Comparison of the Hybrid II, FAA Hybrid III, and THOR-NT in Vertical Impacts

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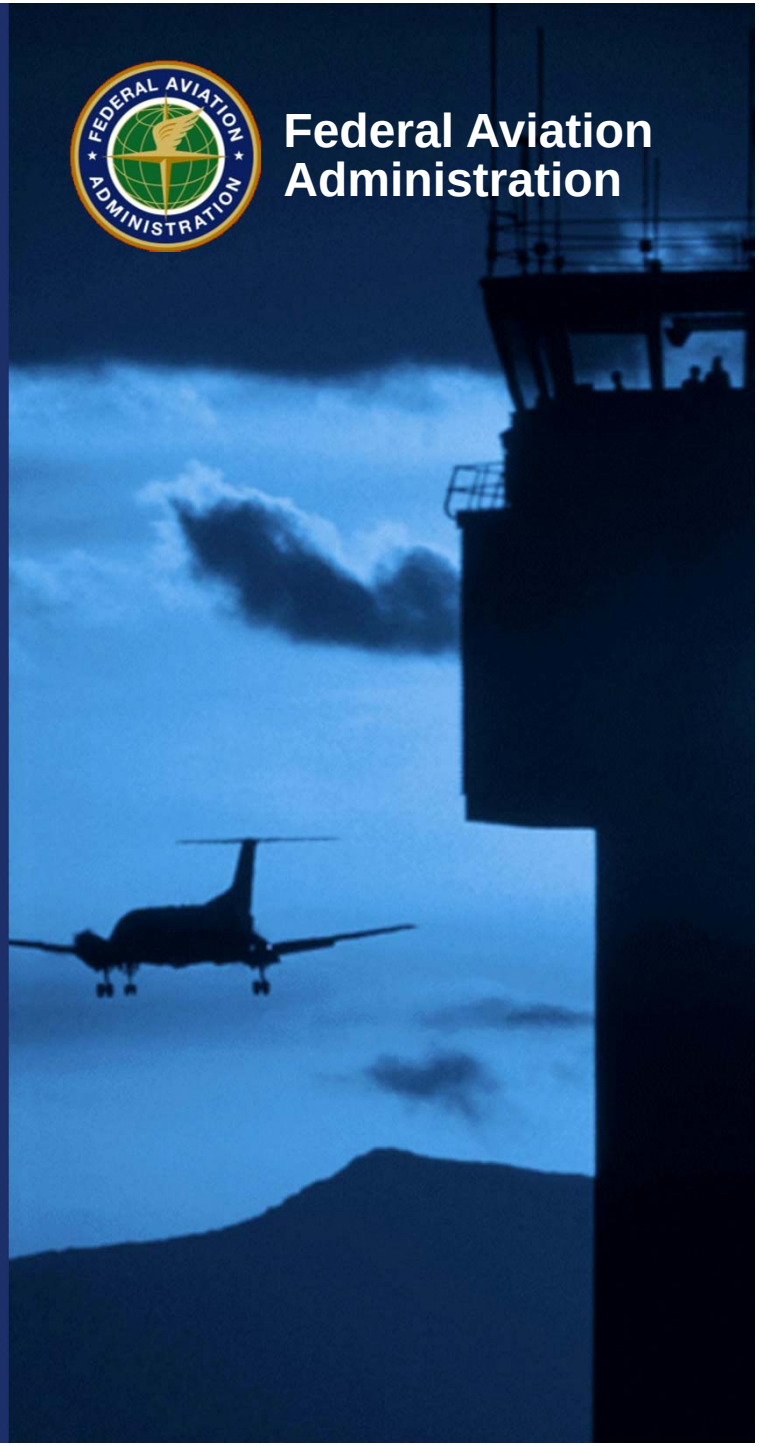
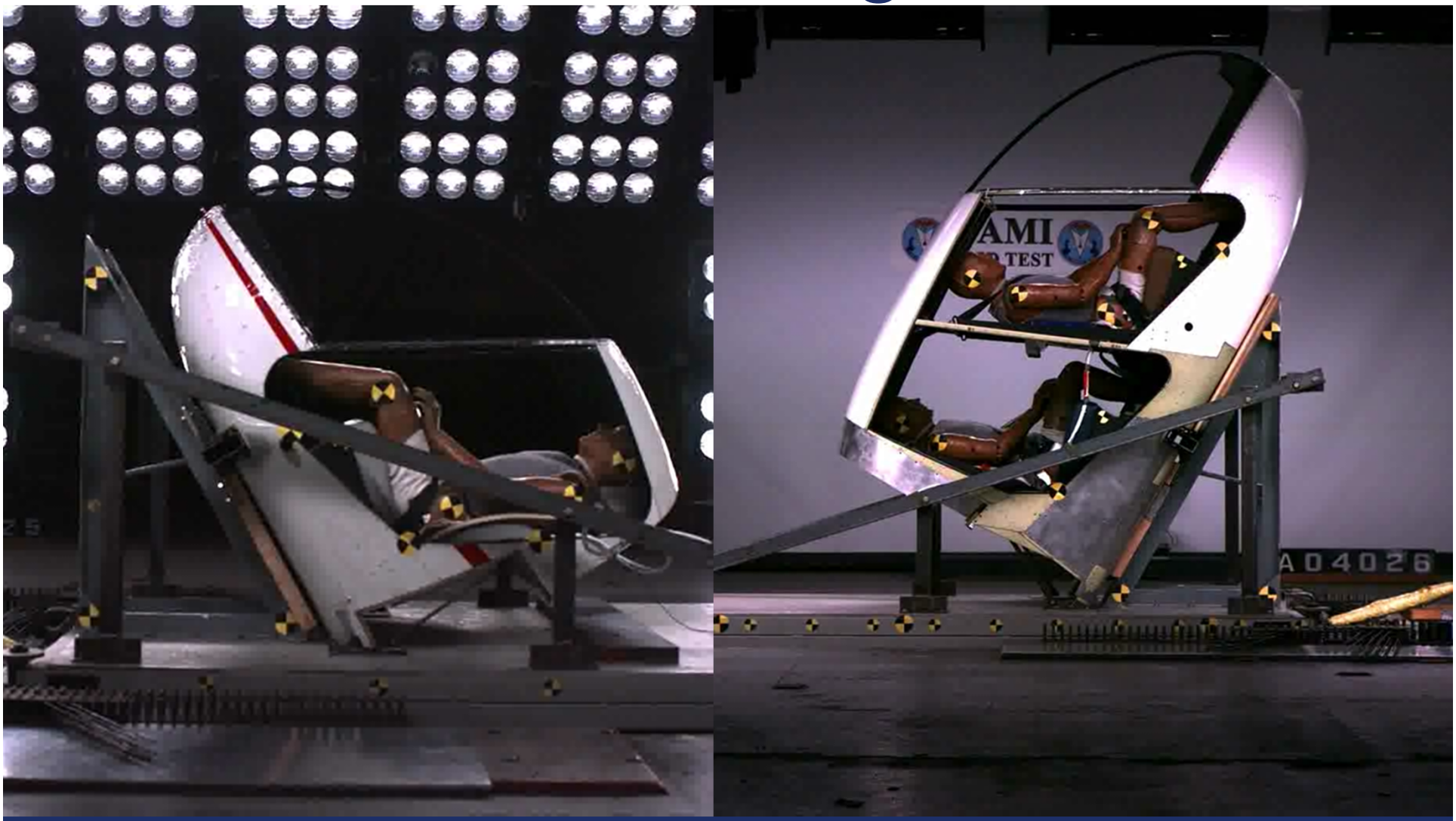
Federal Aviation Administration



Talk Overview

- **Basis of the Regulations**
- **Vertical Impact Standards**
- **Current ATDs**
- **New Environments**
- **THOR-NT**
- **Motivation**
- **Test Set-Up**
- **Instrumentation**
- **Results**

Basis of the Regulations



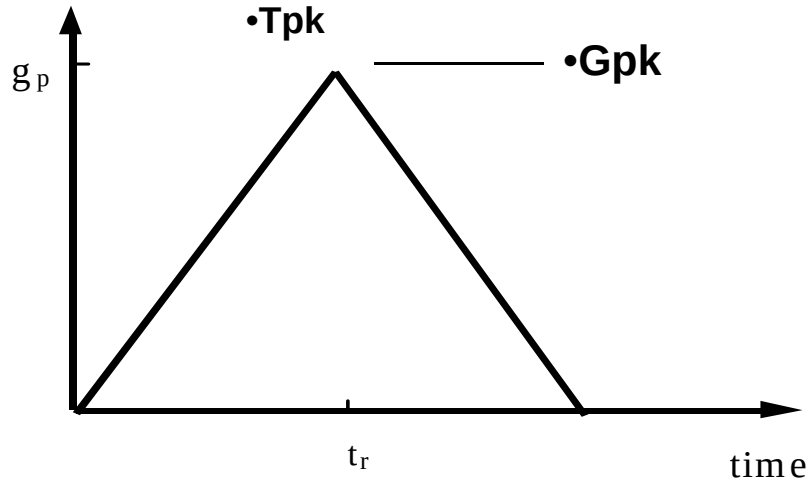
Regulations

- **Regulations in place to protect occupants in the event of a crash**
- **Qualification tests of crashworthy seats require two crash tests severity based upon installation**

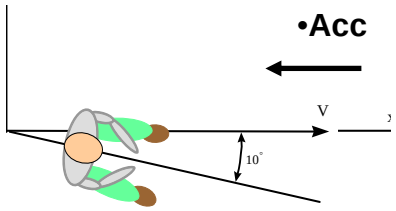
Horizontal Impact Standards

Requirements for **NEW**

- General Aviation Aircraft
- Transport Aircraft
- Rotorcraft



Test-2 Condition



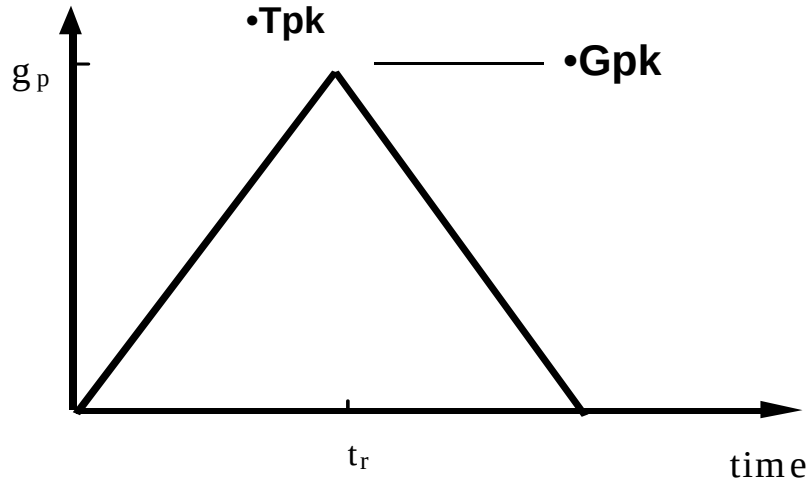
•From Above

Horizontal 10° Yaw Orientation	Small Airplanes (Part 23)		Transport (Part 25)	Rotorcraft (Part 27)
	Pilot	Passenger		
Gpk (gs)	26	21	16	18.4
Impact Velocity (f/s)	42	42	44	42
Onset Time (Tpk)	0.06	0.08	0.09	0.07

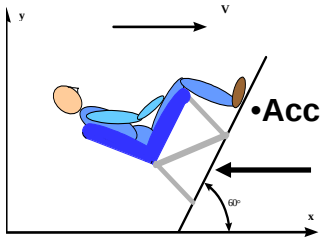
Vertical Impact Standards

Requirements for **NEW**

- General Aviation Aircraft
- Transport Aircraft
- Rotorcraft



Test-1 Condition



•From Right Side

Combined Vertical Horizontal Orientation	Small Airplanes (Part 23)		Transport (Part 25)	Rotorcraft (Part 27)
	Pilot	Passenger		
Gpk (gs)	19	15	14	30
Impact Velocity (ft/s)	31	31	35	30
Onset Time (Tpk)	0.05	0.06	0.08	0.03

Injury/Pass-Fail Criteria

$$HIC = \left[(t_2 - t_1) \left\{ \frac{1}{(t_2 - t_1)} \int_{t1}^{t2} a(t)dt \right\}^{2.5} \right]_{max}$$

Parameter	Injury Criteria
Head Injury Criteria (HIC)	1000
Shoulder Harness loads	1750 lb. (single) 2000 lb. (dual)
Lumbar Load Fz	1500 lb.
Femur Load (axial)*	2250 lb.

Hybrid II

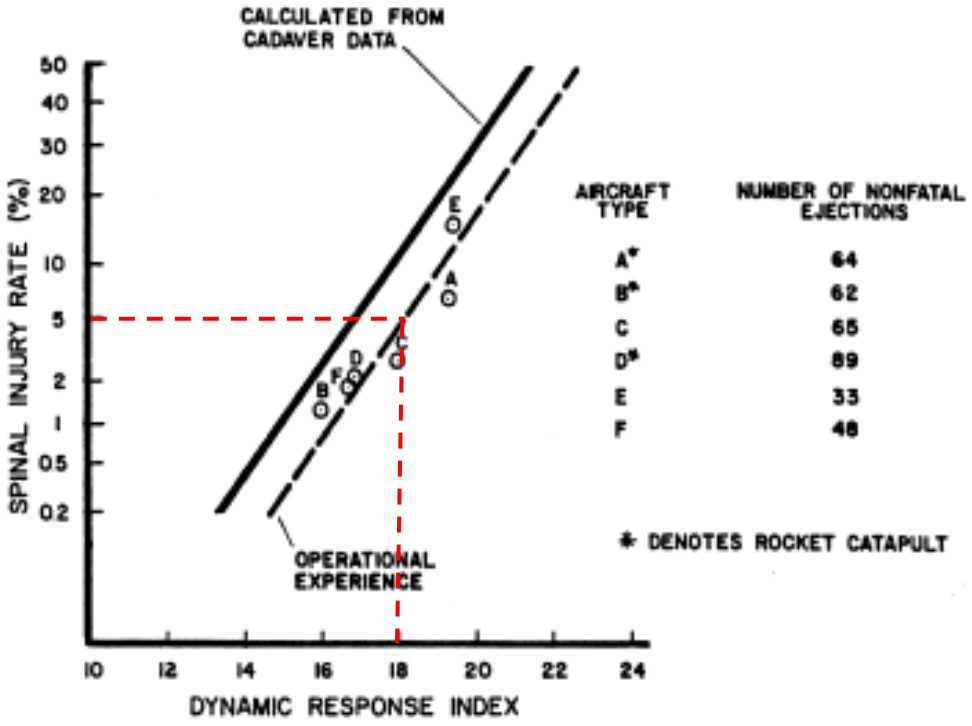
Specified in Part 23.562, 25.562, 27.562, and 29.562

Measured for Part 572 Subpart B (Hybrid II)

* (part 25 only)

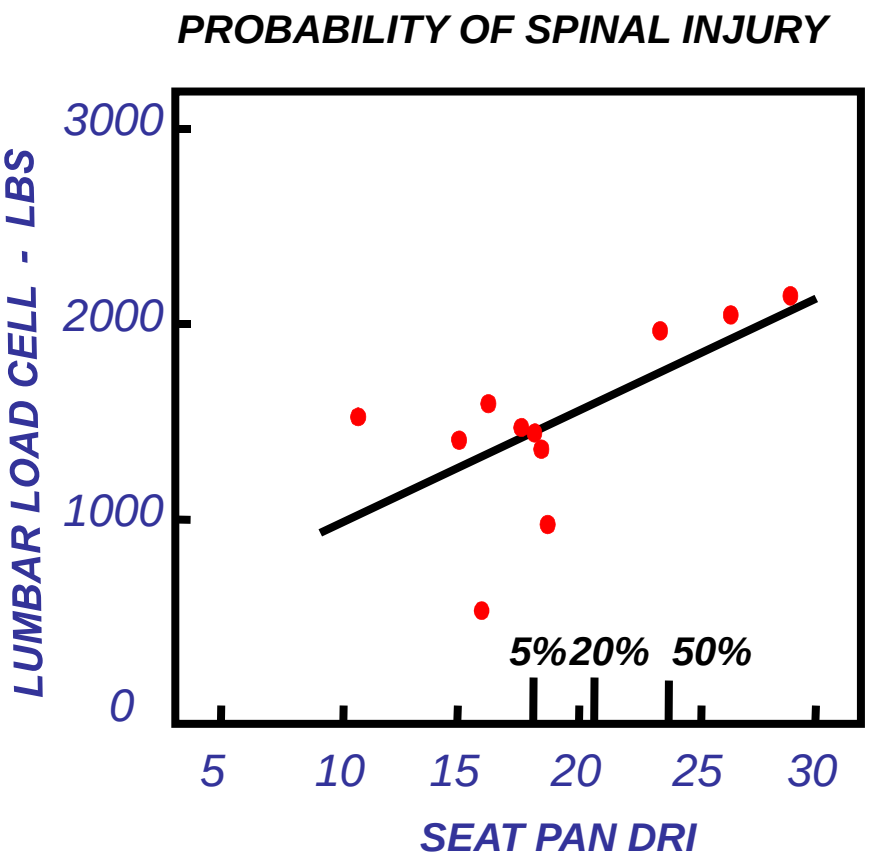
Basis of the Regulations

- **Dynamic Response Index (DRI)**
  - Developed by the US Air Force (USAF) to evaluate likelihood of spinal injury during a seat ejection
  - Based upon seat acceleration and assumed thin stiff seat bottom cushion
  - DRI of 19 is a 9% probability of a detectable spinal injury



Basis of the Regulations

- **Lumbar Load**
  - Testing at CAMI showed that DRI was not valid for civilian seating systems that are flexible and lightweight, which makes it difficult to measure seat pan acceleration
  - Data allowed for the derivation of a relationship between lumbar load and DRI
  - Comparison suggested a lumbar compression load of 1500 lb measured in a 50th percentile male Hybrid II was equivalent to a DRI of 19

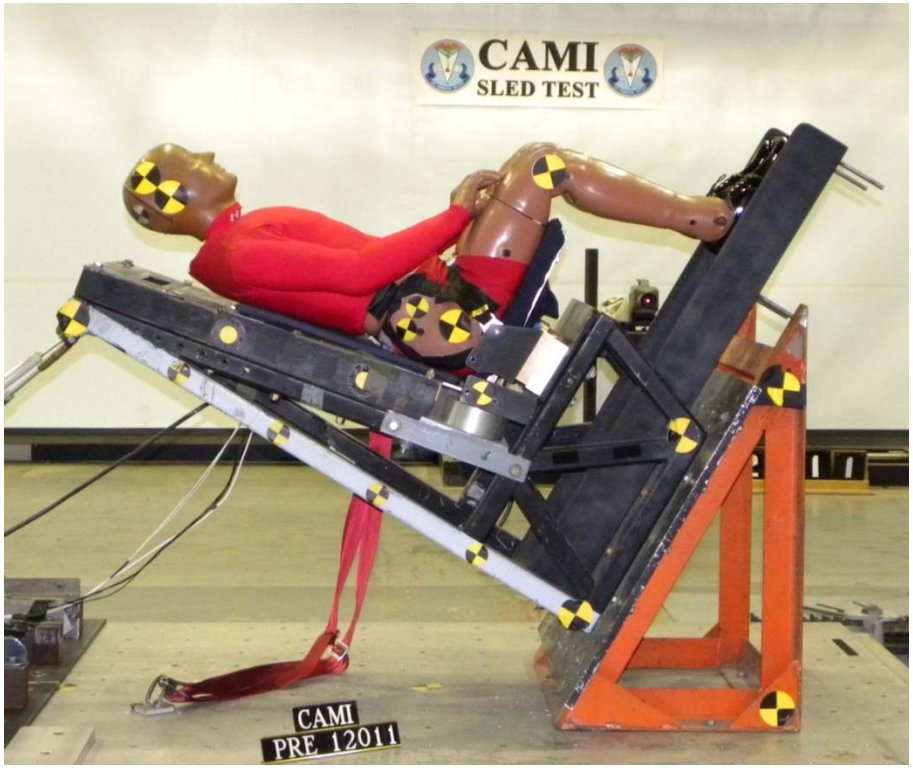


Current ATDs

- **ATDs for use in certification**
  - Hybrid II (49 CFR Part 572 Subpart B)
  - FAA Hybrid III (deemed equivalent, AIR-100-3-3-2000)

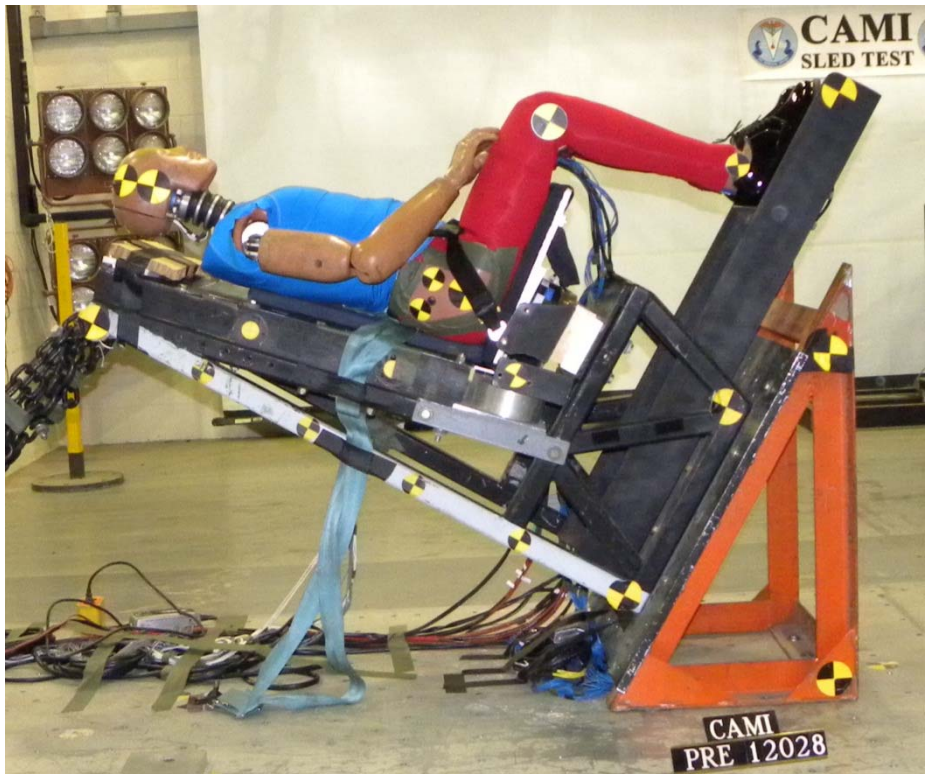
Current ATDs

- **Hybrid II**
  - 49CFR Part 572 B
  - Instrumentation
    - Accelerometers
      - Head, Pelvis
    - Load Cells
      - Lumbar, Femur



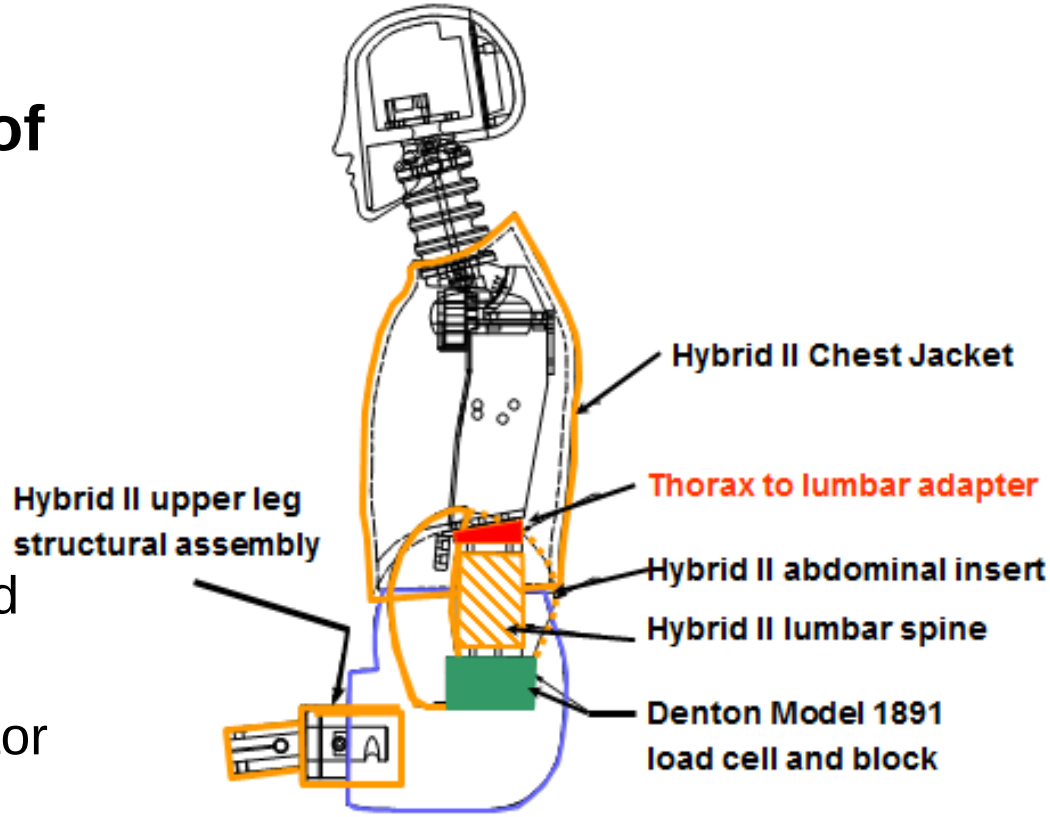
Current ATDs

- **FAA-Hybrid III**
  - SAE paper 1999-01-1609
  - Accepted for all FAA tests using Hybrid II in AIR-100-3-3-2000
  - Instrumentation
    - Accelerometers
      - Head, Pelvis
    - Load Cells
      - Neck, Thorax, Lumbar, Femur, Tibia



Current ATDs

- **FAA-Hybrid III is predominantly made up of Hybrid III parts except:**
  - Hybrid II lumbar spine
  - Hybrid II abdominal insert
  - Hybrid II chest jacket
  - Hybrid II upper leg bone
  - Hybrid II lumbar load cell and pelvic adaptor block
  - Custom thorax/lumbar adaptor



New Environments

- **Transport category passenger seats continue to evolve, with the latest development being a partially enclosed (pod) seat that is oriented obliquely with respect to the aircraft centerline, in what is commonly referred to as a "herringbone" arrangement**

Delta

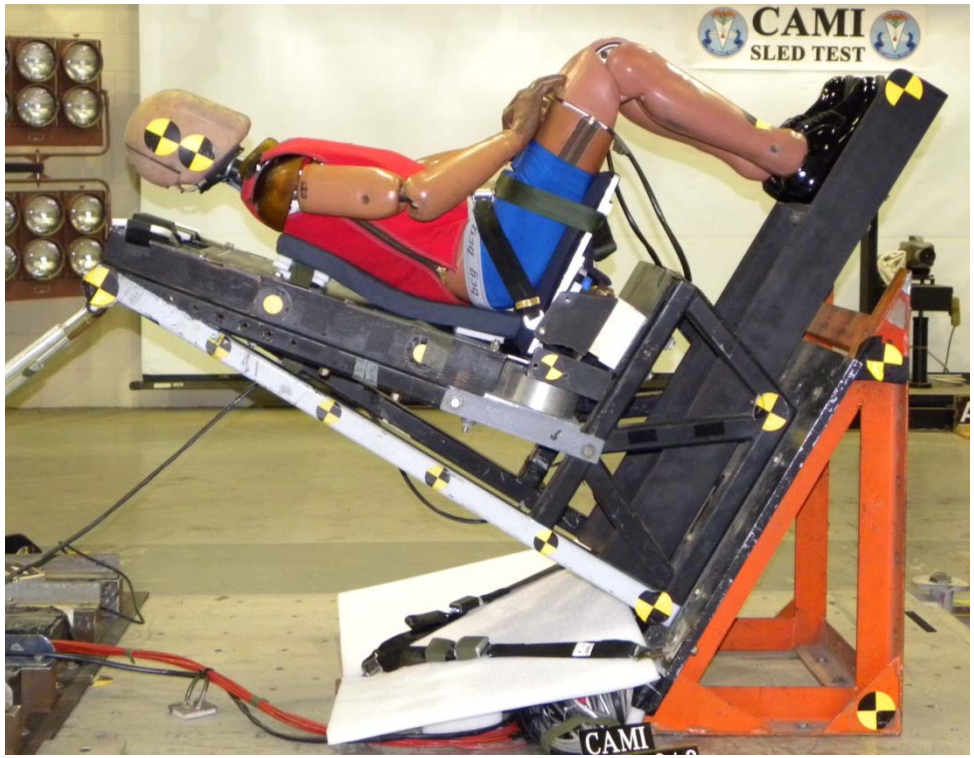
New Environments

- **In commercial space flight multiple types of vehicles are being proposed**
- **In 2013 THOR was specified by NASA due to is extensive array of instrumentation**

NASA

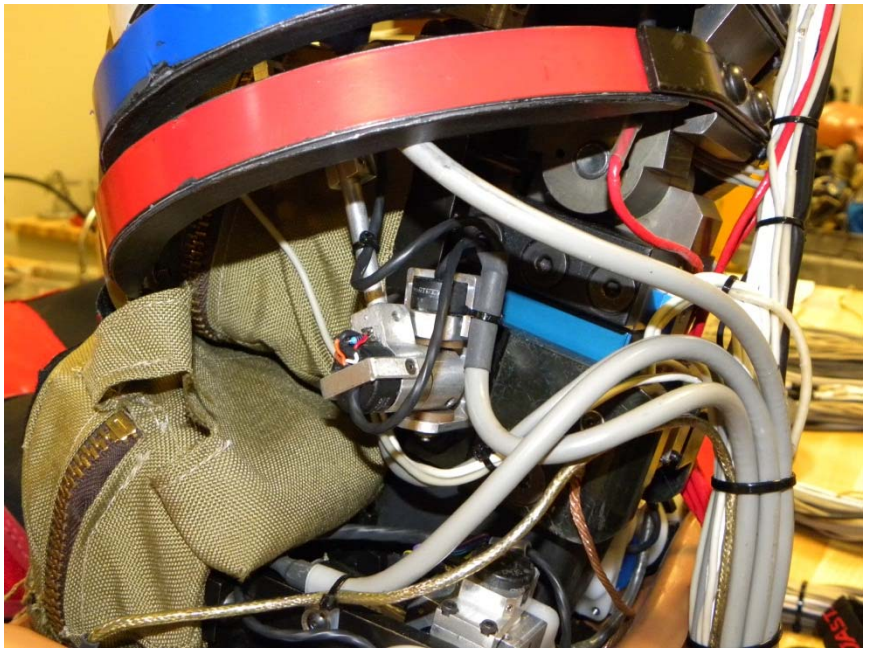
THOR-NT

- **Test Device for Human Occupant Restraint (THOR-NT)**
  - Loaned from NHTSA
  - Instrumentation (over 100 channels)
    - Accelerometers
      - Head, Thorax, Sternum, Abdomen, Pelvis, Foot
    - Load Cells
      - Face, Neck, Shoulder, Thorax, Pelvis, Femur, Tibia
    - Potentiometers, Tilt sensors, Knee Displacement



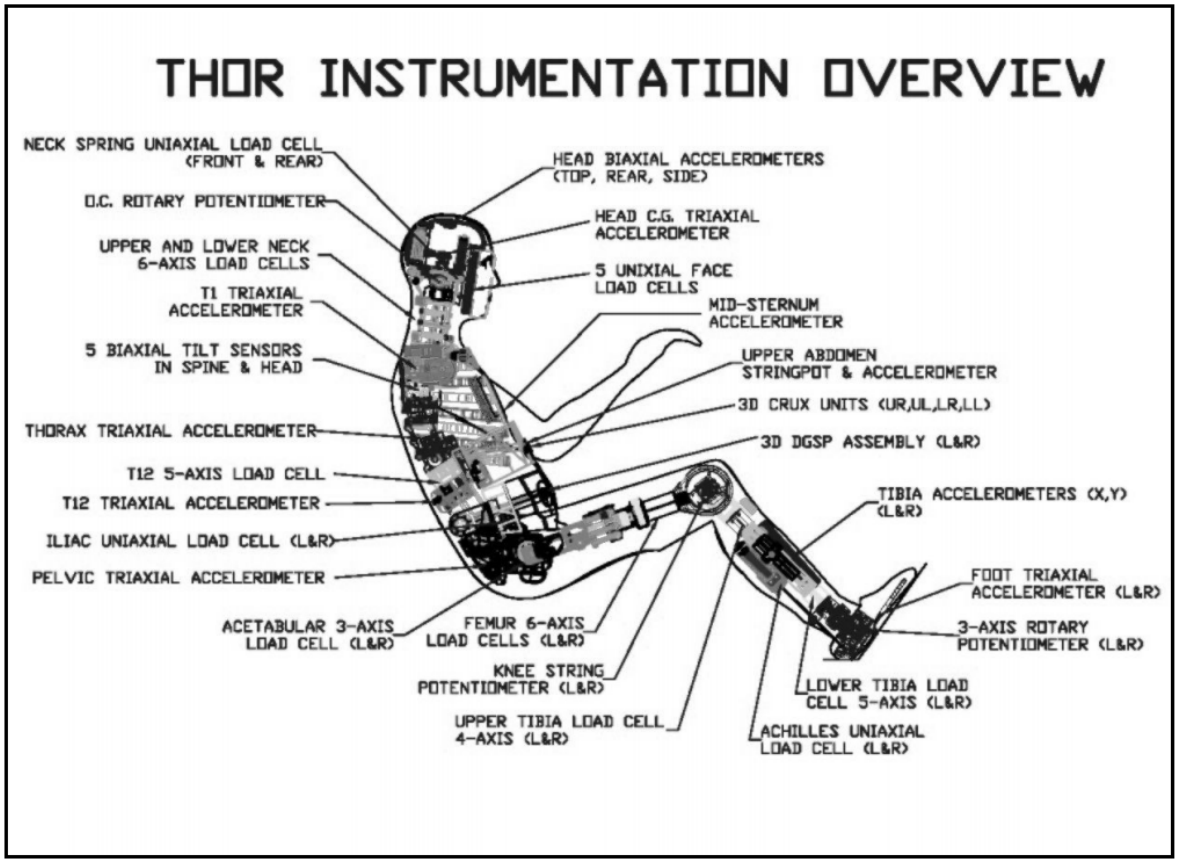
THOR-NT

- **The THOR ATD is under development in the automotive community as a potential replacement for the Hybrid III for frontal crash tests, and is on version -M.**
- **It has an extensive array of instrumentation, particularly in the thoracic and abdominal regions.**



THOR-NT

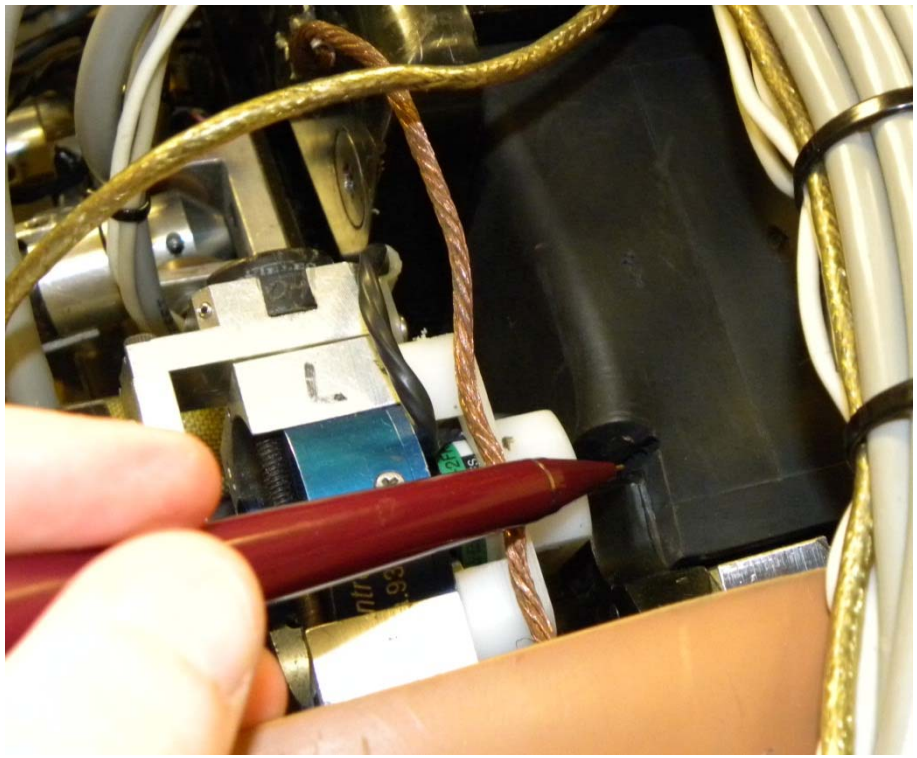
- **This instrumentation greatly increases the types of injuries that can be predicted**



THOR Users Manual

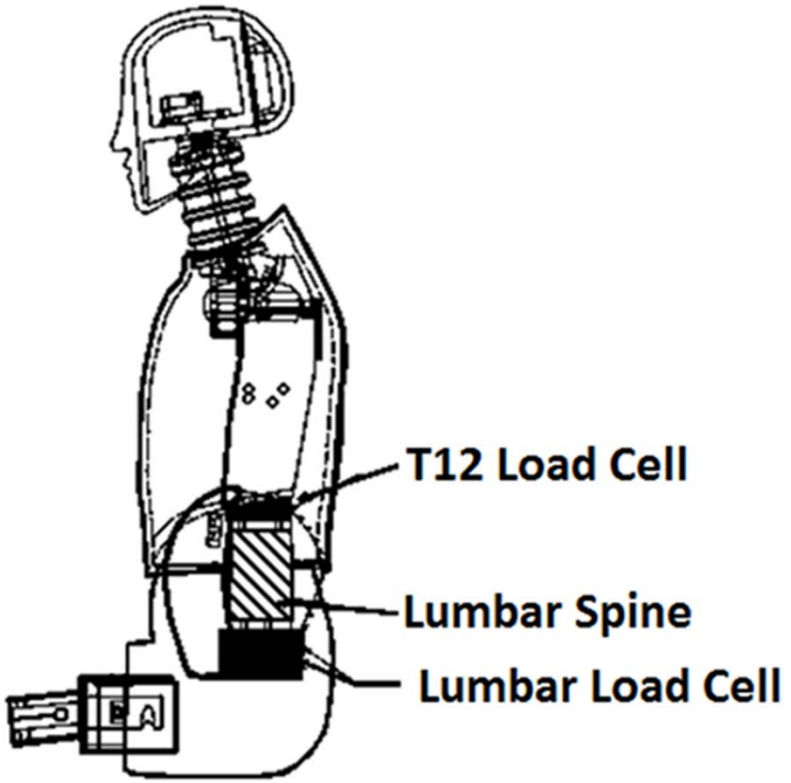
THOR-NT

- **After static evaluation, extensive damage to the instrumentation and the lumbar spine element would likely occur during any test that induced lateral or forward flexion at the lumbar**
- **It was deemed safe to test vertically**



ATD Comparison

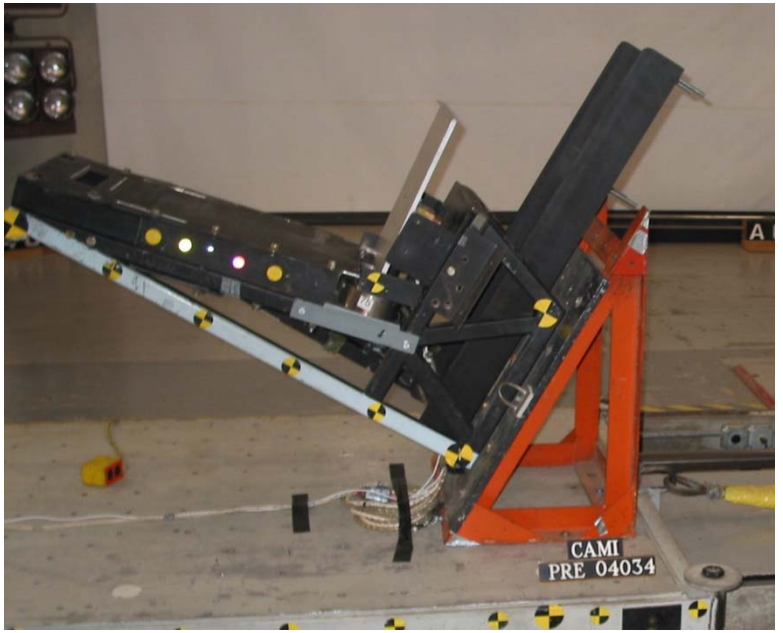
- **The FAA Hybrid III instrumented with a T-12 load cell, to allow direct comparison**
  - Hybrid II - FAA Hybrid III (Lumbar load cell)
  - THOR-NT - FAA Hybrid III (T-12 load cell)
- **Loads normalized per AS8049B to the goal acceleration for comparison**



$$\text{Normalized load} = \frac{\text{recorded load} * \text{goal acceleration}}{\text{peak acceleration}}$$

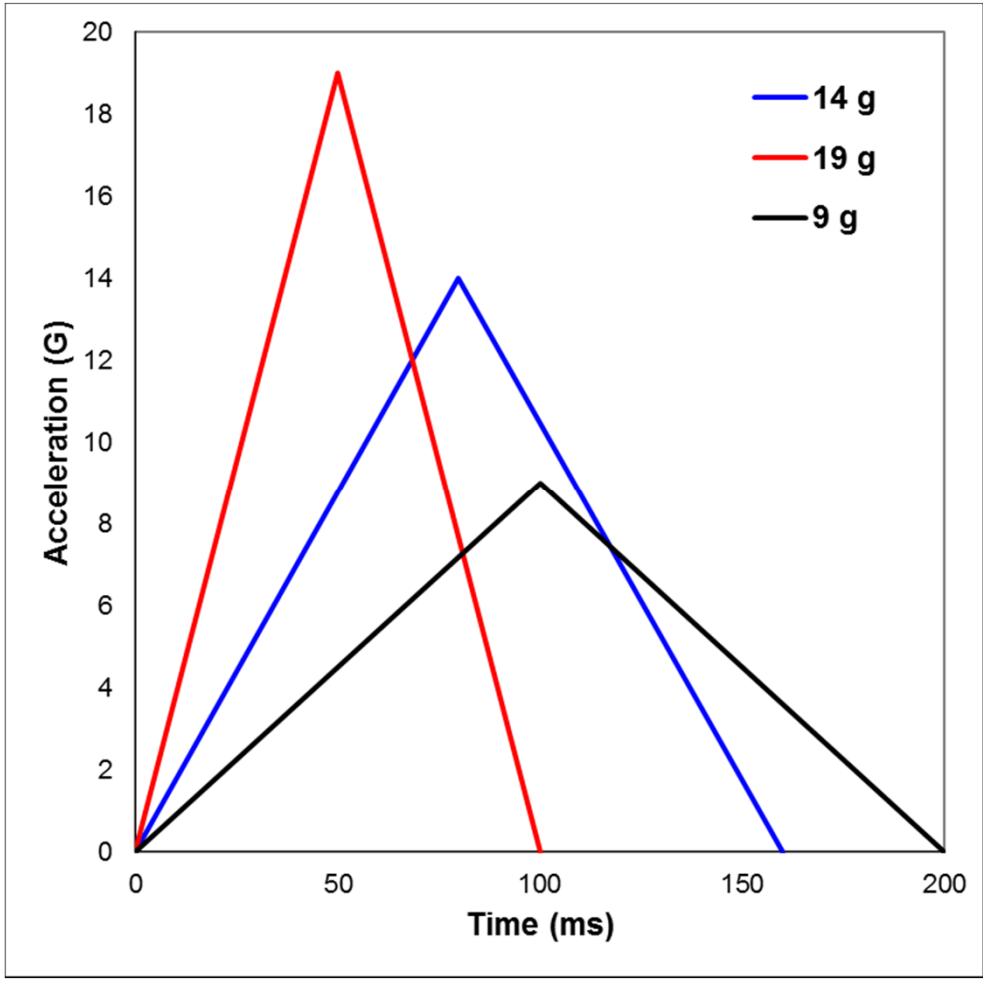
Methods

- **To compare the THOR-NT against other FAA approved ATDs, a rigid fixture pitched up to 60 degrees was utilized to minimize variability**
- **A 1-inch very firm, rate sensitive cushion was chosen to distribute load on the pelvis while minimizing spinal load amplification**



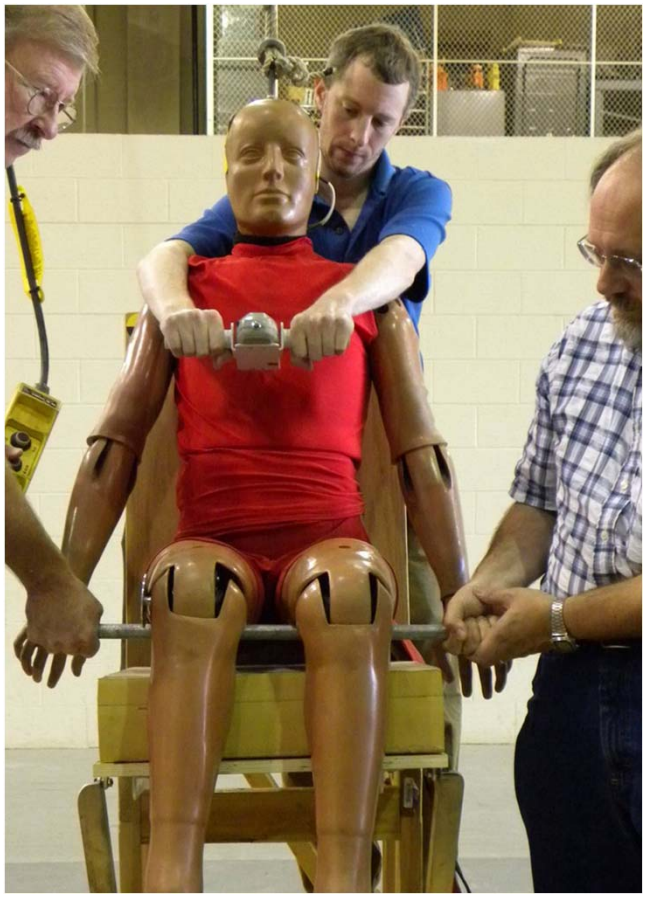
Methods

- **Tests were carried out on a rigid seat using the deceleration sled**
  - 14 G, 44 ft/s impact severity defined in 14 CFR 25.562
  - 19 G, 31 ft/s impact severity defined in 14 CFR 23.562
  - 9 G, 30 ft/s impact severity selected to be approximately proportional to the above conditions



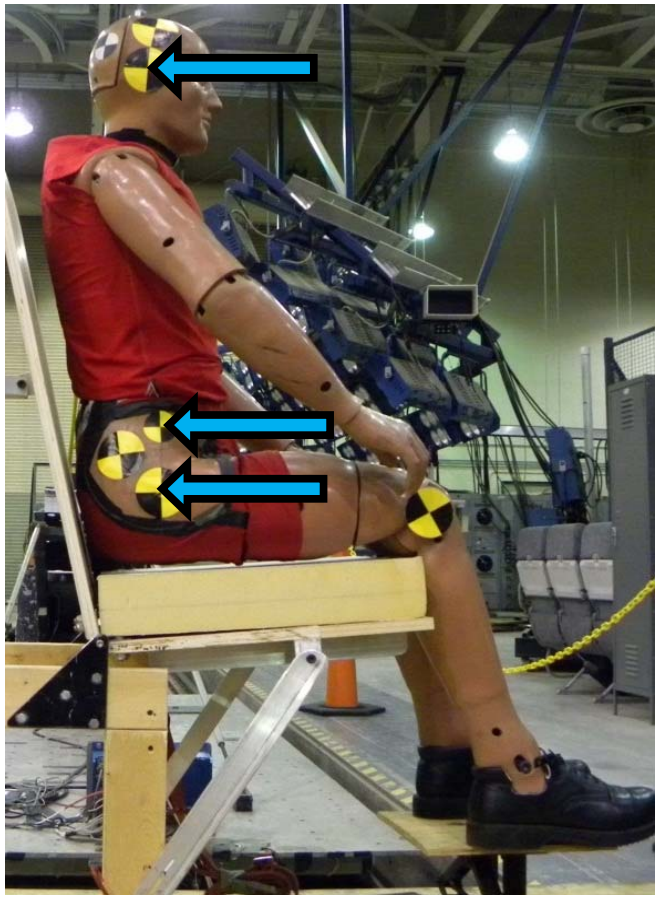
Methods

- **Wooden representation of rigid seat geometry was used to get 1-G position**
  - ATD was lowered into the seat while pressing on the sternum with 20 lb and holding knees up



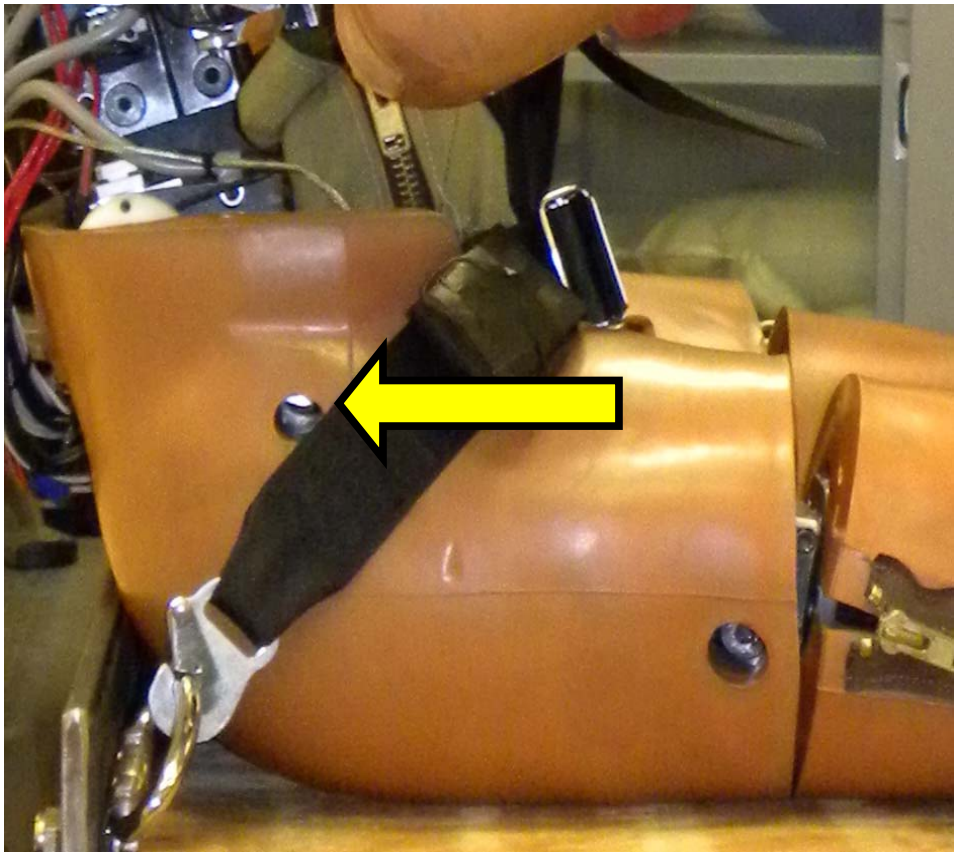
Methods

- **Hybrid II and FAA Hybrid III**
- **Points were measured on the pelvis and head to record nominal pelvis angle and location, as well as torso angle**



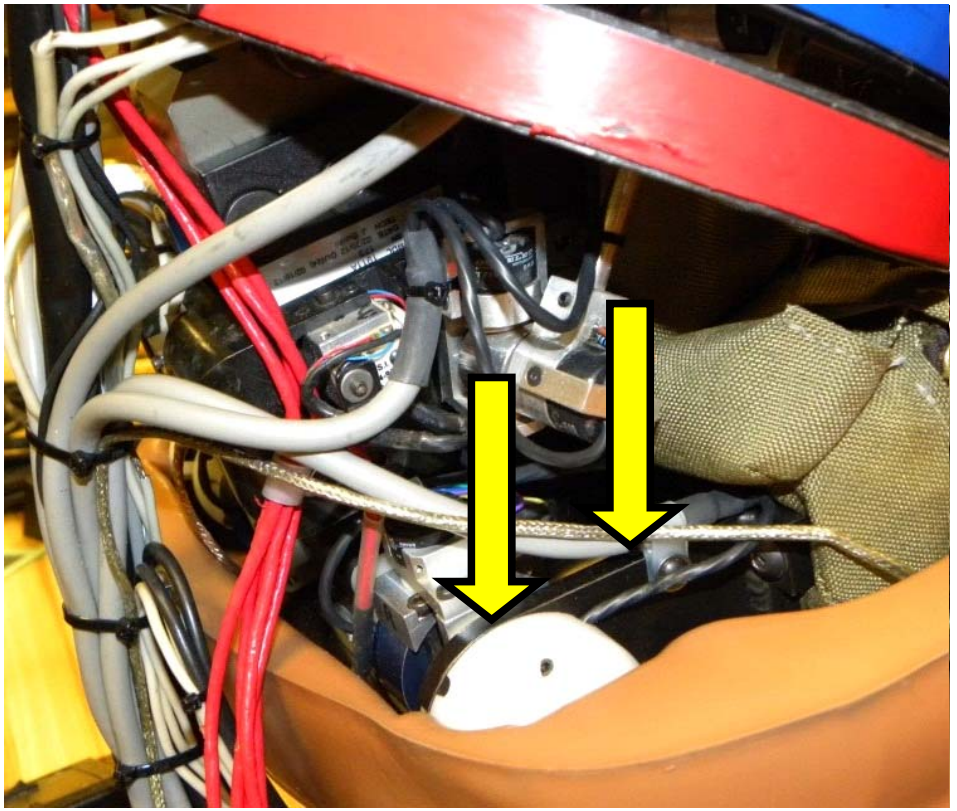
Methods

- **Thor-NT flesh is not well coupled to pelvis**
- **H-Point tool access hole on internal rigid structure of pelvis was used for positioning**



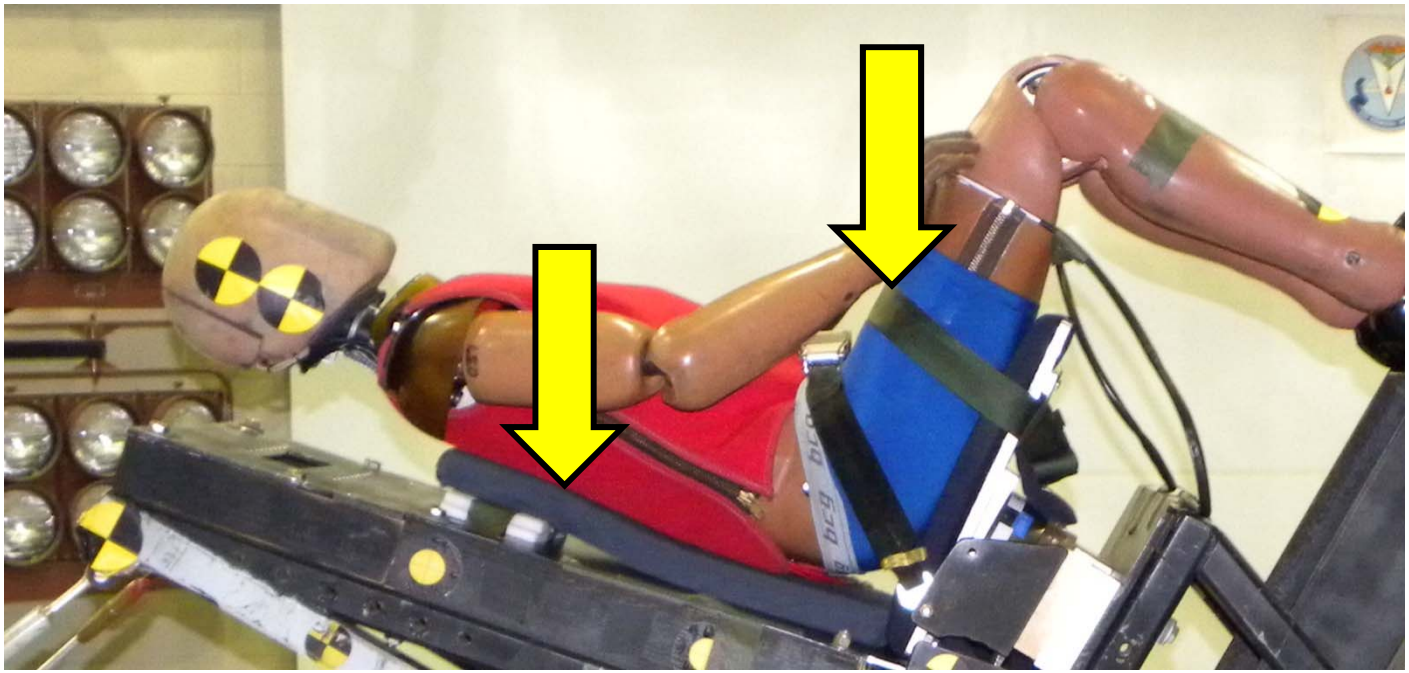
Methods

- **Thor-NT flesh is not well coupled to pelvis**
- **Alternate points on internal rigid structure of pelvis were used for pelvis angle**

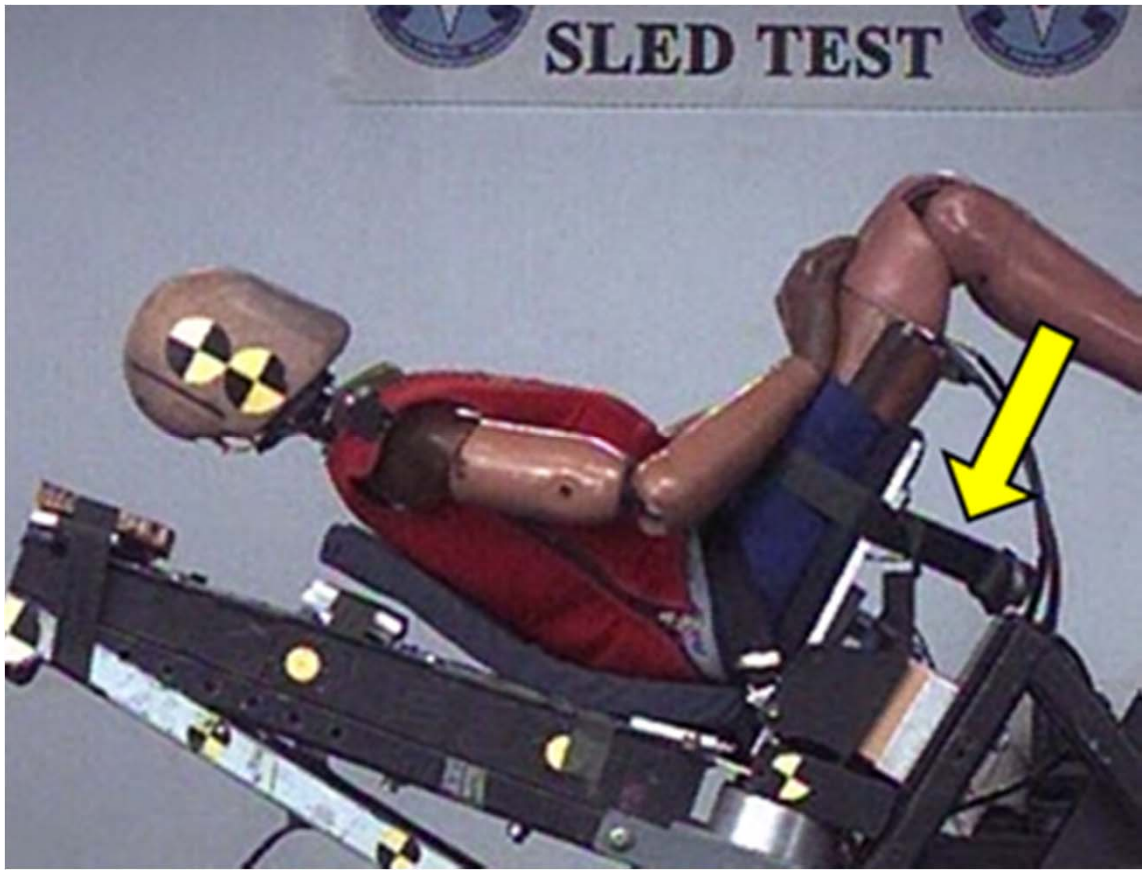


Methods

- **Thigh strap to prevent rebound**
- **Shim to get in correct position**



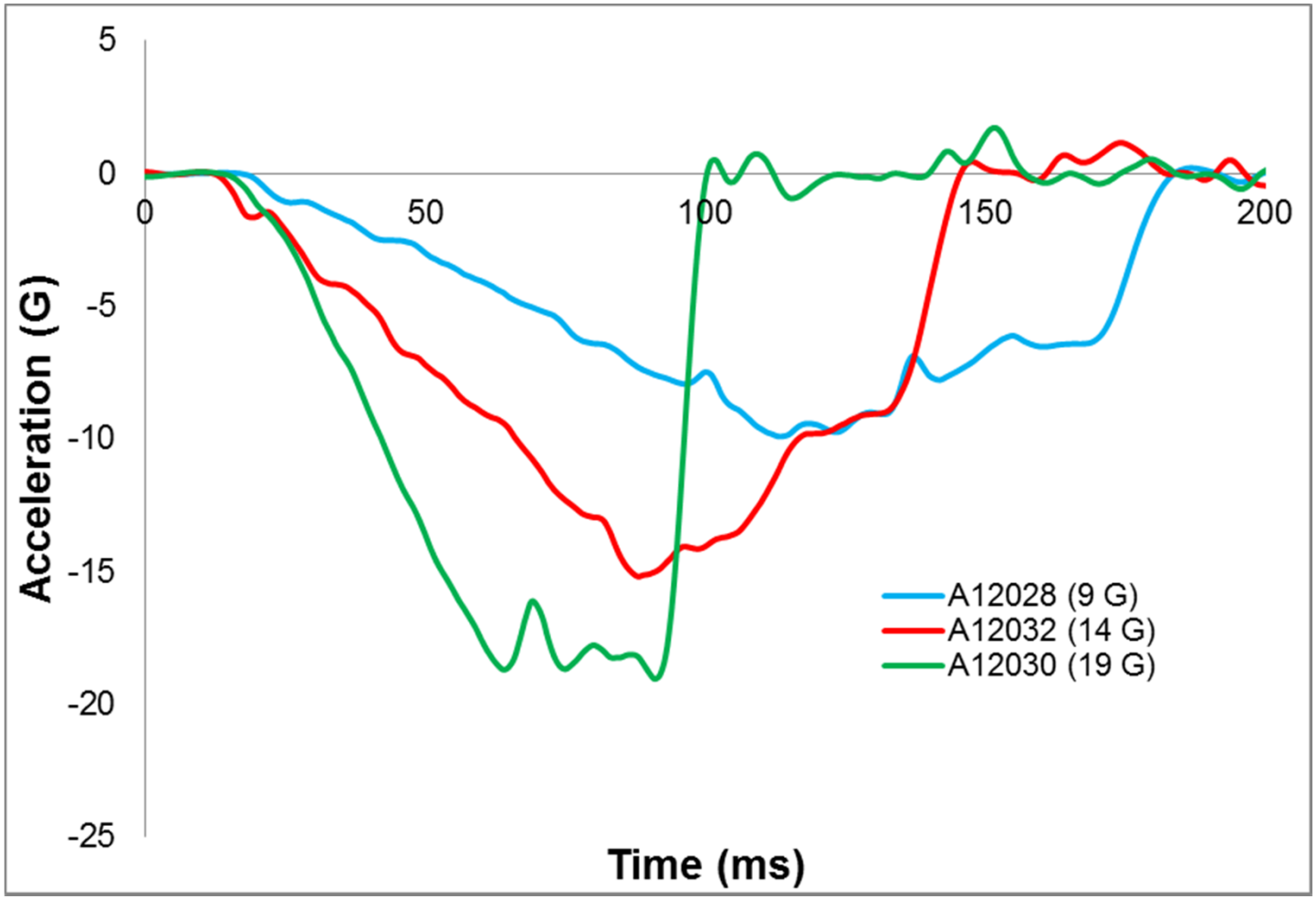
Methods



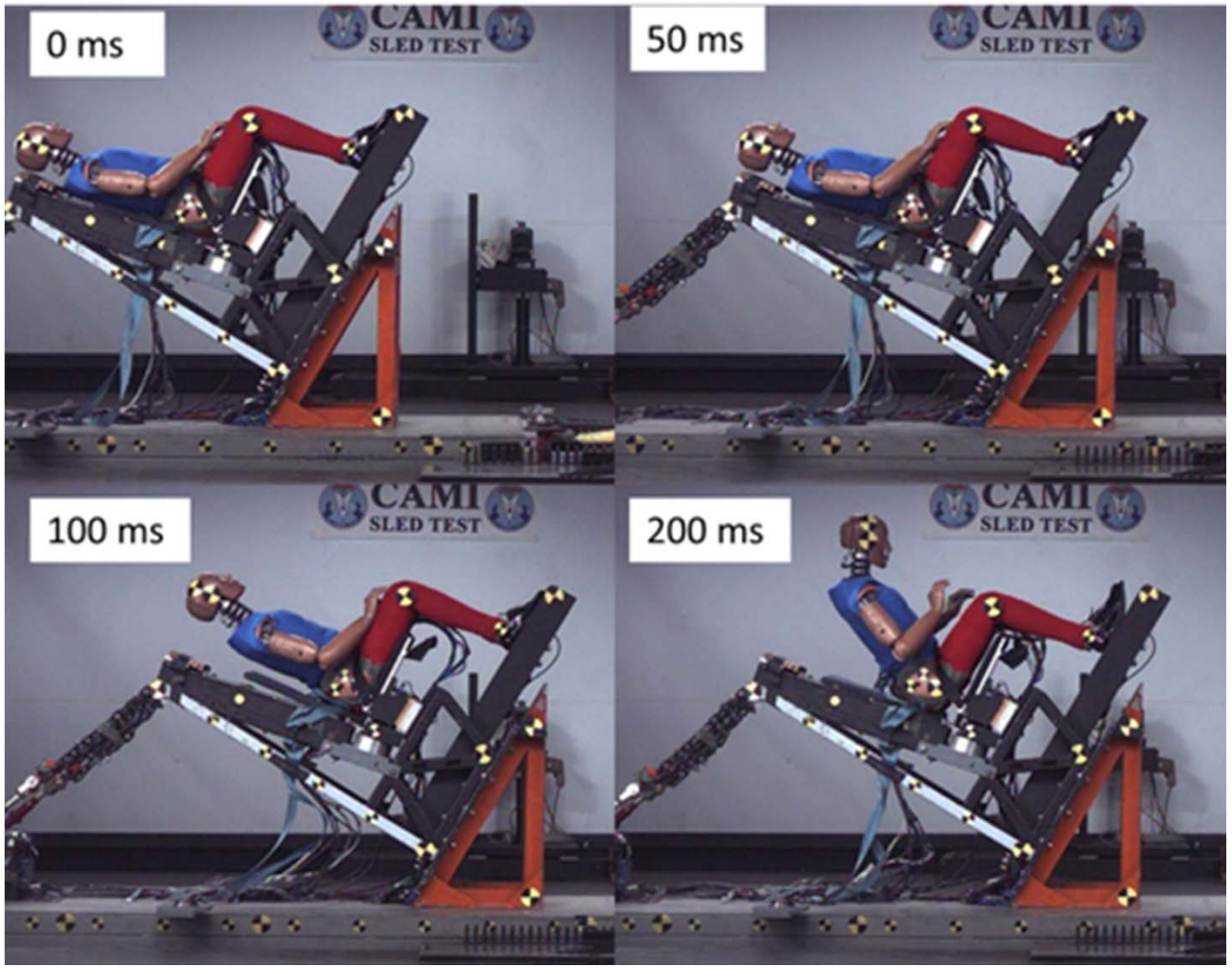
Methods

- **14 Tests**
  - 7 Hybrid II
    - Additional tests were run due to the addition of a foot rest load cell
  - 3 FAA Hybrid III
  - 4 THOR NT
    - Additional test due to pulse failure

Methods


5
0
-5
-10
-15
-20
-25
0
50
100
150
200
Acceleration (G)
Time (ms)
A12028 (9 G)
A12032 (14 G)
A12030 (19 G)

Kinematics


0 ms
CAMI SLED TEST
50 ms
CAMI SLED TEST
100 ms
CAMI SLED TEST
200 ms
CAMI SLED TEST

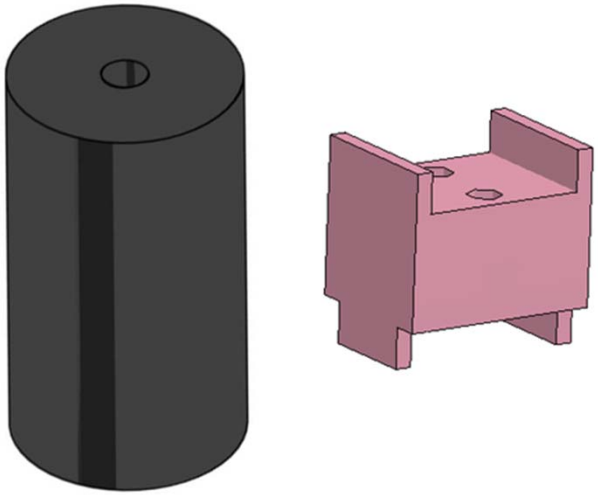
HII and FAA Hybrid III Lumbar

ATD	Test Number	Peak G	Goal G	Normalized Lumbar Load (lb)
Hybrid II	A12013	9.9	9	580
Hybrid II	A12031	10.2	9	553
Hybrid II	A12011	14.5	14	909
FAA Hybrid III	A12028	9.9	9	519
Hybrid II	A12032	15.5	14	1040
Hybrid II	A12012	20.0	19	1860
Hybrid II	A12014	19.4	19	1827
Hybrid II	A12033*	18.4	19	1986
FAA Hybrid III	A12030*	18.7	19	1806

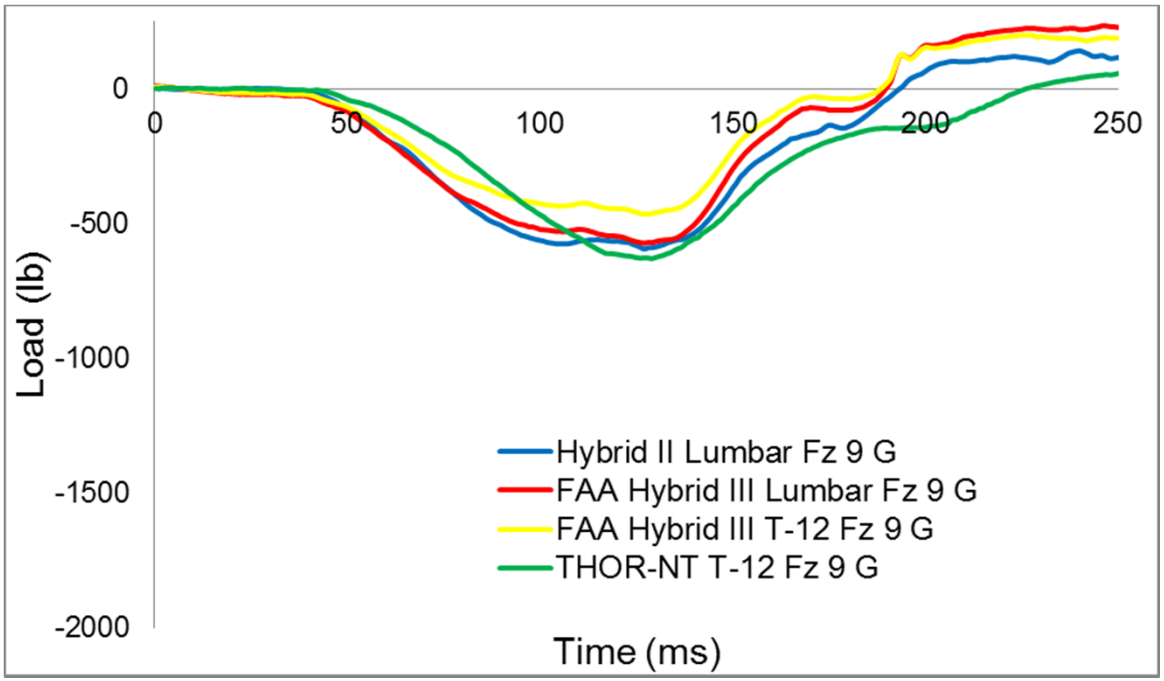
* Pulse failed

FAA Hybrid III and THOR-NT T-12

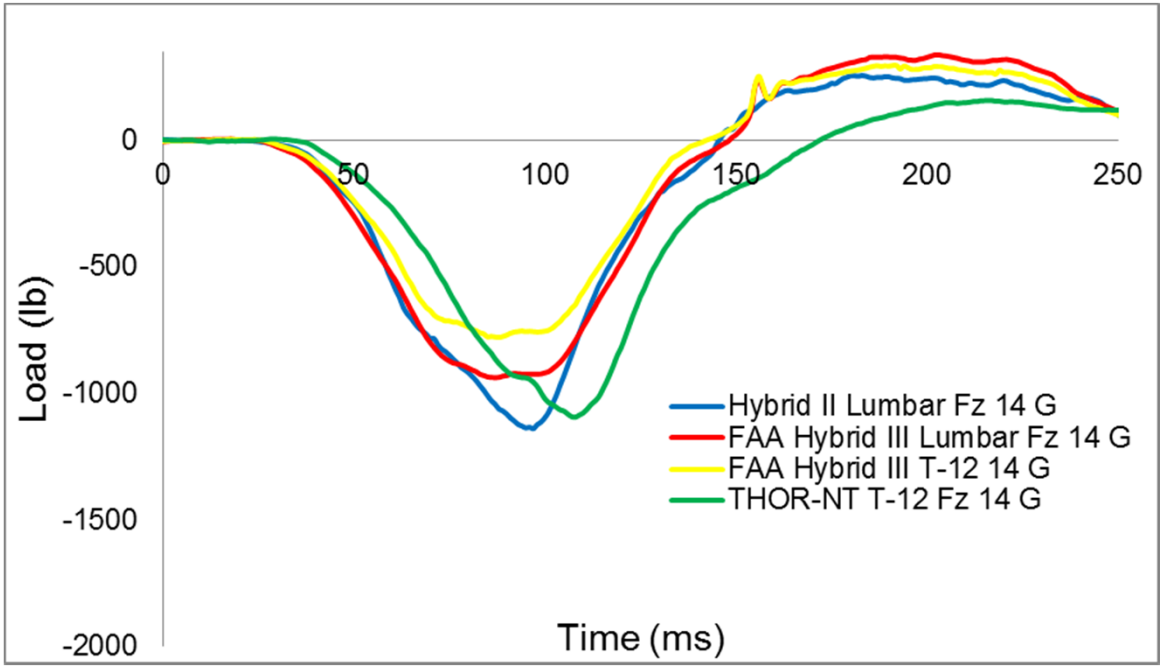
ATD	Test Number	Peak G	Goal G	Normalized T12 (lb)
FAA Hybrid-III	A12028	9.9	9	423
THOR-NT	A12015	8.9	9	640
FAA Hybrid-III	A12029	15.0	14	726
THOR-NT	A12016	12.8	14	990
THOR-NT	A12017	14.3	14	1074
FAA Hybrid-III	A12030	18.7	19	1535
THOR-NT	A12018	19.1	19	1457



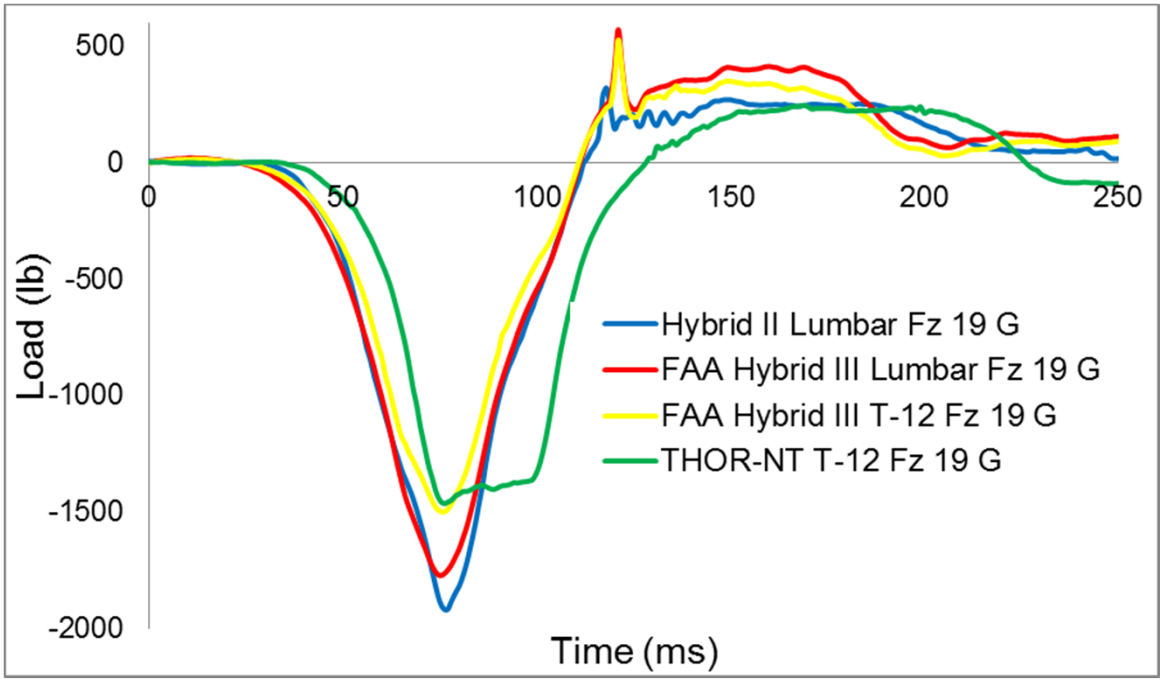
Lumbar and T-12 loads versus time for 9 G pulse



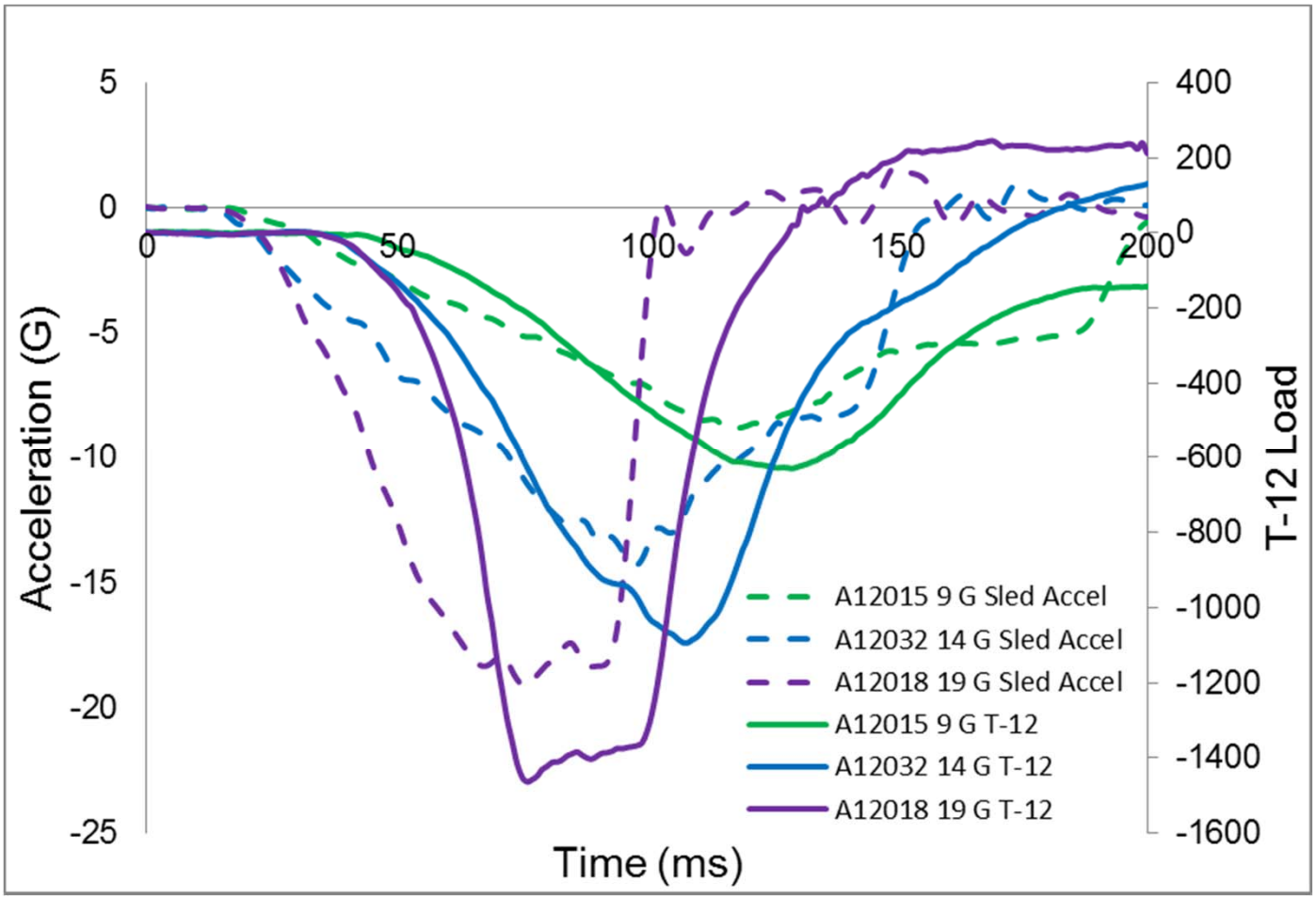
Lumbar and T-12 loads versus time for 14 G pulse



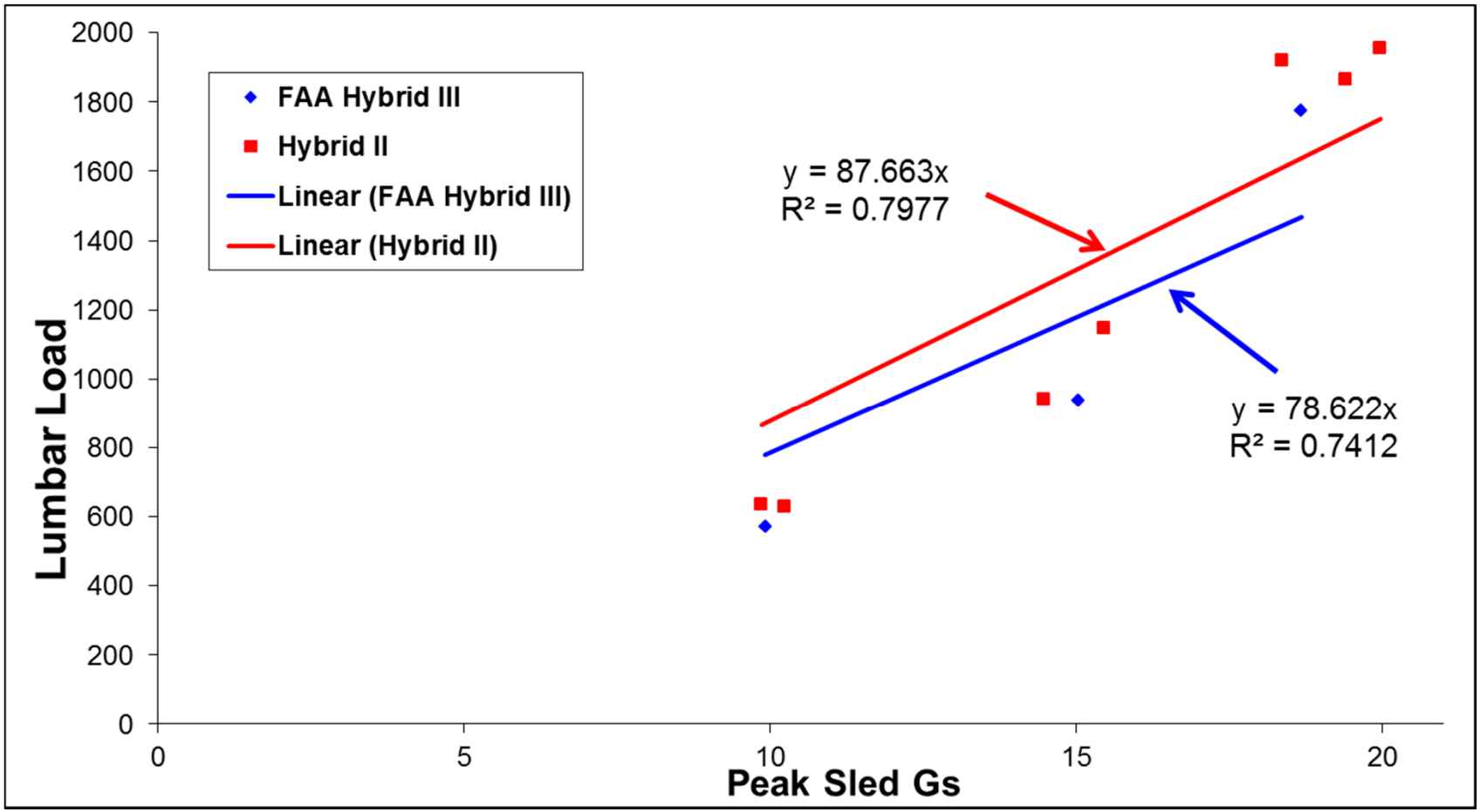
Lumbar and T-12 loads versus time for 19 G pulse



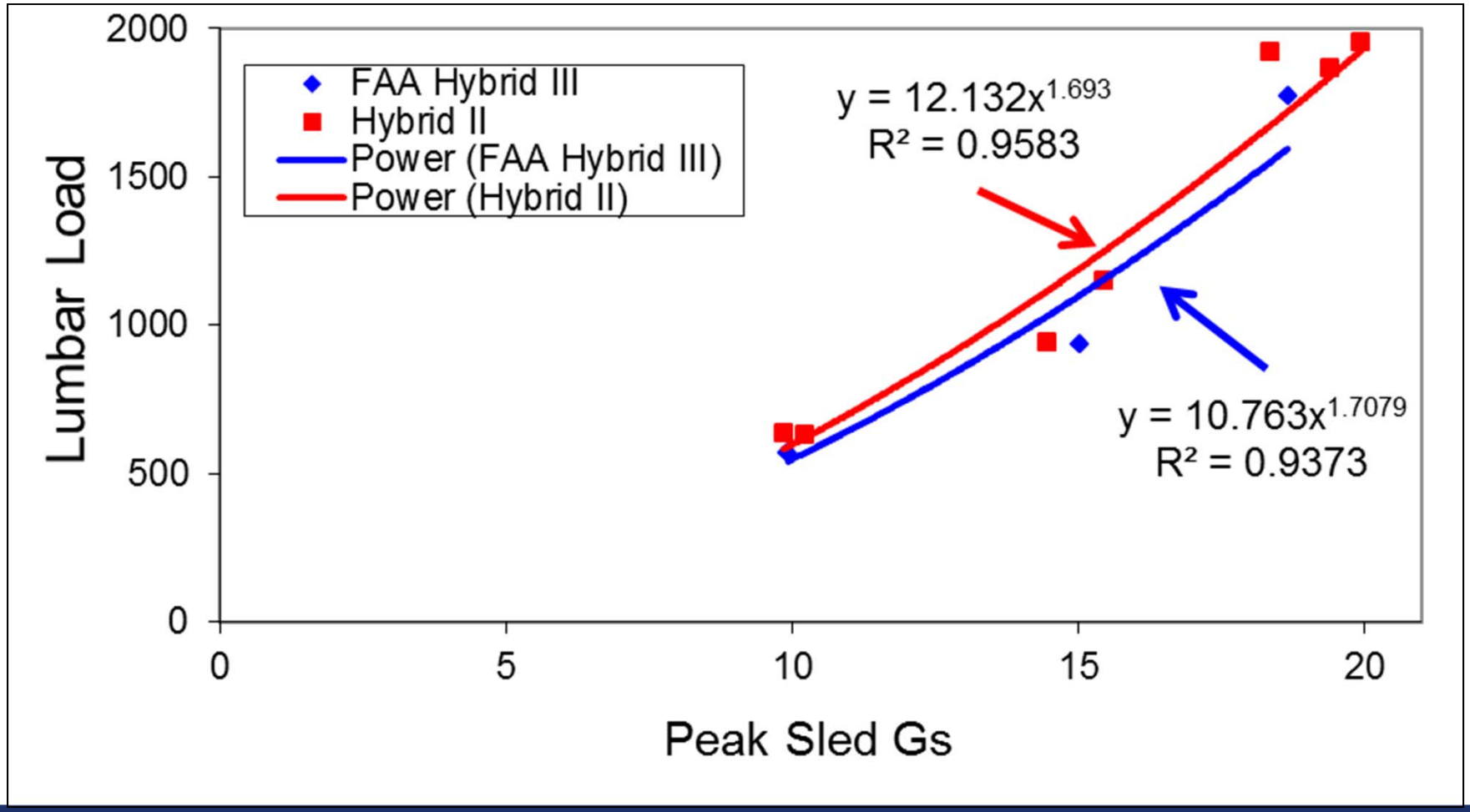
Sled Acceleration and THOR-NT T-12 Loads versus Time



Hybrid II vs FAA Hybrid III



Hybrid II vs FAA Hybrid III

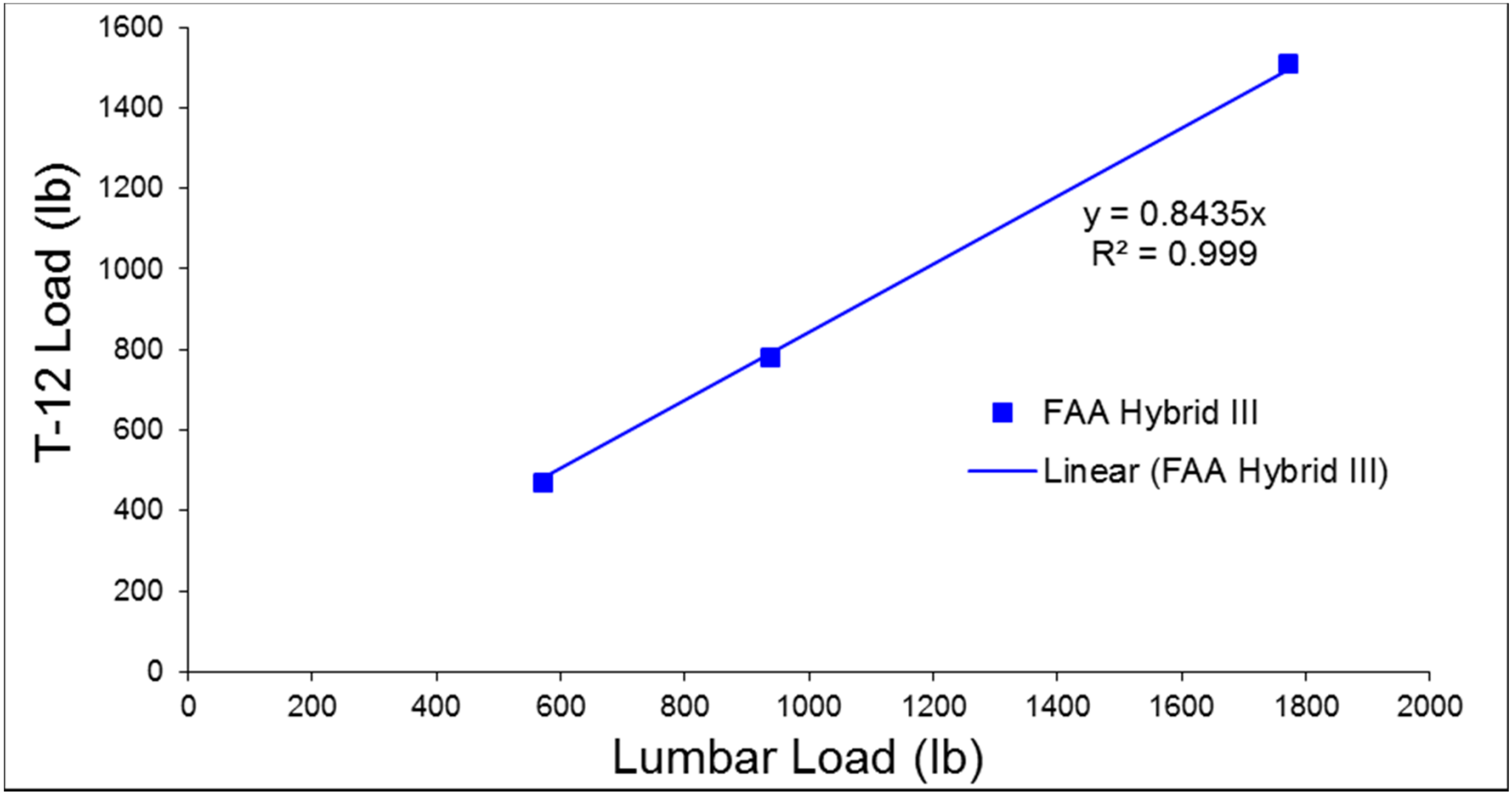


Hybrid II vs FAA Hybrid III

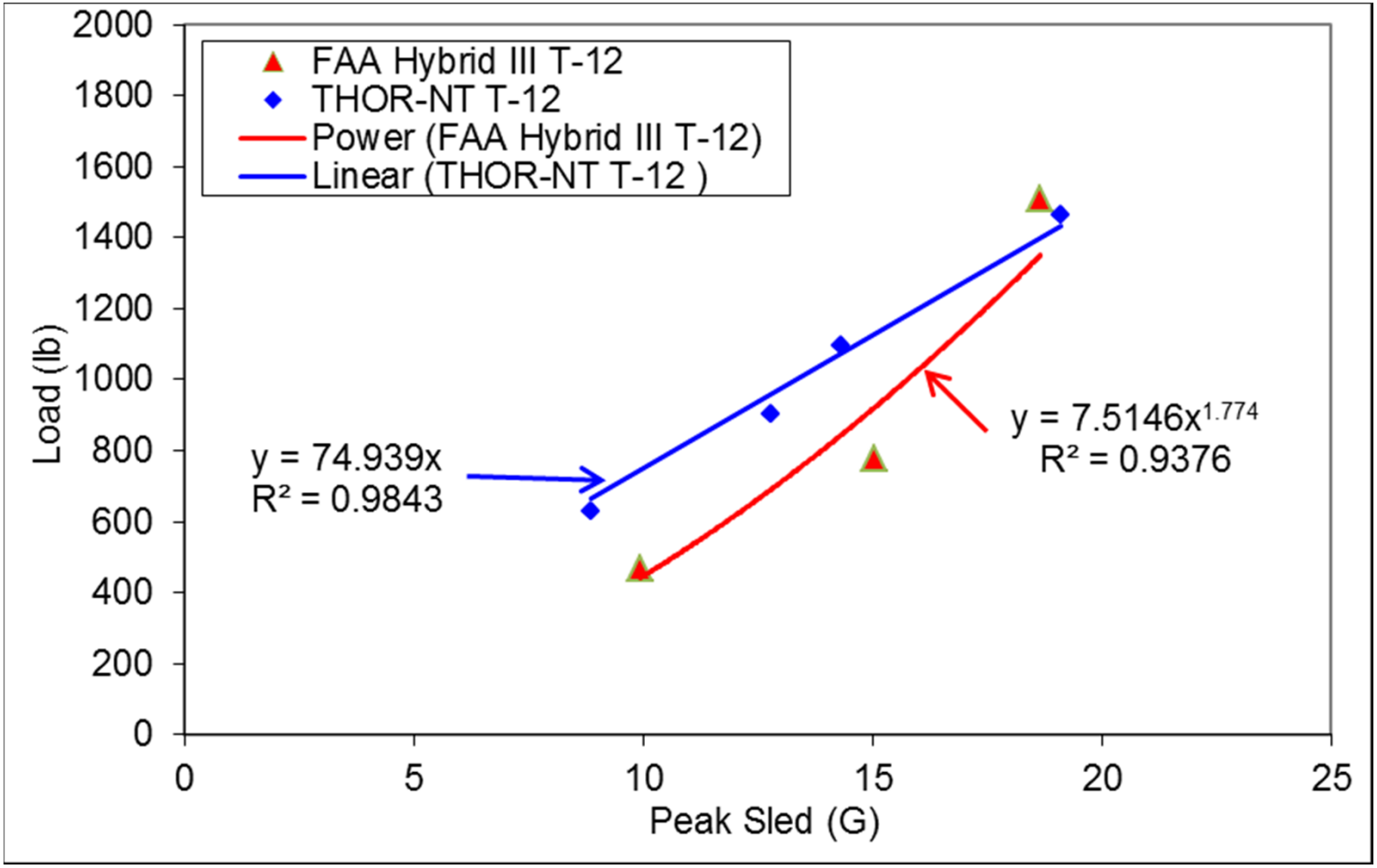
- **Hybrid II was stiffer than the FAA Hybrid III**
- **Relative error between the lumbar loads**
  - 9 G = 8%
  - 14 G = 10%
  - 19 G = 4%
- **Error within 10%**
- **Small sample size**

$$\text{Relative Error} = \frac{\text{FAA Hybrid III Lumbar Load} - \text{Hybrid II Lumbar Load}}{\text{Hybrid II Lumbar Load}}$$

T-12 versus Lumbar Load for FAA Hybrid III



Load vs Sled Acceleration for Thor and FAA Hybrid III



Discussion

- **Direct injury evaluation was originally made with the Hybrid II**
- **Using DRI and lumbar load a limit of 1500 lbs is a 5% risk of a detectable spinal injury**
- **Hybrid II was stiffer than the FAA Hybrid III**
- **Relative error between the Hybrid II and FAA Hybrid III was 10% or less supporting equivalency**

Discussion

- **Hybrid II and FAA Hybrid III lumbar load did not exhibit a linear trend with respect to sled acceleration suggesting the ATD is rate sensitive**
- **Same spinal unit for both Hybrid ATDs, currently no dynamic calibration exists, but would be appropriate to ensure consistent results for certification**
- **No T-12 limit has been established**
- **For FAA Hybrid III T-12 and Lumbar exhibited linear relationship**
- **FAA Hybrid III T-12 was less than the THOR-NT T-12, at the lower loading rates, but higher at 19 G**

Conclusion

- **Based on the tests run in this series, the THOR-NT would not be considered an equivalent ATD to the Hybrid II for vertical testing**
- **Thor does not exhibit same rate sensitivity as FAA Hybrid III which precludes a simple transfer function between them.**
- **Additional research is needed to determine appropriate lower thoracic spine injury metrics**

Questions?

References

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