THE MECHANICS OF PROJECTILE ARREST FOR COMPLIANT CROSS PLIED UNIDIRECTIONAL LAMINATES

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TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

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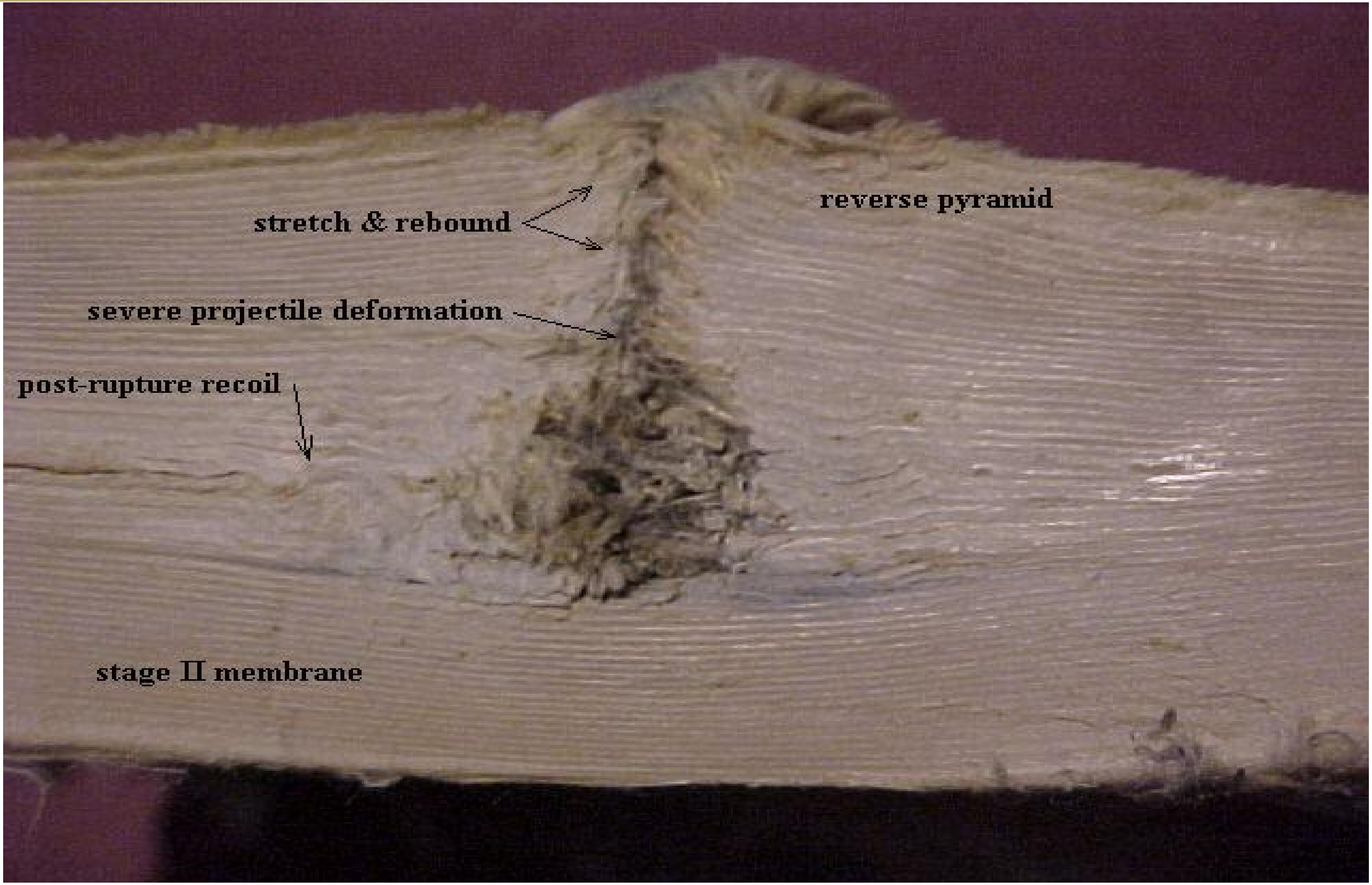
Outline

- Experimental observations
- Mechanics hypothesis
- Numerical simulations
- Conclusion

- Penetration of Kevlar Laminate by Long Rods and Jets, Scott,B and Walters, W., 12th ISB, San Antonio, 1990
- Good performance with woven architectures of high strength fibers with 20% phenolic matrix
- Better performance is obtained with:
  - Cross ply unidirectional layup
  - Finer ply architecture
  - Higher strength reinforcements
  - Elastomer (thermoplastic or thermoset) matrices
  - Lower resin content laminates

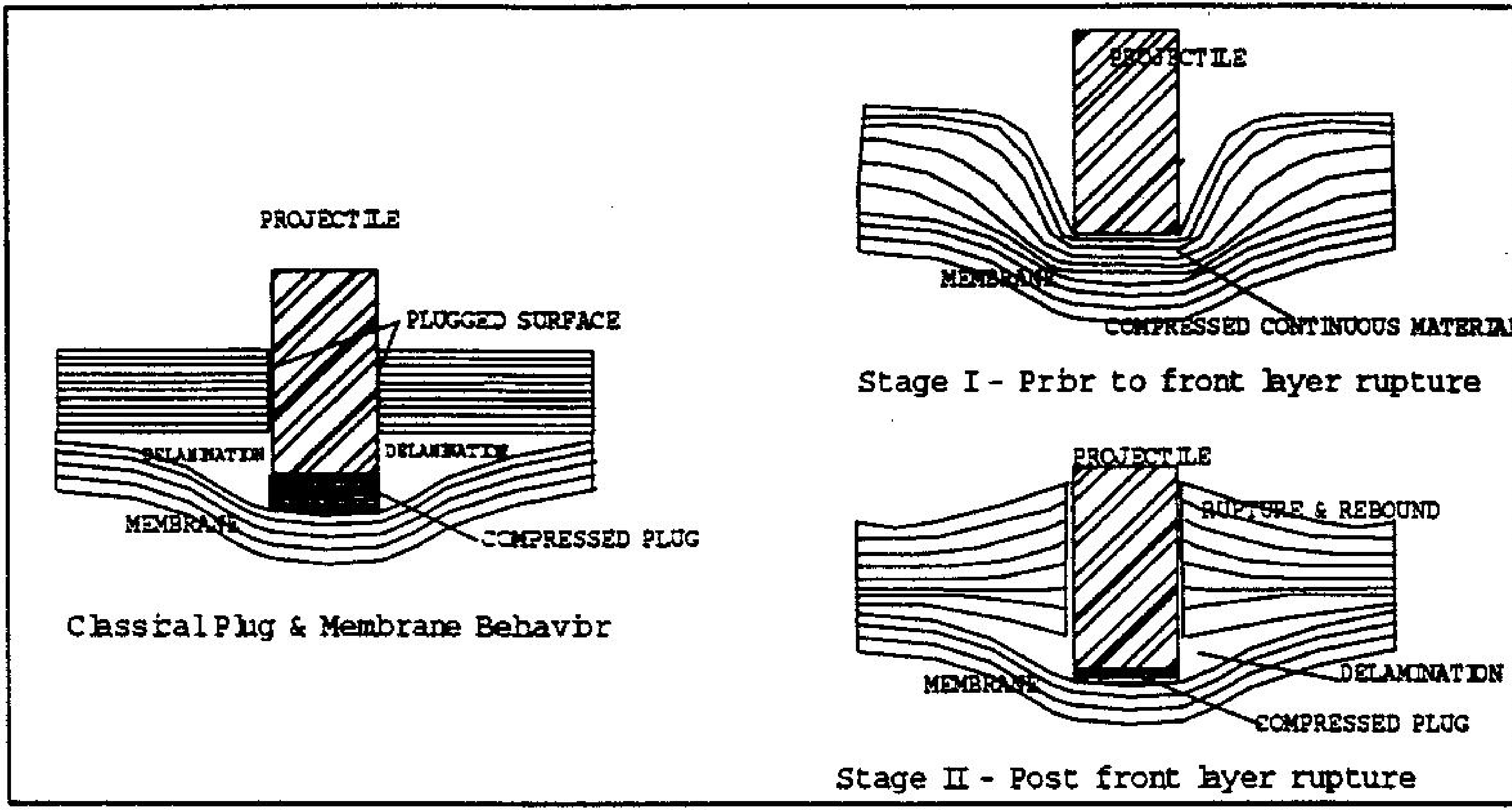
Experimental Observations



Summary of experimental observations

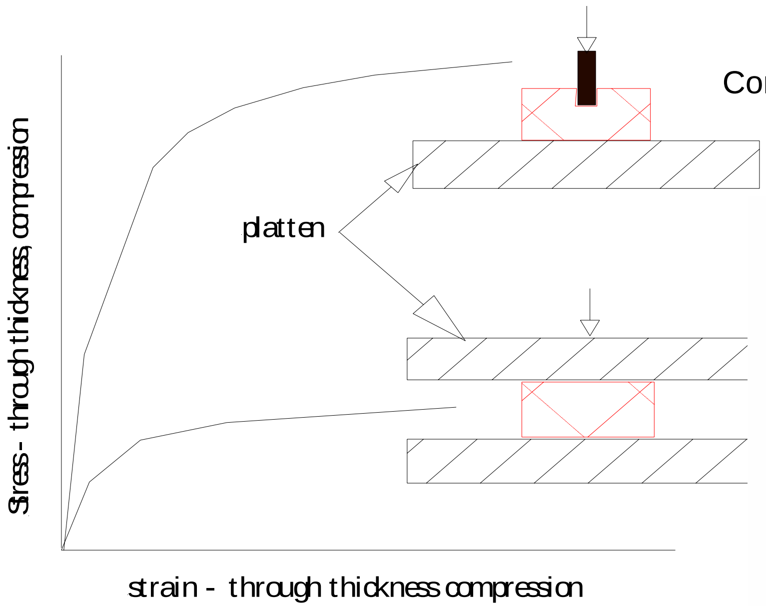
- **Video observations:**
  - **Uni structures exhibit global extension and displacement (first inward, then outward)**
  - **Woven structures exhibit more localized ruptures with less of the far field deformation**
- **Evidence of fiber stretching prior to tensile rupture**
- **Thru thickness compression of underlying layers**
- **Aramids exhibit little evidence of transverse shear failure**
- **UHMWPE difficult to discern due to localized melting of fiber ends**
  - **Presumably due to passage of or contact with hot projectile**
- **Tensile fiber strength: > 500ksi**
- **Transverse fabric shear strength 3 – 5 ksi (aramid or UHMWPE) ASTM D732**
- **Transverse compression strength ? Not well defined yield point (behaves like elastomer)**
- **UHMWPE 20% thicker than aramid laminate at equal areal density**

Experimental Observation

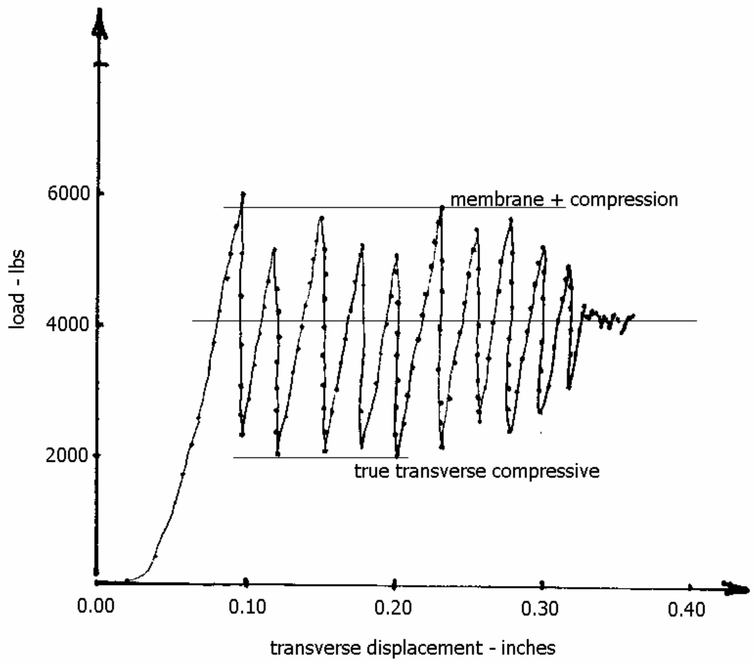


Experimental Observation

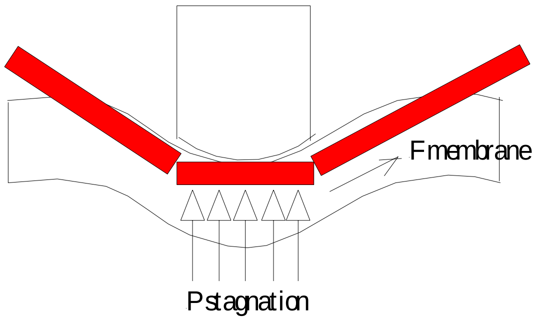
Constrained Compression Test

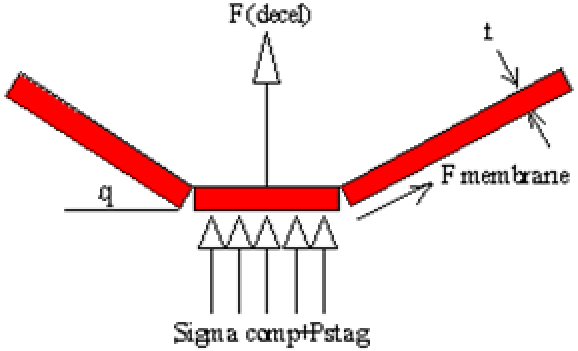


Composites Engineering, Vol 4, No. 3, Woodward, et al, 1994

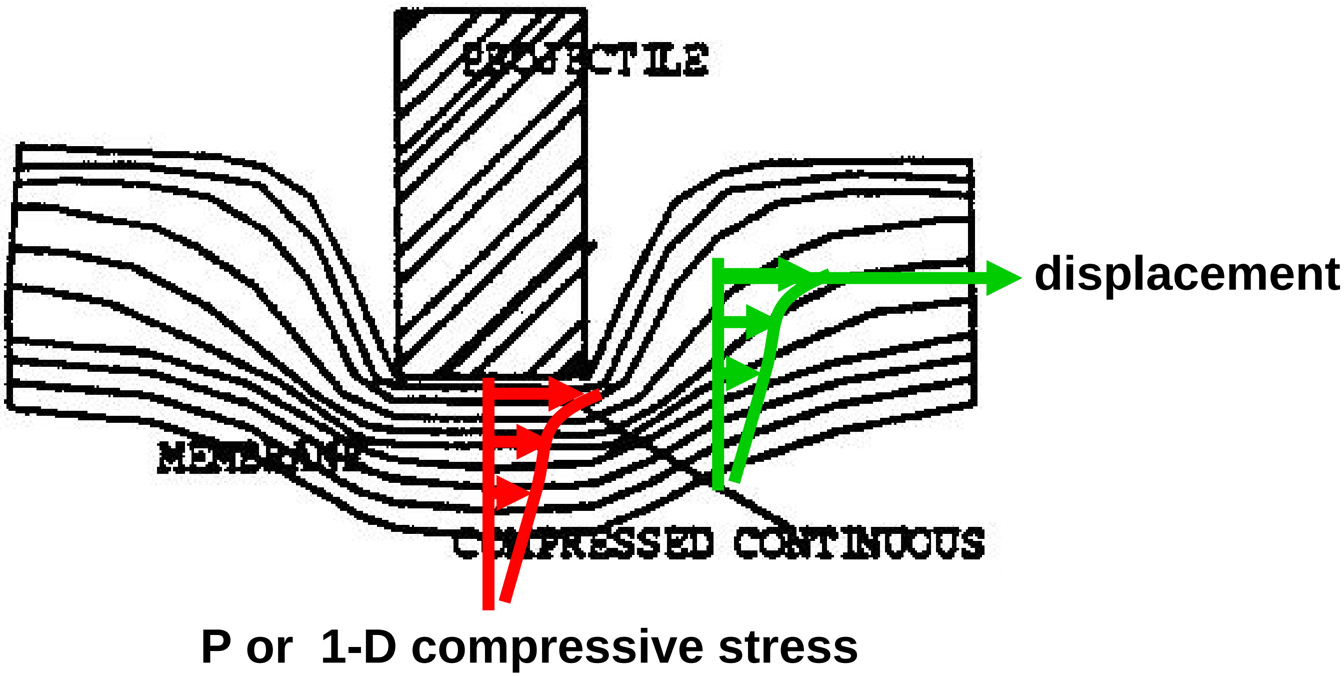


Predominant deceleration forces





Hypothesis



Surface fibers impacted
Material cannot flow until fibers rupture (approx. 4%)
Surface fibers are compressed transversly and forced into underlying layers
“Self-Confined” material develops large comp stress or hydrostatic pressure
Large compressive stresses decelerate projectile

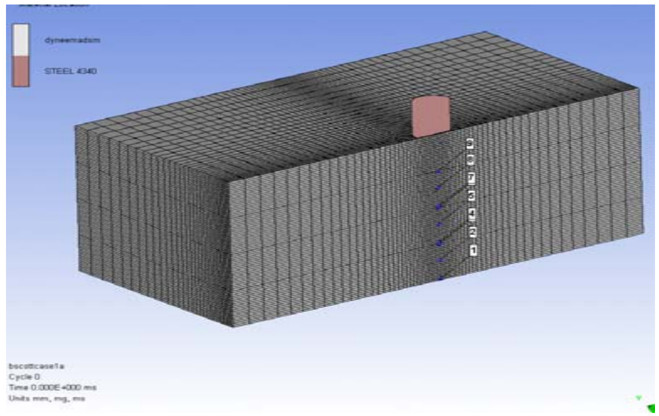
Ansys Autodyn

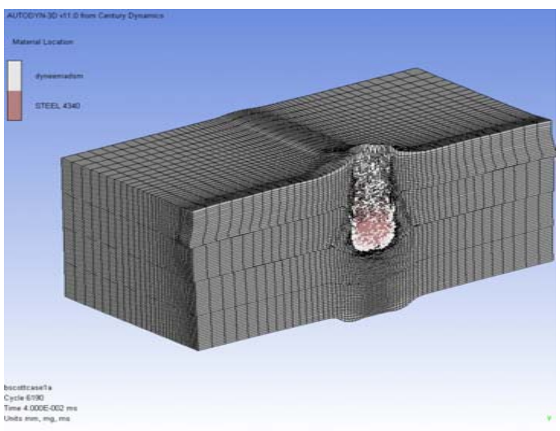
Dyneema HB2

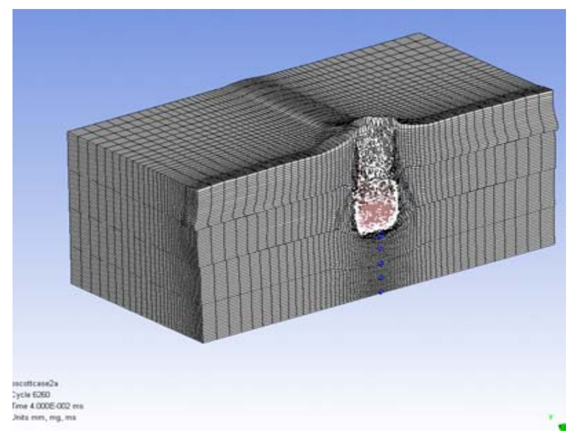
O'Donoghue, P.E., Anderson, C.E., Jr., Friesenhahn, G. J. and Parr, C. H. 1992. "A Constitutive Formulation for Anisotropic Materials Suitable for Wave Propagation Computer Programs*," J.Comp. Materls*., p.p. 26(13), 1860-1884.
Anderson, C.E., Jr., Cox, P. A., Johnson, G. R. and P.J. Maudlin, P.J. 1994. "A Constitutive Formulation for Anisotropic Materials Suitable for Wave-Propagation Computer Programs 2," *Computational Mechanics*, 15(3), 201-223.
Hiermaier, S., Riedel, W., Clayhurst, C.J., Clegg, R.A. and Wentzel, C.M. 2003. "AMMHIS Advanced Material Models for Hypervelocity Impact Simulations," EMI Report No. 175/03, Freiburg, Germany.
Riedel, W., Harwick, W., White, D.M. and Clegg, R.A. 2003. "ADAMMO Advanced Material Damage Models for Numerical Simulation Codes," EMI Report No. 175/03, Freiburg, Germany.
Stijnman, P.W.A., 1995. "Determination of the elastic constants of some composite by using ultrasonic velocity measurements," *Composites*, 26, 597-604.
Hayhurst, C., Leahy, J., van der Jagt-Deutekom, M., Jacobs, M. and Kelly, P. 2000. "Development of Material Models for Numerical Simulation of Ballistic Impact onto Polyethylene Fibrous Armour," *Proceeding of the Personal Armour Systems Symposium, Colchester, U.K.*
"Data used to model the ballistic behaviour of HB25 in ADAMMO model of Autodyn," Oct. 17 2006. *DSM Dyneema*, Urmond, The Netherlands.

20 mm diameter 50 gram 4340 steel cylinder
2.0 km/s impact velocity
100 mm thick initial 40 microseconds
Two b.c. Rigid backing / simple frame

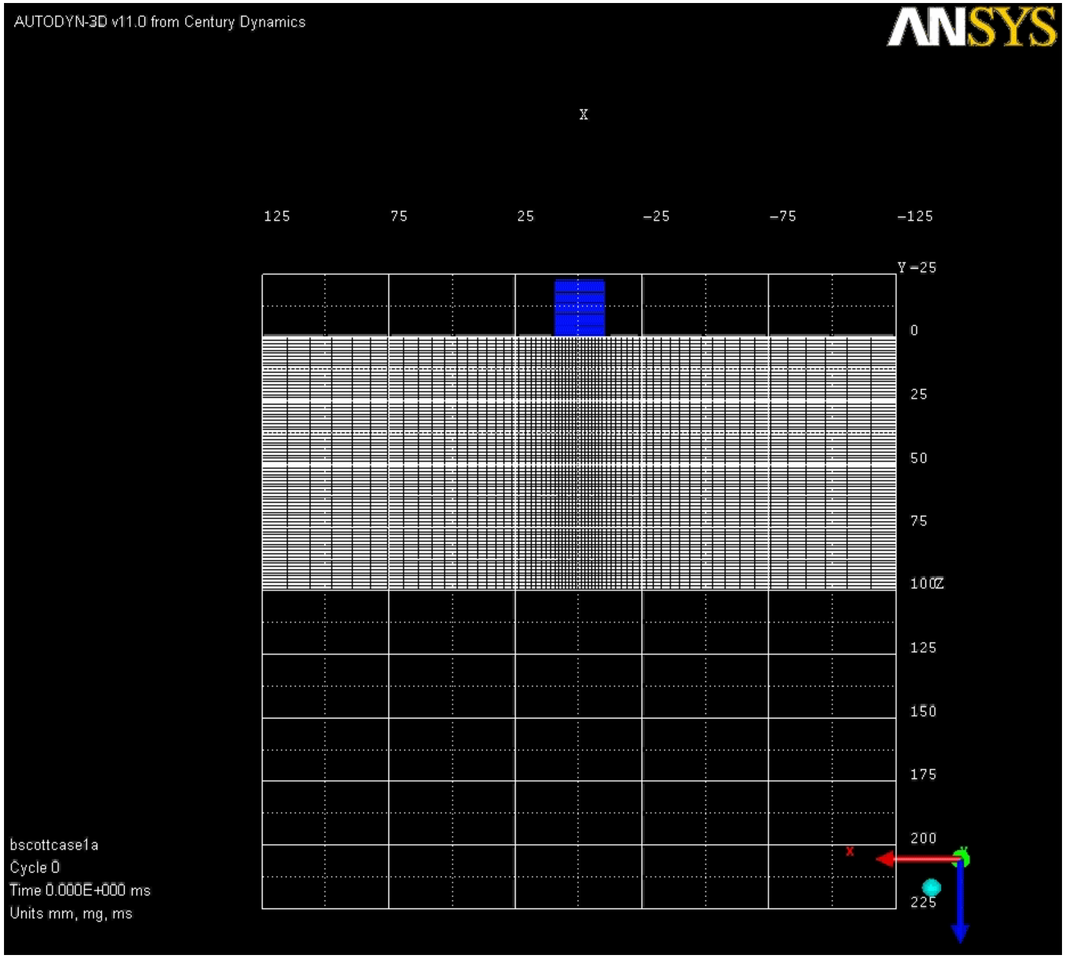
Simulation


dyneemadsm
STEEL 4340
bscottcase1a
Cycle 0
Time 0.000E+000 ms
Units mm, mg, ms

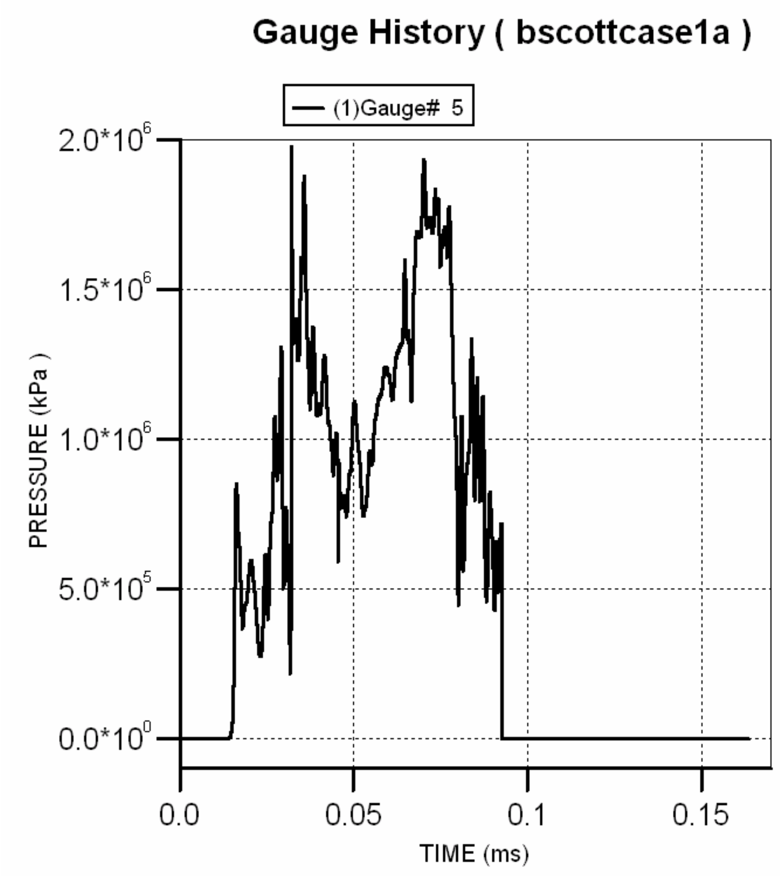

AUTODYN-3D v11.0 from Century Dynamics
Material Location
dyneemadsm
STEEL 4340
bscottcase1a
Cycle 6190
Time 4.000E-002 ms
Units mm, mg, ms


scottcase2a
Cycle 6260
Time 4.000E-002 ms
Units mm, mg, ms

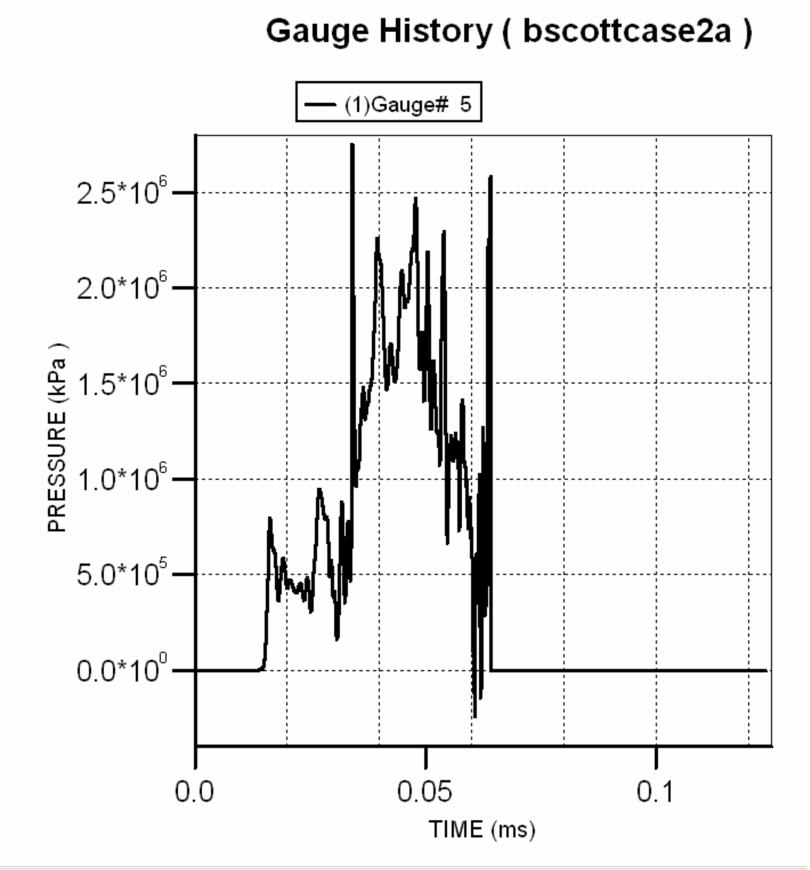
Simple frame b.c. movie



Pressure transient in front of projectile

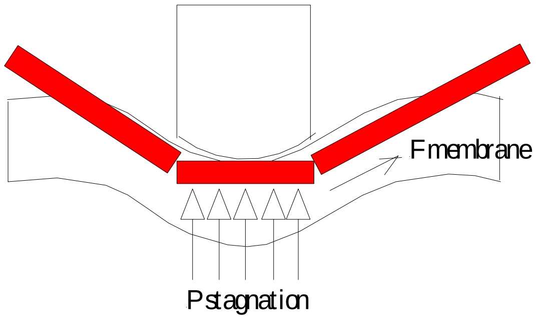


Simple frame b.c.



Rigid backing b.c.

Implication of large pressures



$$\int F \cdot dt = \delta(mv)$$

assume: penetration rate: $u = v/(1+\sqrt{\rho_t/\rho_p})$

	target thickness:	10.0 cm
	impact velocity:	2000 m/s
	projectile diameter	1.0 cm
	projectile mass	5.0 gm
	$\sqrt{\rho_t/\rho_p}$	.35
	linear f(t)	

Initial axial momentum: 100 kg m/s
Pressure from simulation: 2M kPa (300 ksi)
Assume uniform over cross-section
First 40 microseconds: 25 kg m/s

Conclusions

- Hypothesis of self-constrained compression leading to extraordinary axial retardation stresses is confirmed by transient simulations
- Comparing two distinct boundary conditions, we identify the benefit of higher thru thickness pressures with the rigid backing case
- The high pressures account for a large fraction of the impulse delivered to the projectile
- The failure modes involving fiber axial tensile strength and transverse compressive strength appear to be uncoupled
- Uni construction allows for more global extension prior to rupture than woven architecture
- Compliant matrix and elastomeric transverse compressive behavior of fibers may be most important