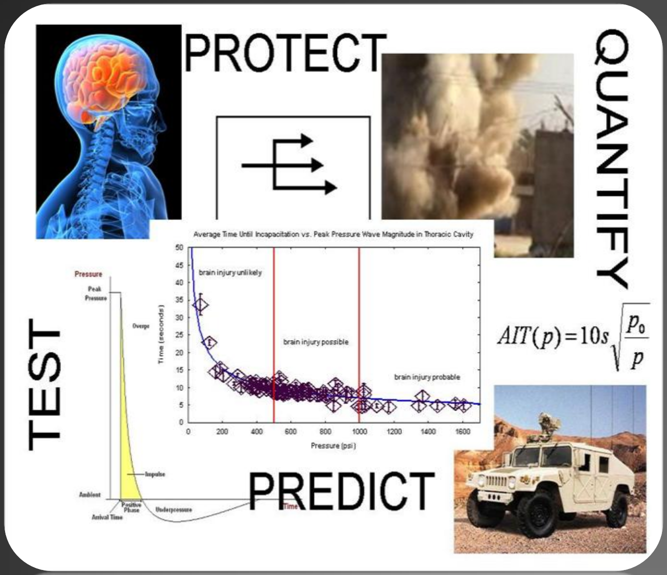
Attenuation of a Blast Wave Through Cranial Bone



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Motivation

- Experimental data on the transmission of blast waves through cranial bone is sparse. (e.g., Romba 1961; Chavko et al., 2007, 2011)
- Methods are needed to apply realistic blast loading to test specimens in the laboratory.
  - Explosive-driven shock tubes are difficult and expensive to install and operate.
  - Compression-driven shock tubes produce suboptimal pressure wave profiles and have an undesirable “jet effect.”

Table-Top Blast-Driven Shock Tube

Courtney, M.W., Courtney, A.C., 2010. A table-top blast driven shock tube. *Rev. Sci. Instrum.*, 81:126103.

This is an explosive driven shock tube employing a rifle primer which explodes when impacted by the firing pin. The firearm barrel acts as the shock tube, and the shock wave emerges from the muzzle.

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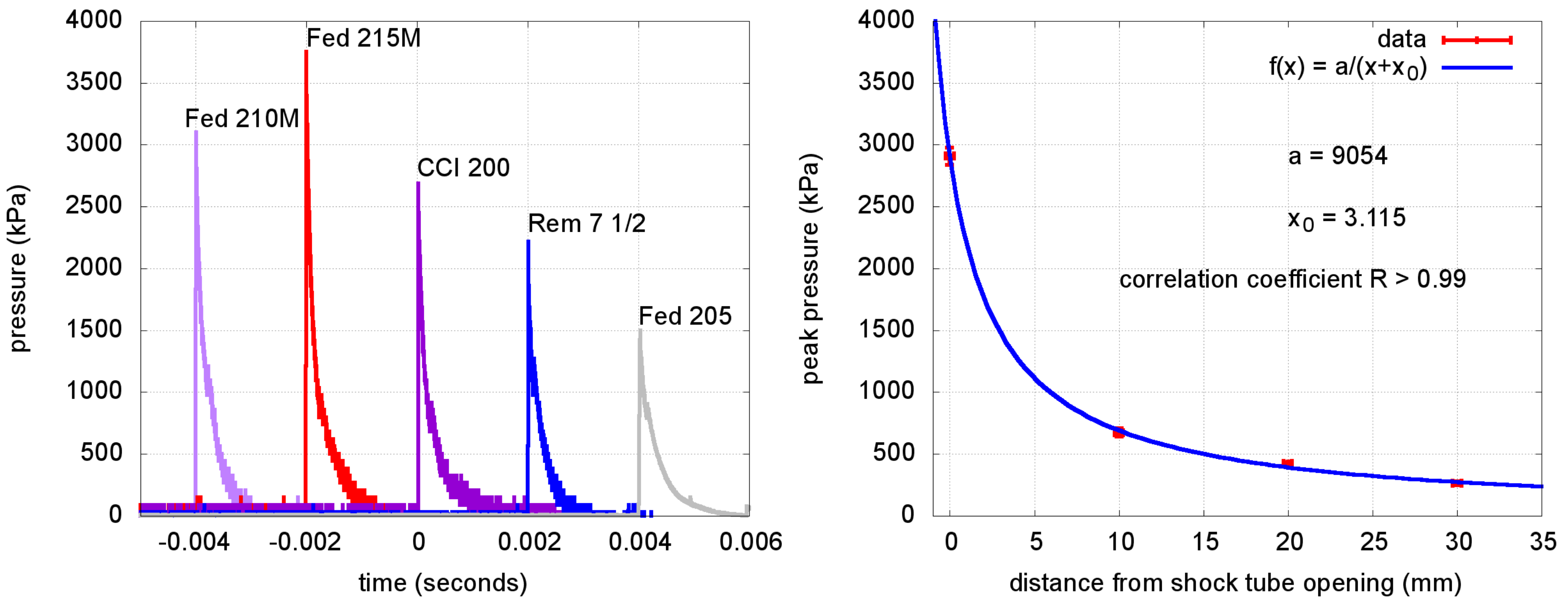
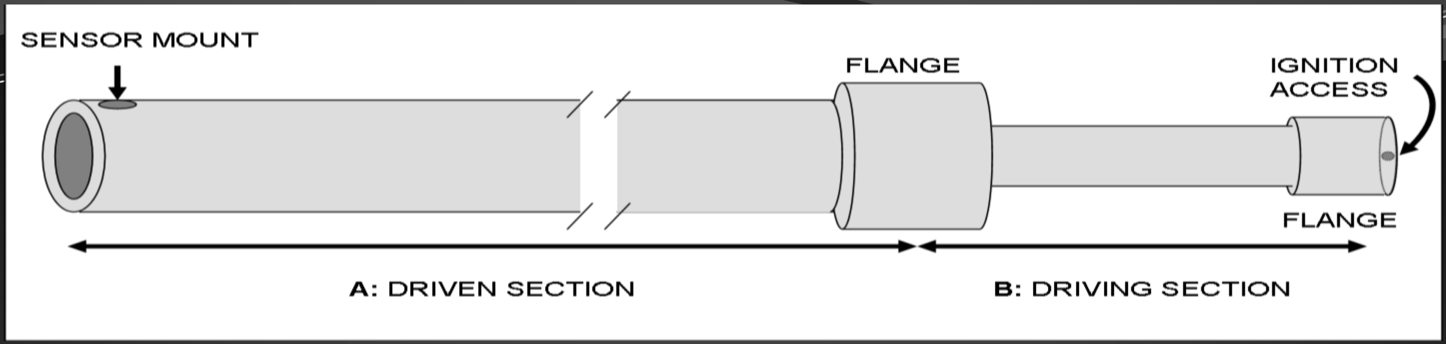


Oxy-Acetylene Driven Laboratory Scale Shock Tubes

- 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.



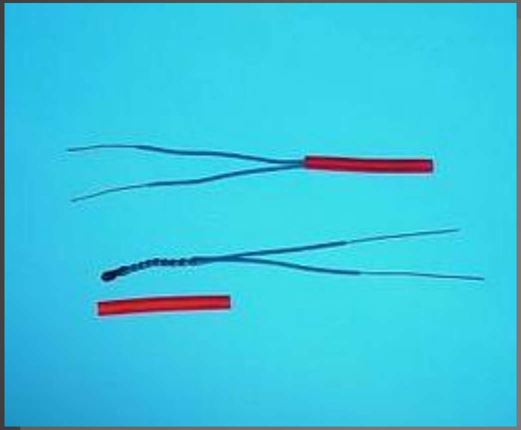
A: DRIVEN SECTION	27 mm	41 mm
Length (cm)	183	305
Inner diameter (cm)	2.65	4.10
Outer diameter (cm)	3.35	4.86
Sensor mount center distance from opening (cm)	1.12	1.22

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.

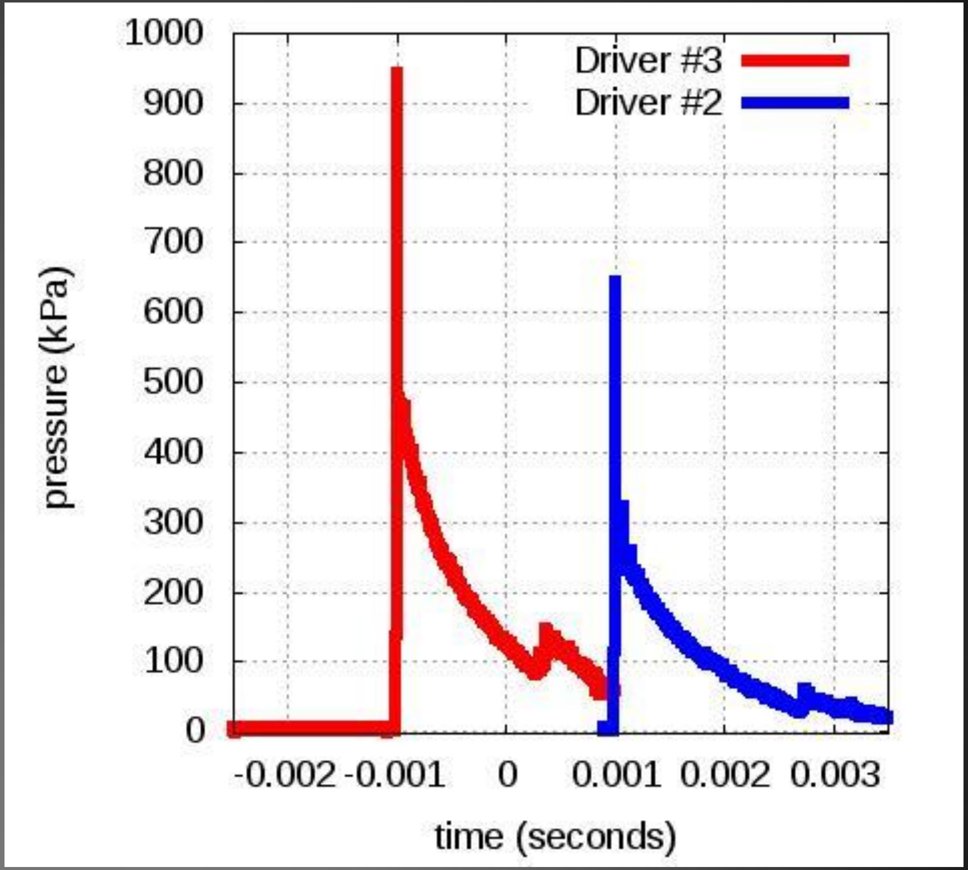
Blast Wave Characterization

Internal Pressure Sensor	PCB 102B15
External Pressure Sensor	PCB 102B18
Sample Rate	1 MHz
Signal Conditioner	PCB 842C
Digitizer	NI PXI-5105 or NI USB-5132

Tests were conducted at 20°C and air pressure of 587 mm Hg

Characterization Results

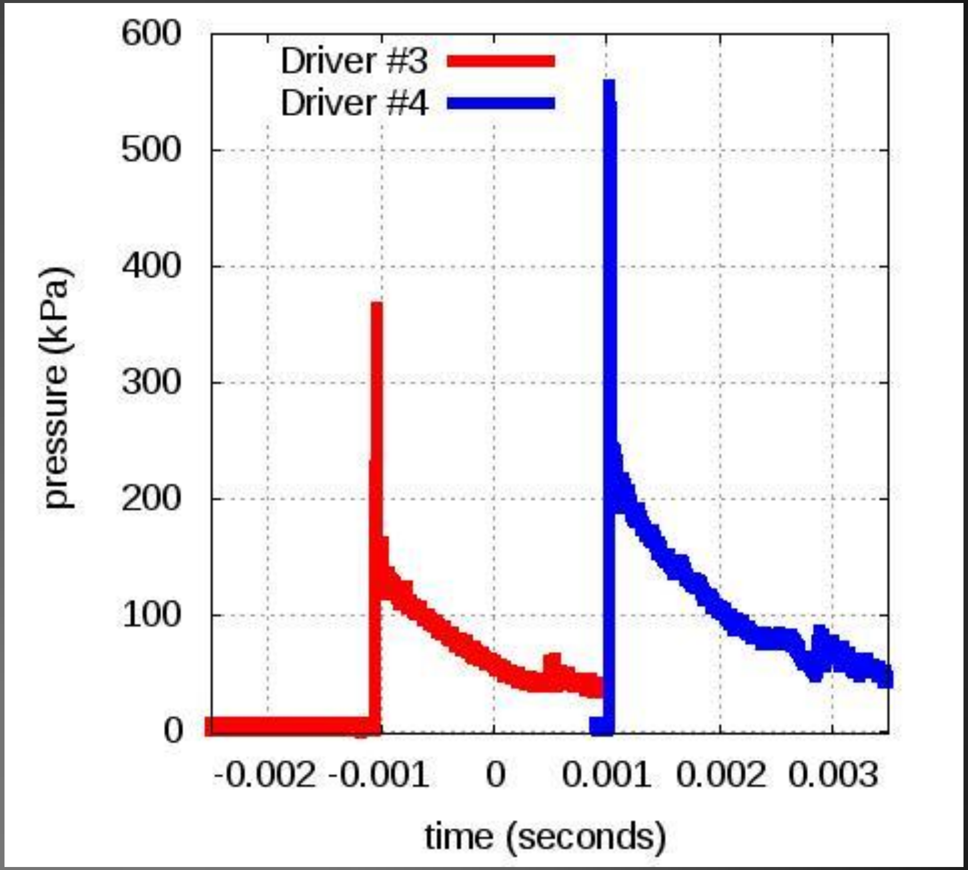
- Steep shock front
- Exponential decay
- Positive pulse duration of about 2 ms
- Larger driver volume ⇨ higher peak pressure



27 mm Diameter Driven Section

Characterization Results

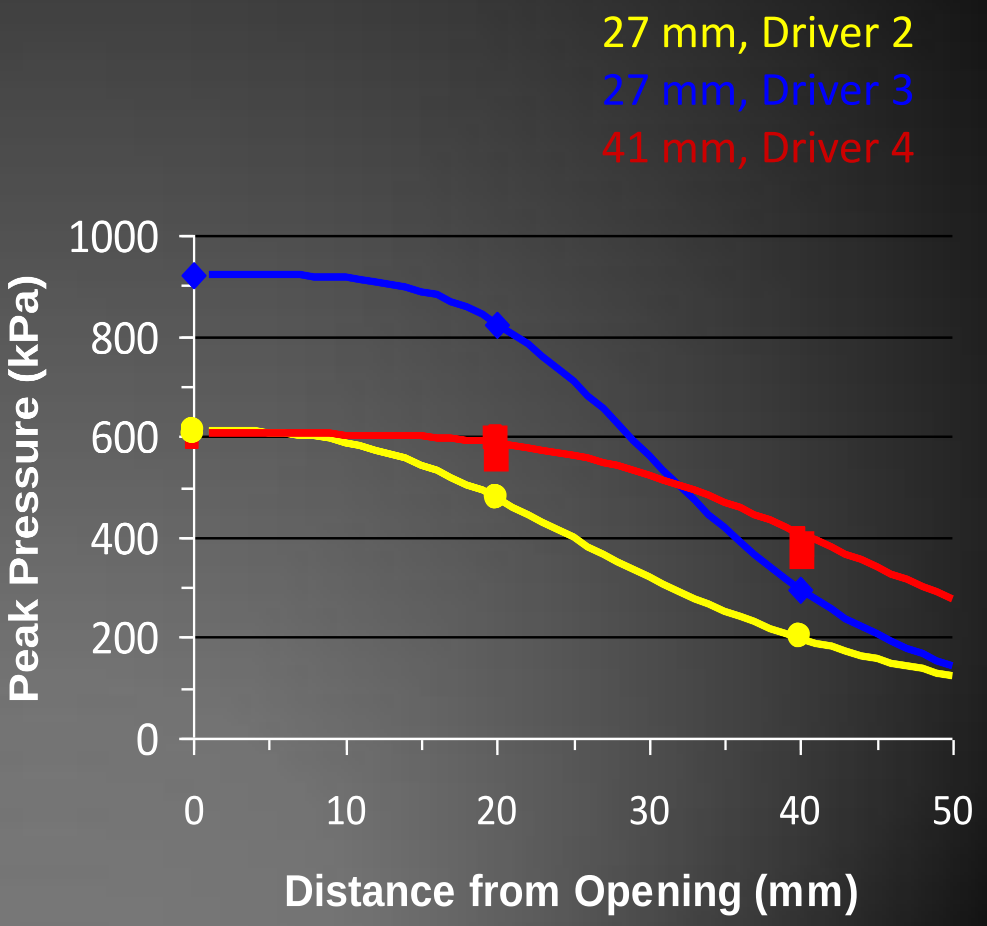
- Same driver, larger shock tube ⇨ lower peak pressure
- Shock wave characteristics consistent across driver/driven section combinations



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



Jet Effect: The volume of additional gas produced by the fuel in a shock tube. The jet follows the shock front and imparts momentum to the test object, possibly confounding primary blast effects.

In calculations for a 632 cm^3 volume driving section*, for example, it can be shown that the oxy-acetylene driven shock tube produces a dramatically smaller jet effect compared to a compressed gas driver.

Source of blast or shock wave	Volume of additional gas produced (cm^3)	
Oxy-acetylene	534 – 632 =	**-98**
RDX	171 – 0 =	**+171**
Compressed Gas	23,177 – 632 =	**+22,545**

*5.1 x 30.5 cm cylinder. Comparisons are based on equating the total energy produced. Calculations do not consider temperature effects.

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

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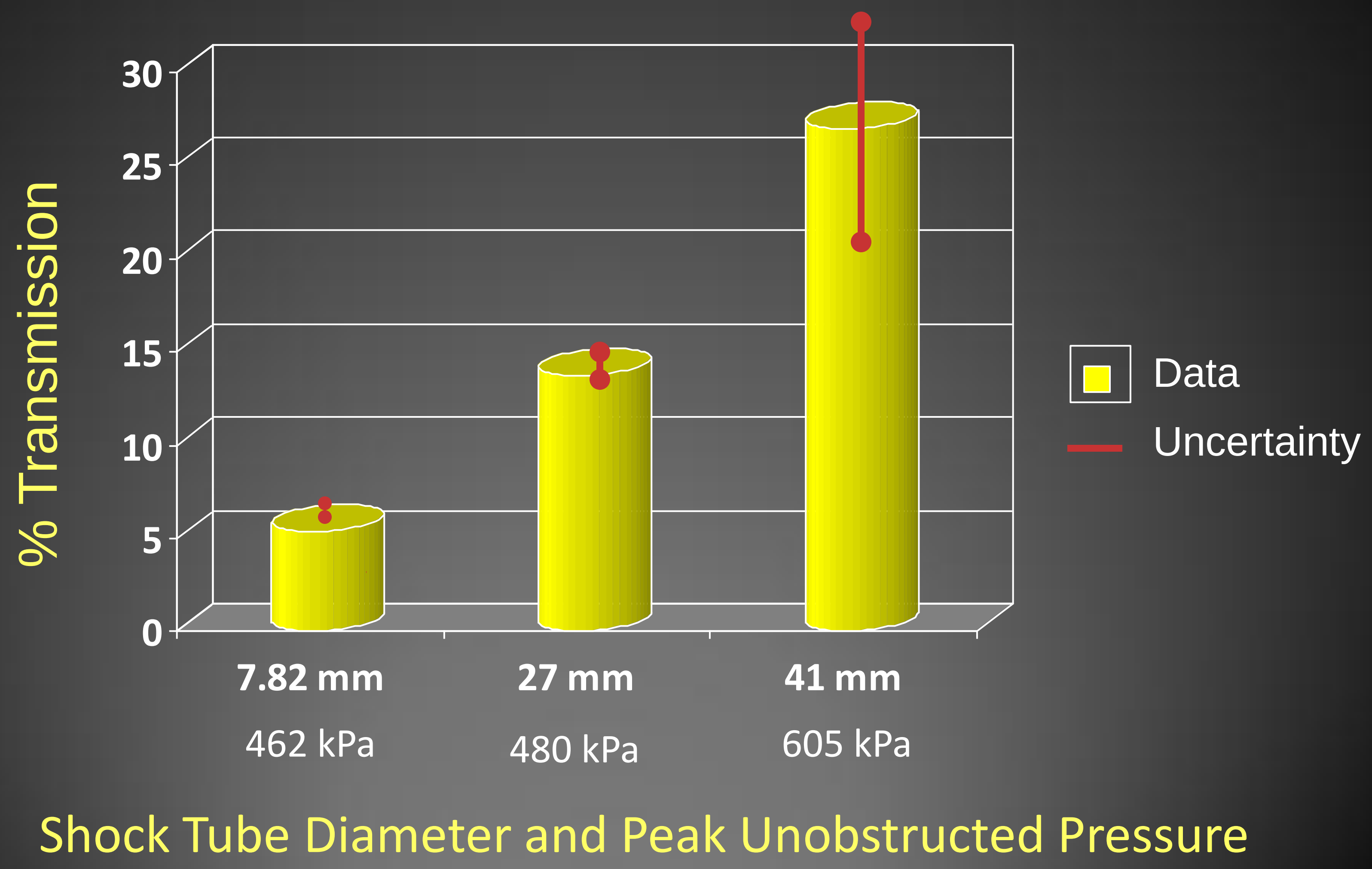
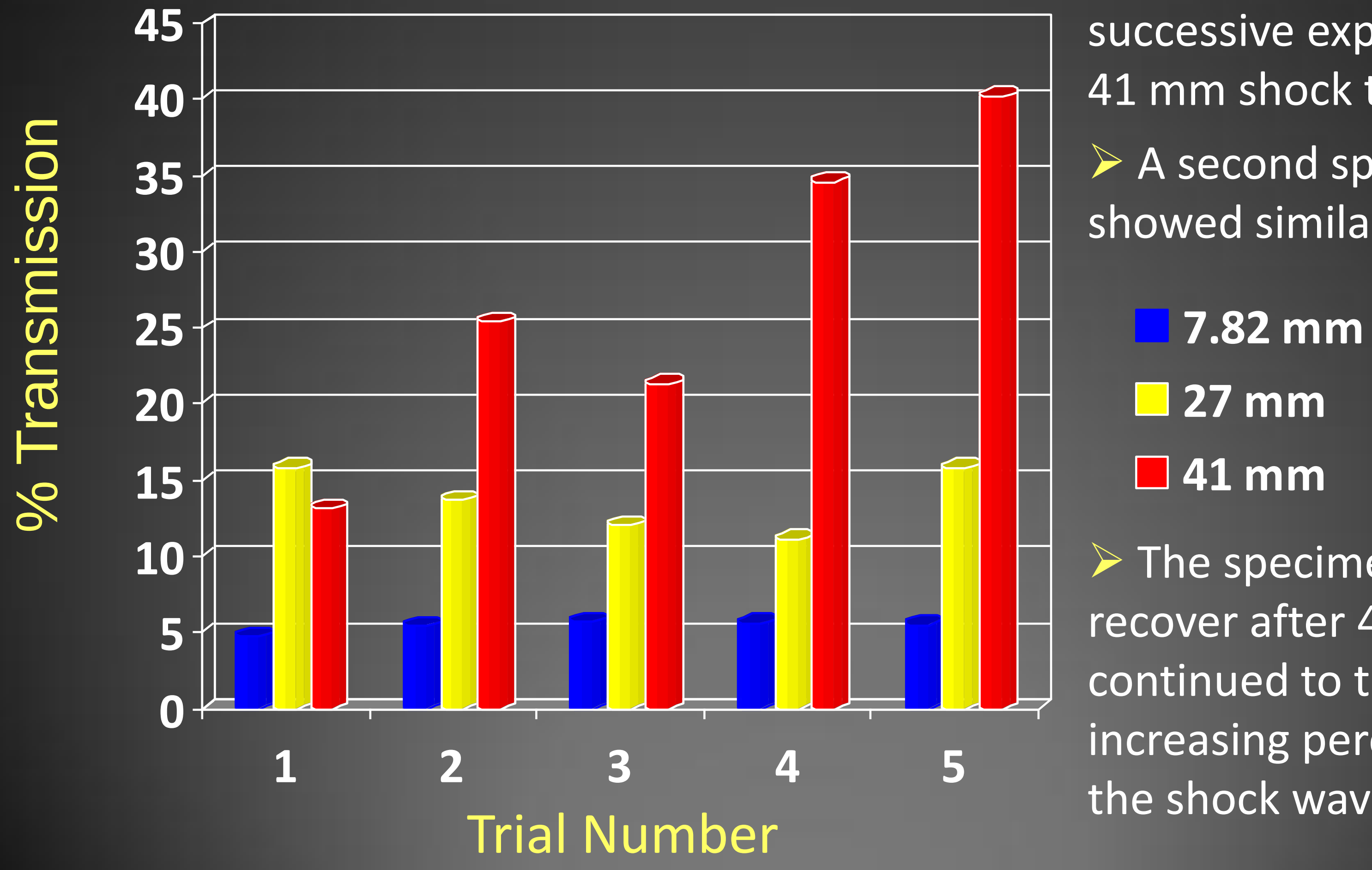


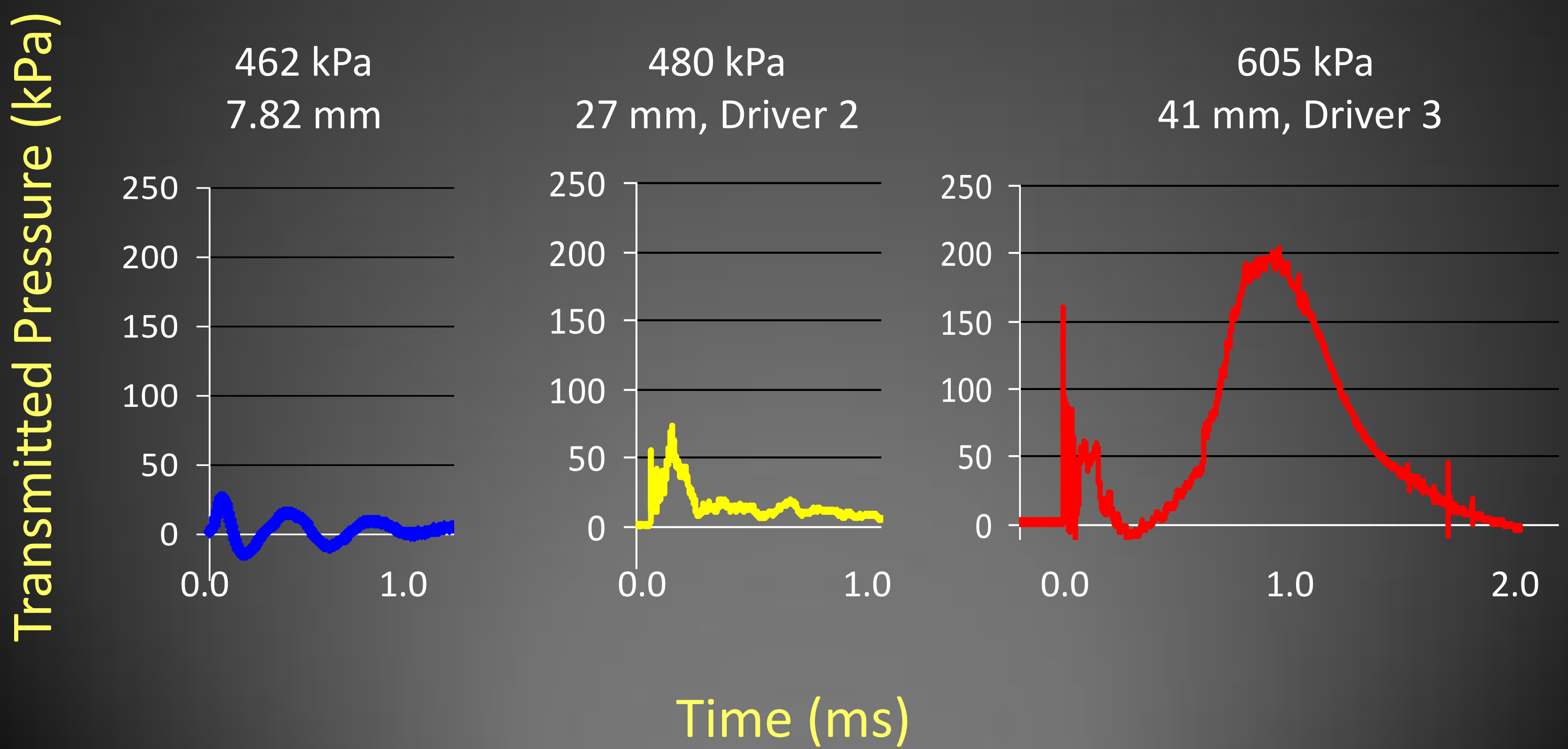
Application: Transmission Through Cranial Bone



- 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.

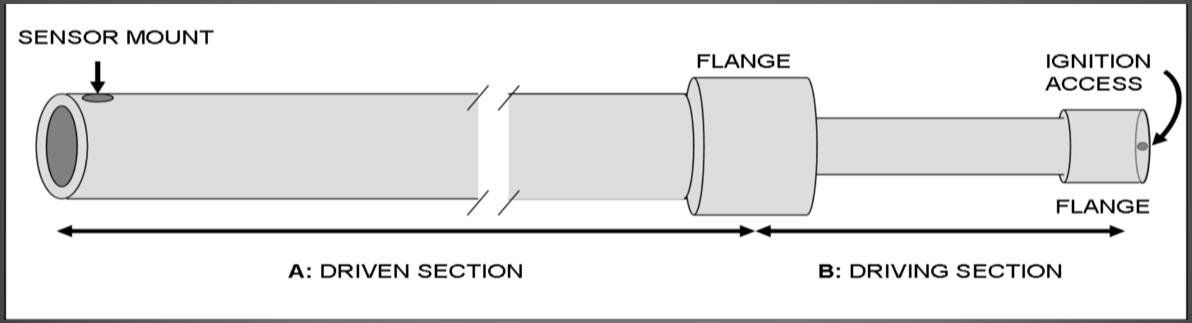
Application: Transmission Through Cranial Bone

Shock Tube Diameter and Peak Unobstructed Pressure



Oxy-Acetylene Driven Laboratory Scale Shock Tubes

- Produce true shock waves with realistic pressure-time profiles and relevant durations.
- Can be used to study effects of blast waves on materiel or biological samples.
- Modular design facilitates selection of peak pressure and area of application. *New 51 mm and 79 mm diameter designs work just as well.*



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