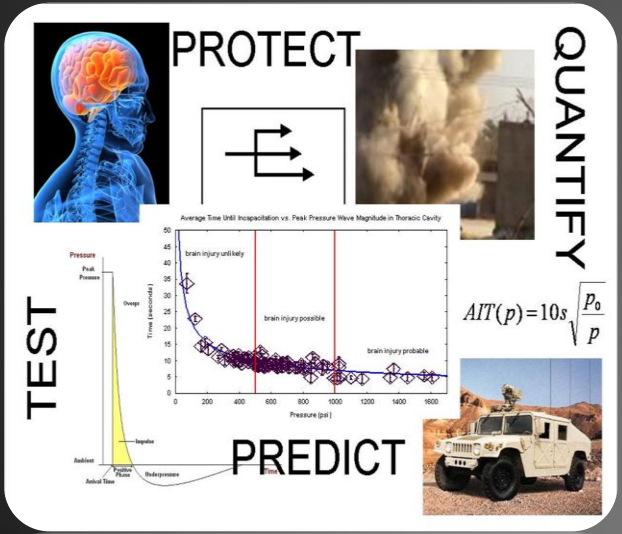
Development and characterization of laboratory scale shock tubes for studies of blast wave effects.



Amy Courtney
R&D, Force Protection Industries, Inc.
amy_courtney@post.harvard.edu

with

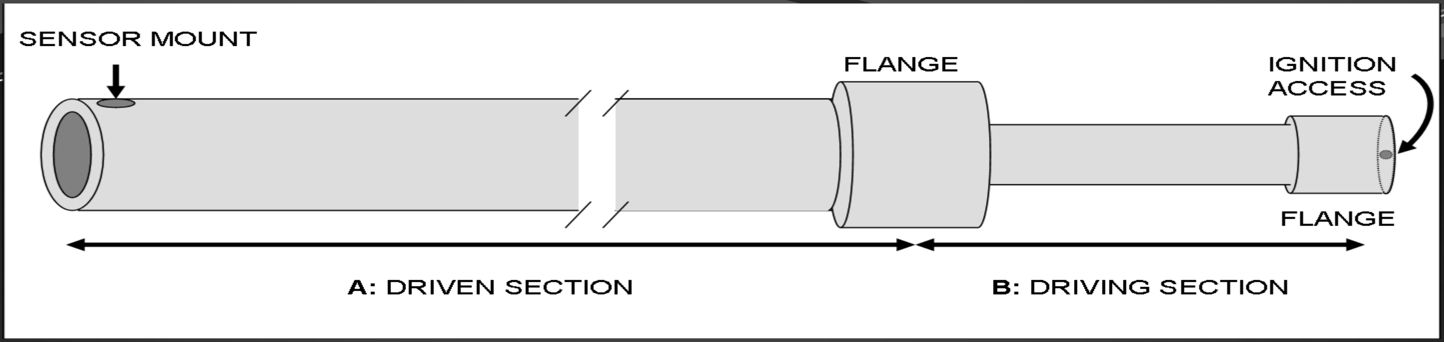
Michael Courtney, Alivia Berg and George Michalke
United States Air Force Academy
Michael.Courtney@usafa.edu

Motivation

- Current compressed-gas designs do not produce realistic shock profiles or durations.
- Current blast-driven designs require significant investment and permissions for facilities and specialized personnel.

Laboratory Scale Blast-Driven Shock Tube

- Produces true shock waves with realistic pressure-time profiles and relevant durations.
- Can be employed to study effects of blast waves on materiel or biological samples.
- Modular design facilitates selection of peak pressure and area of application.



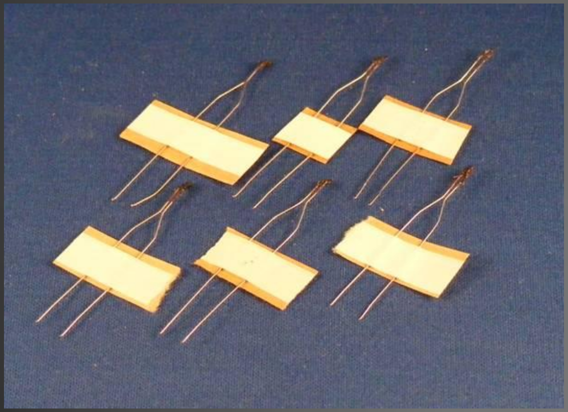
A: DRIVEN SECTION	27 mm	41 mm
Length (cm)	183	305
Inner diameter (cm)	2.65	4.10
Outer diameter (cm)	3.35	4.86
Sensor mount center distance from opening (cm)	1.12	1.22

B: DRIVING SECTION	2	3	4
Length (cm)	26.7	25.4	30.5
Inner diameter (cm)	1.57	2.13	2.71
Outer diameter (cm)	2.17	2.70	3.35

Blast Wave Production

A stoichiometric mixture of oxygen and acetylene was used to produce the blast wave.

$2\ H_2C_2\ (g) + 5\ O_2\ (g) \Rightarrow 4\ CO_2\ (g) + 2\ H_2O\ (g)$



The ignition source consisted of an electric match.

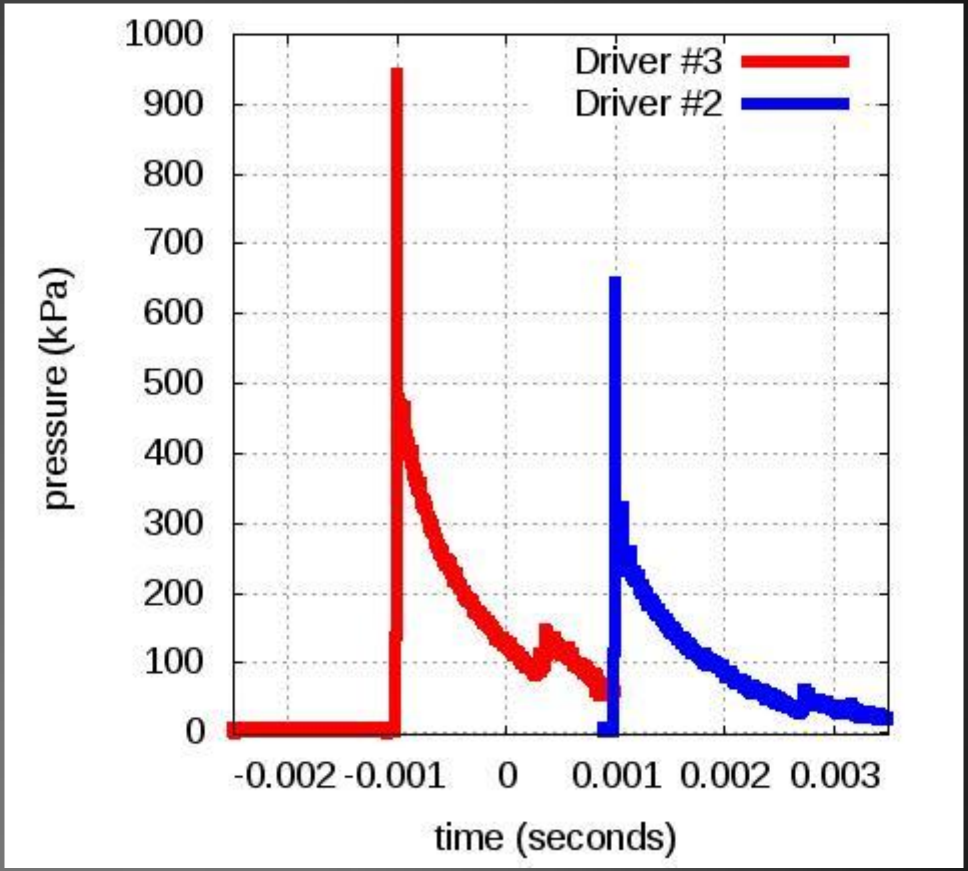
Blast Wave Characterization

Internal Pressure Sensor	PCB 102B15
External Pressure Sensor	PCB 102B18
Sample Rate	1 MHz
Signal Conditioner	PCB 842C
Digitizer	NI PXI-5105

Tests were conducted at 15°C.

Characterization Results

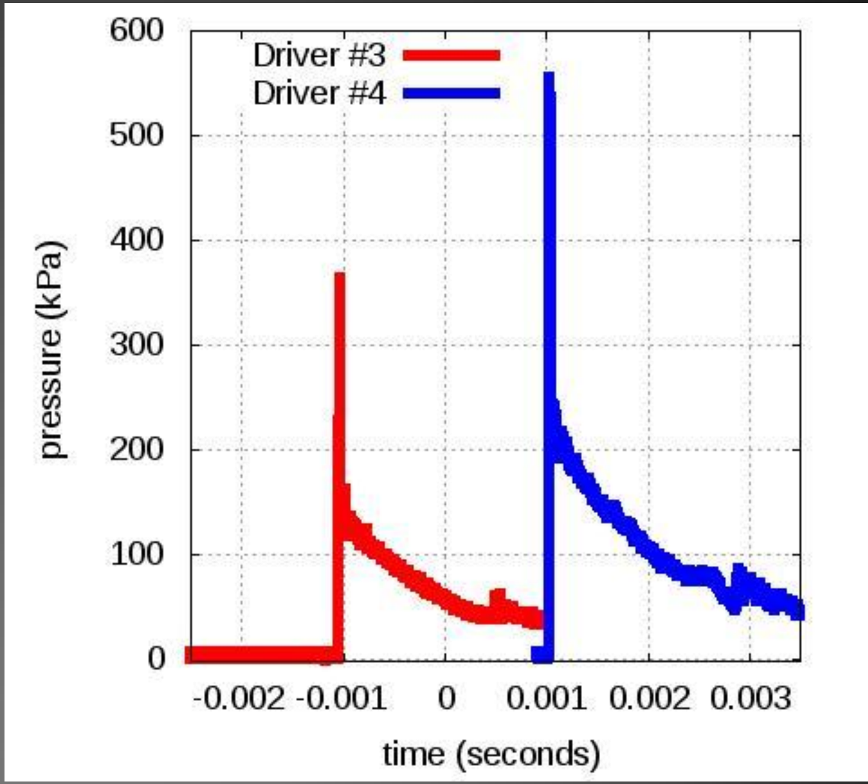
- Steep shock front
- Exponential decay
- Positive pulse duration of about 2 ms
- Larger driver volume ⇨ higher peak pressure



27 mm Diameter Driven Section

Characterization Results

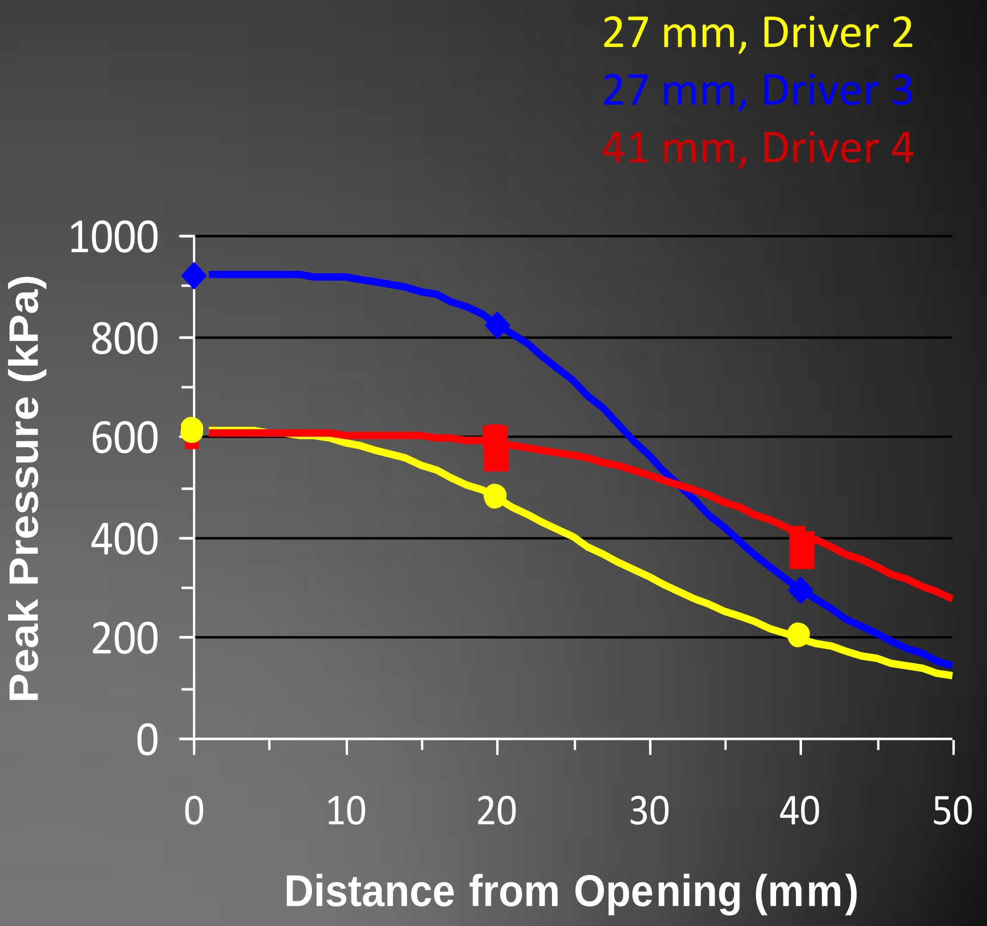
- Same driver, larger shock tube ⇨ lower peak pressure
- Shock wave characteristics consistent across driver/driven section combinations



41 mm Diameter Driven Section

Characterization Results

- Peak pressure decreased with distance from opening
- Allows finer control of peak pressure applied to a test sample
- Pattern of decreasing peak pressure is affected by shock tube diameter



Application: Transmission of a Blast Wave Through Cranial Bone

How does a blast wave reach the brain to cause injury without external wounding?

- **Head acceleration**
- **Thoracic** (pressure surge and/or vaso-vagal response)
- **Direct cranial entry** (transmission, entry through openings, skull flexure?)

These mechanisms are **not mutually exclusive**.

Application: Transmission Through Cranial Bone

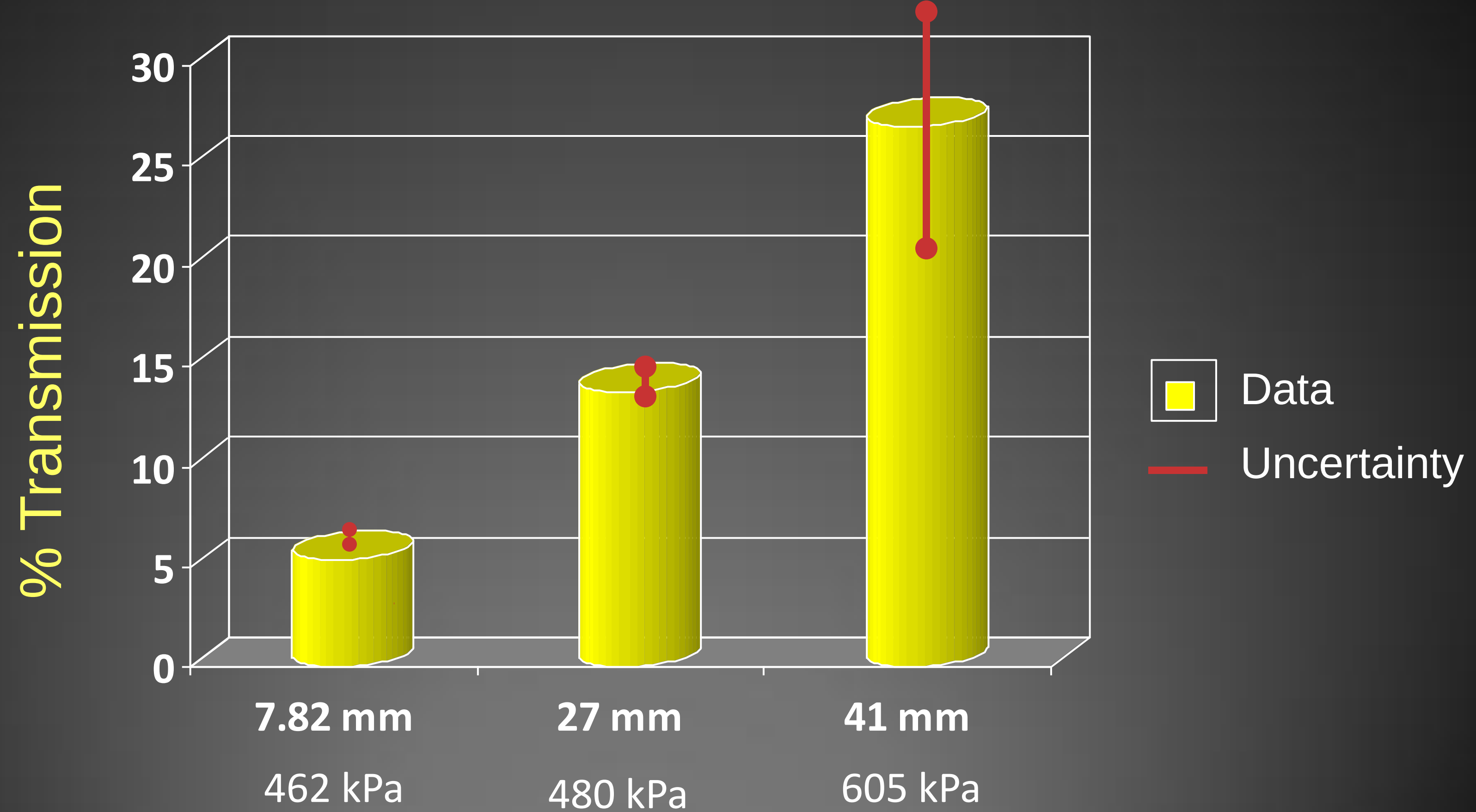
Study	Peak (MPa)	Duration (ms)	Magnification*
Hoberecht	0.18	4.0	1.7
Moss et al.	0.20	0.7	1.5
Zhang et al.	0.49 1.50	3.0 0.6	7.0 3.7
Moore et al.	0.51 1.82	0.7 0.6	1.0 2.75
Taylor & Ford	1.30 2.60	1.0 1.0	3.8 3.8

* Approximate factor of predicted magnification of peak intracranial pressure compared to the incident blast wave (at any intracranial location, not including the cranial bone itself).

All studies cited were published in 2009.

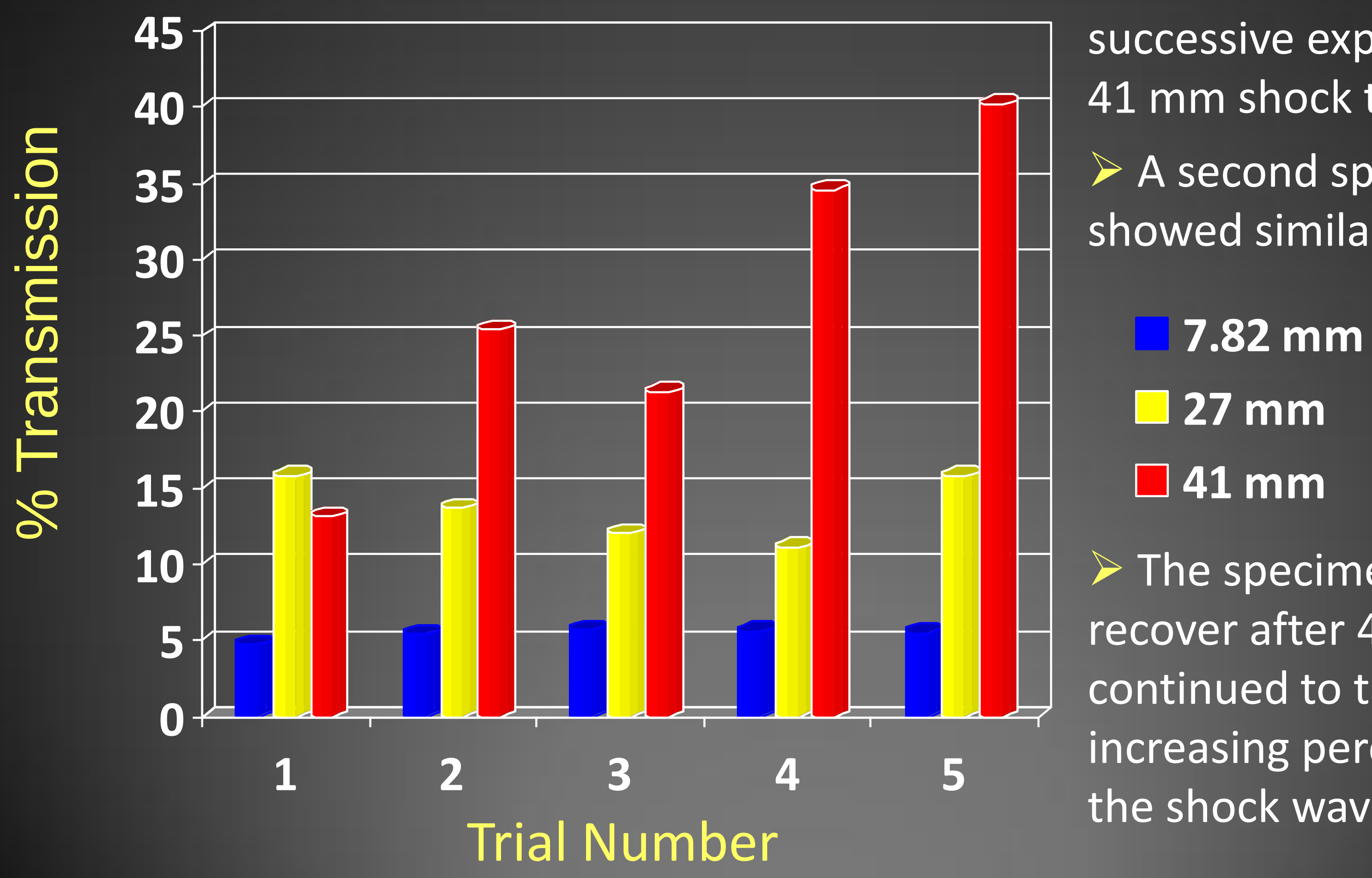
Application: Transmission Through Cranial Bone

Application: Transmission Through Cranial Bone



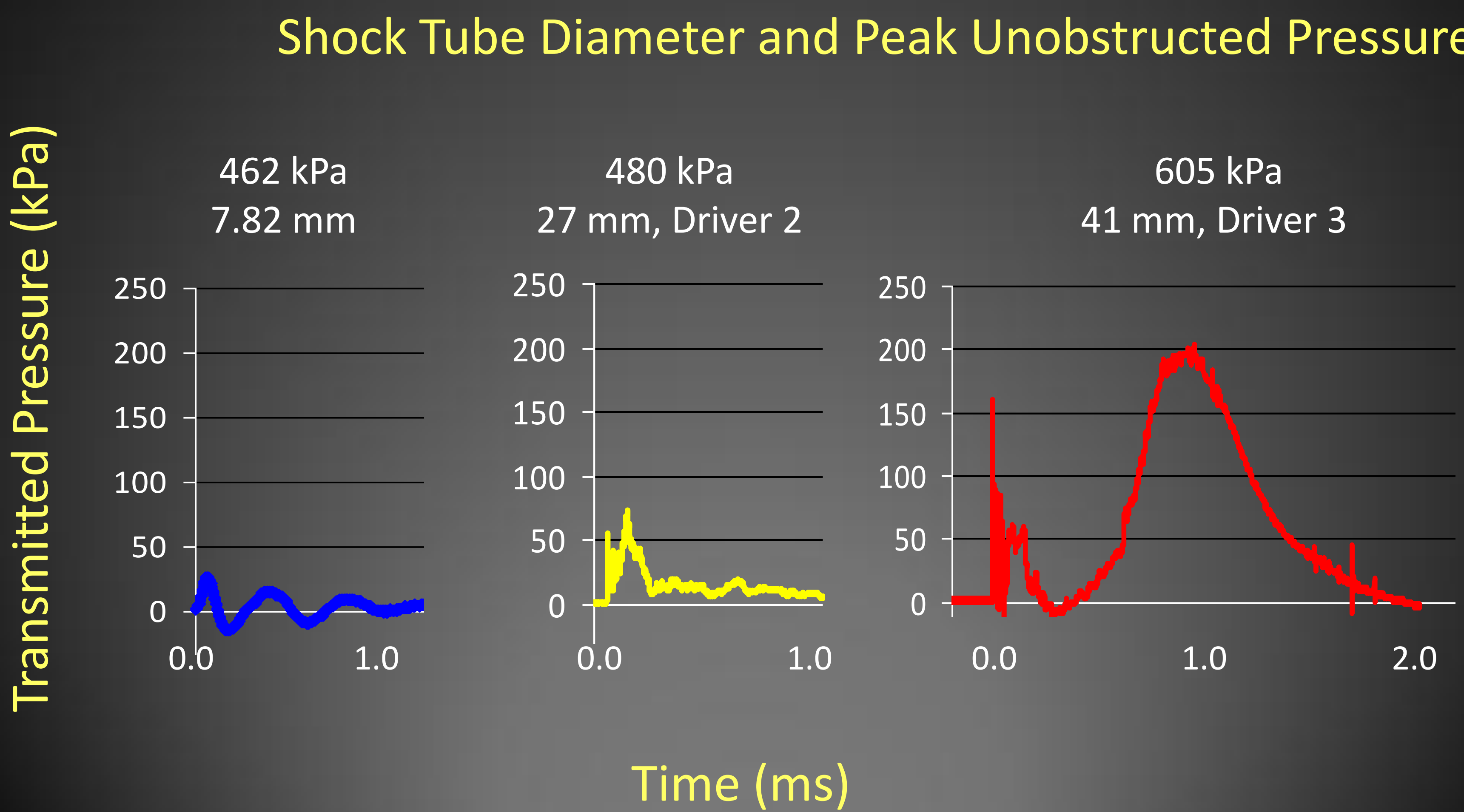
Shock Tube Diameter and Peak Unobstructed Pressure

Application: Transmission Through Cranial Bone

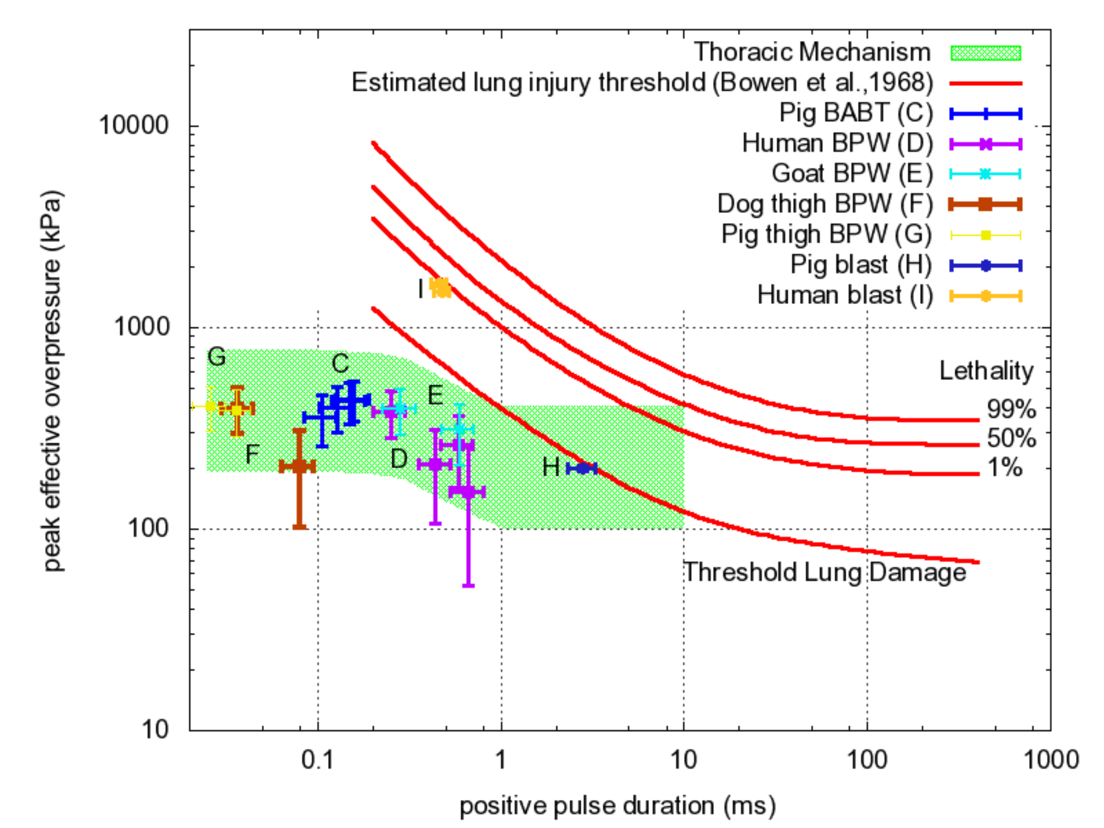


- Transmission increased with successive exposures from the 41 mm shock tube.
- A second specimen showed similar results.
- The specimen did not recover after 48 hours but continued to transmit an increasing percentage of the shock wave.

Application: Transmission Through Cranial Bone



At least three kinds of mechanical mechanism of primary blast-induced TBI are possible and they are not mutually exclusive.

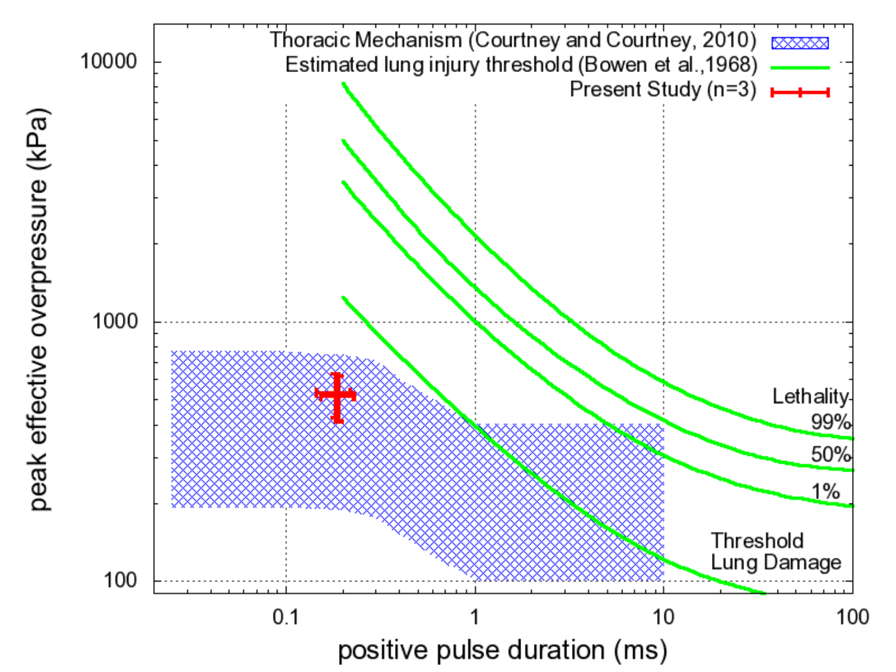


Thoracic Mechanism

Working toward exposure thresholds for blast-induced traumatic brain injury: thoracic and acceleration mechanisms.

Courtney and Courtney, 2010, NeuroImage 54(1):S55-S61

Thoracic Mechanism



A ballistic insult to the thorax of deer resulted in visible vascular damage in the brain. This is consistent with human autopsy results published by Krajsa (2009) and recent experiments in rats by Koliatsos et al. (2011).

	Mass (kg)	Brain Mass (g)	Impact Energy (J)	Distance to Incapacitation (m)
Male (antlerless)	49	179	2706	59
	Impact located 4 cm above midline, entered striking rib 7, exited between ribs 6 and 7. Capillary damage: petechiae observed on the occipital lobe, no hematomas.			
Female	80	170	2473	48
	Impact located 4 cm above midline, entered between ribs 8-9, grazed dorsal surface of liver, bullet recovered at 36 cm penetration. Capillary damage: petechiae observed on occipital, frontal and left parietal lobes and choroid plexus.			
Female	66	159	2445	16
	Impact located 12 cm below midline, entered between ribs 4-5, grazed the ventral surface of heart, exited breaking rib 3. Remarkably greater amount of vascular damage, midbrain and pituitary gland stained light red by diffuse petechiae.			

Oxy-Acetylene Driven Laboratory Scale Shock Tubes

- Produce true shock waves with realistic pressure-time profiles and relevant durations.
- Can be employed to study effects of blast waves on materiel or biological samples.
- Modular design facilitates selection of peak pressure and area of application.