The residual damage in CFRP composite after ballistic impacts (experiments & simulations)

Survivability of aircraft

TNO | Knowledge for business

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- Introduction
- Ballistic test data
  - Residual velocity
  - Internal damage
- Material model of CFRP, AS4/3501
- Simulation results:
  - Residual velocity
  - Internal damage
- Conclusions and future work

Introduction

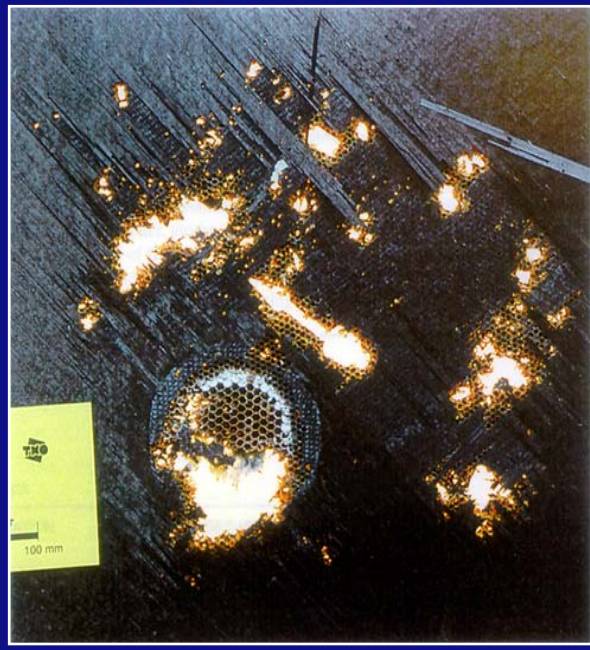
Survivability of aircraft:

- Combined threats : both blast and projectile impacts
- Lighter platforms: more composite material

Combined threats + new materials

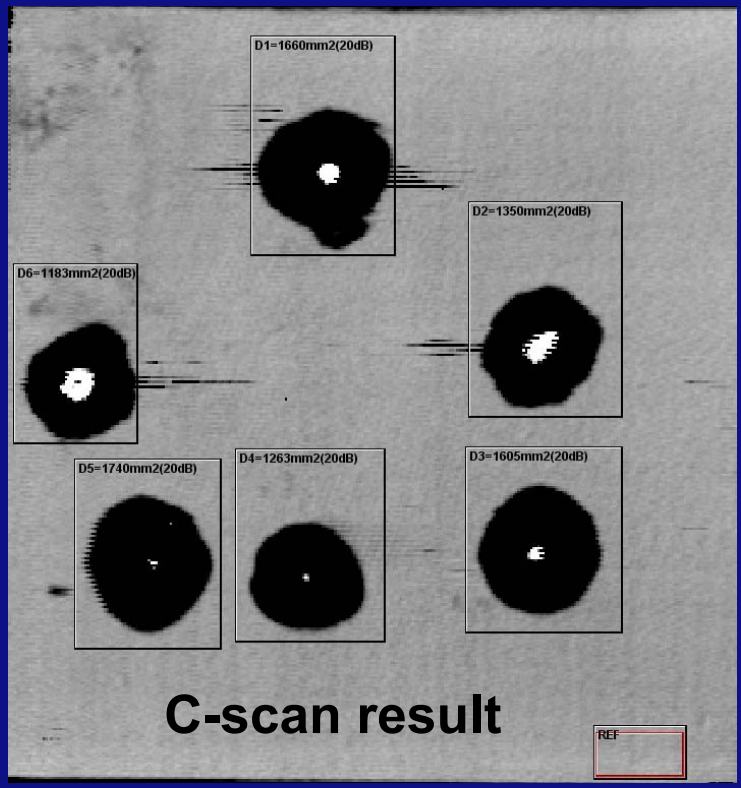
⇒ New failure models

⇒ New survivability tools

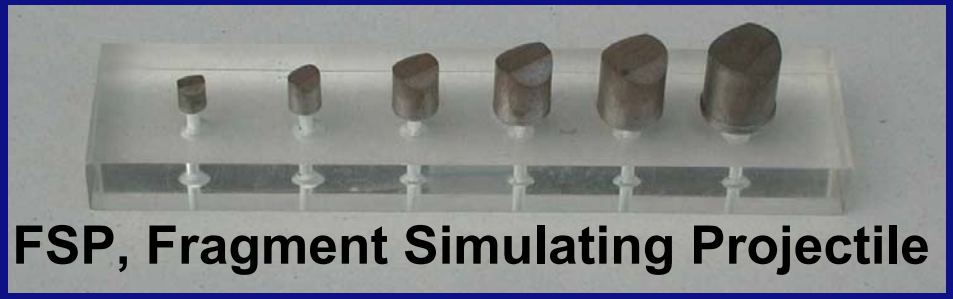


Ballistic tests

CFRP, AS4/3501



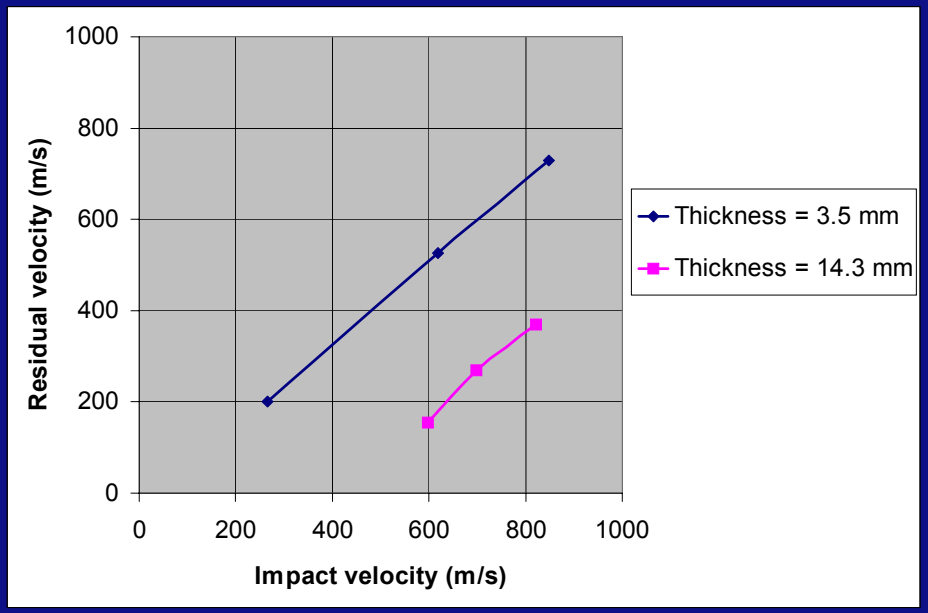
C-scan result



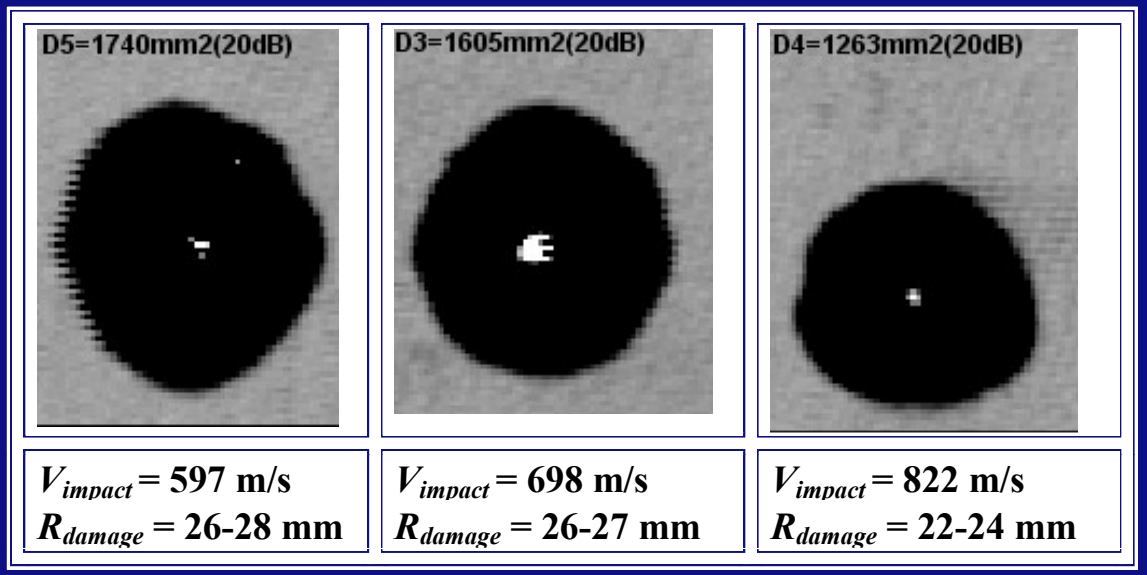
FSP, Fragment Simulating Projectile

Ballistic tests

- Residual velocity:
  Threat : 1.1 gram FSP
  (Fragment Simulating Projectile)



- Internal damage
  14.3 mm (C-Scan):



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  - **Residual velocity**
  - **Internal damage**
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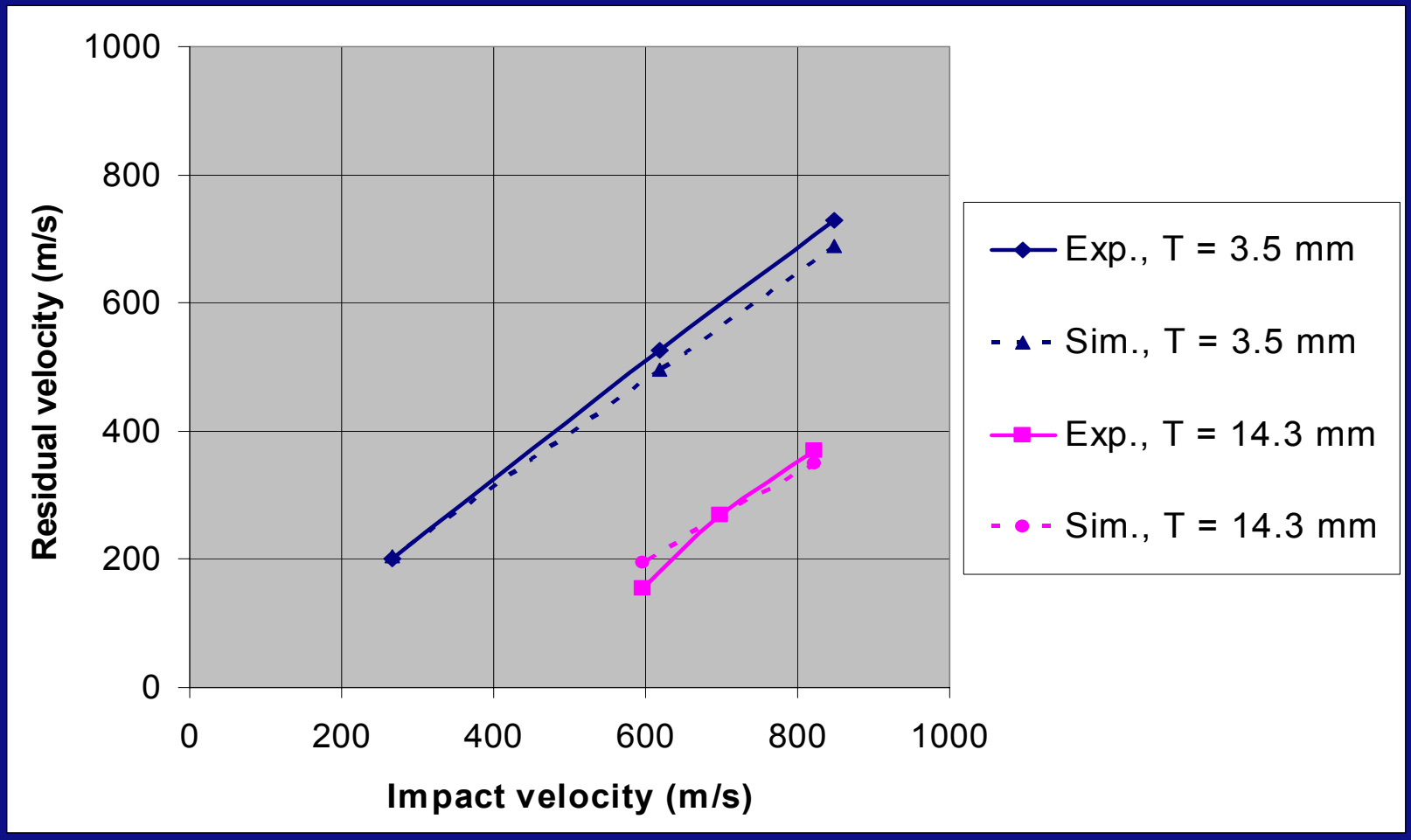
Material model of CFRP, AS4/3501

- Advanced Damage Material Model (ADAMMO) within AUTODYN® :
  - An orthotropic elastic model :
    Parameters from quasi-static material tests (tension and V-notch)
  - A linear EOS (assumed linear; inverse flyer plate necessary)
  - An orthotropic damage model with
    - Orthotropic failure criteria (tension and V-notch)
    - An orthotropic softening algorithm (data from literature)
    - Orthotropic post failure response; tensile stresses are still allowed in non-failed material directions

Simulation results

- Residual velocity (threat 1.1 gram fsp):



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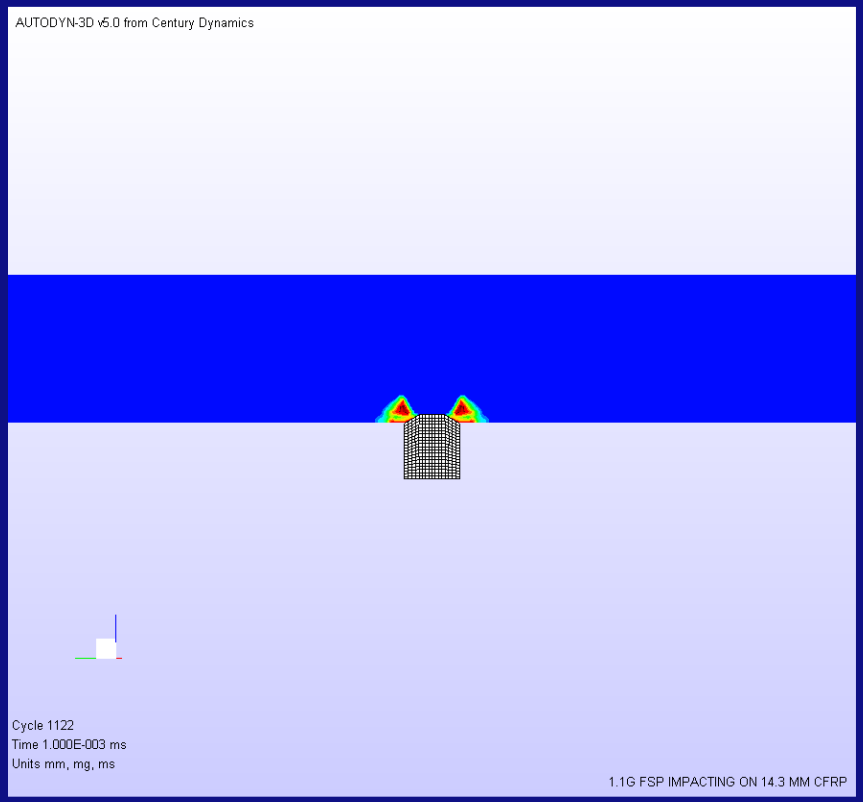
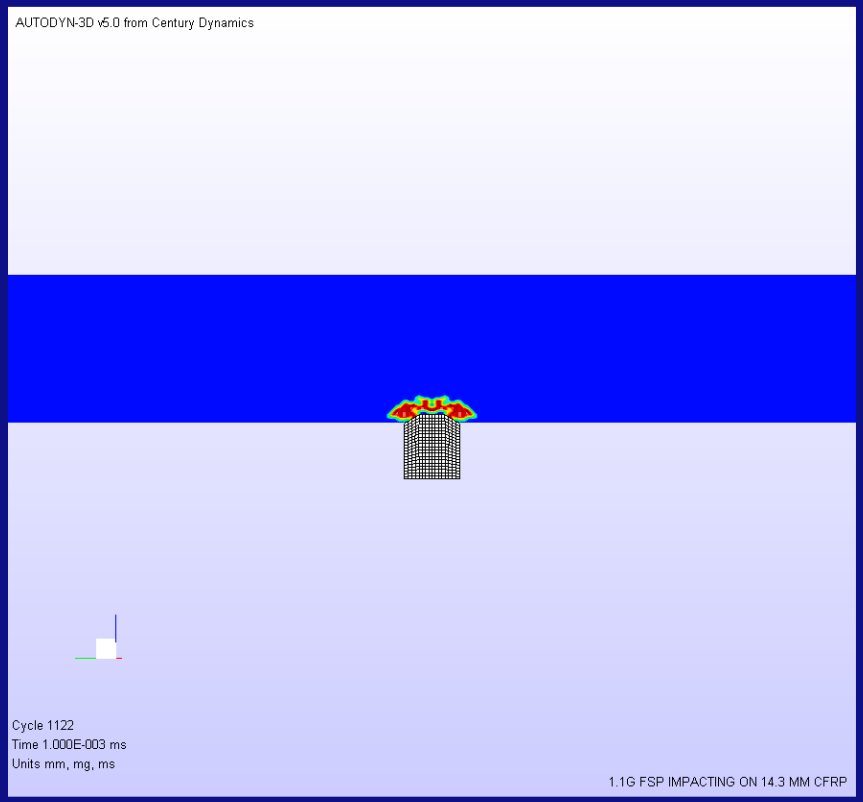
Simulation results

V_{Impact} = 597 m/s, thickness = 14.3 mm

Delamination



Fiber failure



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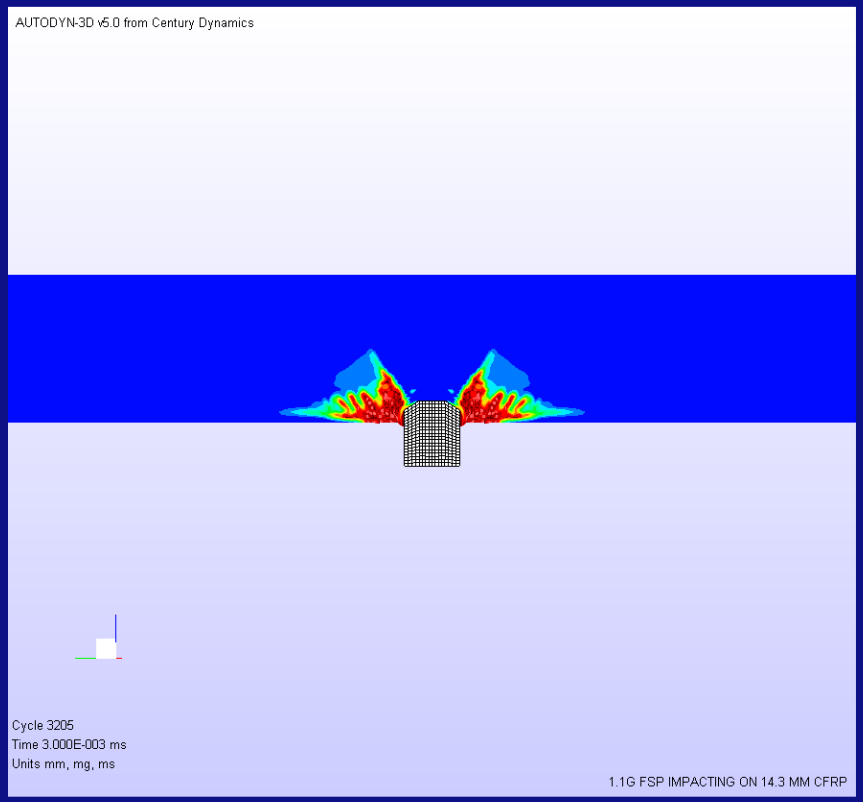

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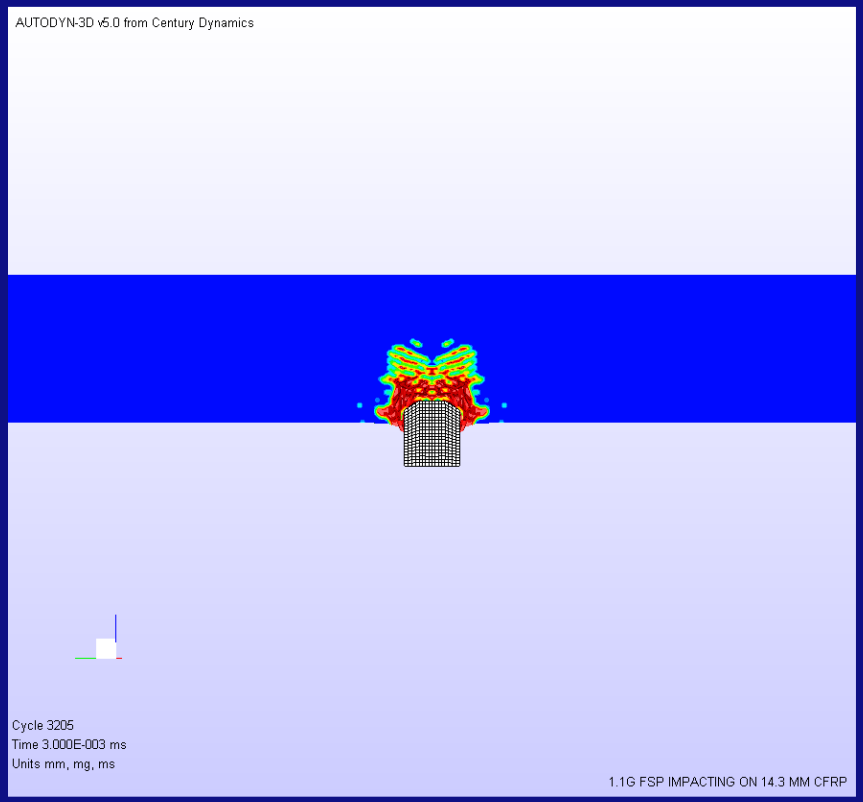

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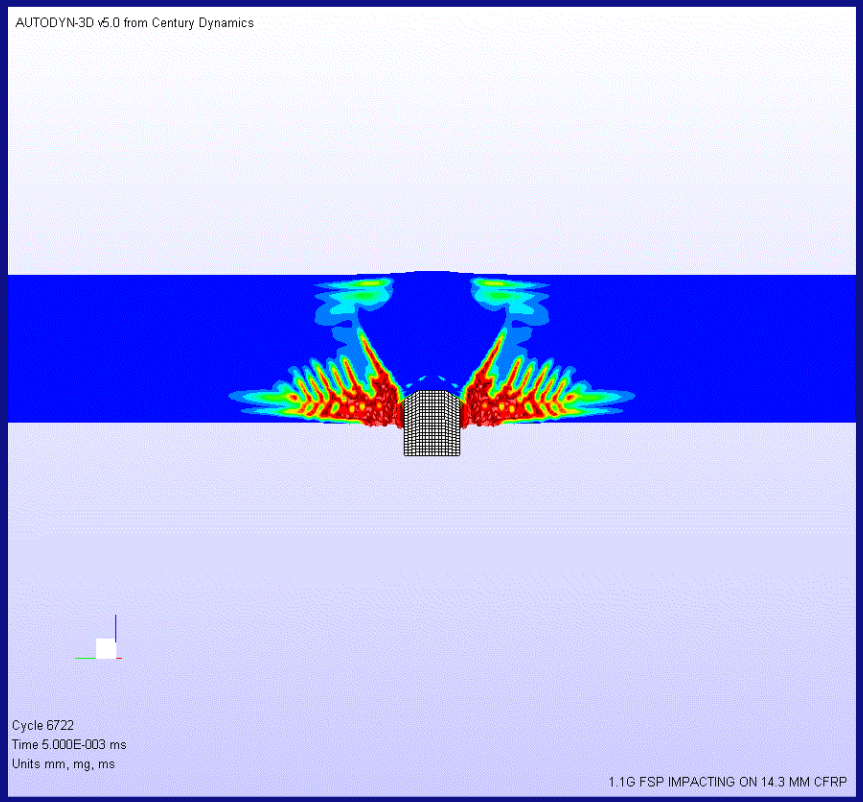

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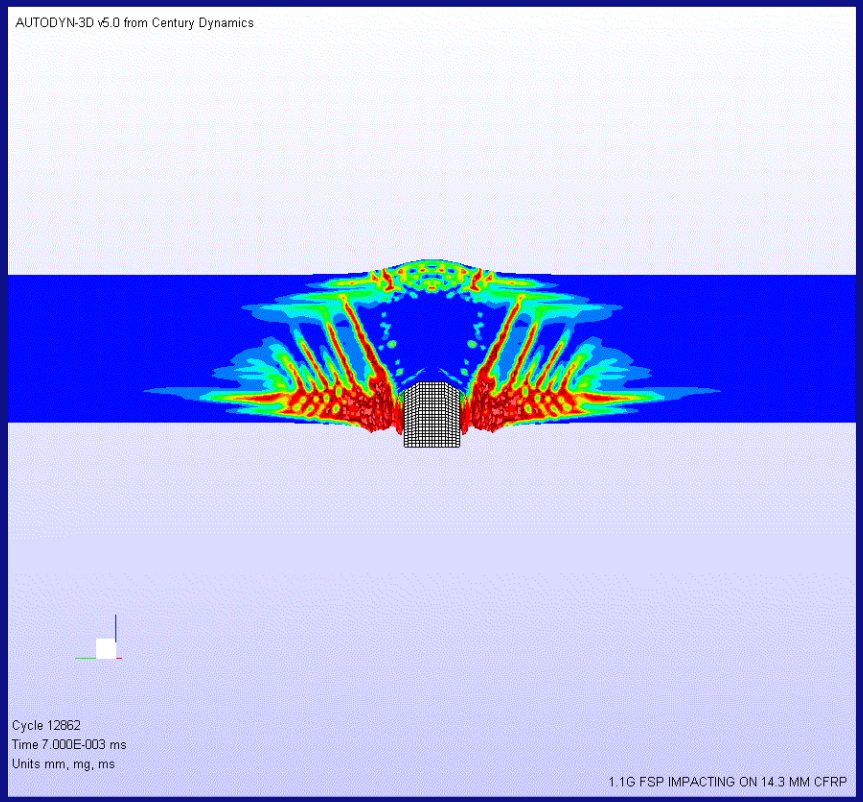

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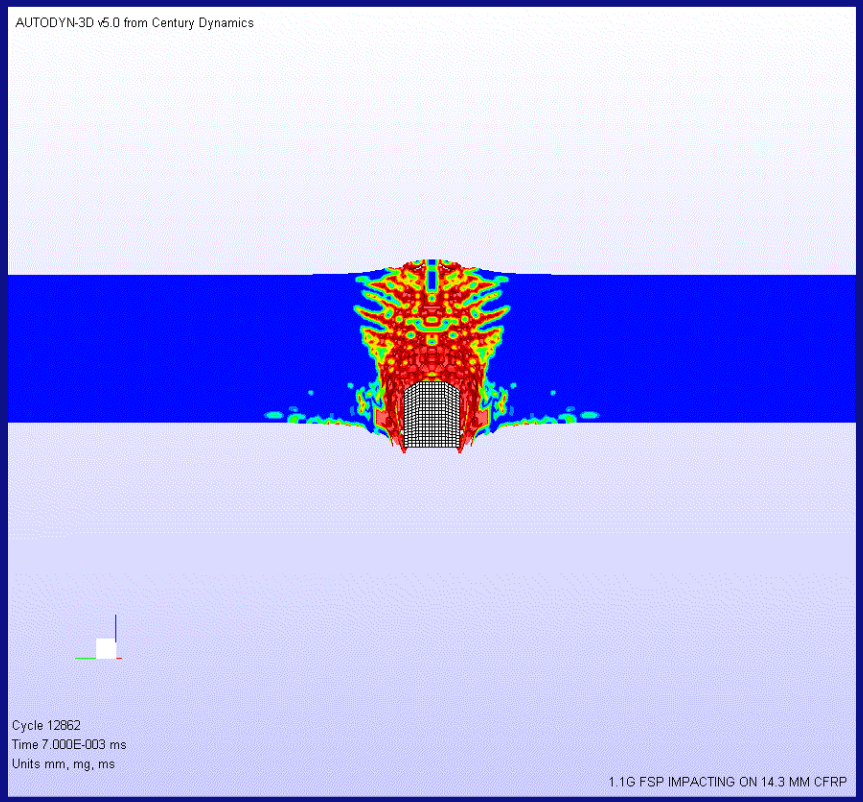

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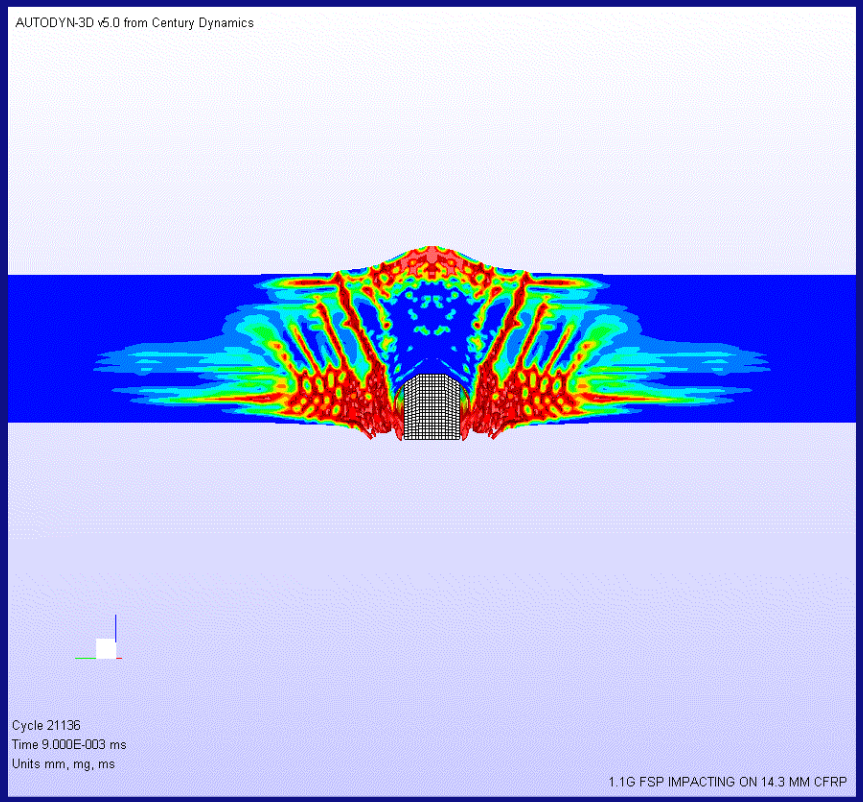

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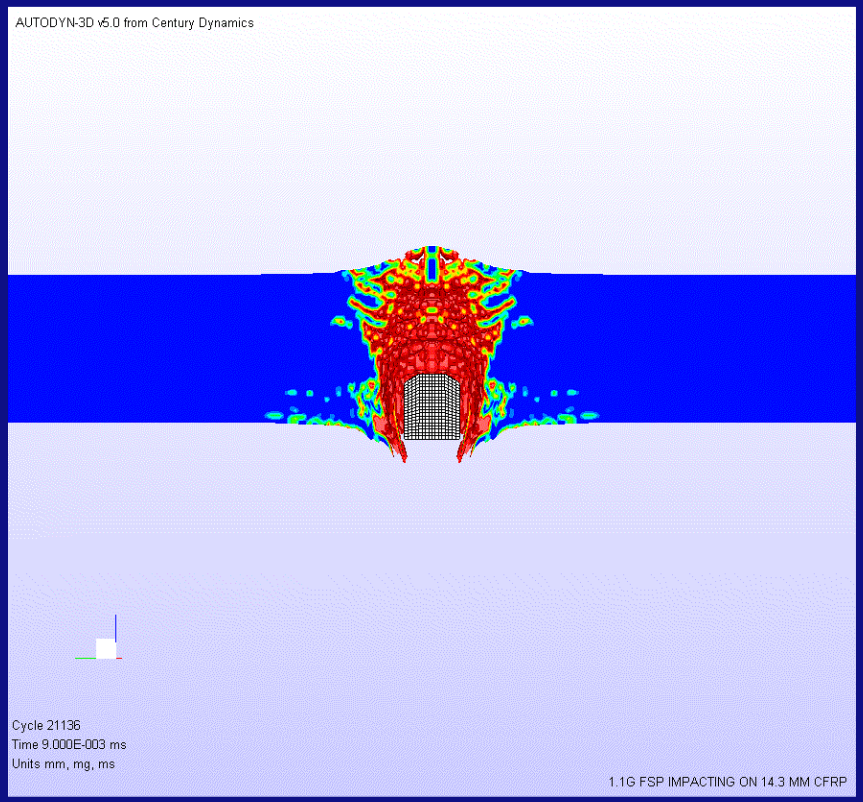

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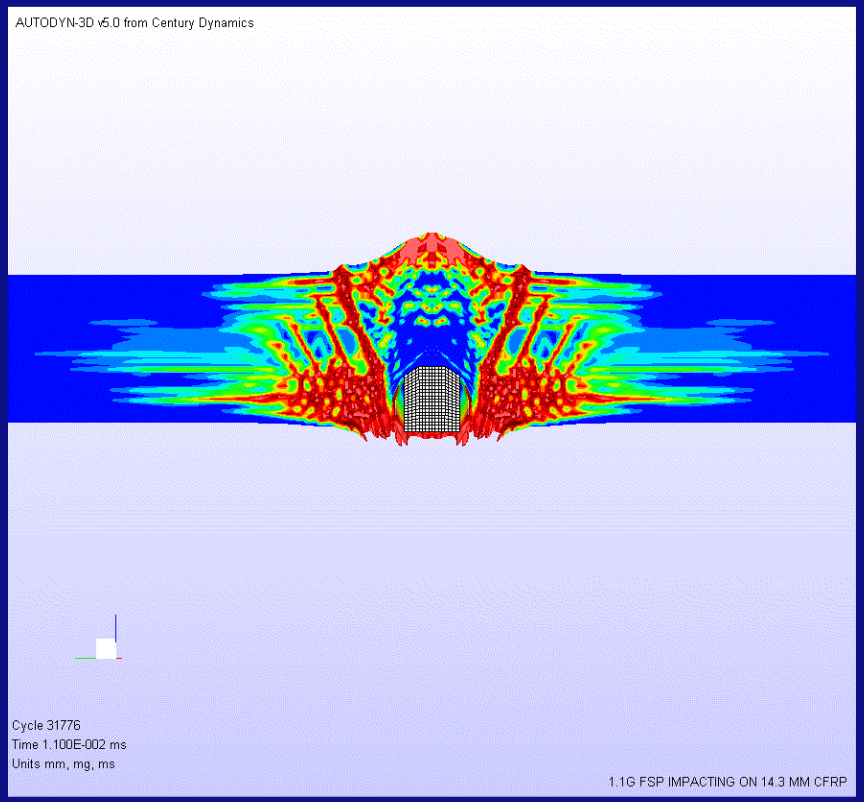

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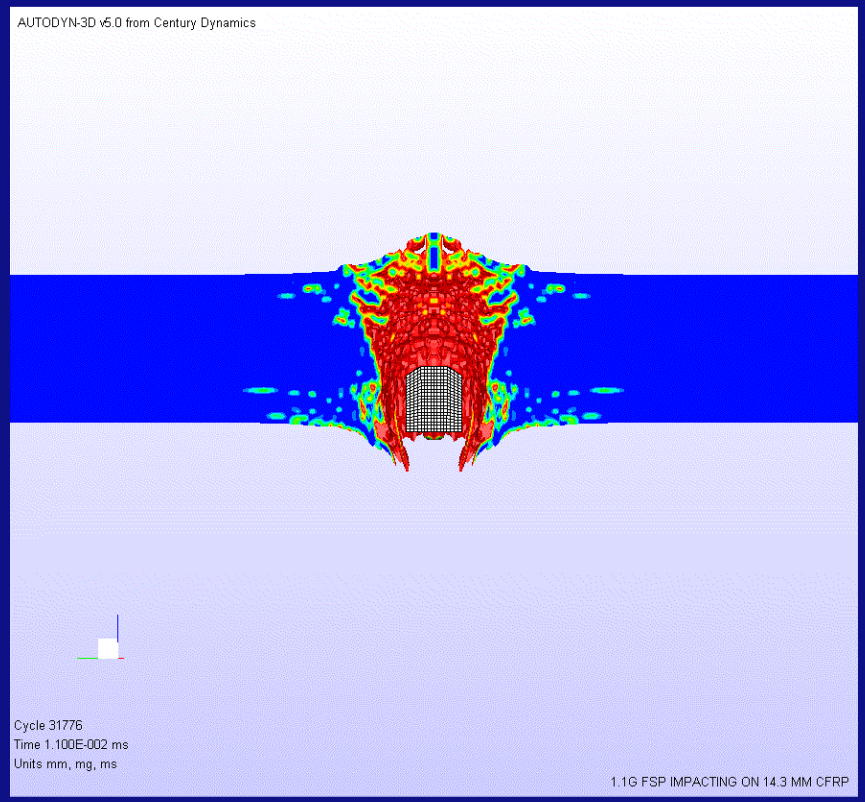

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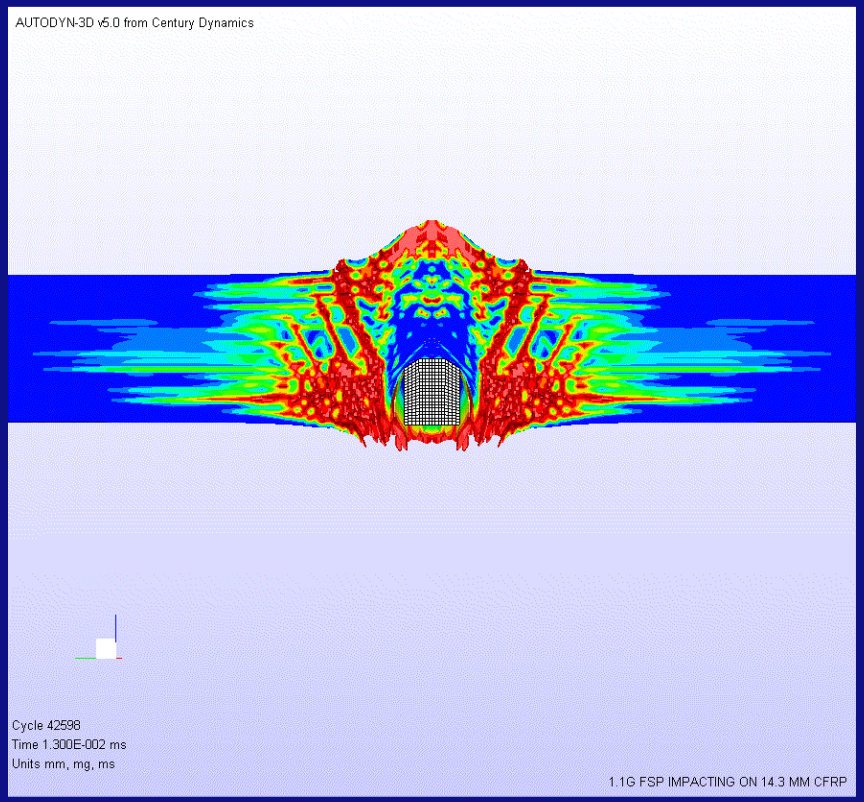

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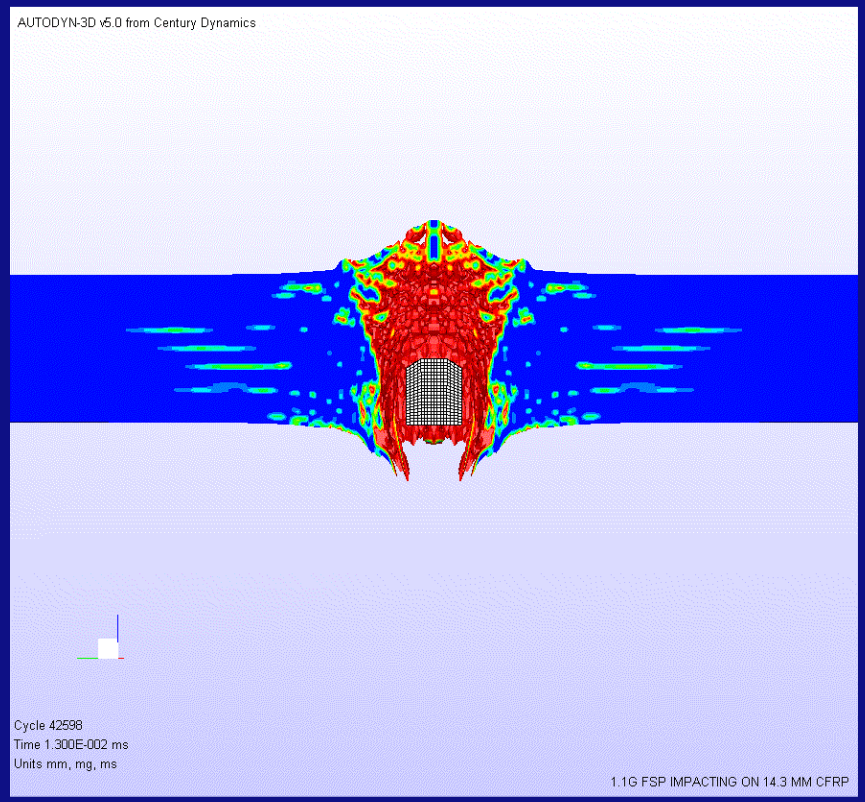
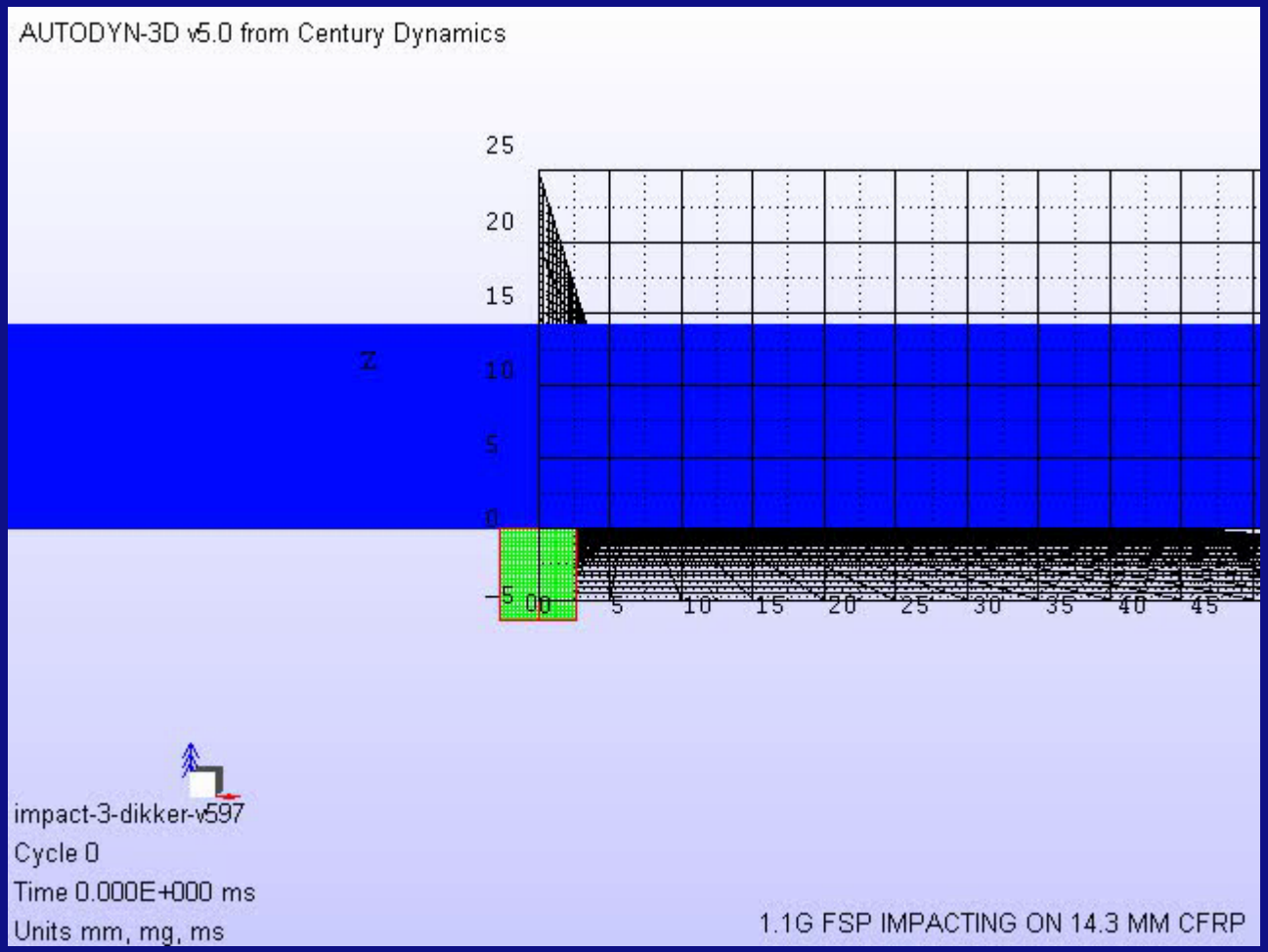
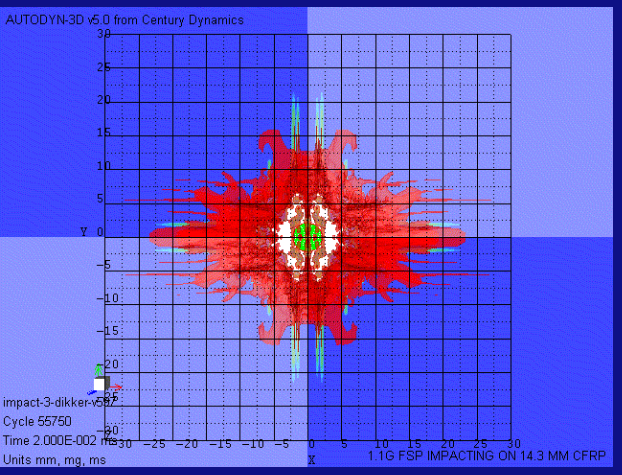


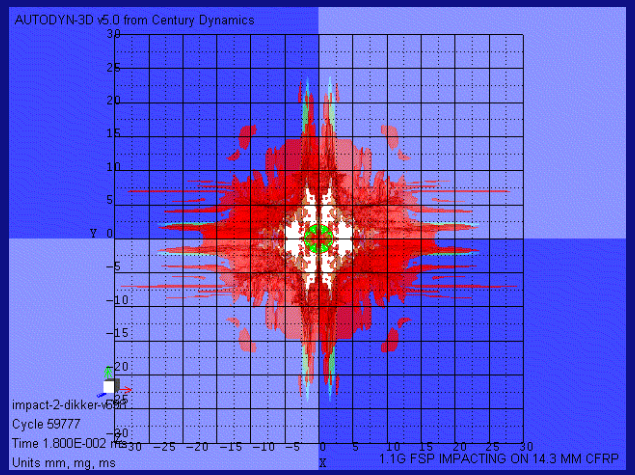
Simulation results, total internal damage

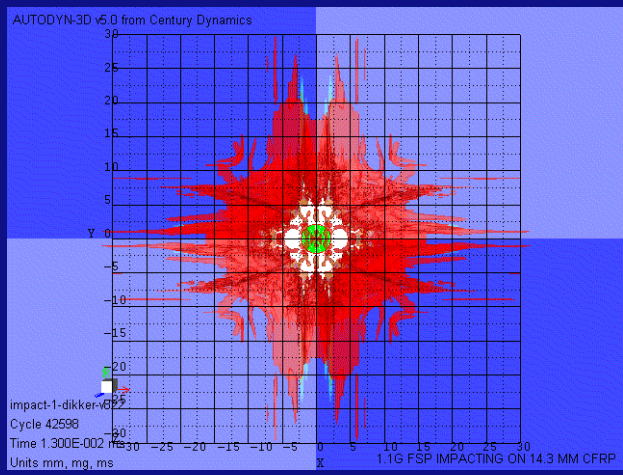
V_{Impact} = 597 m/s, thickness = 14.3 mm

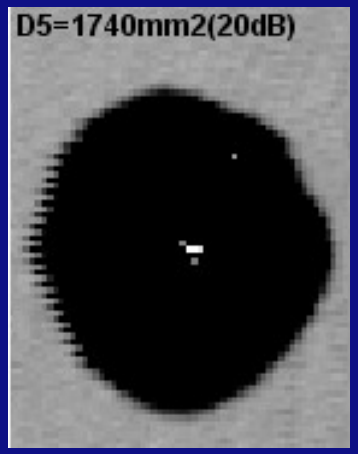


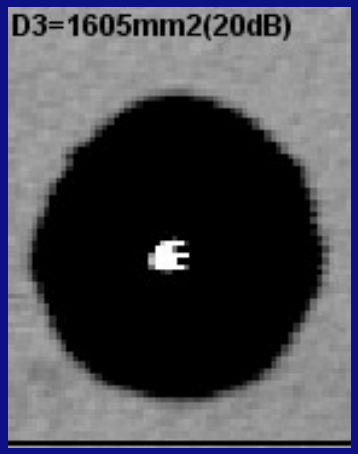
Total internal damage (comparison)

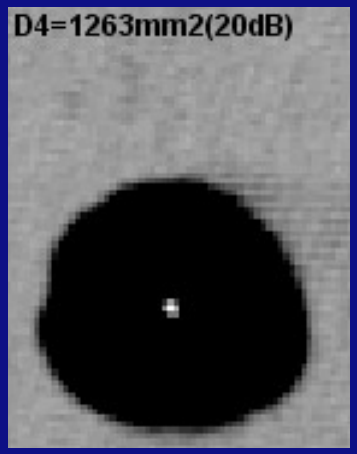












V_{impact} = 597 m/s

V_{impact} = 698 m/s

V_{impact} = 822 m/s

Total internal damage (comparison)

- Quantitative comparison is very difficult → No direct link

Experiments:

- C-scan with 20 dB threshold
- Damage radius ≈ 22 – 27 mm
- Little difference in damaged area within velocity range
- However small trend: V_{impact} increases ⇒ damaged area decreases

Simulations:

- "C-scan" with 60 % threshold
- Damage radius ≈ 20 – 25 mm
- Little difference in damaged area within velocity range
- However small trend: V_{impact} increases ⇒ damaged area increases

Improvements can be made by measuring the softening behaviour in thickness direction and by performing inverse flyer plate tests

Conclusions and future research

- With limited material tests → good material behaviour
- Simulation results are consistent with experimental residual velocity
- Internal damage is difficult to compare with experiments
- The damage observed is in the same order of magnitude, however the trend is inconsistent with the experiments.

Future research:

- Further improvement of material model (softening, flyer plate)
- Combine blast loading with fragment impacts on construction
- Translate damaged area into strength reduction of construction
- With the knowledge from the FEM models → improve the current vulnerability and survivability tools