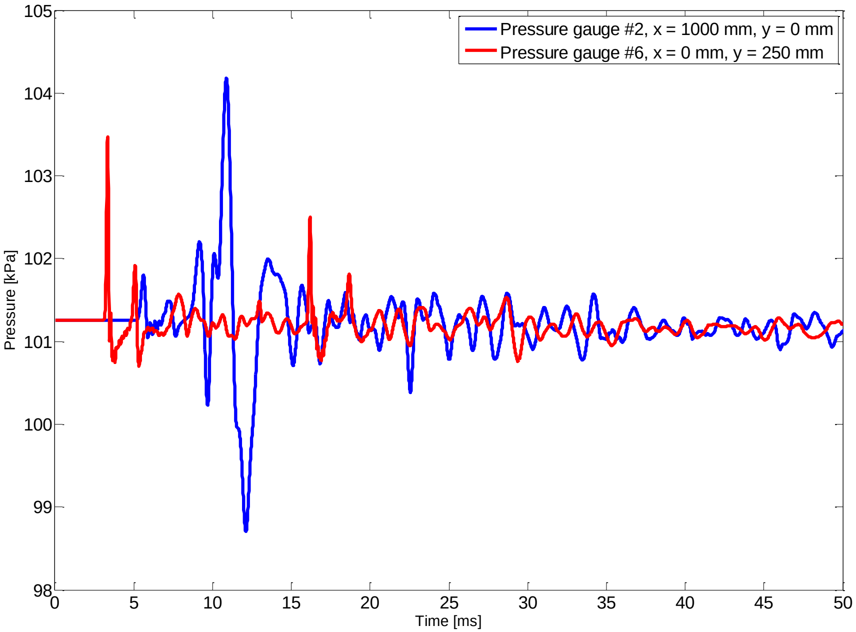
- Three pressure profiles, very close to trajectory of the slug.
- High peak pressure, low duration.
- Solving Axelsson yields a very low chest wall velocity, $ASII_{MAX}$ = 0,0066
  - Trace to slight injury = 0,2 – 1,0 ASII

Detonation Pressure

- Typical stand-off distance of 3 m chosen.
- 1D simulation of 1 kg TNT, remapped to 2D after 1,6 ms.
- Euler grid:
  - 10 mm x 10 mm grid size, 1 mm x 1 mm near symmetry axis
  - Cylinder walls reflect perfectly
  - 20 mm hole from penetration
- Axelsson subroutine for AUTODYN

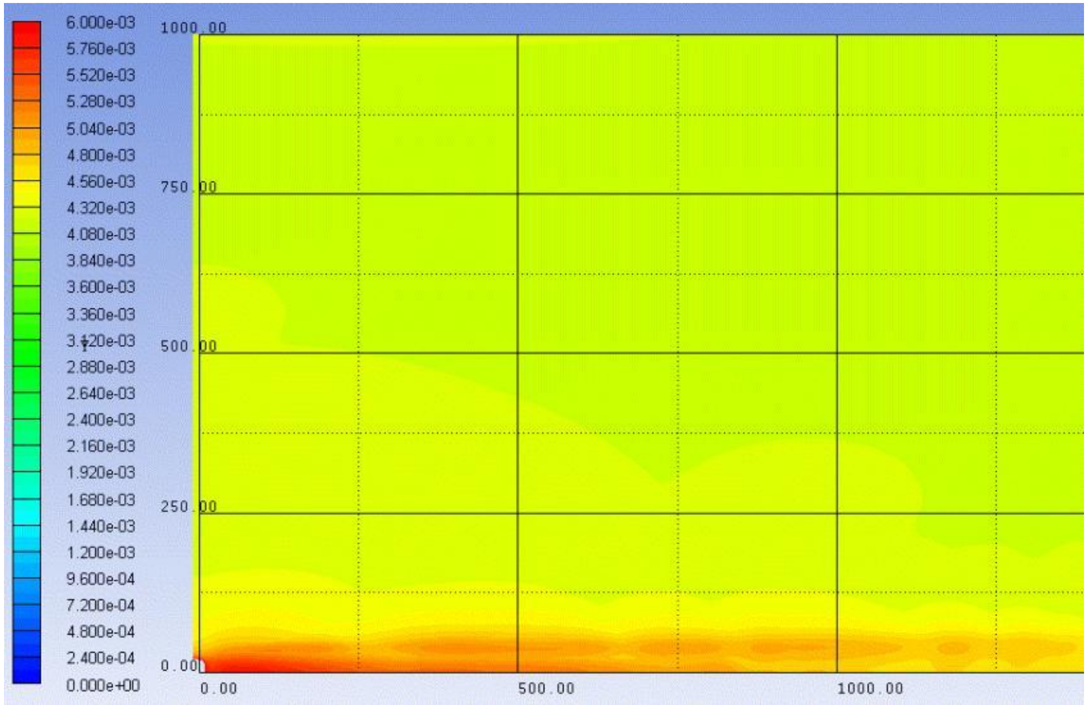
Pressure Propagation





- Peak pressure at hole = 170,5 kPa

ASII Levels



- Highest value along symmetry axis, LOS from point of penetration.
- Max ASII = 0,0096 at opening
  - No injury
- Trace to slight injury = 0,2 – 1,0 ASII
  - Far from lowest injury level

Plate Vibrations

- The impact of the slug on the target incites vibrations and movements in the plate.
- The 5 mm steel plate exhibits the strongest vibrations.
- Acts as a piston the air inside the volume.

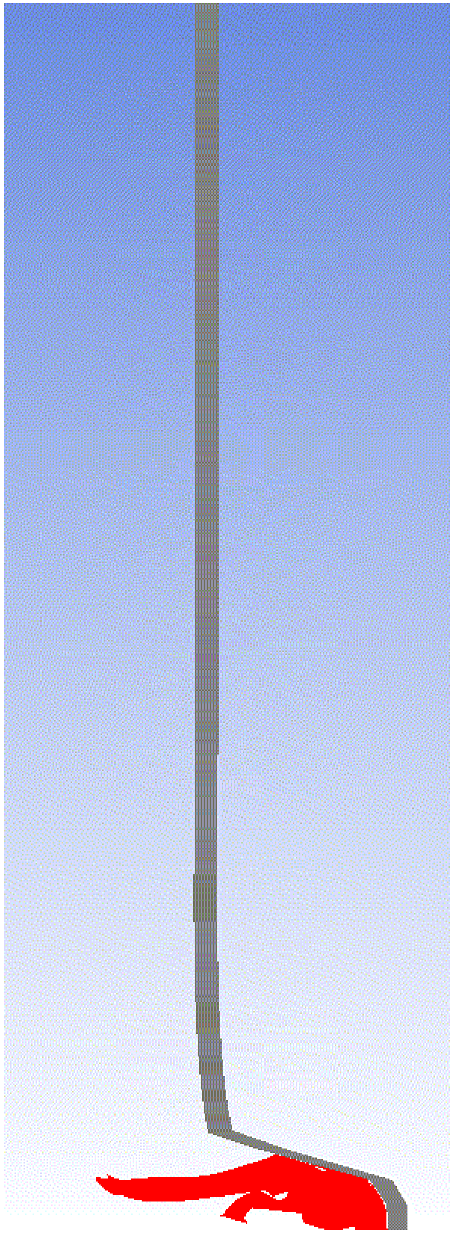


Plate Vibrations - Theory

- From acoustic theory, a circular piston oscillating at

$$U(t) = U_0 e^{i\omega t}$$

sets up a pressure *p* at a distance *r*:

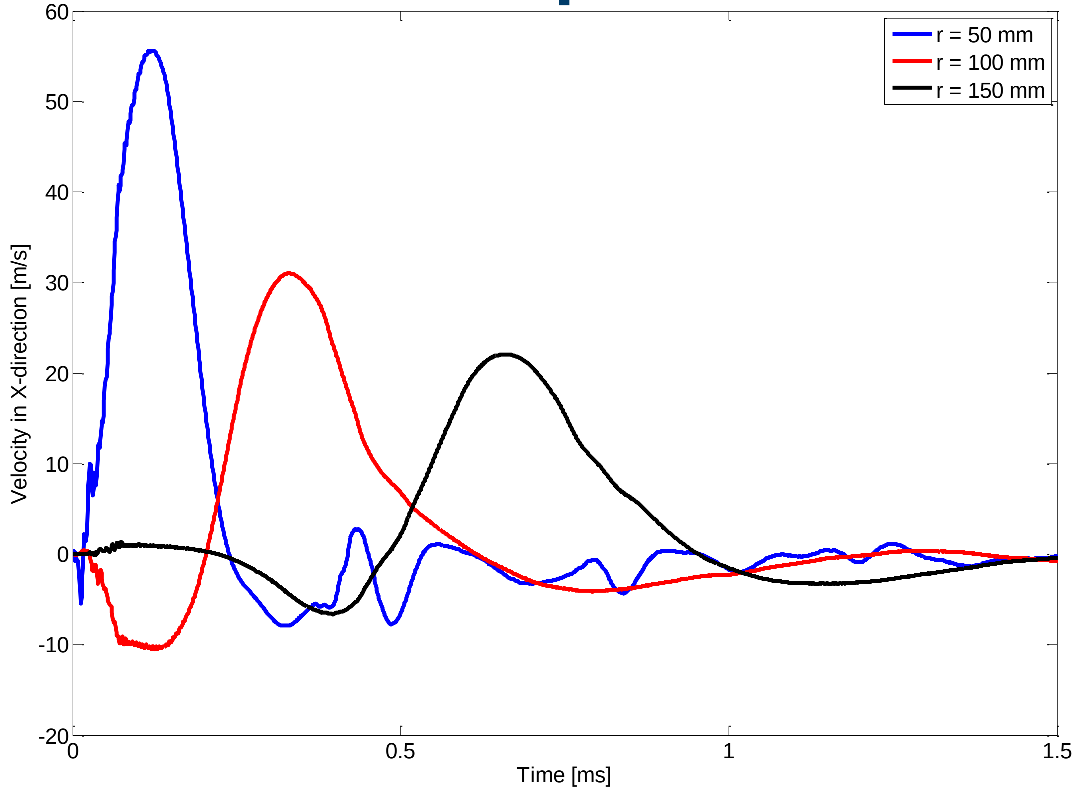
$$p(r,\theta,t) = i\rho_0 c \frac{U_0}{\lambda} e^{i\omega t} \int_S \frac{1}{r'} e^{i(\omega t - kr')} dS$$

- Along the symmetry axis this is solved to give:

$$p(r,0,t) = \rho_0 c U_0 \left(1 - e^{-ik\left(\sqrt{r^2+a^2}-r\right)}\right) e^{i(\omega t - kr)}$$

where *a* is the radius of the piston.

Plate Vibrations - Complications



- The perforated plate does not oscillate harmonically.
- Not uniform oscillation along radius of the plate.

Plate Vibrations - Approximation

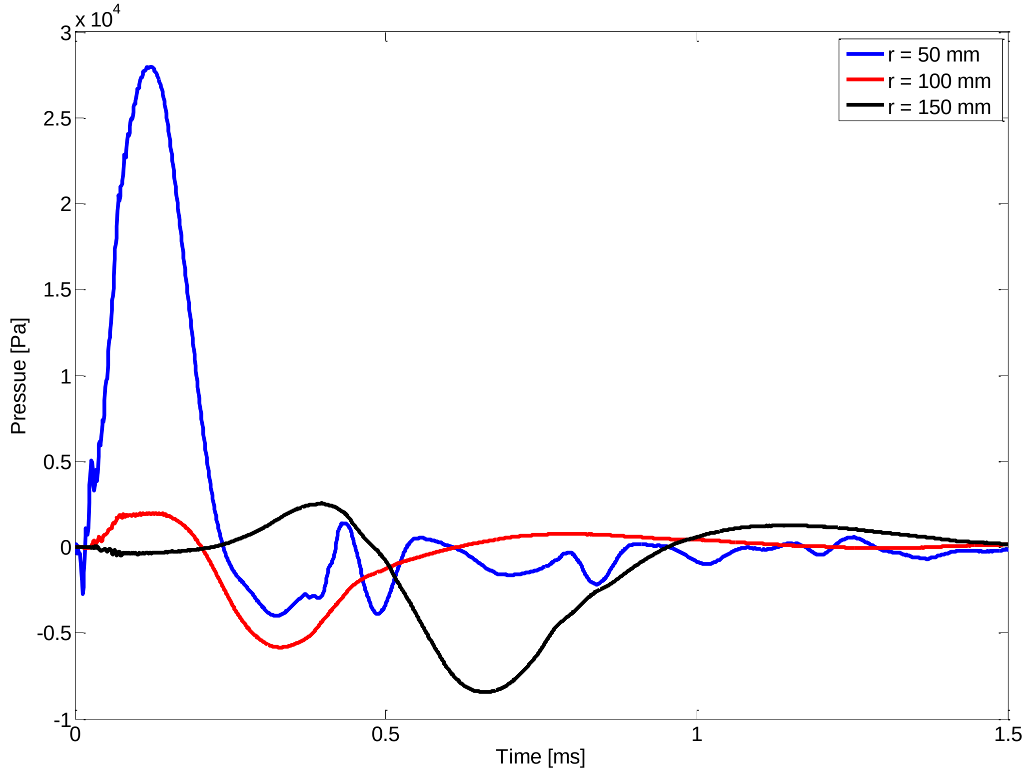
- Assume piston velocity term can be factored out:

$$p(r,0,t) = \rho_0 c \left(1 - e^{-ik\left(\sqrt{r^2+a^2}-r\right)}\right) e^{-ikr}\, V(t)$$

  in which case we can use the velocity profiles.

- The wave number *k* is still unknown
  - Approximation by curve fit, ex. the velocity profile at r = 100 mm gives *k* ≈ 3/m.
- Assume this profile is valid over the entire plate
  - Conservative estimate

Plate Vibrations – Calculated Pressure



- Overpressure calculated 1 m from plate for three velocity profiles
- Fairly high peak overpressure, but short duration
- ASII = 0,0057 << 0,2 (Trace to slight injury)

Conclusion

- Penetrator shock:
  - P_{MAX} = 160 kPa (Overpressure)
  - $ASII_{MAX}$ = 0,0066
- Detonation shock:
  - P_{MAX} = 70 kPa (Overpressure)
  - $ASII_{MAX}$ = 0,0096
- Plate vibrations
  - P_{MAX} = 28 kPa (Overpressure)
  - $ASII_{MAX}$ = 0,0057

- Very far from lowest ASII injury level
  - Trace to slight injury: ASII = 0,2 – 1,0

Conclusion

- Possible sources of error:
  - Short duration → Questionable validity of Axelsson
  - Single Point Approximation
  - Numerical artifacts

- Combination and interaction of the effects have not been considered

THANK YOU!