U.S. ARMY COMBAT CAPABILITIES DEVELOPMENT COMMAND – ARMY RESEARCH LABORATORY

Multi-Degree of Freedom Blast Effects Simulator (MDOF-BES)

Robert Kargus

Mechanical Engineer

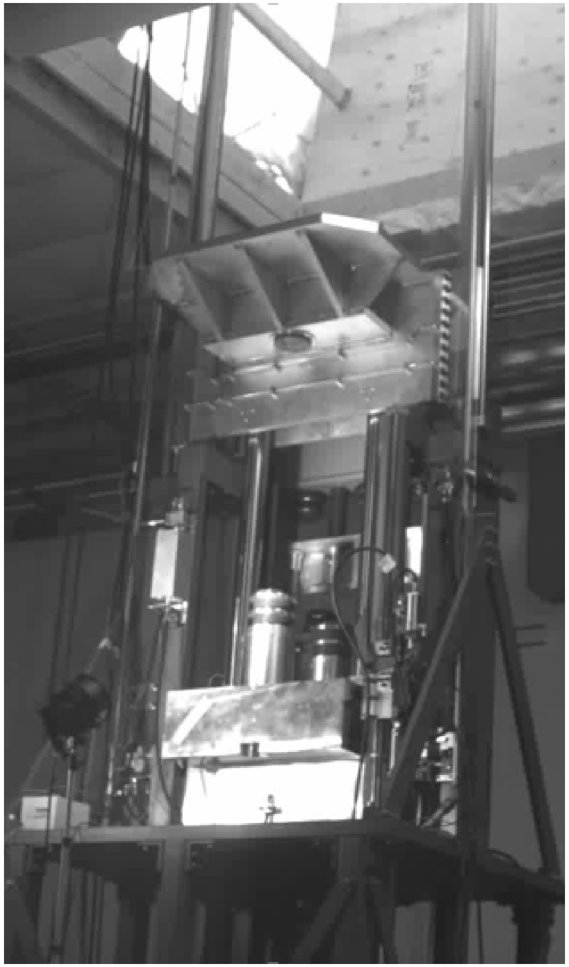
Robert.g.Kargus.civ@army.mil

09 NOV 2022

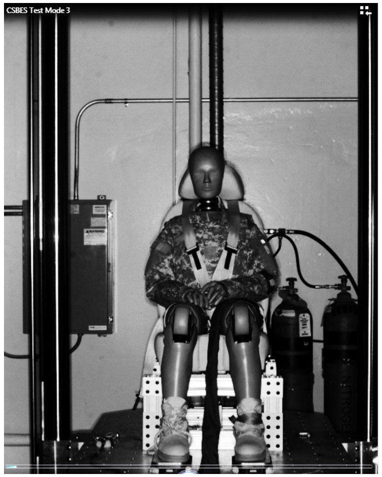
TECHNICAL PROBLEM:
SIMULATING UNDER BODY BLAST RESPONSE OF GROUND VEHICLE

1ST GENERATION SIMULATOR
CREW SEATING BLAST EFFECTS SIMULATOR (CSBES) (2009-PRESENT)

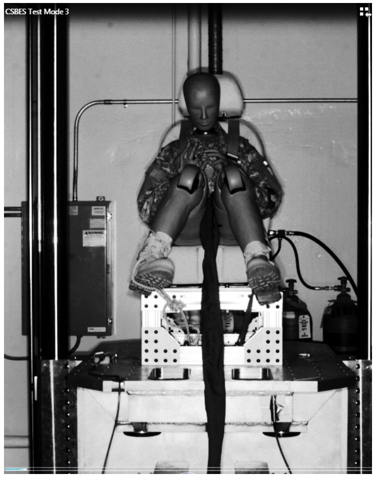
- Vertically oriented shock machine capable of testing large specimens up to a velocity of 9 m/s*
- Capable of both liftoff and slam down phases
- Second, independently driven foot impactor reaches 15 m/s*
- Both the main platform and foot platform produce single sided (unimodal) pulses



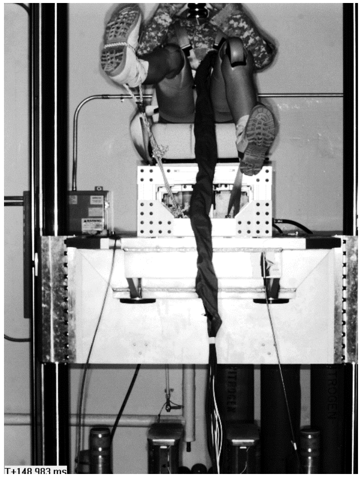
(Below) Seat testing using the CSBES (Crew Seating Blast Effect Simulator)



T = 0



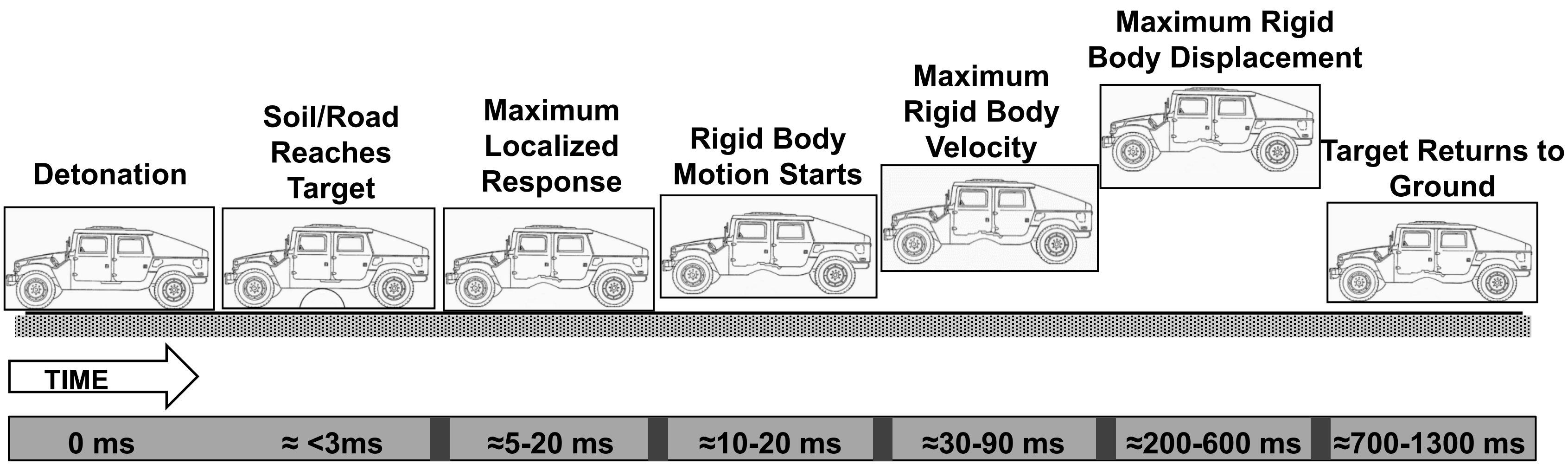
T= 20 ms



T = 40 ms

* Maximum velocity attainable depends on specimen mass and dynamic characteristics

WHEN DO ASSESSED INJURIES OCCUR?



*Pictures from Hofstetter, Dwight. “HMMWV Presentation 2” Power Point, Jan 2012.

Lower leg → spine, thorax

98% of assessed injuries occurred in liftoff phase*

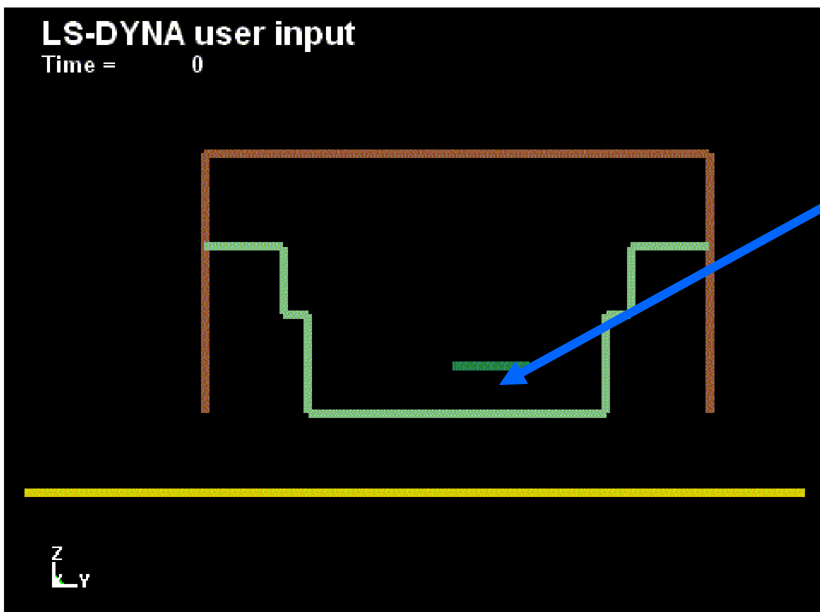
2% of assessed injuries occurred at return to ground

New test apparatus should emphasize kinematics of the liftoff phase

* Data gathered from large tactical vehicle experiment series. HIC and DRI not included in this analysis, but rather the injurious acceleration values for these regions

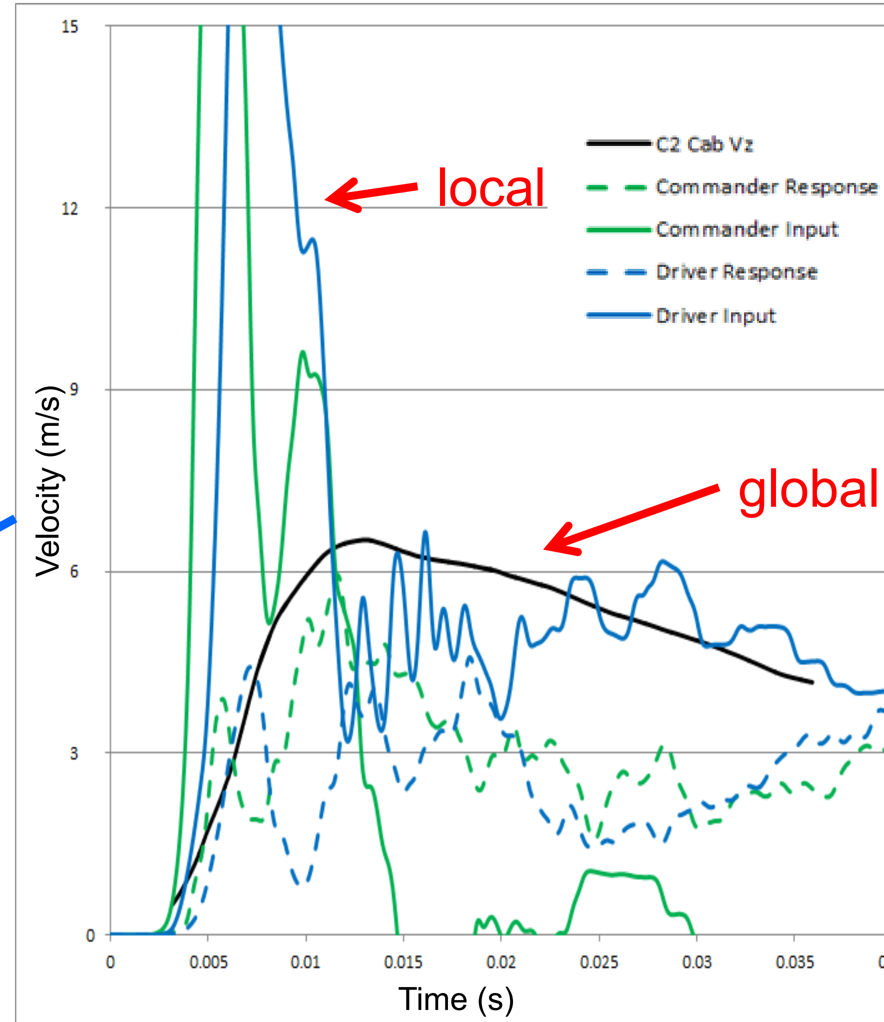
LOCAL VS. GLOBAL EFFECTS

- Vehicle structure response to blast is typically bimodal
- High amplitude, short duration component simultaneous with low amplitude long duration component



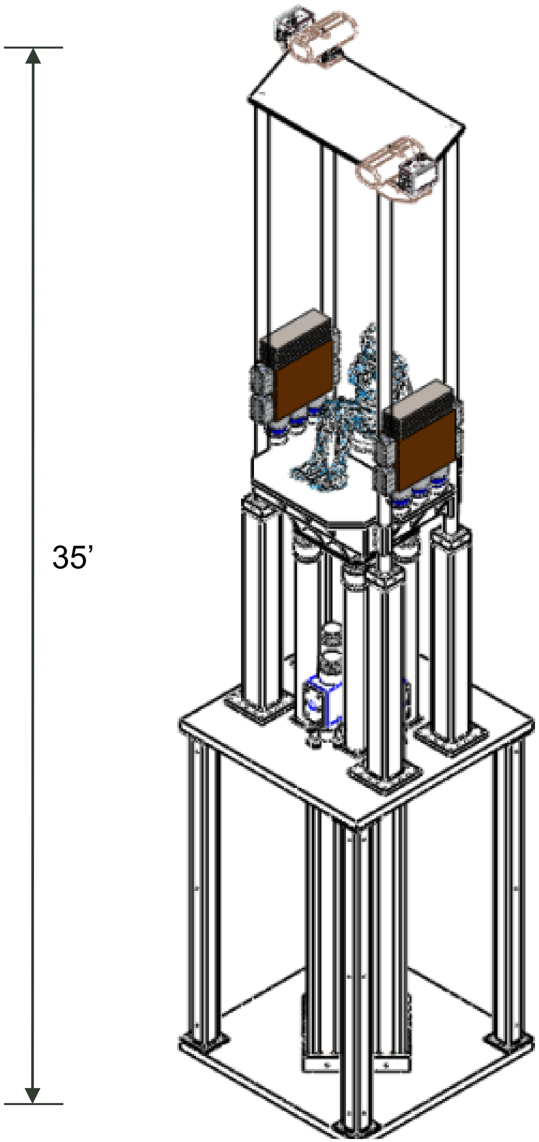
Cross section of a generic hull subjected to under body blast (video)

Velocity time histories from seat input/response field experiments



2ND GENERATION BLAST SIMULATOR

MULTI-DEGREE OF FREEDOM BLAST EFFECT SIMULATOR (MDOF-BES)



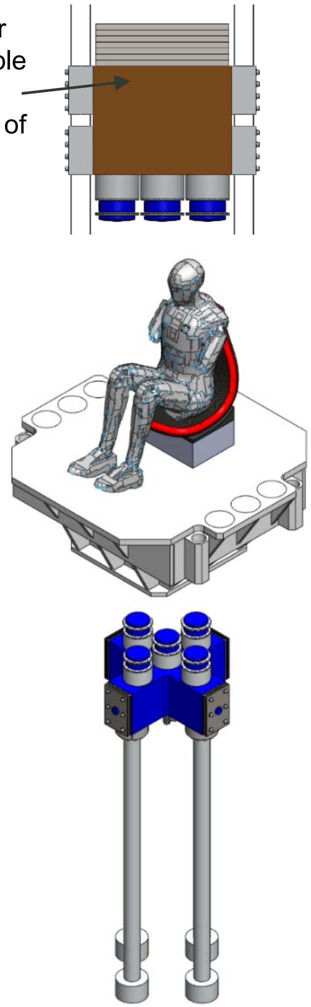
Superstructure:
- Platform Arrestor
- Test Platform
- Positioning System (Platform Arrestor Mass)
- Guide rods

Mid-structure:
- Test Platform Impactor (Impact Mass)
- Test Platform standoffs and framework

Substructure:
- Impact Mass Accelerator
- Structural Frame
- Mid-structure and Superstructure Footing

MDOF-BES PULSE SHAPE
2-SIDED HAVERSINE

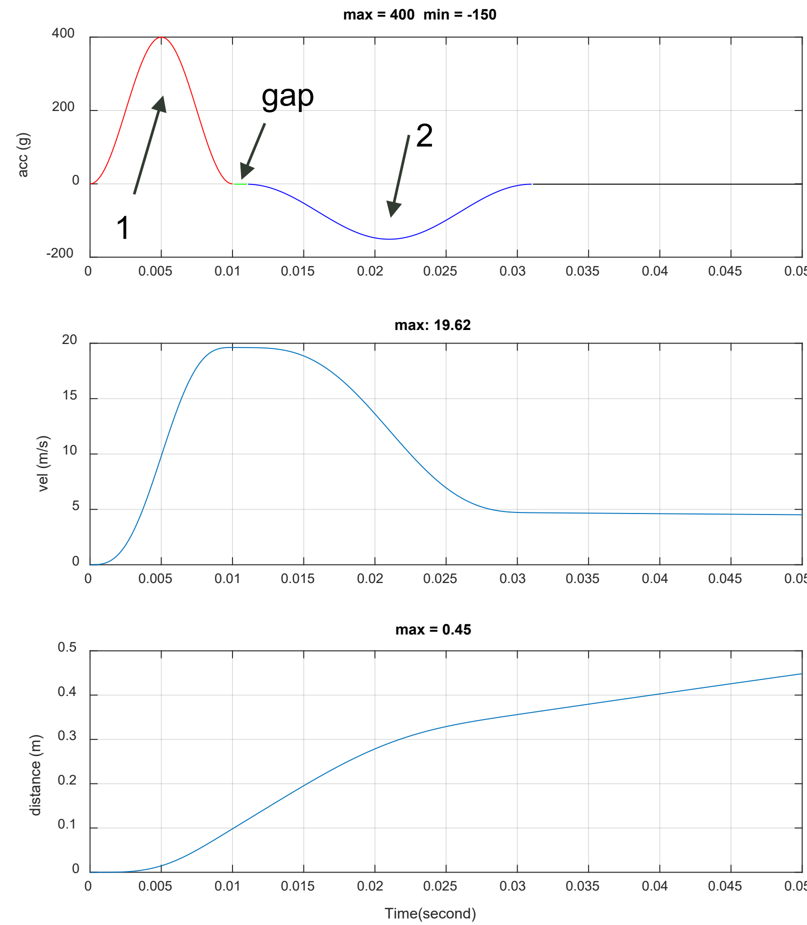
Platform arrestor mass is adjustable to give desired residual velocity of the platform



2nd collision

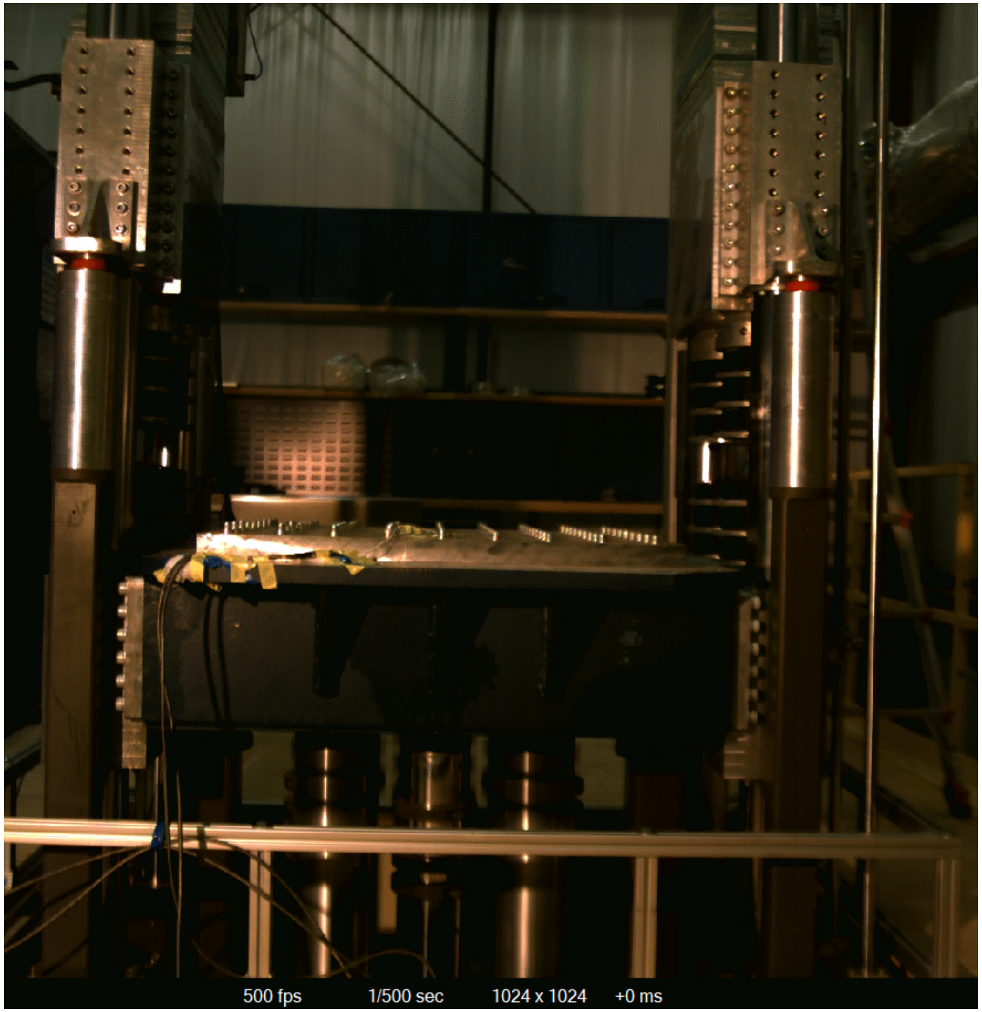
1st collision

Test platform kinematics resulting from two collisions (momentum exchanges)

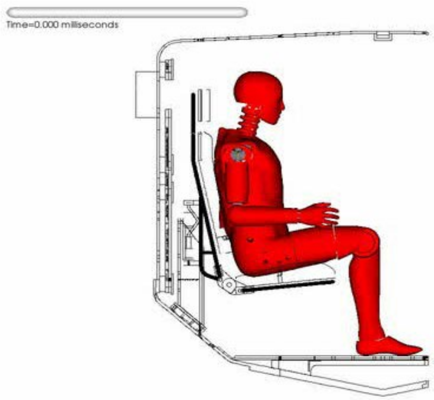


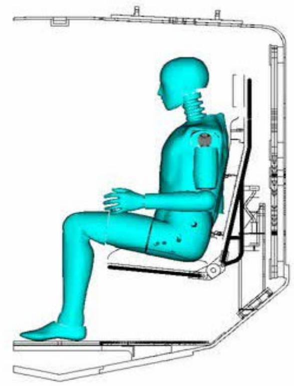
MDOF-BES

Acceptance test – 20 m/s at 750 psi charge pressure

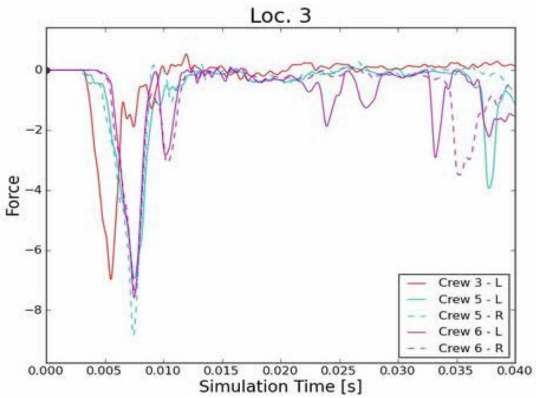


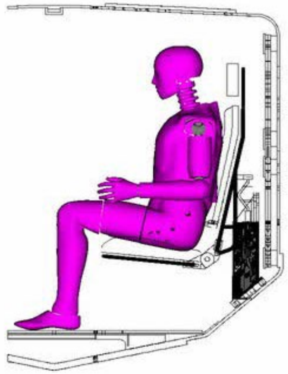
MULTI-DIRECTIONAL LOADING TO CREW





3 separate seating locations





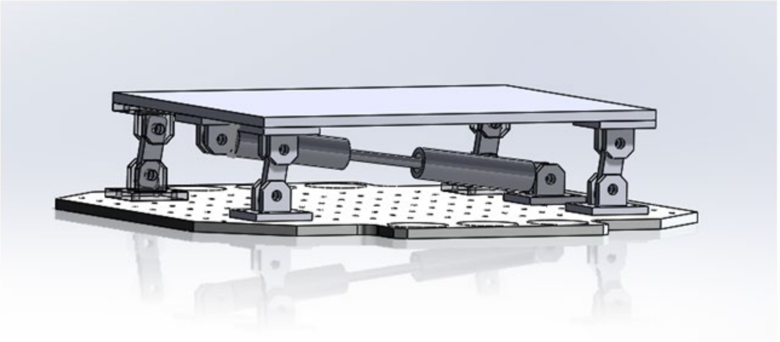
Simulation from USMC/SYSCOM

- Simulation verified by blast event data. Input may be asymmetric
- Dominant motion lies in the section plane
- Transverse motion at seat attachment can induce binding in energy absorbing mechanisms, altering response of the occupant

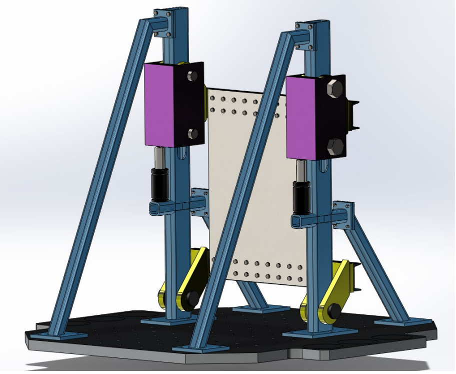
MULTI-DIRECTIONAL RESPONSE USING MECHANICAL FIXTURES

- Surface plate remains parallel with the test platform
- Biasing the orientation of the short bars causes collapse and translation of the linkage
- Shock absorber beneath the plate mitigates the plate translation
- Displacement rates and magnitudes are tuned by configuring,
  - Linkage length
  - Shock absorber characteristics, mounting points
  - Mass/payload
  - Initial orientation
- Dynamics model created in Matlab to quickly explore fixture kinematics

Parallel four-bar linkage with passive shock absorber (horizontally oriented)



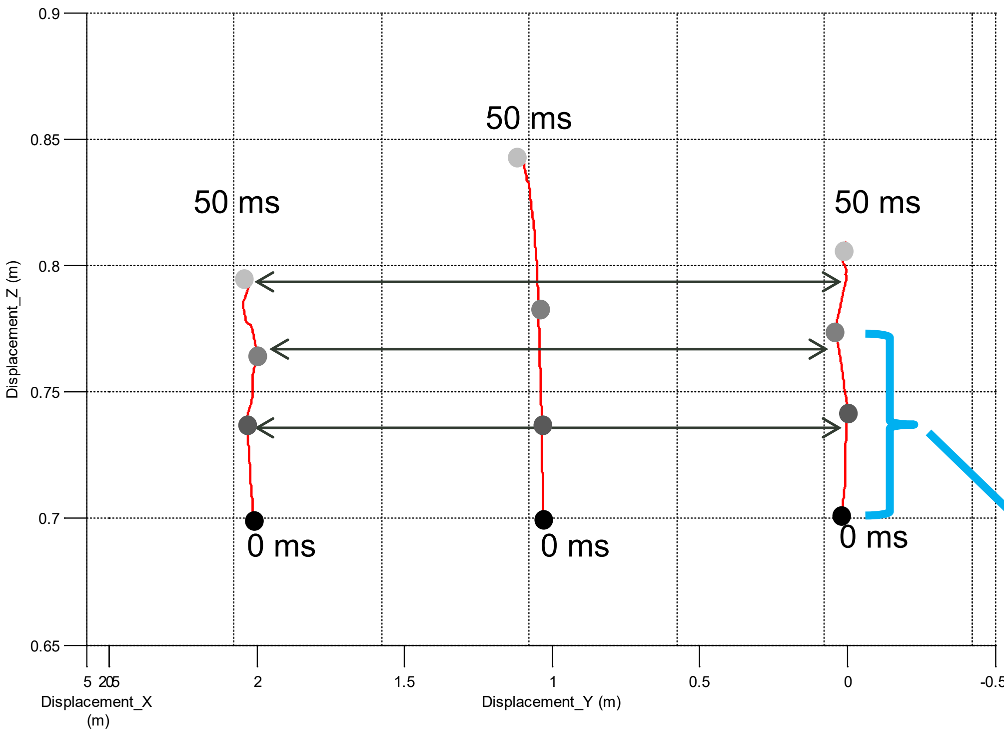
Vertically oriented four-bar fixture



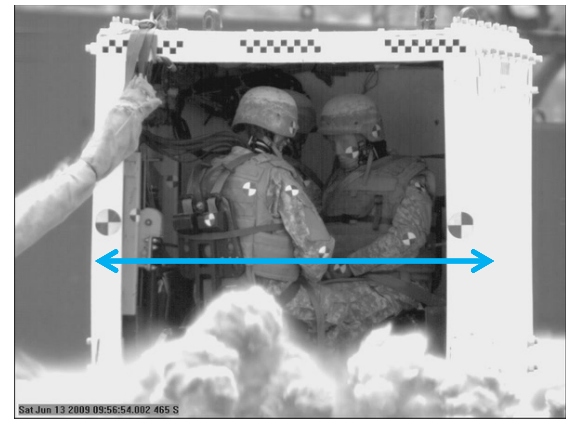
Distribution A. Approved for Public release

MECHANICAL FIXTURE KINEMATIC SIMULATION
VERTICAL ORIENTATION

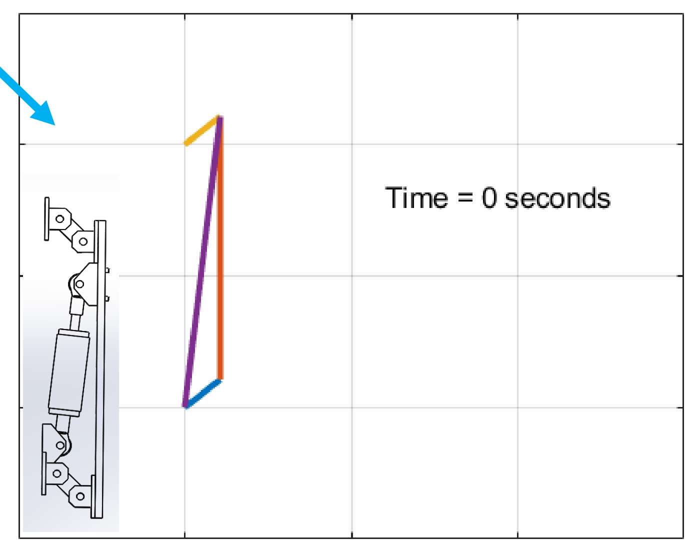
Wall displacement traces from blast box experiment



Blast box experiment showing dominant wall mode



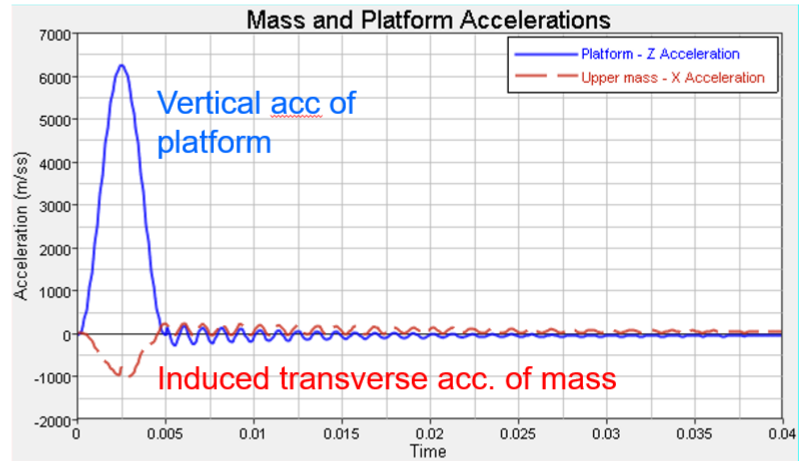
Vertical orientation case for four-bar fixture

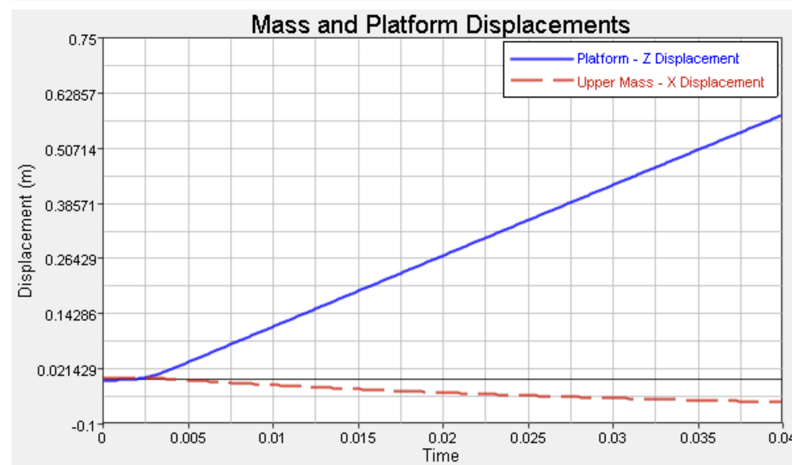


- Seated dummy test specimen would be placed on this face of the mechanism, facing left

Distribution A. Approved for Public release

MECHANICAL FIXTURE KINEMATIC SIMULATION
HORIZONTAL ORIENTATION

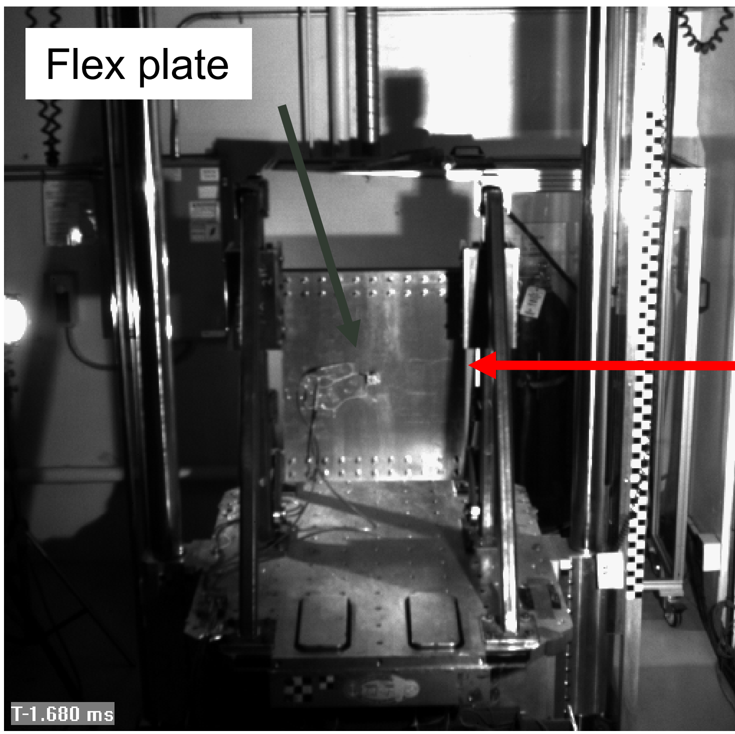




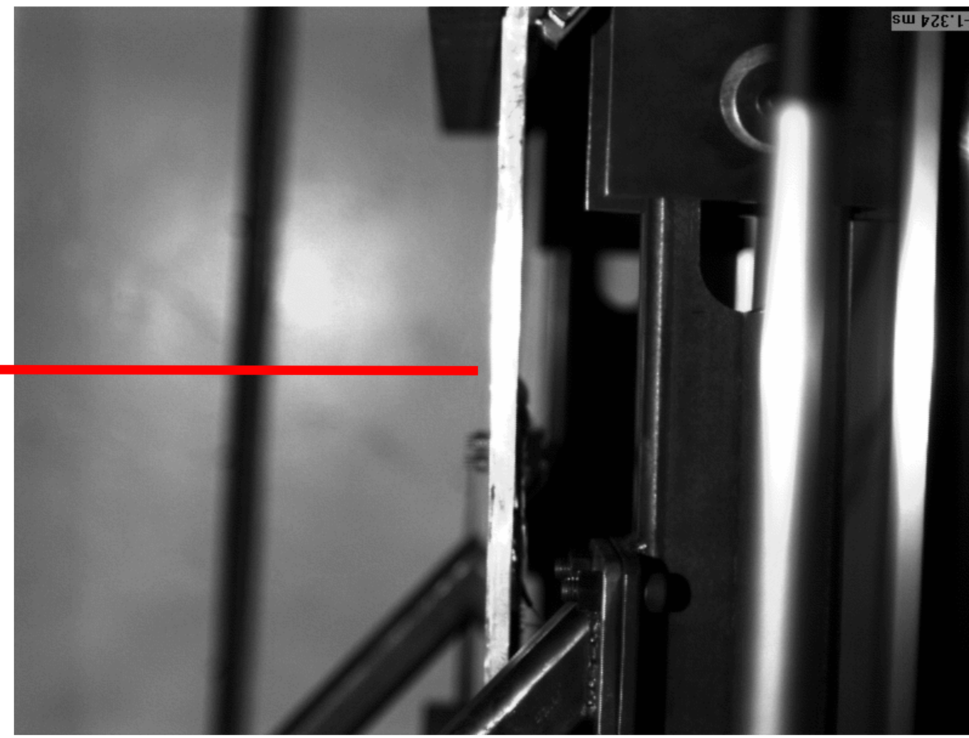
Distribution A. Approved for Public release

INDUCED TRANSVERSE MOTION WITH PLASTIC STRAIN

- Elastic-Plastic strain is induced in the plate



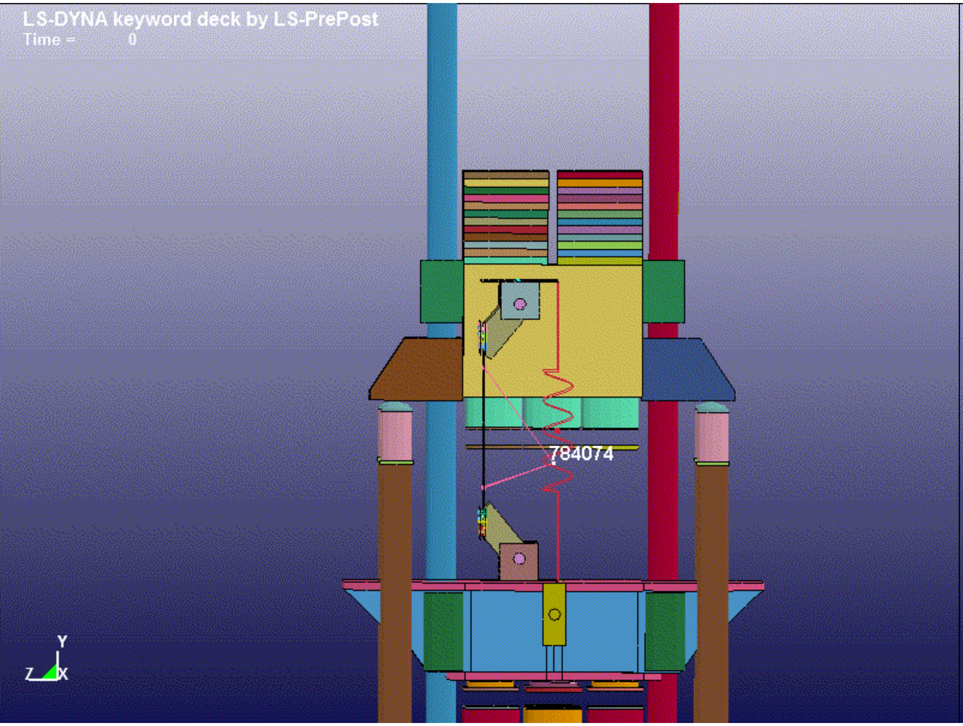
CSBES Experiment (front view)

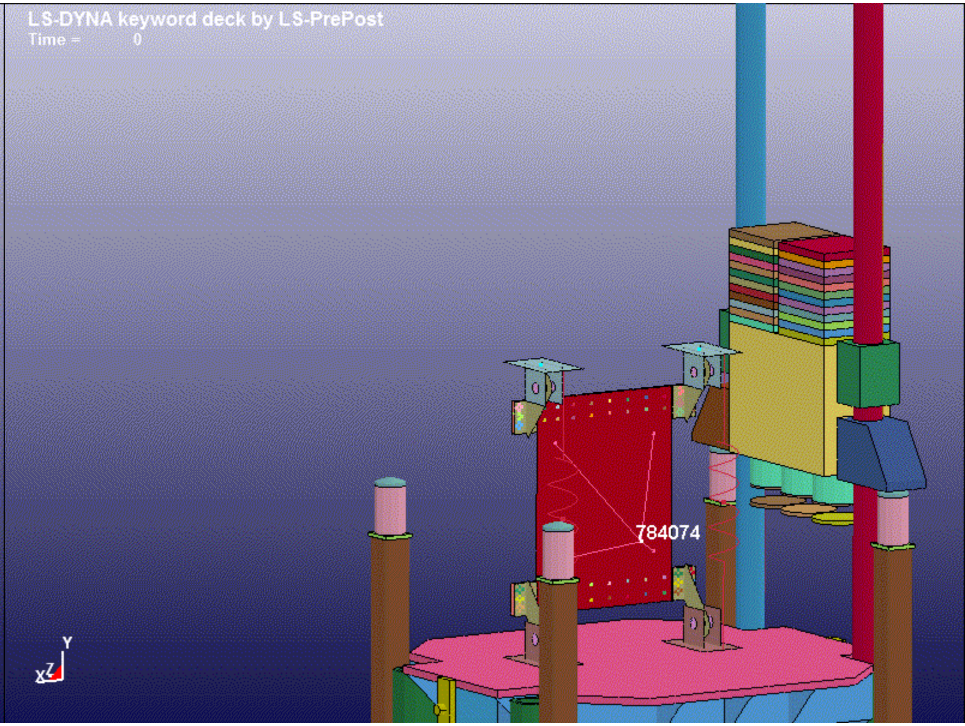


Side view of flex plate

MDOF-BES FINITE ELEMENT MODEL WITH MECHANICAL FIXTURE

- LS-Dyna FE model of the MDOF-BES was created to explore various mechanical fixture concepts
- Can be used as a tool to determine the achievable kinematics prior to performing experiments

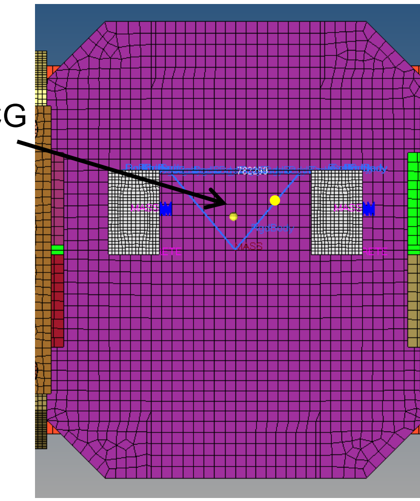


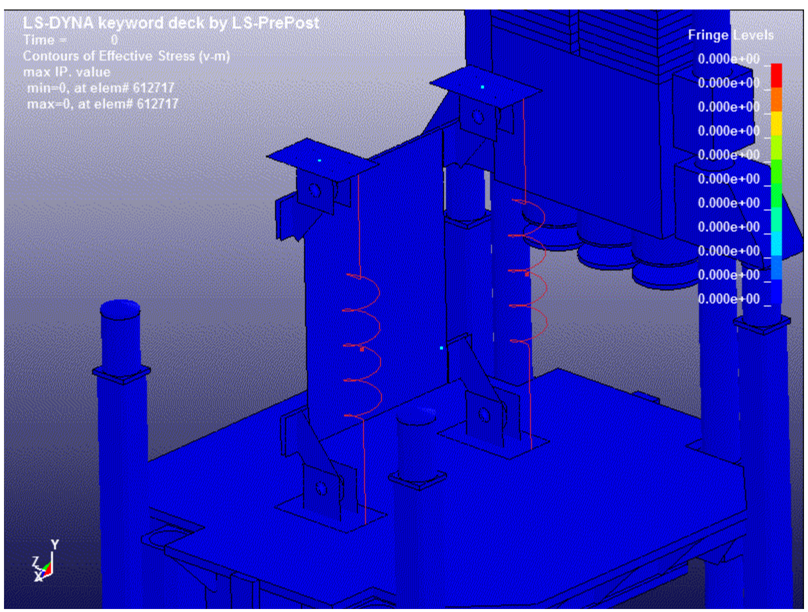


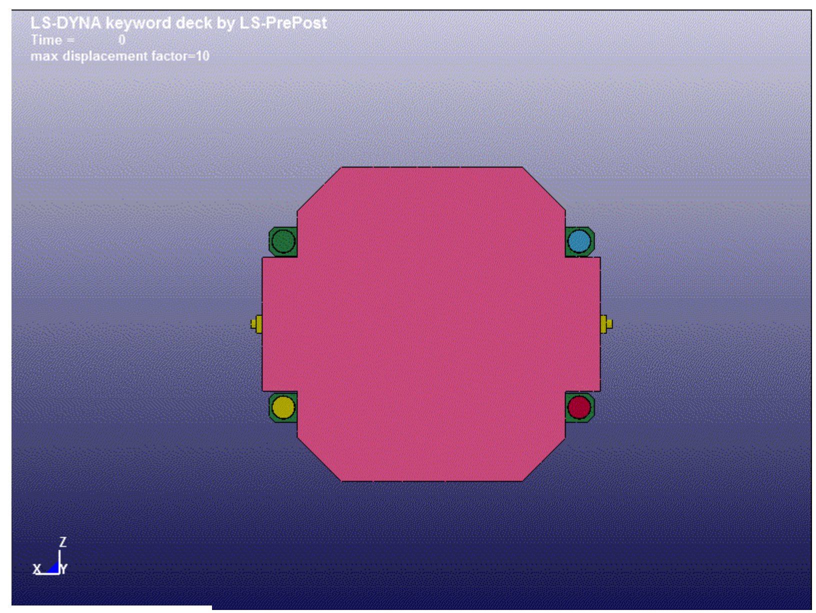
EFFECTS OF TRANSVERSE LOADS FROM MECHANICAL FIXTURES

- Animation below shows simulation used to determine if reaction loads on the MDOF-BES structure would be detrimental
- The use of 4 guide rods (compared to 2 in the 1st gen. machine) significantly improves the structures resistance to moment couples and transverse load

Slight CG offset







SUMMARY AND NEXT STEPS

- Significantly higher velocity (20 m/s with 600 lb payload) compared to similar machines
- Combines global and local motion effects
- Addition of mechanical fixture introduces a second transient shock component
- Operational in July 2019
- Considering biological/PMHS specimen capability
- Mechanical fixture development and experiments with seated ATDs

ACKNOWLEDGEMENTS

- Ami Frydman and Dean Li (ARL, retired)
- Rodney Peterson, Jeff Bradle, Howie Draisen, Maureen Foley (ONR)
- Neil Gniazdowski, Timothy Cline and the staff of the ARL Blast Protection Branch
- Jim Breault, Loren Galarza and the staff of Lansmont Corporation

CONTACT INFO

Robert Kargus
Mechanical Engineer, Occupant Safety
Soldier Protection Sciences Branch
FCDD-RLW-TB

Office: (410) 278-7855
Mobile: (810) 610-9623
robert.g.kargus.civ@mail.mil

Aberdeen Proving Ground
BLDG 309/RM 101
6917 Civil Road,APG MD 21005

Mechanical Shock Laboratory (B463)