DEFENCE R&D DÉFENSE

A Blast Headform Surrogate for the Assessment of Blast-Induced Traumatic Brain Injury

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Introduction

- Incidence of brain injuries has increased significantly during recent conflicts. This might be due to :
  - Improved body armour that enhances soldier survivability
  - Changes in nature of combat and associated threats
- The sequelae of mTBI can be devastating
- Hypothetical cause of the mTBI appears to be single or repetitive exposure to shock/blast loading conditions
- It has became the subject of strong research interest in the defence and health care community
- Current combat helmets **may not protect adequately** against primary blast effects

1- Wagner, C., "Brain injuries high among Iraq casualties", ARNEWS, Army News Services, November 24, 2003
2- Jontz, S., "More head injuries in Afghanistan, Iraq push improvements in protective gear", Stars and Stripes, January 30, 2004.
3- Amburn, B., "Brain injuries lead Iraq war injuries", United Press International, July 23, 2004
4- Jaffe, G., "An Army Surgeon Says New Helmet Doesn't Fit Iraq", The Wall Street Journal, August 25, 2004
5- Okie, S., "Traumatic Brain Injury in the War Zone", N. Engl. J. Med., 335:20, pp. 2043-2047, May 2005

Objectives

- Develop a test device *to evaluate headgear performance* for mitigating blast overpressure induced mTBI
  - Robust and reusable: *Capable of withstanding repeated blast exposure*
  - Repeatable and consistent: *Minimal variation in response between tests and between copies*
  - Instrumented adequately: *Record the relevant physical parameters inside and outside the headform*
  - Biofidelic wrt external geometry: *Correct fit of headwear, Representative blast diffraction around headform*
  - Biofidelic wrt internal geometry and material selection: *Stress transmission/reflection within the headform*
- Perform a series of CFD simulations to examine the blast wave propagation between a headform and various helmet designs
  - Featureless, channelling and padding

Development Strategy

- Develop successive versions of a headform, increasing complexity and biofidelity at each iteration
  - Start from a simplified shape (ovoid) and evolve to a more complex geometry
  - Progressively increase number of physiological features (CSF, membranes, etc...).
  - Gain experience with:
    - Manufacturing and durability of the selected materials
    - Performance and suitability of selected instrumentation
    - Wave dynamics occurring outside and within the surrogate brain
- Conduct CFD and FEM studies in parallel to the experimental work
- Final validation stage including direct comparison with PMHS data

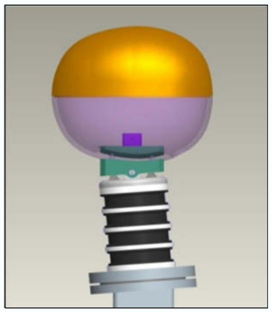
Testing facilities

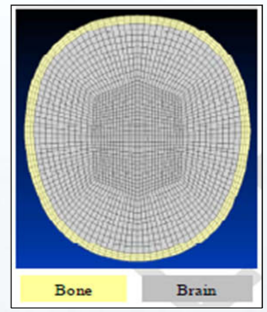
- Different test facilities were used
  - Blast chamber
  - Detonics Bay
  - Free-field blast test site
- Care was taken to generating representative blast waves of various magnitude and duration

Design Iterations

Mk .5 Headform:

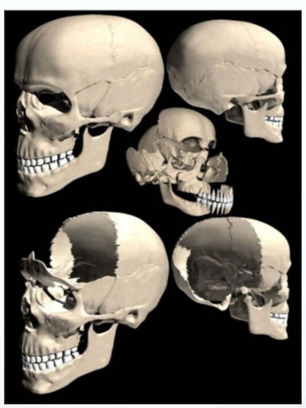
Simplified ovoid geometry (based on ISO-J headform) with skull and brain component





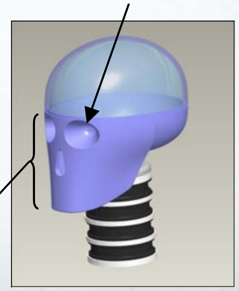
Mk 1 Headform:

Introduce skull geometry, thickness and simplified physiological features, material identification, fabrication and assembly of a biofidelic skin surrogate

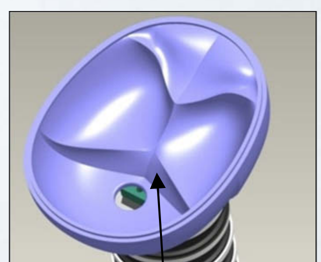


Urethane rubber to mimic the skin

Eye orbits



Facial geometry

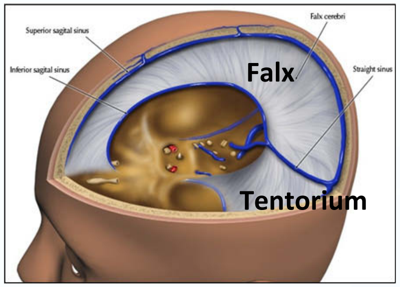


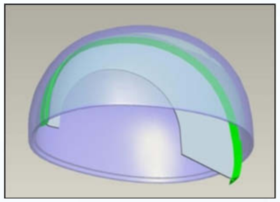
Details of the skull base geometry

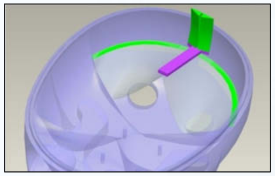
Design Iterations

Mk 2 Headform:

Implement brain structure with falx and tentorium membranes as well as inclusion of cerebrospinal fluid (CSF) surrogate

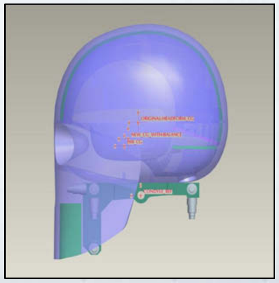






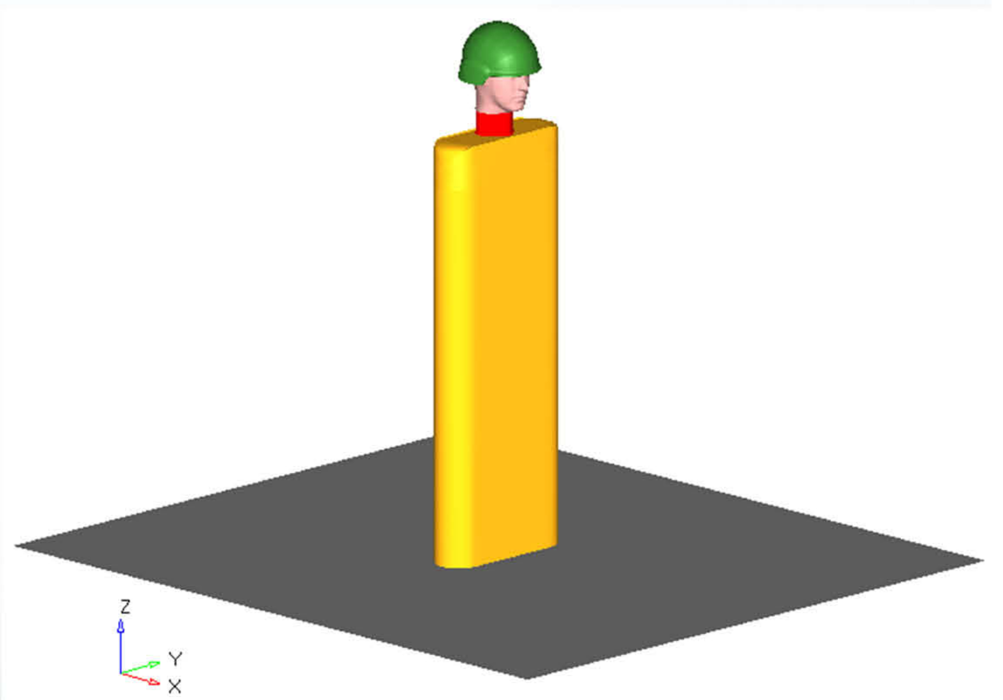
Mk 3 <u>or</u> Blast Induced Brain Injury Protection Evaluation Device (BI^{2}PED):

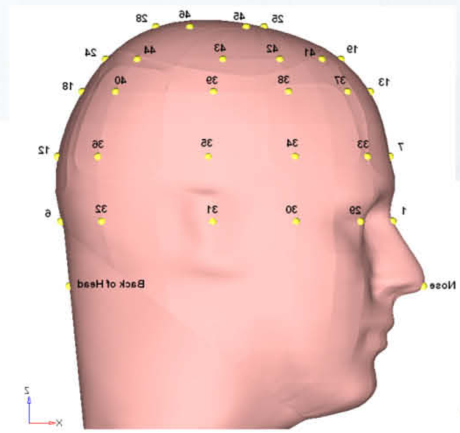
Anthropomorphic external and internal geometry, cast-in ICP transducers, external surface pressure transducers, mounted on HIII neck and six-accelerometer package

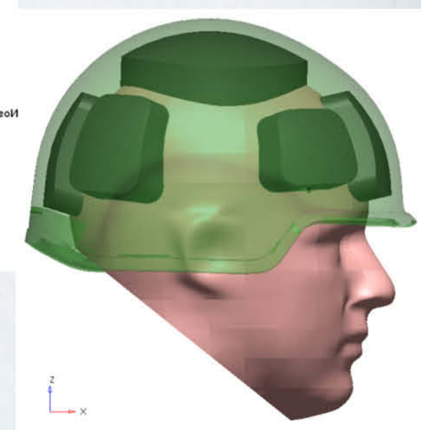


CFD Calculations

- Simulations have been carried out to examine the blast wave propagation between a headform and various helmet designs
- Helmet, head form, neck, and torso are all rigid and non-responding, so no shock propagation through these components occurs

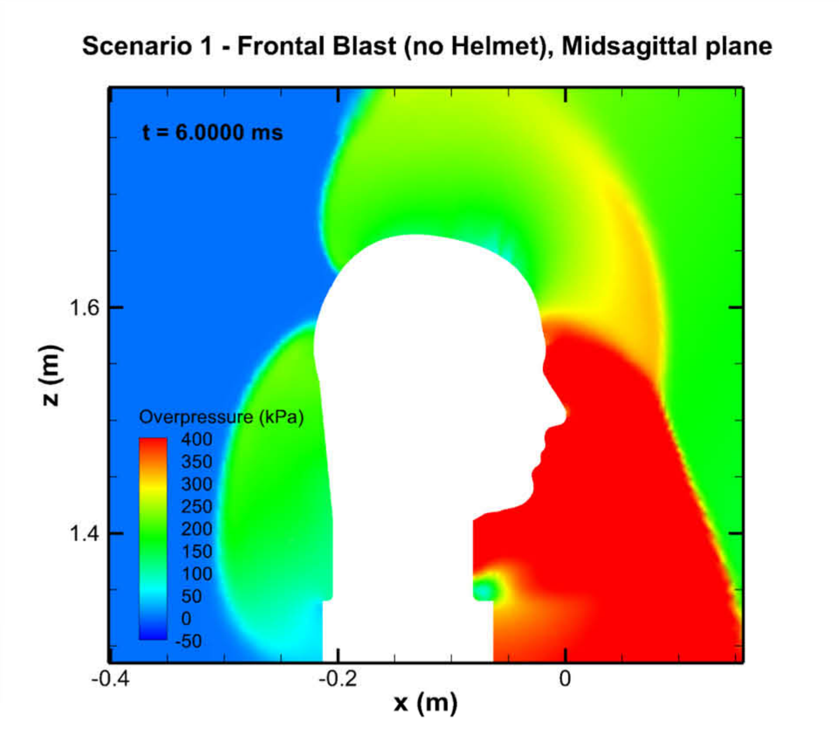


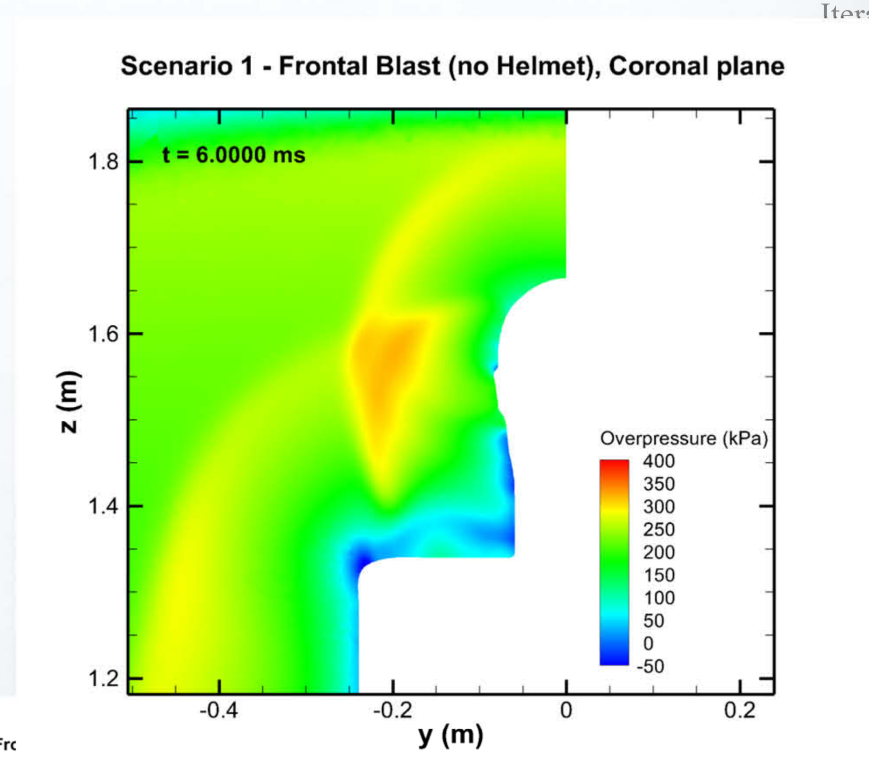


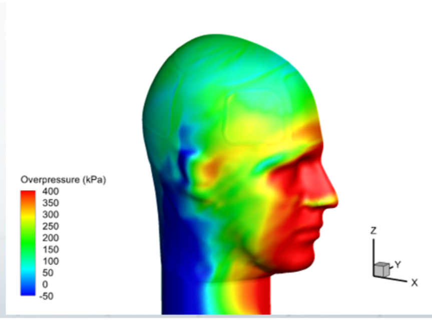


Frontal Blast, No Helmet

- The shock front arrived at the nose point, travelling upwards and rearwards, and then reflected off and diffracted about the head

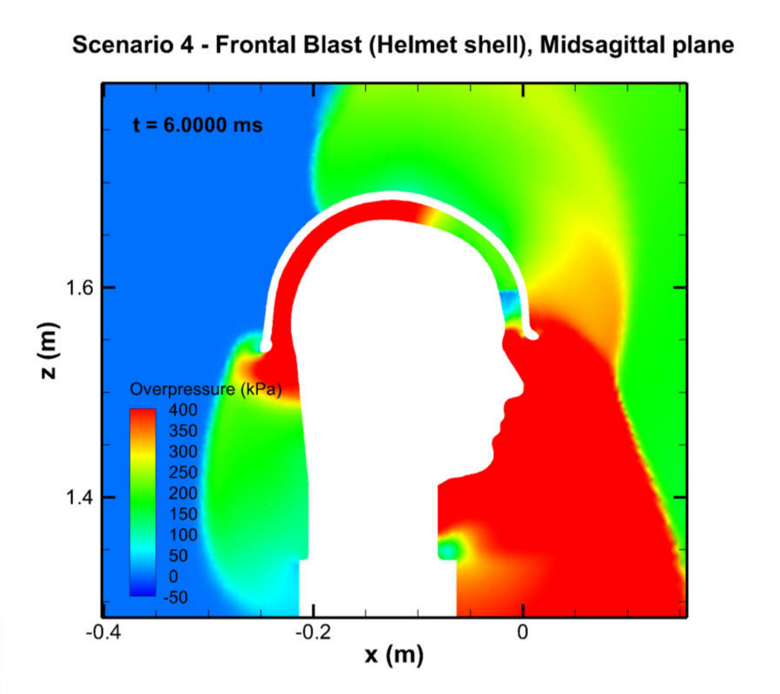


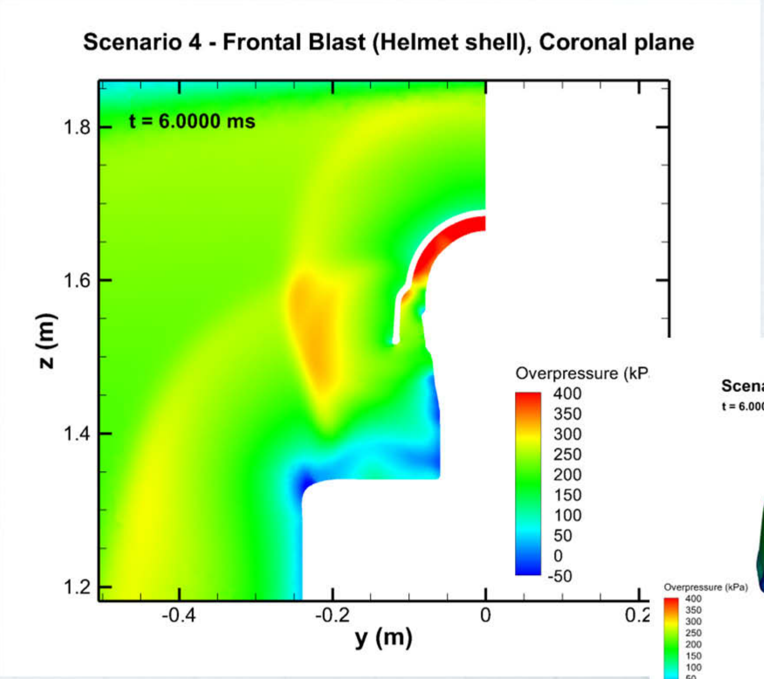


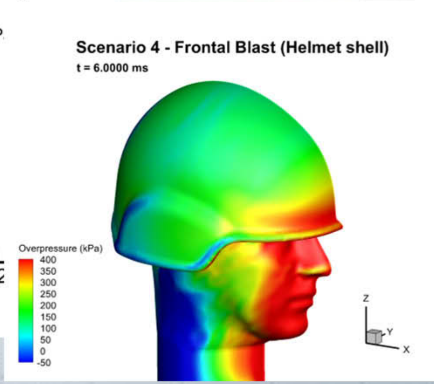


Frontal Blast, HELMET SHELL

- The shock front enters the head-helmet gap in the front and exits in the rear, while being turned and amplified by the shape of the head and helmet shell.
- Regions of high pressures were observed throughout the head-helmet gap
- Data such as forces on the helmet were computed

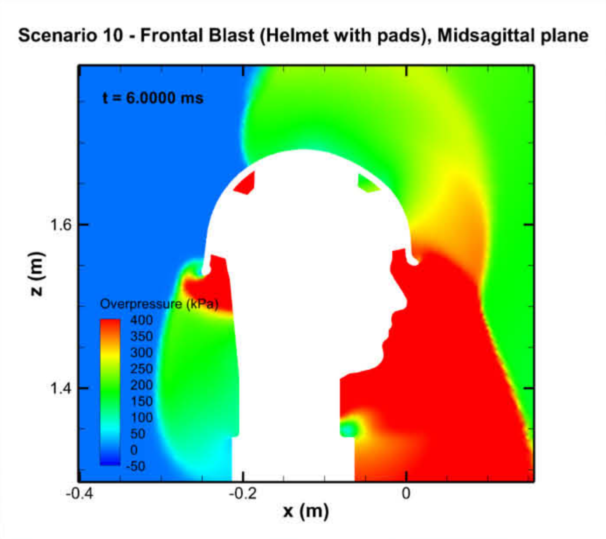


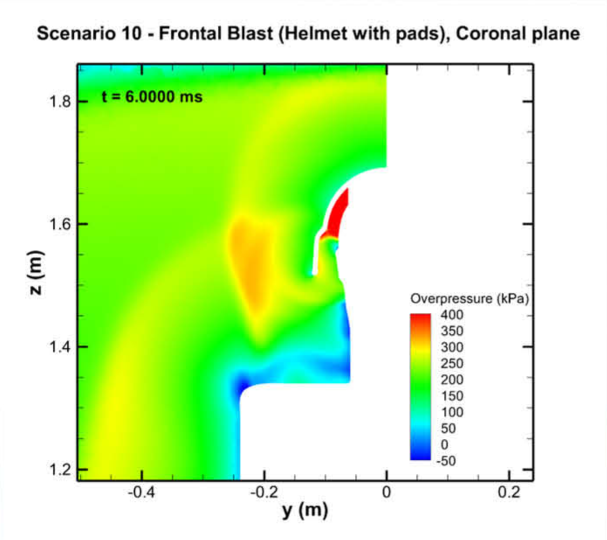


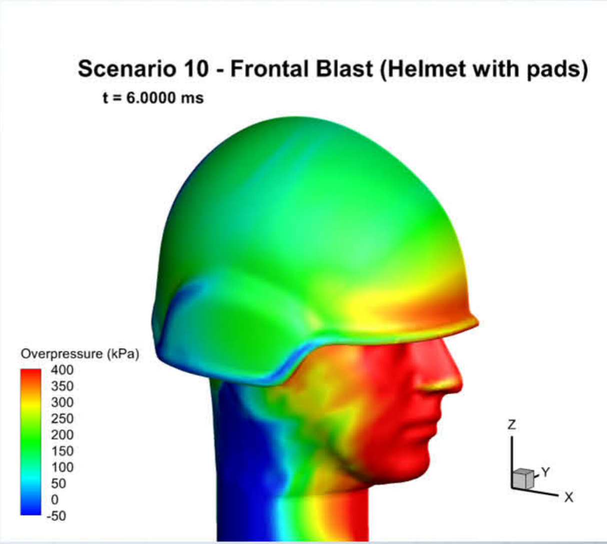


Frontal Blast, Helmet with Pads

- The shock front enters the head-helmet gap in the front and exits in the rear, while being turned and amplified by the shape of the head and helmet shell, and the confinement of the space between the pads
- Regions of high pressures were observed throughout the head-helmet gap
- In general initial peak pressures were higher than those observed in the case with the helmet shell, but secondary pressure peaks were, in general, lower





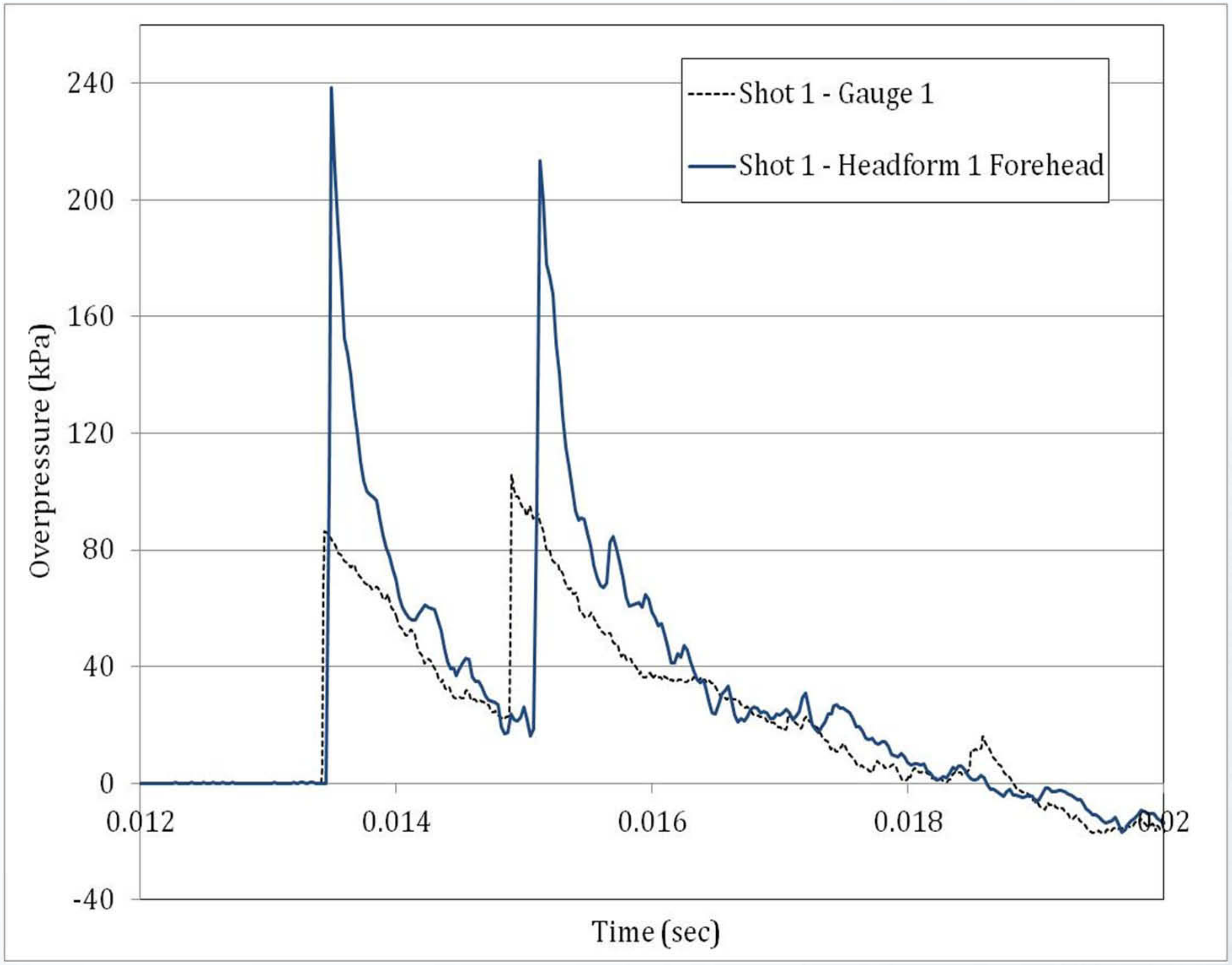


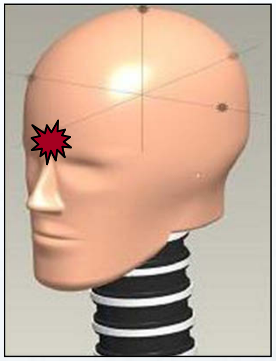
BI²PED – Recent results

- **Free-field blast tests**
- **18 tests** ; 3 repeats per conditions
- **5 kg C4 charges, HOB=1.5m ;** Providing the desired peak overpressures and durations as well as a tracking feature in the blast wave (i.e. ground reflection secondary peak)
- **Stand-off between 5m and 4m**; Assessing headform response at different overpressure levels
- **40 channels of instrumentation**
  - **2x Bi²PED headform**
  - **1x HIII headform** for comparing the general head dynamics with the BI²PED headform
  - **2x Incident pressure gauge** providing reference incident overpressure histories
- **With and without protective headwear**

BI²PED – Recent results (Nov 2011 trial)

- **External pressure field**

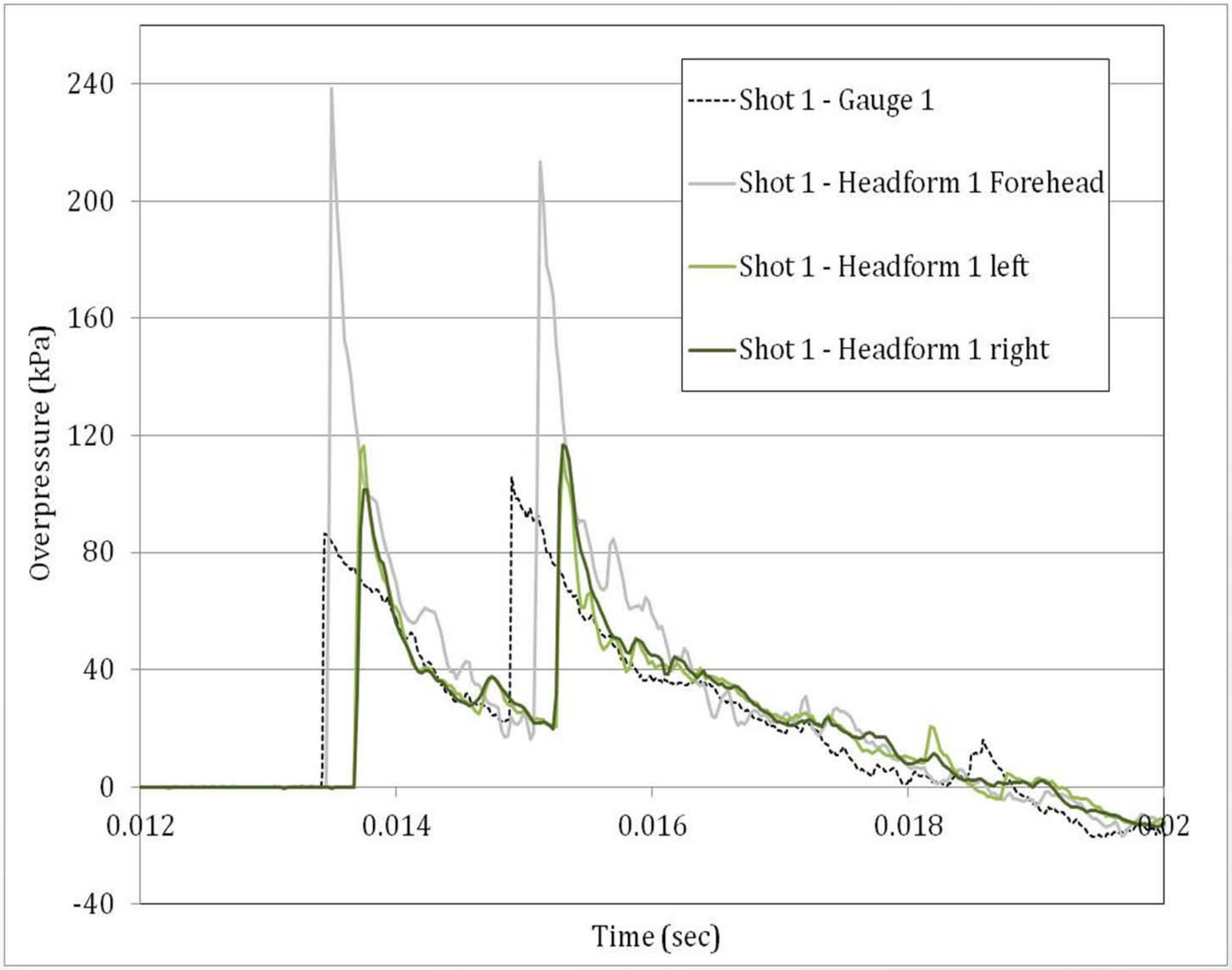




- **Forehead and reference gauge see blast wave first**
- **Forehead pressure is about 3 times incident reference pressure**

BI²PED – Recent results (Nov 2011 trial)

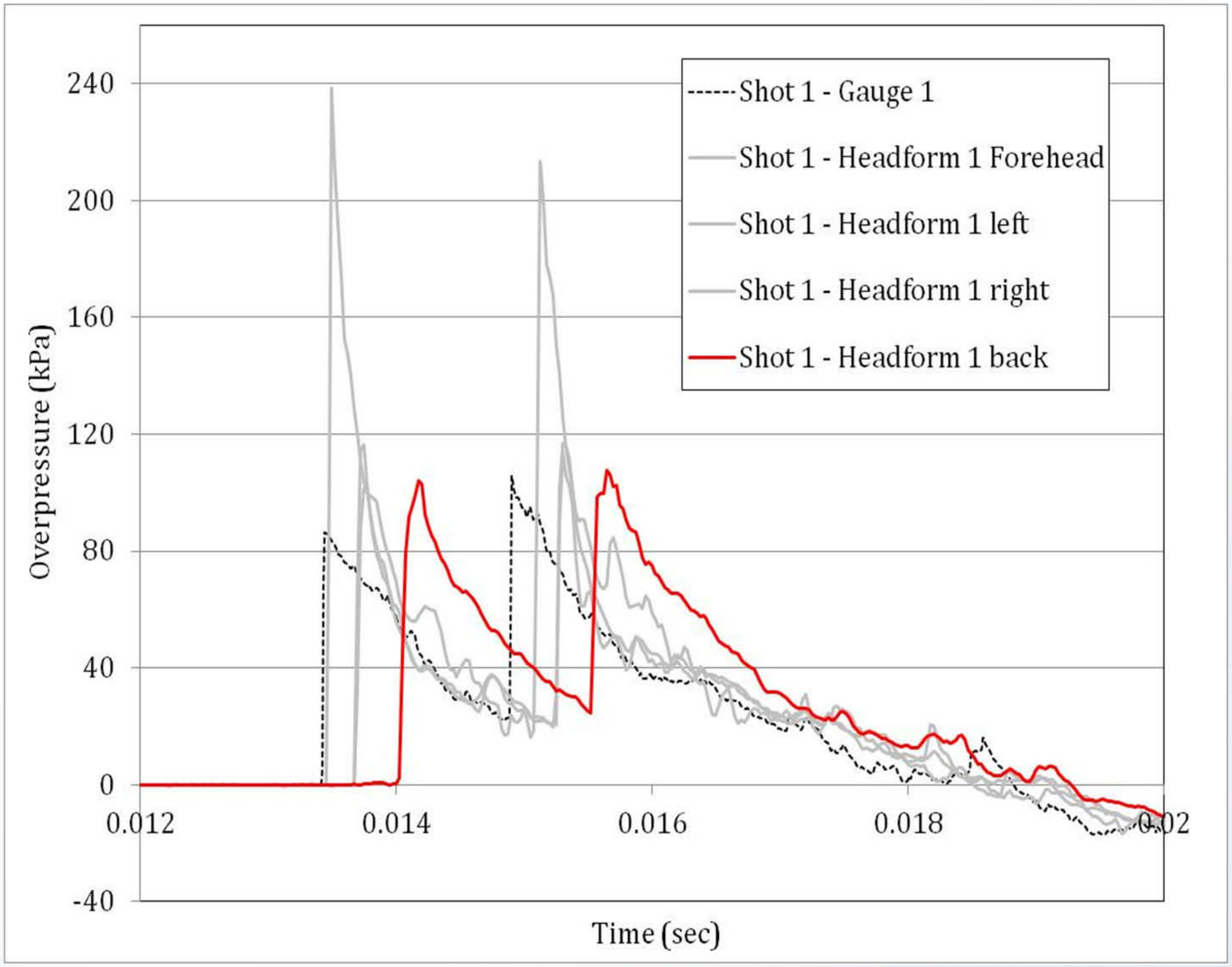
- **External pressure field**



- **Side gauges follows**
- **Great symmetry confirms orientation of headform**
- **Magnitude of overpressure slightly over reference incident pressure**

BI²PED – Recent results (Nov 2011 trial)

- **External pressure field**



- **Back gauge sees blast wave last**
- **Positive pressure signal following incident overpressure history**
- **Magnitude of peak is less than on the sides, and close to the incident overpressure**

Conclusion

- A test device has been developed to evaluate headgear performance for mitigating blast induced mild traumatic brain injury (mTBI)
- The BI^{2}PED has shown potential for discriminating between unprotected and protected configurations
- In general, initial peak pressures were higher than those observed in the case with the helmet shell
- The shock is amplified by the confined space between the pads
- Validation of the device against PMHS data was initiated

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