Dr. Paver

President, Center for Injury Research, a nonprofit 501.3c

Education:

- B.S., 1977, Harvey Mudd College
- M.S., 1980 and PhD, 1985, Duke University

Expertise:

- Physical testing of fresh cadaveric and ATD necks and lumbar spines at Duke University
- WPAFB Summer Faculty fellowship and follow-up research grants 1987-1989: Testing, modeling, and troubleshooting lab snafus
- Membership in SAE Dummy Users Group since 1987 and recently in SAE Aircraft Seat Committee
- Finite-element WPAFB Head-Spine Model and LS-DYNA simulations and lumped-parameter ATB modeling of automotive, aerospace and other injury-producing environments
- Full-scale dynamic rollover crash testing with ATDs and development of a more biofidelic compliant neck for physiological loading
- 35 years of expert biomechanical engineering analysis of real-world injuries

AAL Task Order 2 GOAL: To Facilitate a Safe Environment for the New Small and Pregnant Female Aircrew Population

MOTIVATION: Until recent years, aircrew have been mostly 50th to 95th percentile males. The design of the aircraft occupant compartment, catapult thrust, helmets and head-supported masses has focused on the safety of that population.

STI-TEC Work-To-Date: Extensive anthropometric studies to optimize the operational functionality of the aircraft occupant compartment and aircrew PPE have been performed.

MY FOCUS: To address the prevention and mitigation of female aircrew injury by:

1. Identifying spinal and fetal injury patterns and mechanisms due to the aircrew loading
2. Evaluating and updating the criteria used to assess spinal and fetal injury potential in the aircrew environment
3. Physical and virtual testing as tools to evaluate the effects of seats and catapult thrust, helmets, HMDs, NVGs, etc. on spinal injury potential and restraint systems on fetal injury potential

Proposed Research Projects:

- Specify lower neck and lumbar injury metrics for the evaluation of helmet and other head-mounted devices
- Implement patented programmable catapult ejection seats that reduce accelerations and spinal injury potential for small and pregnant female aircrew
- Evaluate and implement alternate restraint systems for pregnant aircrew to reduce fetal injury potential

Aircrew Loading Conditions and Injury Patterns

Ejection Catapult Thrust Phase:

- **Occupants experience > 9 G's multi-axial loading**
- **Injury Patterns**: Lower neck and thoracolumbar **(We rarely see upper neck injury)**
  - Compression, burst, and wedge fractures
  - Bilateral facet dislocation
  - Lateral bending and compression-extension injury
  - Fetal injury

Parachute Opening Phase:

- **Injury Patterns:** Neck and low back pain/fatigue, unilateral facet dislocation and extension, tension, and torsion AIS <=2 soft tissue ligamentous and disc injuries.

Parachute Landing Phase:

- **Injury Patterns:** Thoracolumbar spinal compression fracture, leg and ankle compression, bending, torsion injury and foot compression fracture

Aircrew Loading Conditions and Injury Patterns

Blast:

- Impact level: >9 g
- **Injury Patterns**: Lower neck and thoracolumbar compression, burst, and wedge fractures, bilateral facet dislocation, lateral bending, and compression-extension injury… rarely upper neck.

High-G maneuver:

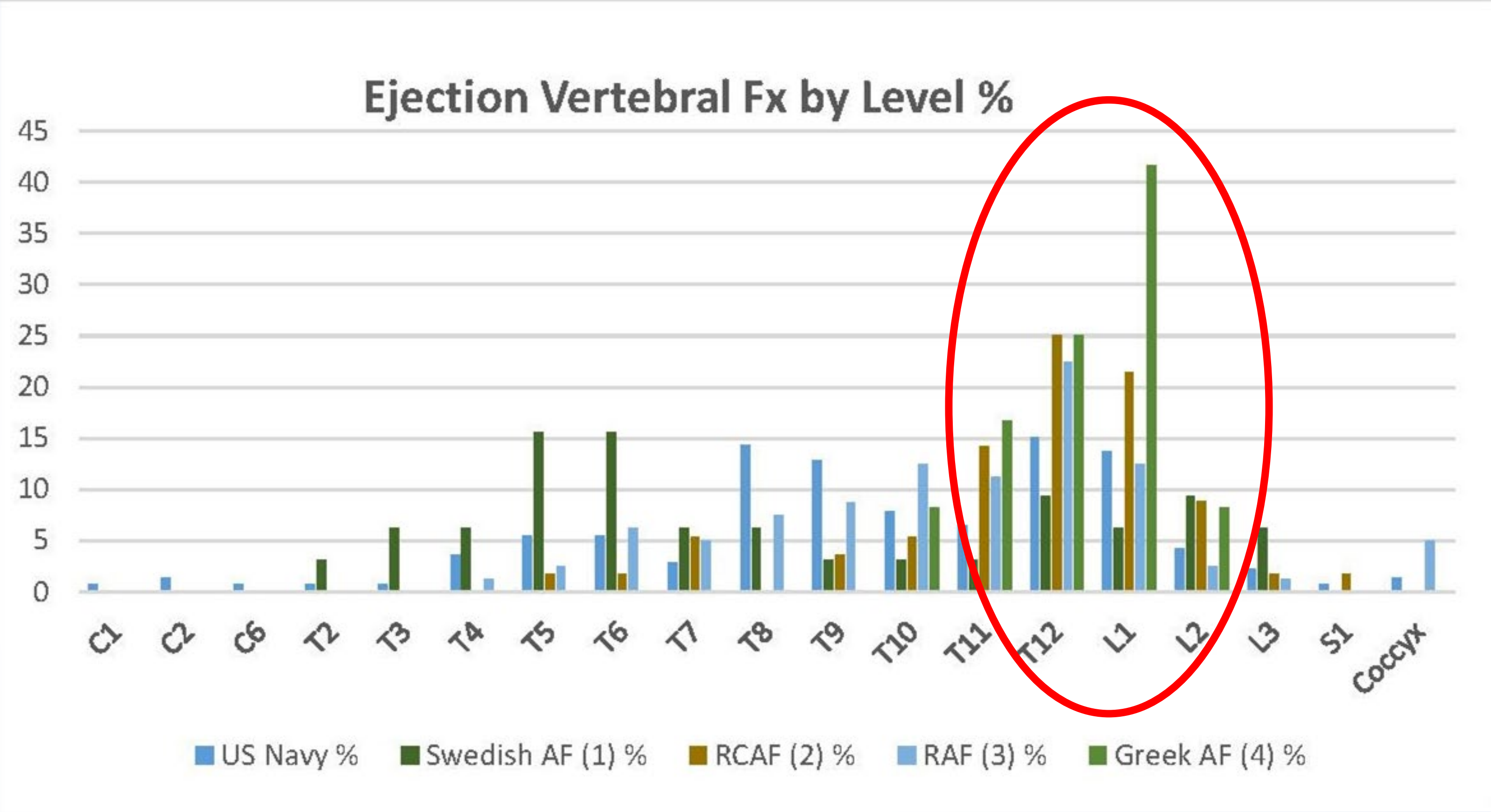
- Impact level: 4~9 g
- Duration: 200~400 ms
- **Injury Patterns**: Neck and low back pain/fatigue, unilateral facet dislocation and extension, tension, and torsion AIS <=2 soft tissue ligamentous and disc injuries.

Vibration:

- Acceleration level: low < 4g
- Duration: Persistent
- **Injury Patterns:** Motion sickness, neck and low back pain/fatigue, disc deterioration, herniation.

Nonfatal Vertebral Ejection Fracture Levels 1958-1969

Ewing, 1971



Ejection Vertebral Fracture Levels 1977-2021

Sommer et al., 2022

TABLE 2. Spine injuries of the included aircrew members

Spine Injury	No. (%)
Fracture	66
C2	3 (4.5%)
C3	1 (1.5%)
C4	1 (1.5%)
C6	2 (3.0%)
T3	2 (3.0%)
T4	1 (1.5%)
T5	2 (3.0%)
T6	2 (3.0%)
T7	2 (3.0%)
T8	7 (10.6%)
T9	2 (3.0%)
T10	5 (7.6%)
T11	9 (13.6%)
T12	12 (18.2%)
L1	12 (18.2%)
L2	1 (1.5%)
L3	2 (3.0%)
Soft-tissue injury	31
Contusion	27 (87%)
Disc protrusion	2 (6.5%)
Disc herniation	
T11–12	1 (3.25%)
L5–S1	1 (3.25%)

66 Vertebral Fxs

Neck: 11% (7)

T-Spine 67% (44)

L-Spine 23% (15)

Total aircrew = 103

1.9 fxd vertebra per crew member

Physical v. Virtual Testing

to Evaluate Ejection Seats, Helmets, HMDs or NVGs, Anthropometry, etc.

Physical Testing is important, but often limited due to:

- cost of test equipment, personnel, instrumentation and ATD maintenance and calibration
- ATDs like ADAM, LOIS, LARD, Hybrid II and III are 20-30 years old and degradation is a huge problem due to age or excessive loading
- difficulties obtaining replacement LOIS or LARD dummies and parts

Virtual Testing allows parametric studies to be performed without test limitations varying:

- occupant anthropometry
- seat and restraint parameters
- helmet, HMD, NVG weight, cg, and moment of inertia
- input pulses including multiaxial loading
- occupant positioning and ATD setup

Aircrew Surrogates

5th Female, Pregnant Female, 50th Male, 95th Male

- **Human Volunteer**
- **Human Cadaver (PMHS)**
- **Frontal ATD (FAA, NHTSA Hybrid II and III, THOR)**
- **Side Impact ATD (SID, Biosid, Eurosid, WorldSid)**
- **Rear Impact ATD (RID, RID2, Biorid)**
- **Air Force ATD (ADAM, GARD, LOIS, LARD)**
- **Navy Blast ATD (WIAMAN)**

ATDs

Hybrid II	1972
Hybrid III	1976
SID,BIOSID,EUROSID	~1980
ADAM	1984
GARD	<1991
LOIS	<1999
LARD	<1999
THOR	2001
WAIMAN	2011

ATD Spine

The WPAFB ATDs have neck and thoracolumbar spines that are NOT BIOFIDELIC in axial loading, bending, shear, torsion or combined loading. The ATD necks and thoracolumbar spines are much stiffer than the human neck.

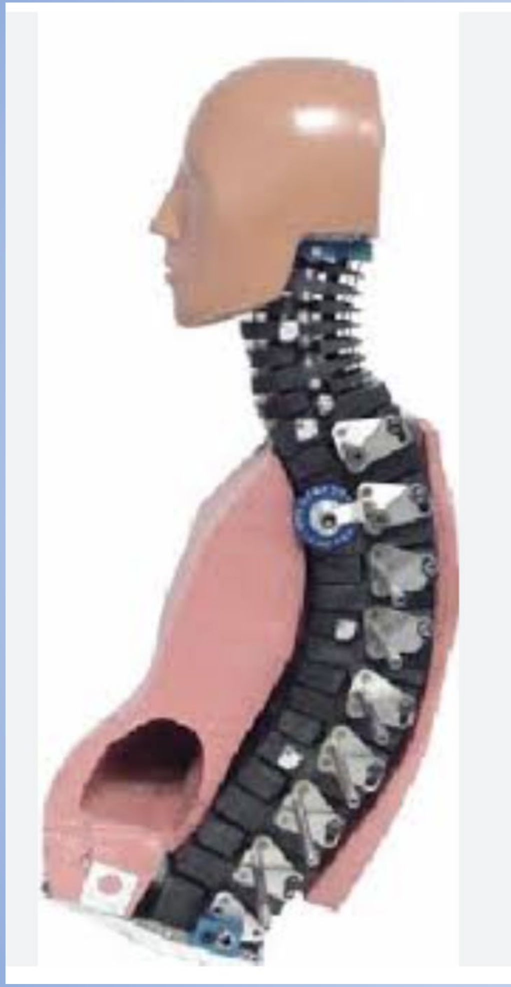
Unlike the human spine with energy-absorbing intervertebral discs, the ATD neck has NO COMPLIANCE in vertical loading.

The state-of-the-art rear impact BIORID, side impact WORLDSID, and frontal impact THOR ATDs have the most biofidelic necks and thoracolumbar spines of all the ATDs.

For the best prediction of aircrew injury, physical and virtual tests to evaluate helmets NVG's and other head-supported masses could be performed with necks and thoracolumbar spines adapted to WPAFBs LOIS, LARD, and H3 ATDs (BIORID for -Gx, THOR for Gx, and WORLDSID for Gy).

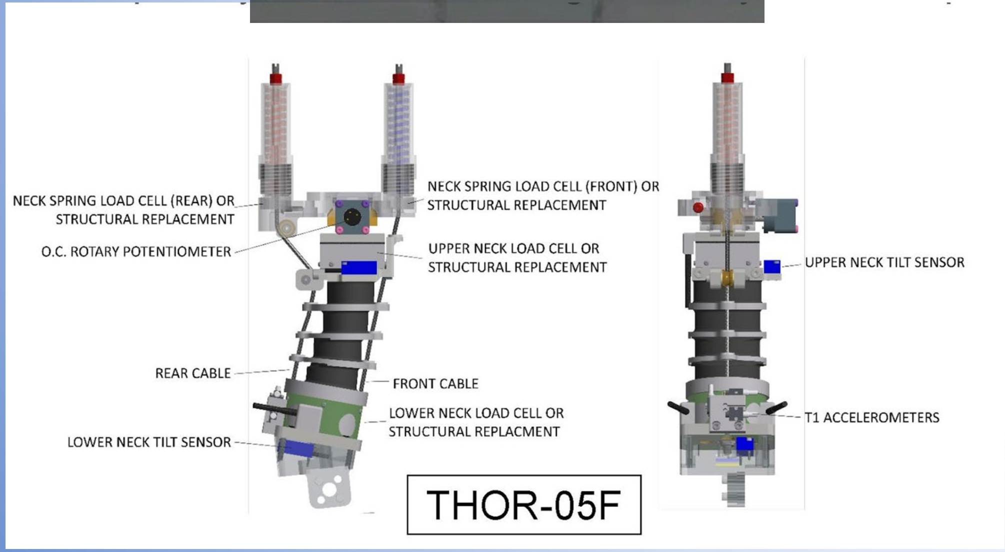
To account for the known prevalence of lower neck and thoracolumbar spine injuries, metrics at these locations must be specified as injury criteria.

BIORID

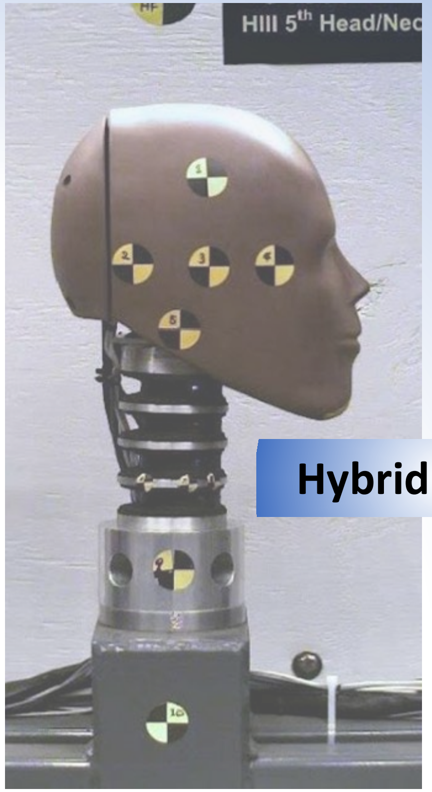


WORLDSID

THOR Neck

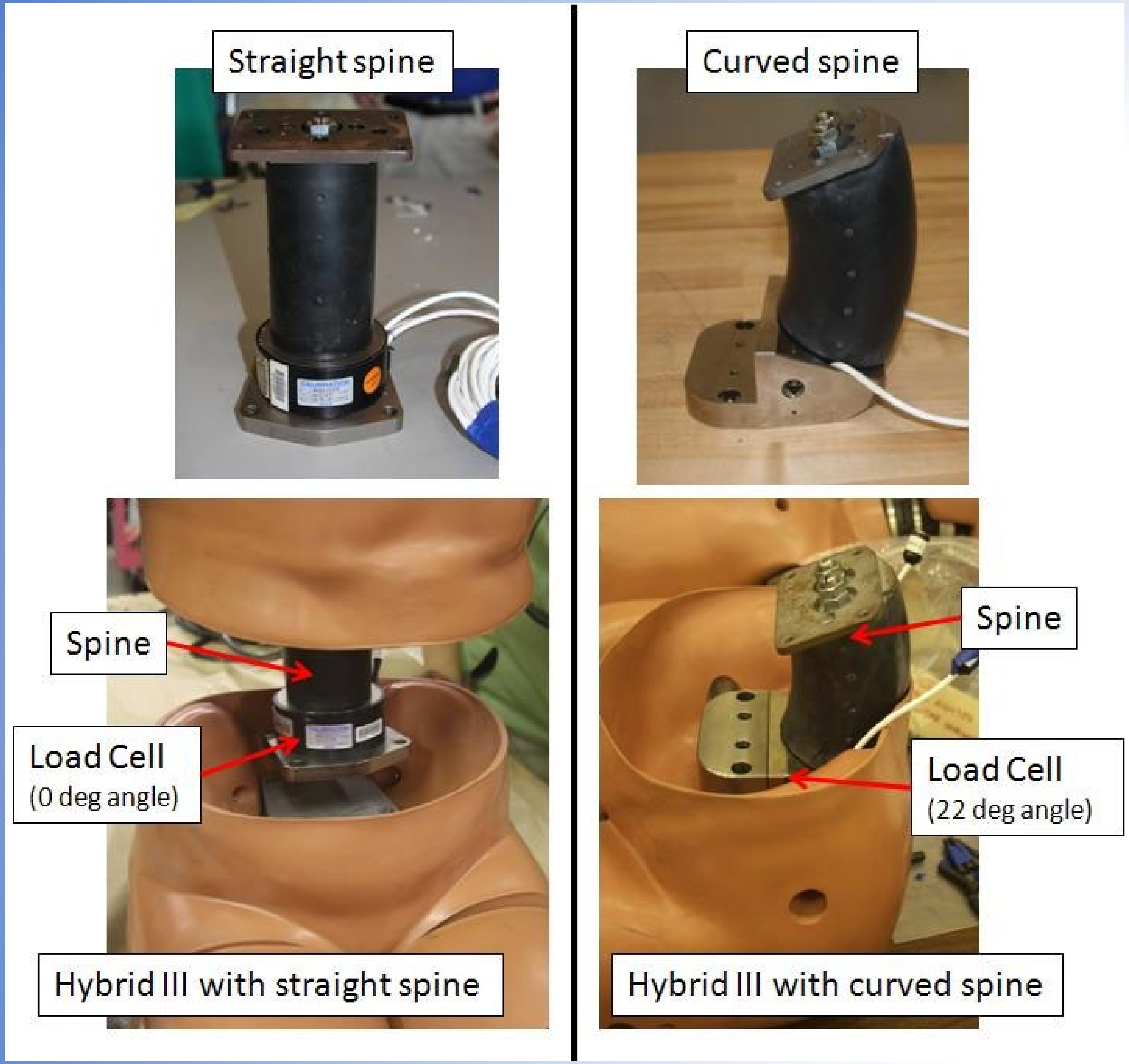


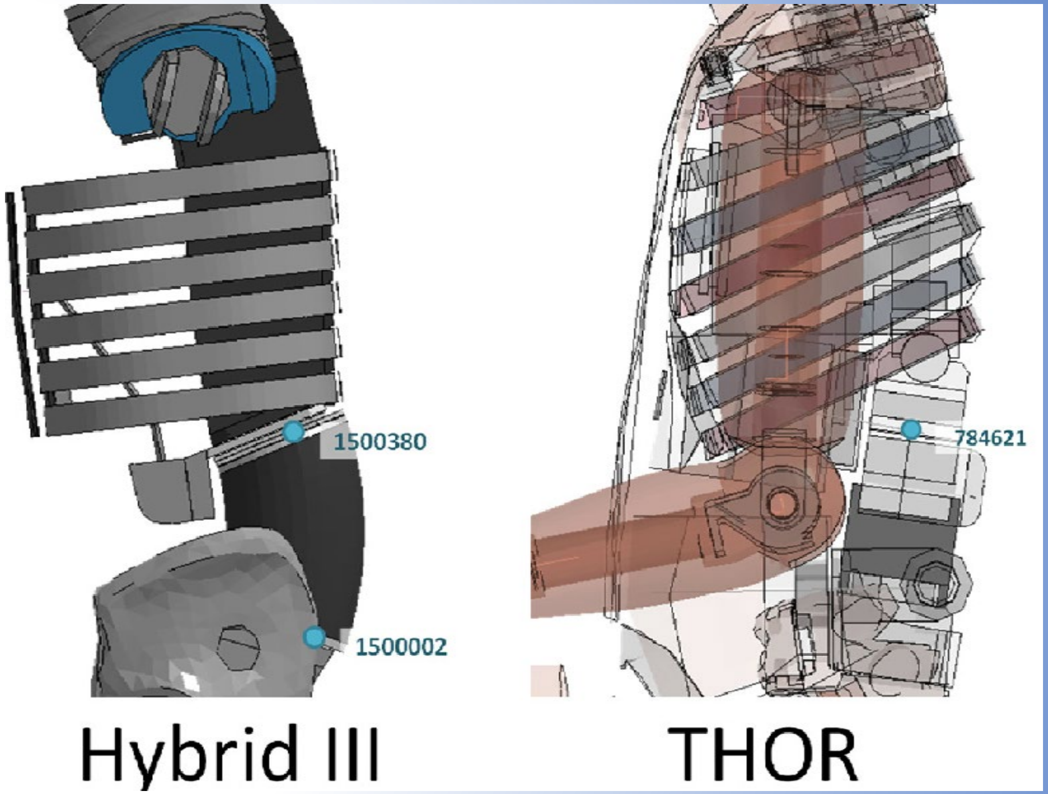
Hybrid III Neck



Hybrid II Neck

Lumbar Spines





Injury Metrics

	Injury Risk	Risk Function	Multi-Axial?	ATD sizes	Location	Validated for HSM
MANIC	5% for AIS>=2	Yes	Axial load, shear, bending, and torsion	5th, 50th, 95th	Upper Neck	YES
NIC	10% for AIS>=3	Yes	Axial load, shear, bending, and torsion	5th, 50th, 95th	Upper and Lower Neck	YES
Nij (NHTSA)	22% for AIS>=2	Yes	Axial load and flexion-extension	5th, 50th, 95th	Upper Neck	NO
Beam Criterion BC	50% for AIS>=2	Yes	Axial load and flexion-extension	50th	Lower Neck	YES
LNic	50% for AIS>1	Yes	Axial load and flexion-extension	5th, 50th, 95th	Lower Neck	N/A
Knox Box	NO	NO	N/A	N/A	N/A	YES
Eiband	5% for AIS>=2	Yes	Axial load	5th, 50th, 95th	Thoracolumbar	YES
DRI	5% for AIS>=2	Yes	Axial load	5th, 50th, 95th	Thoracolumbar	YES
Forces/Moments		Yes	Axial load and flexion-extension		Thoracolumbar	

Despite known prevalence of lower neck and thoracolumbar spine ejection injuries, Upper Neck MANIC is the ONLY metric used to predict spinal injury in the WPAFB lab.
WPAFB does not use thoracolumbar spine metrics in the evaluation of seats and devices.

Catapult Thrust

$Force = m*a = (w/g)*a = (w_{male}/g)*a_{male} = (w_{female}/g)*a_{female}$

- ➢ $a_{female} = (w_{male}/w_{female})*a_{male}$

For a given catapult thrust force, accelerations experienced by a 200# male v. 100# female:

$Accelerations_{female} = 2x\ Accelerations_{male}$

Variable Programmable Catapult Thrust Ejection Seats

Ejection Seat Having Combined Catapult/Rocket Motor Providing Selectable Thrust, EU Patent Application 386113387.4, 1986: The invention is an aircraft ejection seat with combined catapult and rocket motors, where the amount of thrust after ejection is selectable.

Controllable Ejection Seat Catapult, US Patent #4706909, 1987: The invention is an aircraft ejection seat catapult, which provides controllable acceleration to the thrust of the seat to prevent aircrew injury.

Variable Thrust Catapult, US Patent #11300078 B2, 2022: The invention is an escape system with variable thrust catapults for different weight occupants.

Automatic Ejection Seat Performance Optimization Based on Detection of Aircrew Weight, US Patent #11518527 B2, 2022: The invention is an ejection system that includes a sensor configured to detect aircrew weight, a controller coupled to the ejection system and to the sensor that adjusts thrust based on the aircrew weight, and automatic optimization based on aircrew weight.

Variable Programmable Catapult Thrust Ejection Seats

Patents **EXIST** of controllable catapult pulse ejection seats that automatically adjust the thrust that the aircrew experiences based on aircrew weight to reduce the risk of spinal injury.

Collins Aerospace was slated to deliver >3,000 Next-Generation ACES 5 Ejection Seats by 2020 that accommodate the full anthropomorphic range (103-245-pound aircrew). The ACES rocket catapult uses a variable burn profile to provide more energy for heavy aircrews and less for lighter aircrews, varying accelerations between 9 to 12 G's,

In 2021, Irish Times reported the Irish Air Corps is working with Martin-Baker to lower aircrew weight requirements and risk of serious ejection injury due to the strength of the ejection mechanism. The seat modification requires less powerful explosive cartridges to accommodate a broader range of weights.

Implementation:

- Weight-sensing seat as in automotive seats for airbag inflation, or
- Simple manual switch set by the aircrew upon entry

Easy-Peasy

Pregnant Female Aircrew

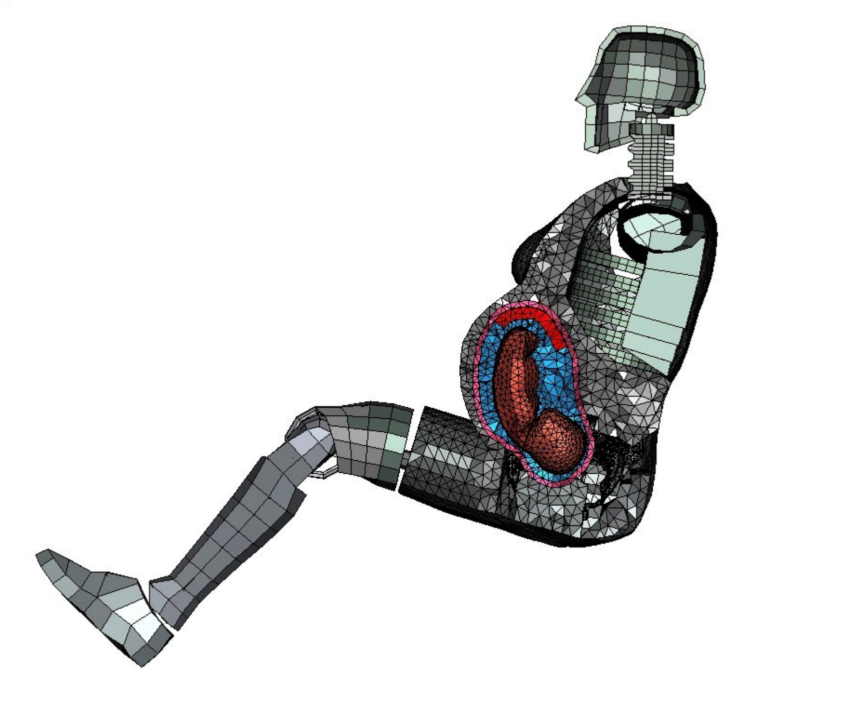
Fetal injuries are typically restraint related…

- **Current Solution:** Waivers
- **Proactive Best Solution:** Replacement of standard seats with seats equipped with redesigned restraint systems that protect the fetus during ejection

Easy-Peasy

Pregnant Female Aircrew Safety

- **The MAMA-2B pregnant abdominal insert is adapted for the existing H3 5th %ile dummy. We do not need to buy an entirely new dummy.**
- **Volvo has a finite element model of the pregnant female.**
- **I propose we acquire and evaluate the MAMA-2B abdominal insert and associated instrumentation, and adapt the Volvo model for the female pregnant aircrew population identified by anthropometric studies.**
- **Since there are no abdominal injury measures to assess fetal injury potential in the aircrew environment, we will need to develop injury metrics. As a preliminary effort, we can use established injury measures used in the automotive industry.**



CONCLUSIONS

- **Aircrew spinal injury locations, patterns and mechanisms are well-documented**
- **Physical and virtual testing are valuable tools for seat, helmet, HMD, NVG evaluation**
- **Proposed Research Projects:**
  - **Specify lower neck and lumbar injury metrics for the evaluation of helmets and other head-mounted devices**
  - **Implement patented programmable catapult ejection seats that reduce accelerations and spinal injury potential for small and pregnant female aircrew**
  - **Evaluate and implement alternate restraint systems for pregnant aircrew to reduce fetal injury potential**