# A Comparative Evaluation of Two Helicopter Crash Tests

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# OUTLINE

- **Introduction**
  - Subsonic Rotary Wing (SRW) Crash Research Program
  - Composite Honeycomb Deployable Energy Absorber (DEA)
  - Summary of DEA development
  - Presentation Objectives
- **Full-Crash Crash Test Program**
  - Test article set-up, component testing, and test conditions
  - Onboard experiments and instrumentation
- **Comparative Results**
  - Test video
  - Structural damage
  - Occupant injury assessment
- **Conclusions**

# SRW CRASH RESEARCH OBJECTIVES

## ➢Develop an advanced composite structural concept for improved energy absorption

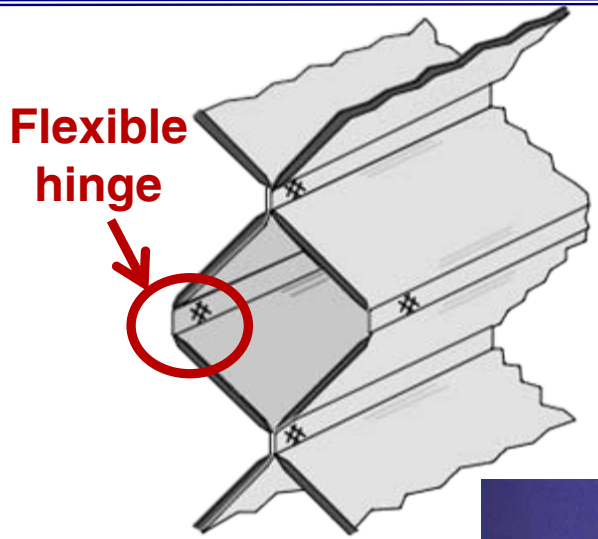
- Develop an externally-deployable composite honeycomb energy absorbing concept and study deployment options
- Demonstrate the effectiveness of the concept through testing utilizing a building block approach
- Optimize the concept for multi-terrain applications


## ➢Demonstrate improved prediction of rotorcraft crashworthiness

- Multi-terrain impact simulation
- Human occupant simulation and injury prediction
- Probabilistic analysis and uncertainty quantification
- System-integrated helicopter crash test, simulation, and model validation study

**Artistic depictions of DEA rotorcraft applications**

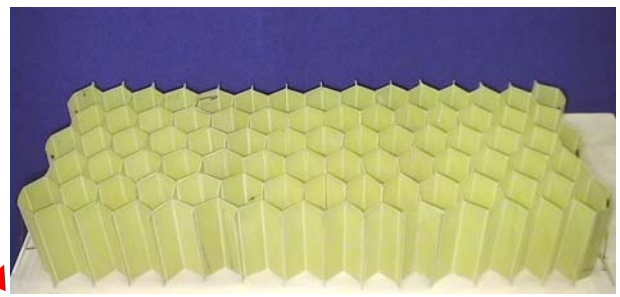
# DEPLOYABLE ENERGY ABSORBER (DEA)



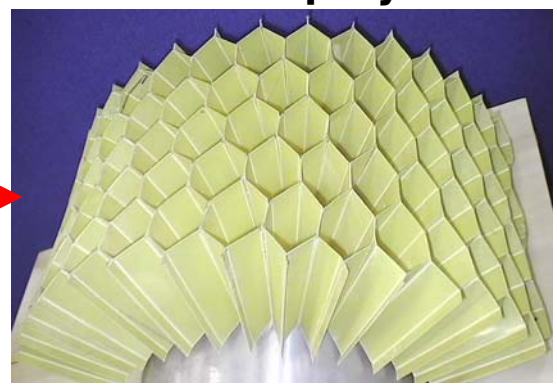

Square cell schematic

- A novel composite honeycomb energy absorber deployed using mechanical or pneumatic methods
- GOAL: Demonstrate the effectiveness of the concept using a building block approach
- Optimize the concept for multi-terrain applications

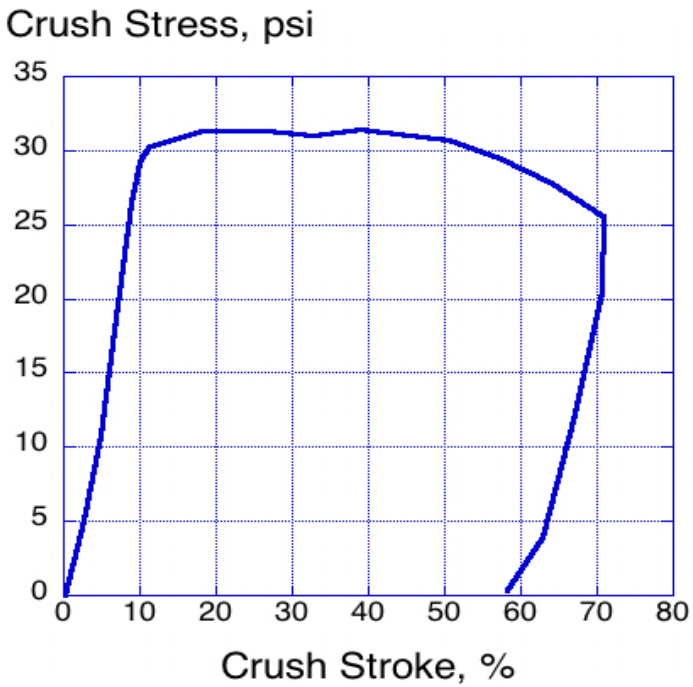
Packed energy absorber



Linear deployment



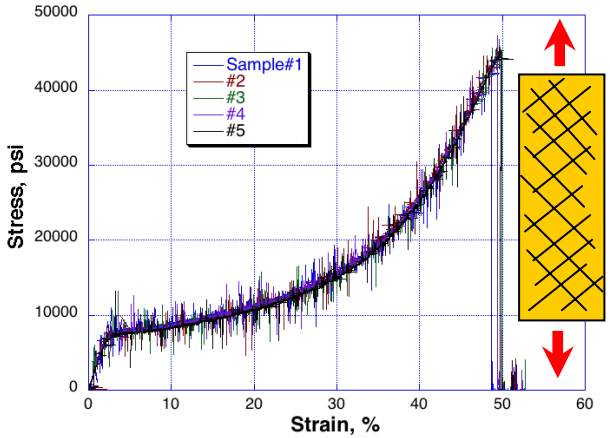
Radial deployment




Component crush test

# SUMMARY OF DEA DEVELOPMENT

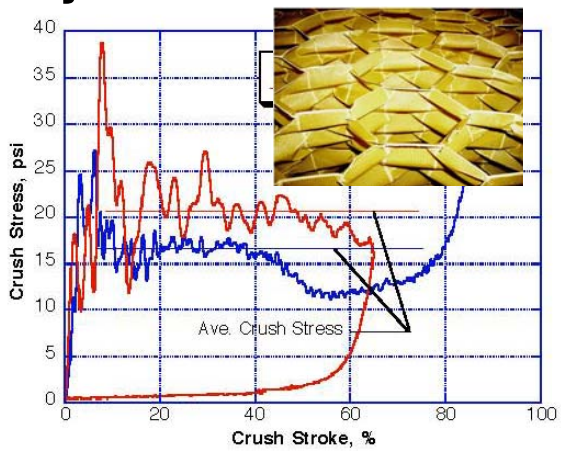
## Materials Testing




±45° Kevlar fabric loaded in tension

## Three-Pt Bend Testing of Single Hex Cells

## Dynamic Crush Tests




59- and 104-Cell DEA components

## Multi-Terrain Impact Testing

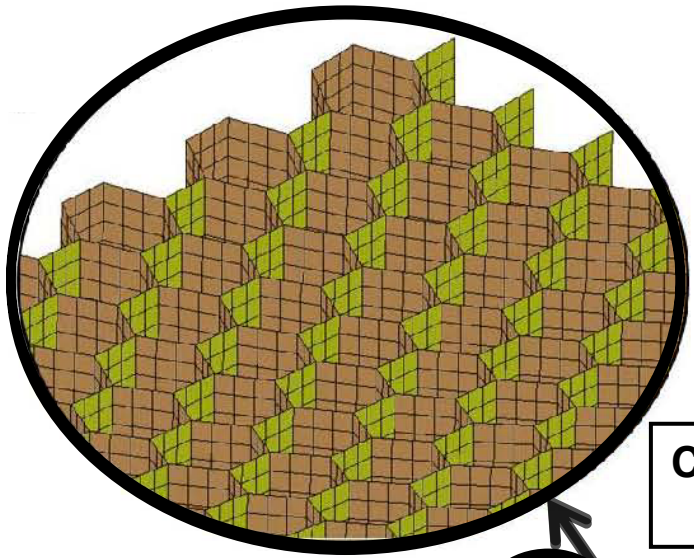
Rigid surface, 38.4-fps

Water, 25-fps

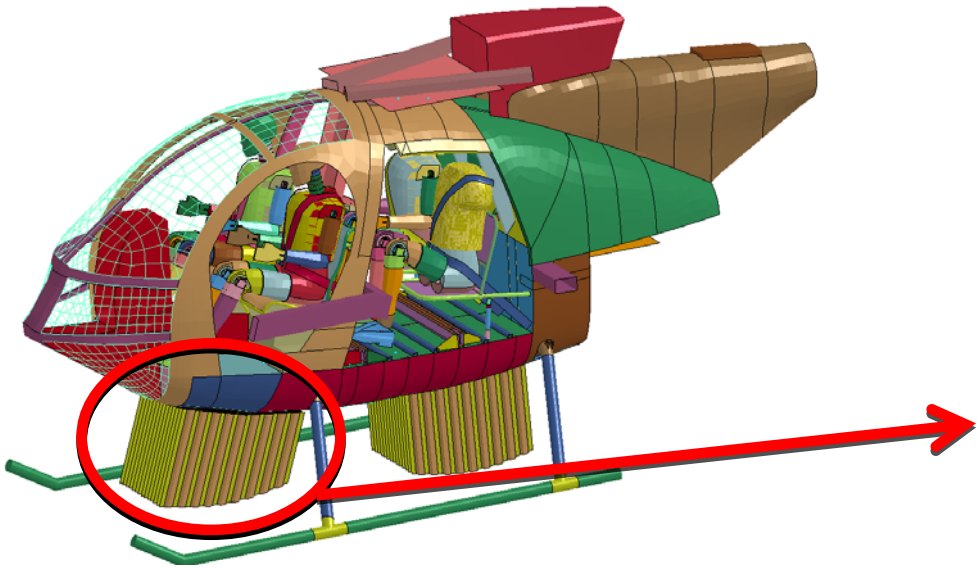
Soft soil, 38-fps

# SUMMARY OF DEA DEVELOPMENT

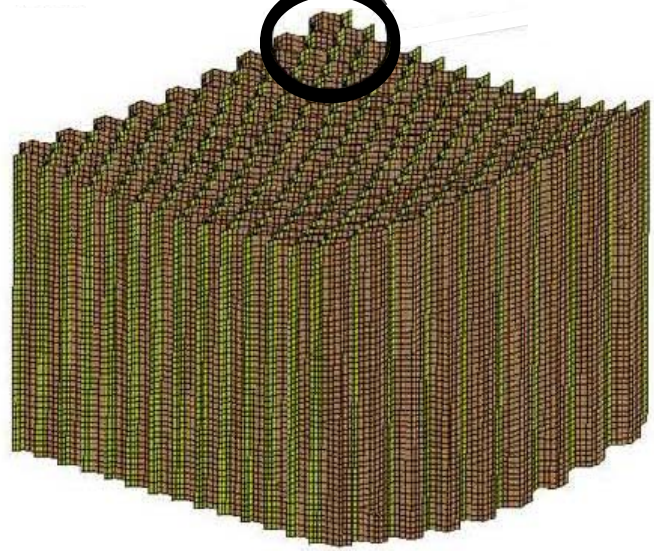
Crash Test of an MD-500 with DEA



Close-up View



System-Integrated Finite Element Model



Shell-Based Model of the DEA

# OBJECTIVES

## This presentation will:

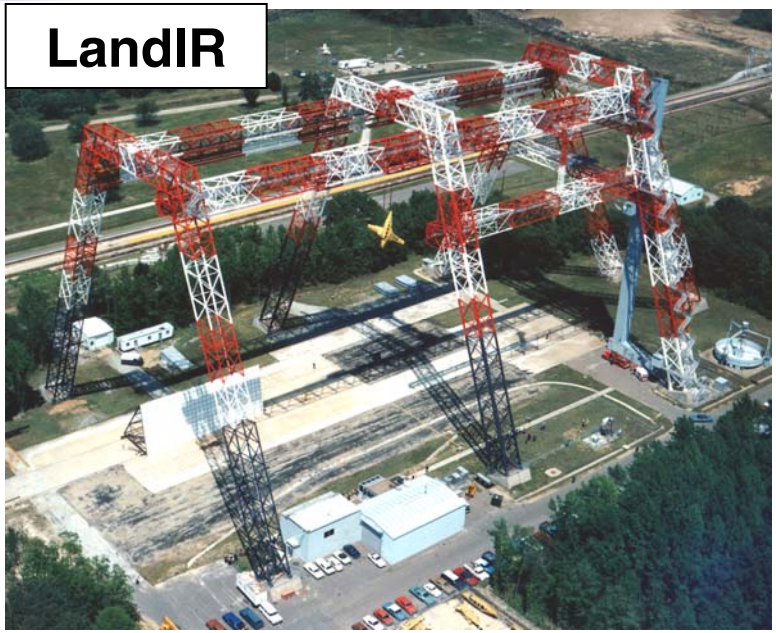
- Describe the full-scale crash test program including test conditions, hardware set-up, instrumentation, and onboard experiments

- Provide test video highlighting two crash tests of the MD-500 helicopter, one test performed with an external energy absorber and the second without

- Summarize and compare test results including: structural damage, and occupant injury assessment

# FULL-SCALE CRASH TEST PROGRAM

**LandIR**



**MD-500**

- Test conducted at NASA Langley Landing and Impact Research Facility (LandIR)
- MD-500 test article and solid geometry provided by US Army Mission Enhanced Little Bird (MELB) Program
- Conduct two full-scale crash tests of the MD-500 helicopter with and without deployable energy absorber (DEA) at LandIR
- 26-ft/s vertical and 40-ft/s forward velocity, zero pitch
- 3,000 lb expected gross takeoff weight (airframe weight ~ 500 lb)


# FULL-SCALE CRASH TEST PROGRAM

## Test Objectives

- To evaluate the performance of the DEA under realistic crash test conditions

- To generate test data to validate a system-integrated LS-DYNA finite element model that includes accurate physical representations of the:

| | | |
|---|---|---|
| - airframe | - shock struts | - occupants |
| - skid gear | - seats | - restraints |
| - ballast | - impact surface | - external DEA |

- To generate test data to evaluate thoracic injuries, including aortic rupture, during helicopter crash impacts

# FULL-SCALE CRASH TEST PROGRAM

## Test Article: MD-500 Helicopter


- Manufactured by MD Helicopters
- 3,000-lb max gross weight
- Defender - Manned military version
- Little Bird - US Army Special Operations
- Civilian utility helicopter
- 156 knots max speed
- 300 nautical mile range
- 31-ft long, 9-ft tail height

# FULL-SCALE CRASH TEST PROGRAM

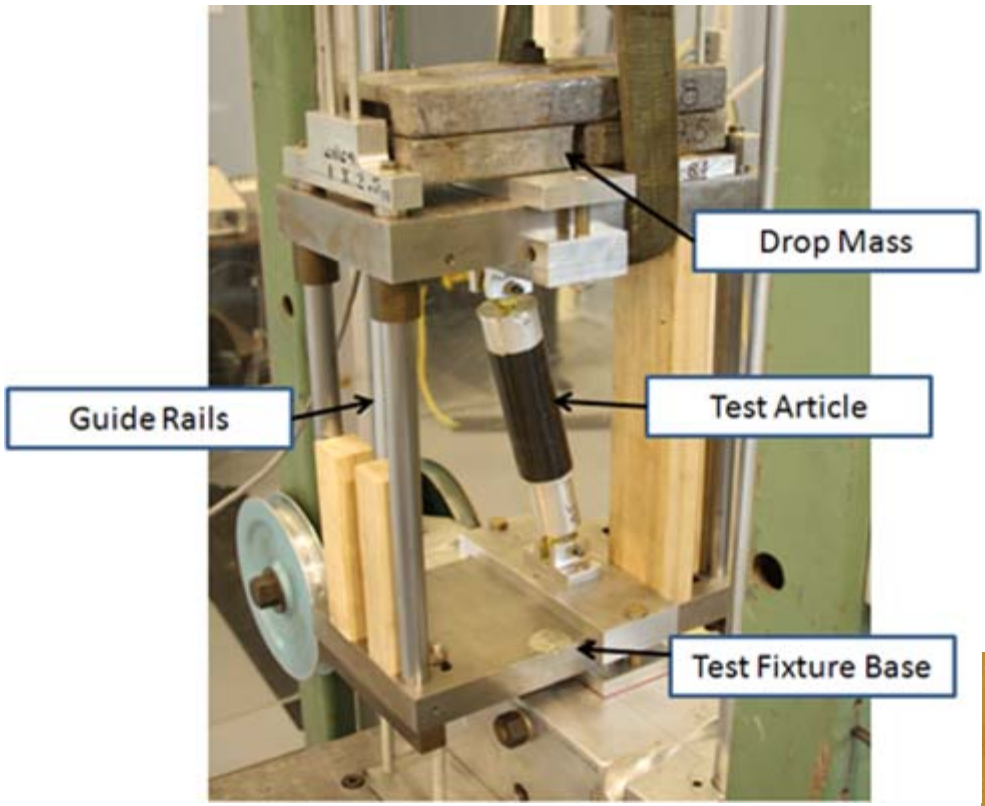
Photograph of as-received helicopter

## Test Article Modifications

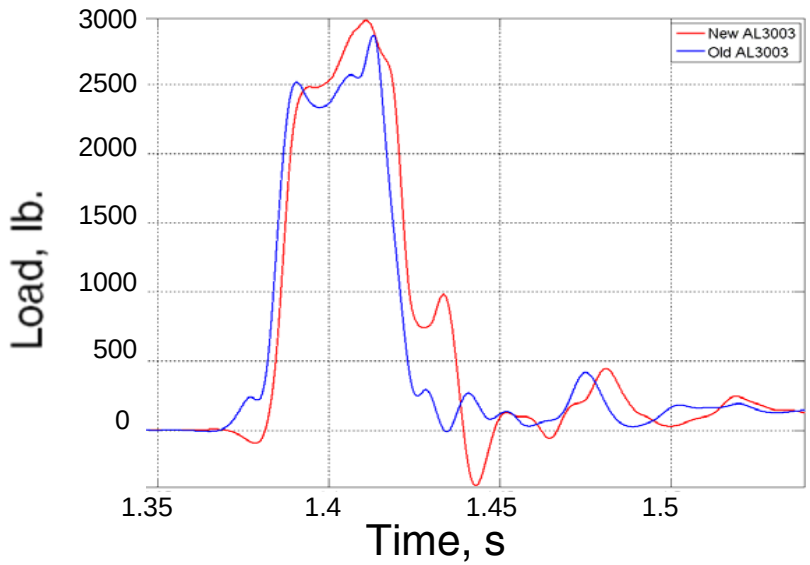
- Repaired damage caused by tie-down pull tests
- Due to anticipated attachment failures, replaced the existing oleo-pneumatic shock struts with inversion crush tube struts designed in-house
- Added four layers graphite/epoxy fabric to cover openings in the lower skin
- Purchased and installed two crew seats and one bench passenger seat with restraints
- Added ballast to represent the engine, rotor transmission, fuel, and tail cone
- Fabricated and installed two DEA blocks (front block at 20°, rear block at 0°)

# FULL-SCALE CRASH TEST PROGRAM

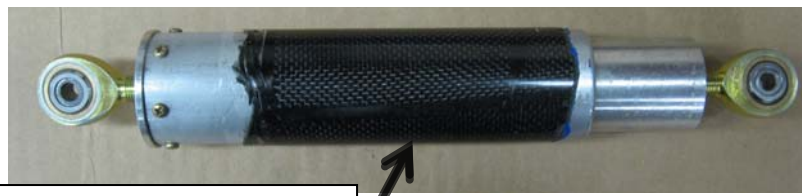
## Crush Tube Shock Strut Design and Testing

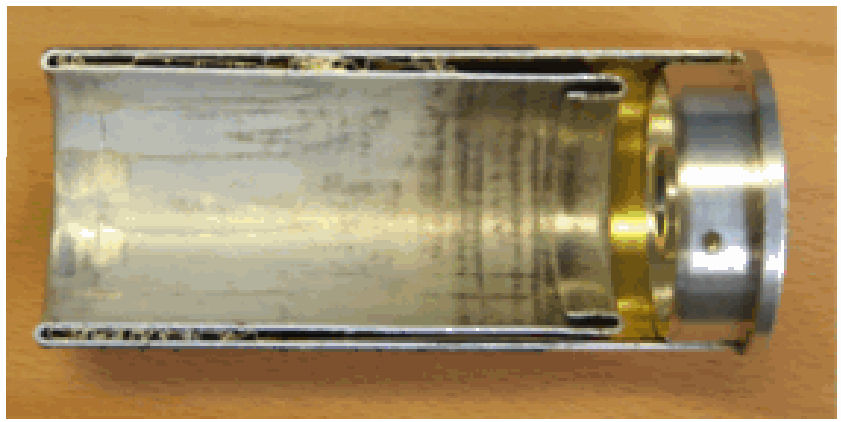



Shock strut compression test




Load response of crush tube



Cut-away view of crush tube post-test

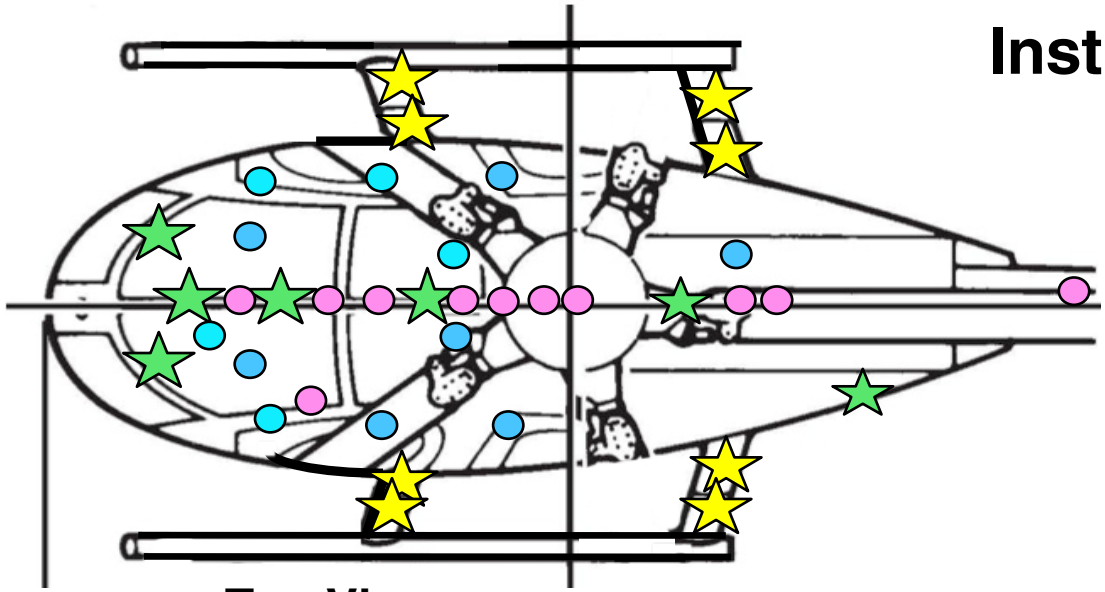
# FULL-SCALE CRASH TEST PROGRAM

| | | | |
|---|---|---|---|
| Pilot | Front left crew | 50th percentile Hybrid III male | 4-pt. restraint |
| Copilot | Front right crew | 50th percentile Hybrid II male | 4-pt. restraint |
| Passenger | Rear left side | HSTM/50th Hybrid III male | 3-pt. restraint |
| Passenger | Rear right side | 50th percentile Hybrid II male | 3-pt. restraint |

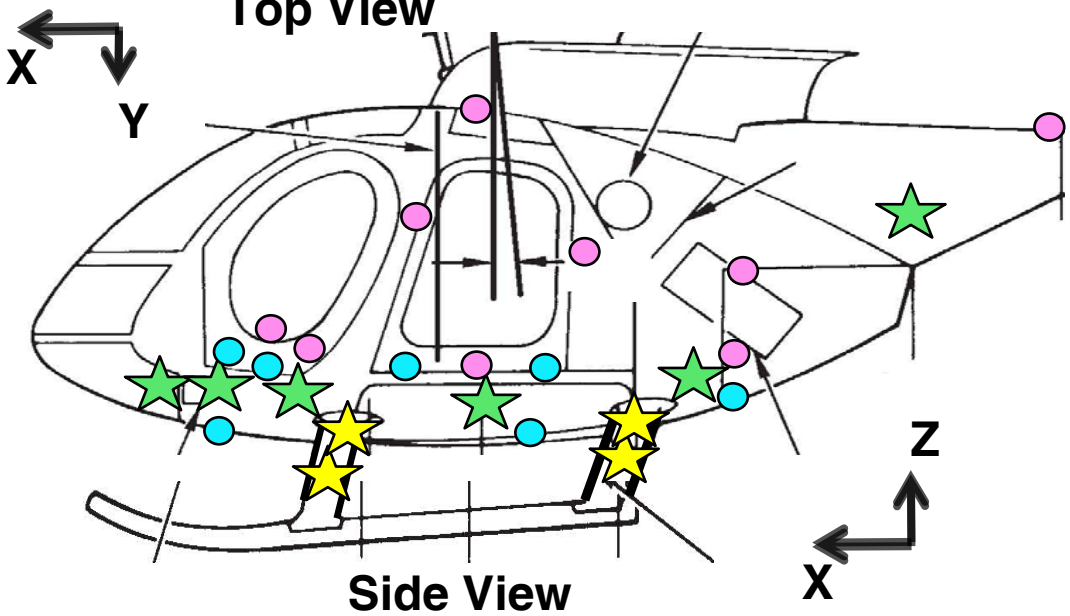
# FULL-SCALE CRASH TEST PROGRAM

- Two DEA blocks were mounted beneath the belly skin of the airframe
- Each DEA block consisted of multiple hexagonal cells, with 1-in. cell wall length, fabricated of ±45° Kevlar-129 fabric/epoxy
- The cells in the front block were canted by 20° with respect to the vertical direction, while the cells in the rear block were oriented vertically. This configuration improved vehicle stability.
- Each block weighed 14-lb. and was designed for 20-psi crush stress

# FULL-SCALE CRASH TEST PROGRAM



Top View




Side View

## Instrumentation Summary

46 ATD channels
- 8 belt loads
- 1 IRIG

32 single strain gages
- 7 strain gage rosettes

12 single vertical accels

12 tri-axial accels

4 load cells

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160 total channels

-Vertical accel

-Tri-axial accel

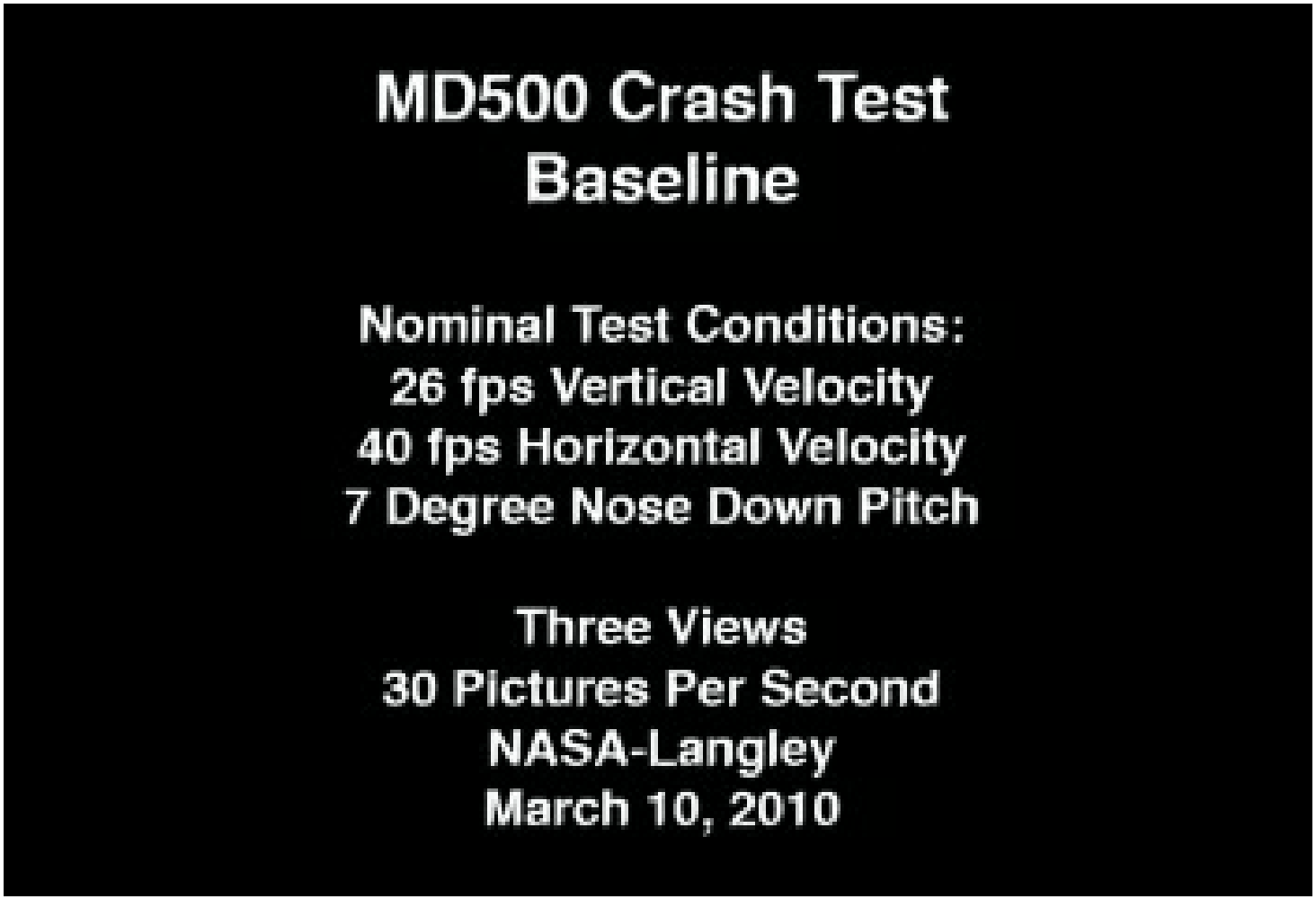
- Strain gage

- Strain gage rosette

# COMPARATIVE RESULTS


**Video of MD-500 Crash Test with DEA**

# COMPARATIVE RESULTS




**Video of MD-500 Crash Test without DEA**

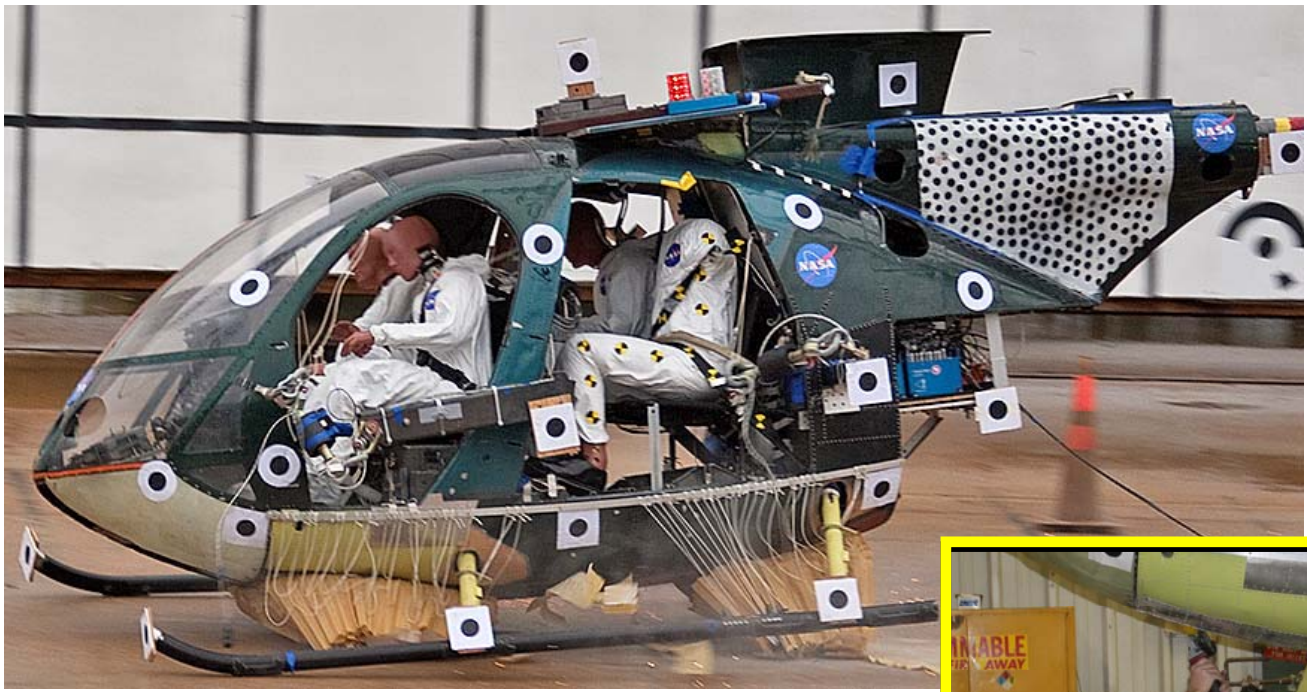
# COMPARATIVE RESULTS

## *Test Conditions*

| Impact Condition | Planned Values | Test #1 Actual | Test #2 Actual |
|---|---|---|---|
| Forward velocity | 40-fps | 38.7-fps | 39.1-fps |
| Vertical velocity | 26-fps | 25.5-fps | 24.2-fps |
| Resultant velocity | 47.8-fps | 46.3-fps | 46.0-fps |
| Roll attitude | 0° | 7.0° | 6.2° |
| Pitch attitude | 0° | 5.7° | 1.9° |
| Yaw attitude | 0° | 9.3° | 2.1° |

# COMPARATIVE RESULTS

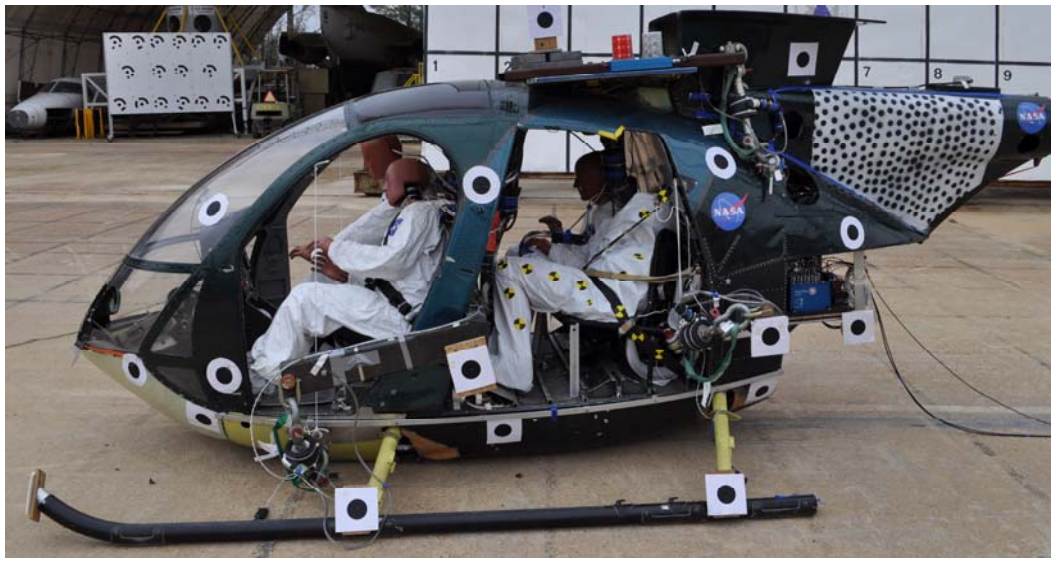
## *Structural Damage – Test #1 with DEA*



- Minor damage to the front right side subfloor and outer skin, which was repaired
- No damage to seats, keel beam, or airframe
- Skid gear, shock struts, seats, and restraints were replaced for the second test

# COMPARATIVE RESULTS

## *Structural Damage – Test #2 without DEA*



- Failure of crew and passenger seats
- Failures of keel beam & subfloor frames
- Outer skin buckling and rupture
- Bearing failures of the skid gear
- Buckling of the center bulkhead

# COMPARATIVE RESULTS

***Shock Strut Crush Data***

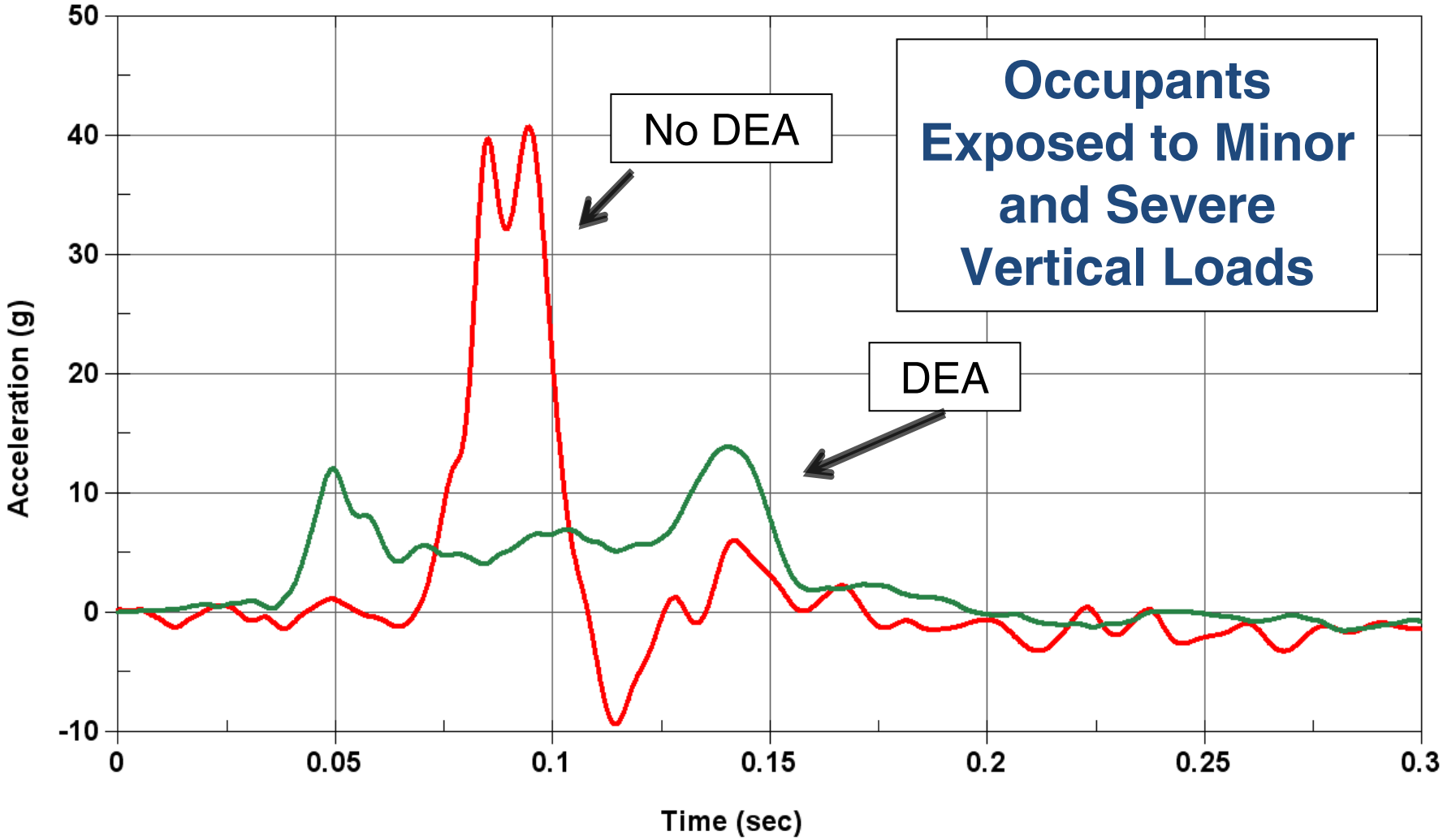
| Crush Tube Position | Test #1 Stroke, in. | Test #2 Stroke, in. |
|---|---|---|
| Front Left | 3.5 | 6.1 |
| Front Right | 5.3 | 5.5 |
| Rear Left | 2.5 | 5.7 |
| Rear Right | 5.0 | 5.8 |

Total stroke difference = 6.8 inches. For an average crush load of 2,000-lb, the total energy dissipated is 1,133 ft-lb, which is equivalent to 0.87-ft/s lower vertical velocity for the 2nd test

Post-test photo of shock struts following Test #1

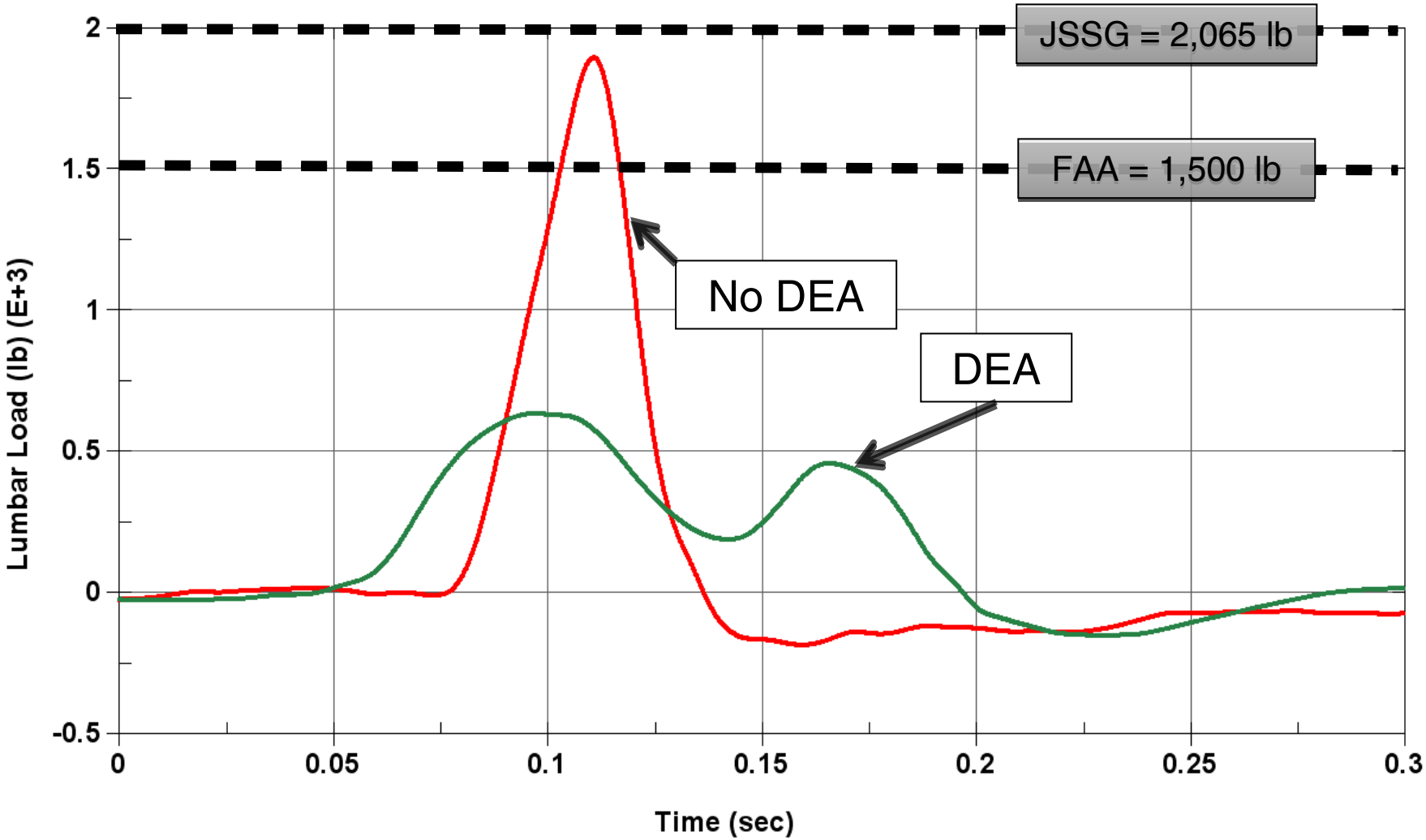
# COMPARATIVE RESULTS

## *Passenger Floor, Vertical Response*

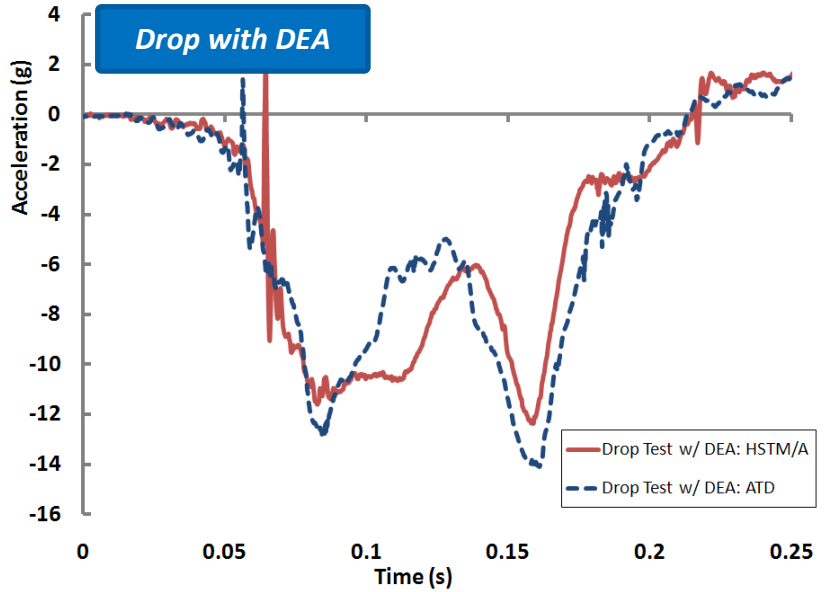


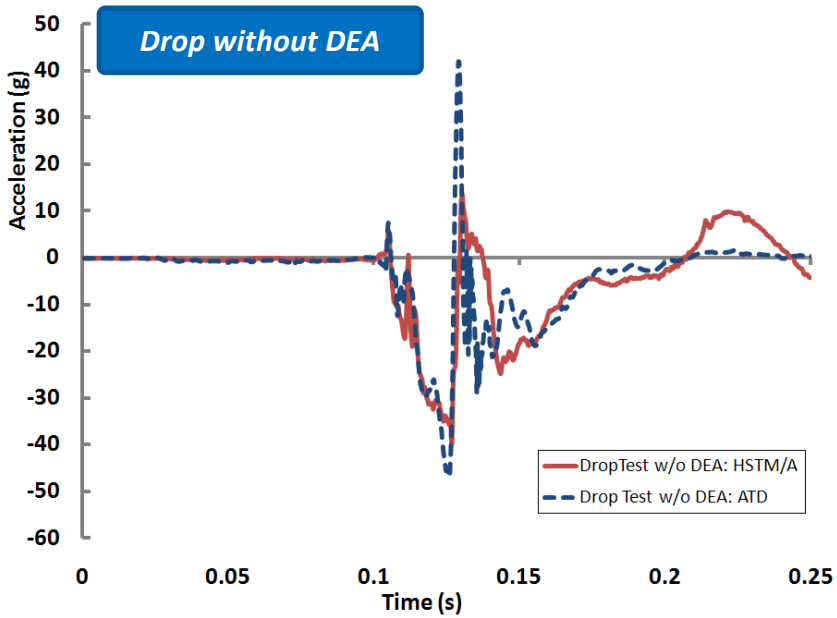
# COMPARATIVE RESULTS

## *Pilot Lumbar Load Response*



# COMPARATIVE RESULTS

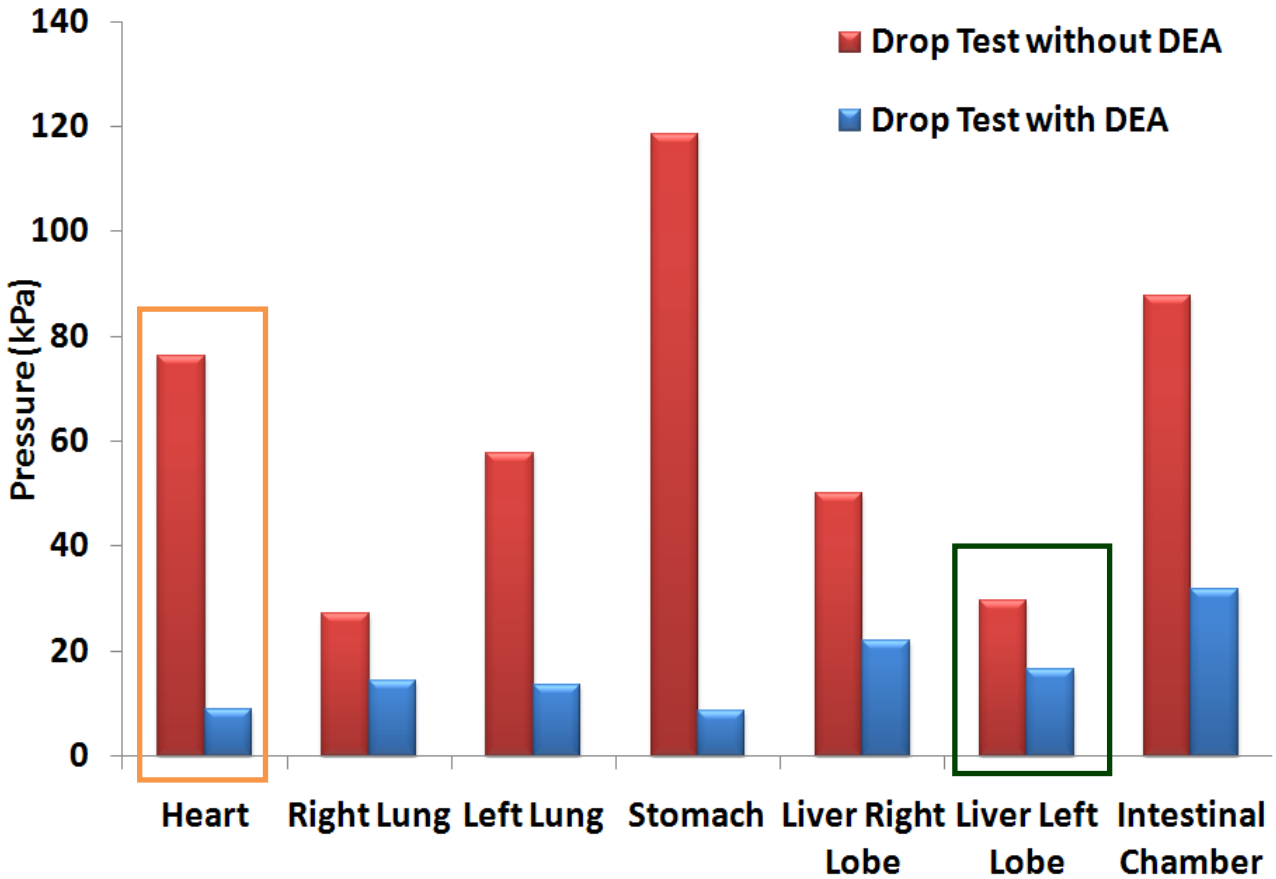



## *Occupant Responses*

- Both Hybrid III and HSTM experienced similar loading through the pelvis and spine
  - Matched peak decelerations and deceleration shape
  - Introduction of DEA reduced peak deceleration by 67% (28 g)

# COMPARATIVE RESULTS




- Increased surrogate biofidelity provides soft-tissue responses not previously investigated
- Test with DEA shows a significant drop in pressure response
- Pressure levels for drop test without DEA indicate potential for serious injury

# Conclusions

- Two full-scale crash tests of an MD-500 helicopter were conducted, one retrofitted with an external energy absorber and the second in a baseline configuration
- Excellent performance demonstrated by DEA's
  - Floor level acceleration peaks reduced from 40- to 12-g
  - Lumbar loads reduced from 2,000 lb. to 700 lb.
- Successful application of a biofidelic dummy to generate soft-tissue responses