Supplemental Injury Risk Considerations for Aircraft Side-Facing Seat Certification

Federal Aviation Administration

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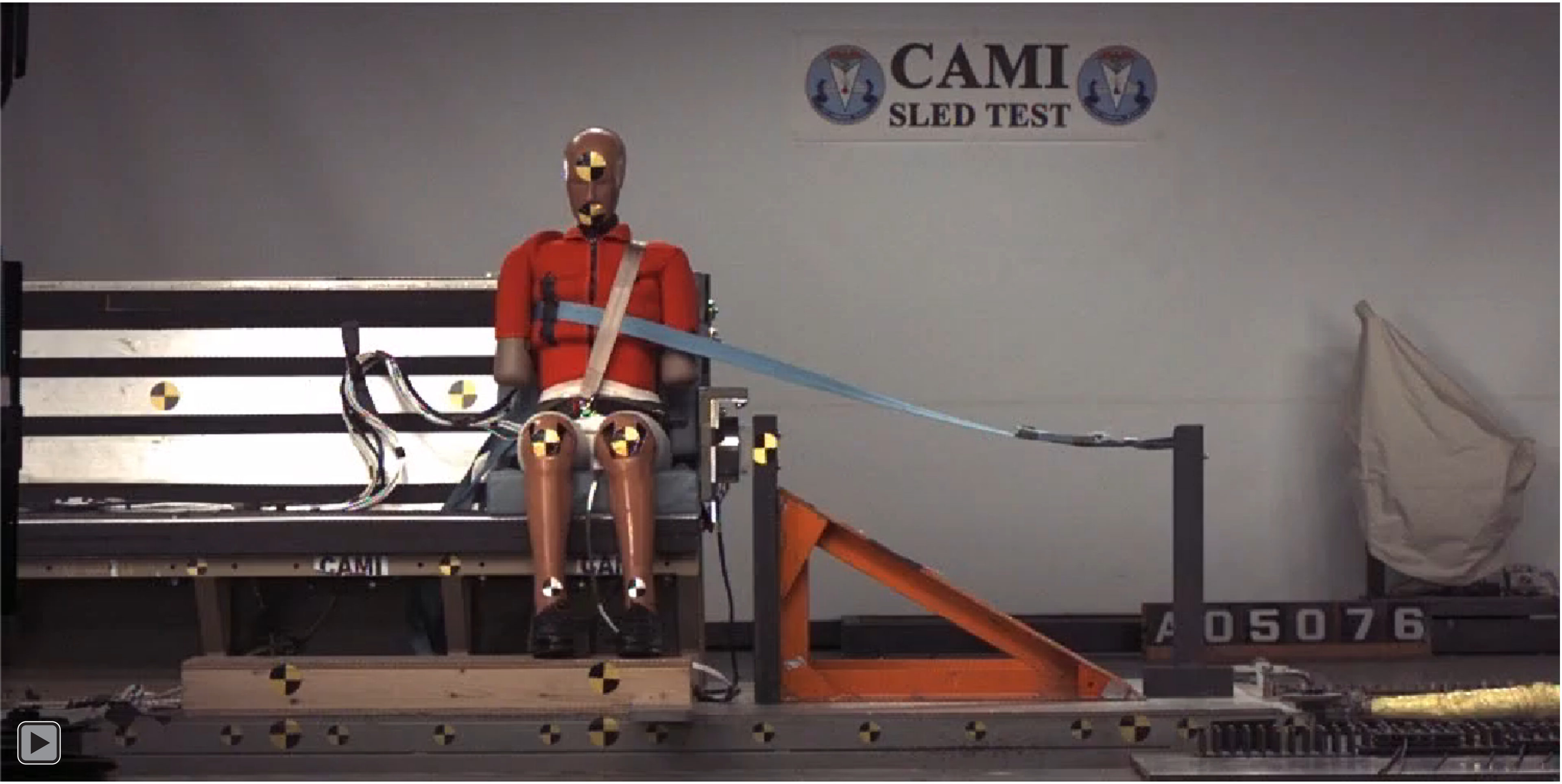
Introduction



Introduction

- **PS-ANM-25-03-R1 defines the technical criteria for approving side-facing seats that provides an equivalent level of safety to forward facing seats [2012].**
- **Industry feedback has highlighted that additional guidance is needed:**
  - Risk of leg injury
  - Protection of occupants during crashes that are not severe enough to deploy inflatable restraints
  - Risk of injury due to submarining during rebound

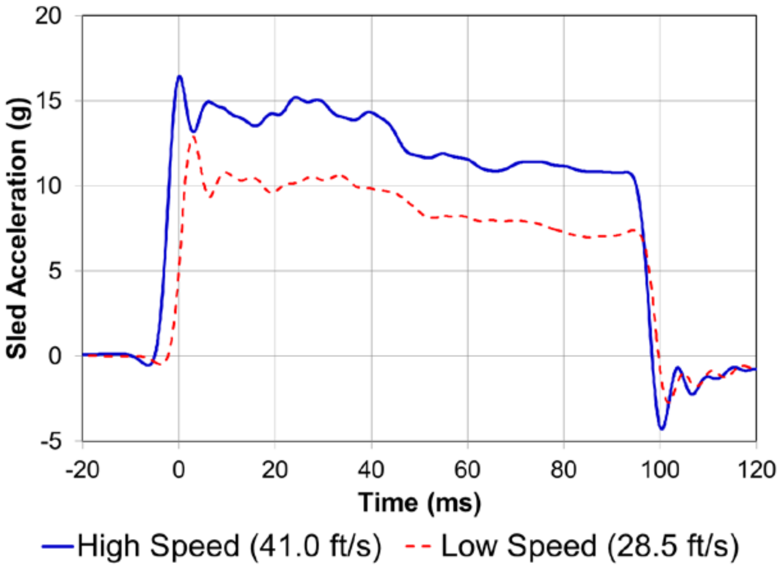
Leg Injury

- **High axial moments in the femur produced by inertia forces acting on the lower leg can result in injury to the occupant that would prevent egress and could be fatal (e.g. spiral fracture in femur).**

X-ray courtesy of Medical College of Wisconsin (MCW)

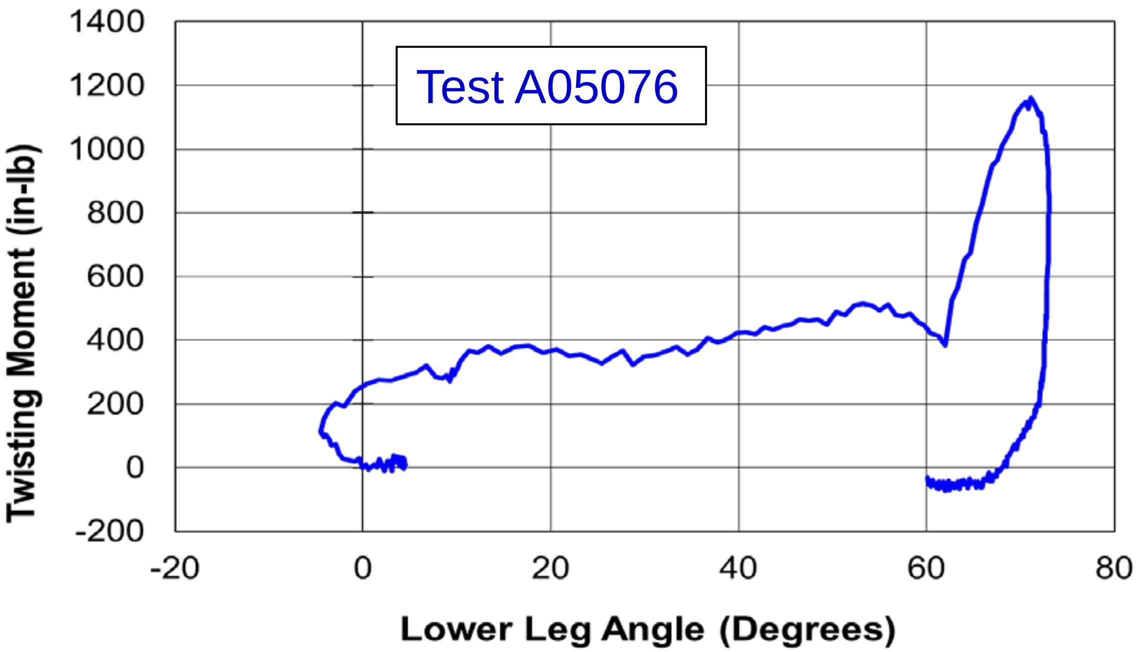
Post Mortem Human Subject (PMHS) Leg Injury

- **Four PMHS tests at MCW**
- **Two tests @ 41 ft/s produced serious leg injuries.**
  – Peak angle of 89° (estimated)
- **Two tests @ 28.5 ft/s did not produce leg injury.**
  – Peak angle of 55-59° (estimated)

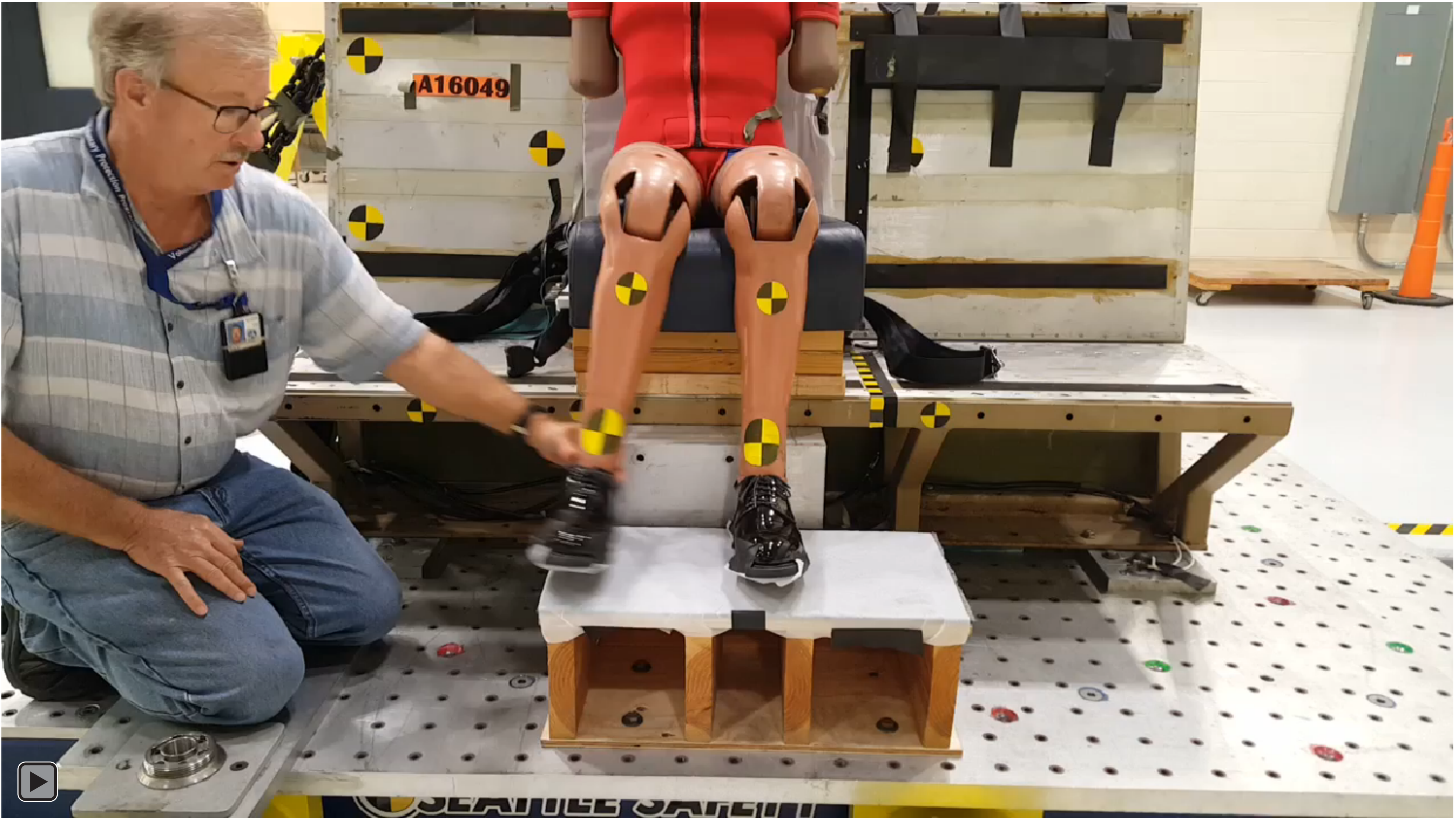


ATD Leg Rotation

- **Maximum ATD leg rotation was identical for both impact severities.**
- **ES-2re demonstrates poor coupling between torque and the amount of rotation.**



ATD Leg Rotation



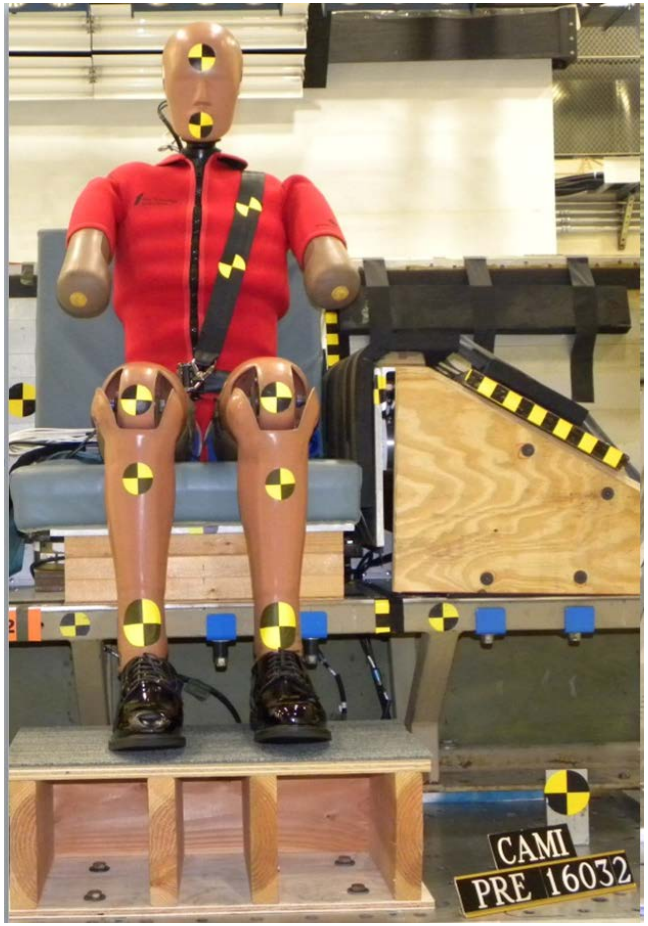
ATD Leg Rotation

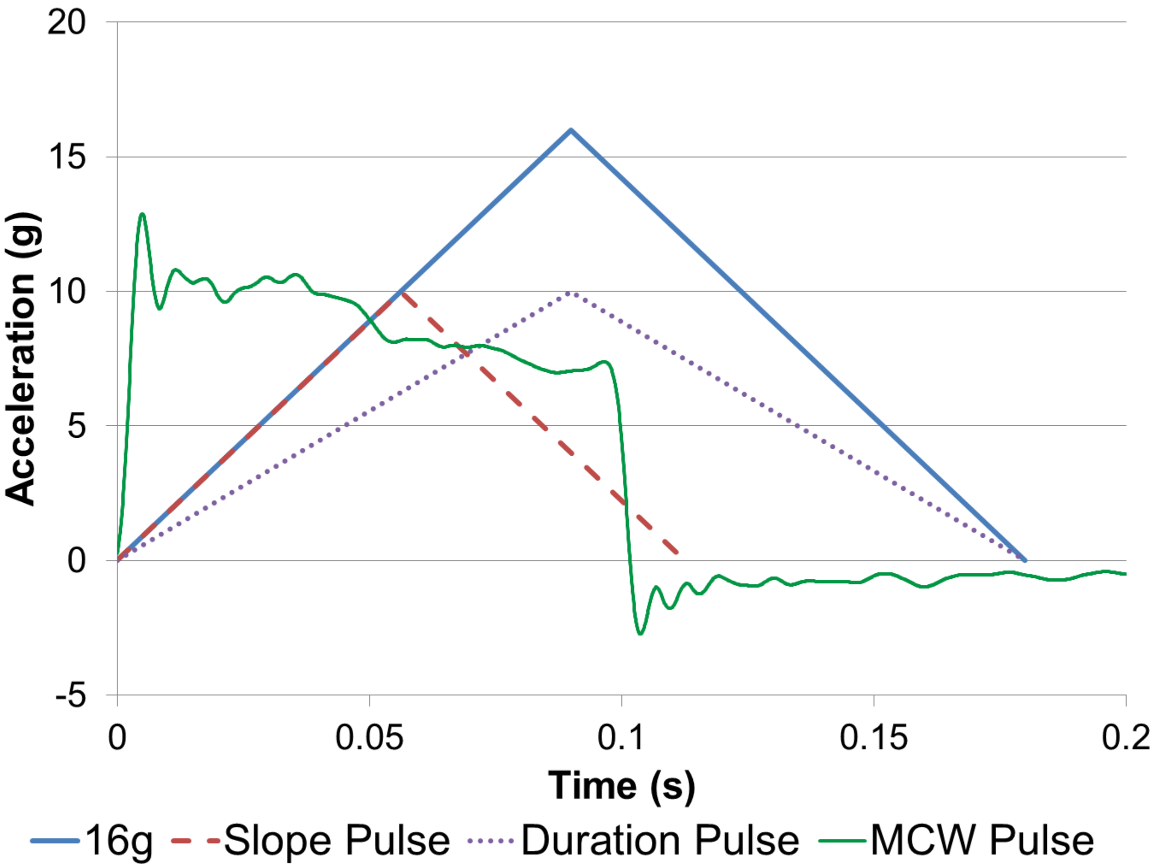
- **Since the ES-2re legs have the same weight distribution and joint articulation range as an average adult male, it is useful for assessing the effectiveness of leg flail mitigation strategies.**
  - i.e. we can get a go/no-go on if the mitigation strategy works.

Airbag Threshold Tests

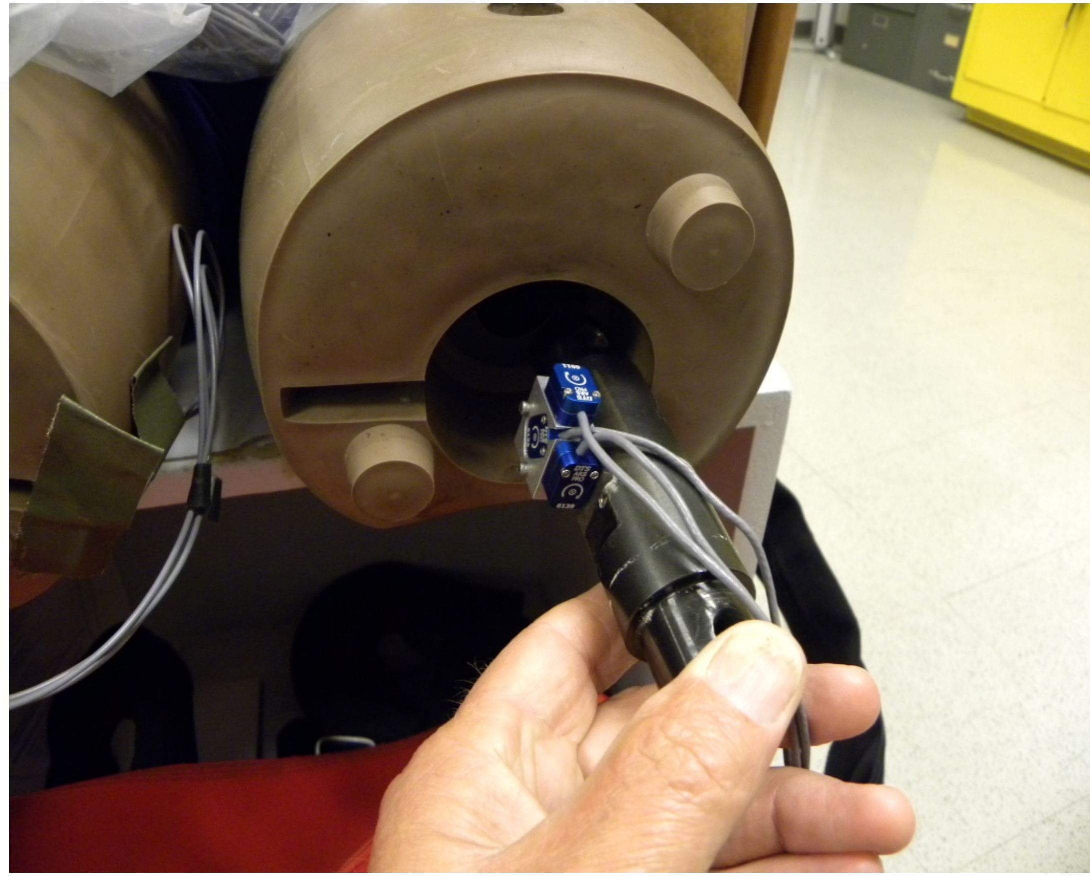
- **Airbag Special Conditions require that the airbag not deploy when it is not needed, in part so that the airbag is available to deploy in the event of a subsequent, more severe impact.**
- **The airbag is designed to only deploy when a design-specific threshold is exceeded.**
- **Special Conditions also state that it "must be shown that the [airbag] will deploy and provide protection under crash conditions where it is necessary to prevent serious head injury or head entrapment."**
- **To demonstrate compliance, a low-G test is included in seat qualification programs to demonstrate that the seat system does not pose an injury risk for impacts with a severity just above the threshold at which inflatable restraints would deploy.**
- **The low-G test is defined by the applicant and is application specific.**

Airbag Threshold Tests (3)





Leg Rotation Instrumentation



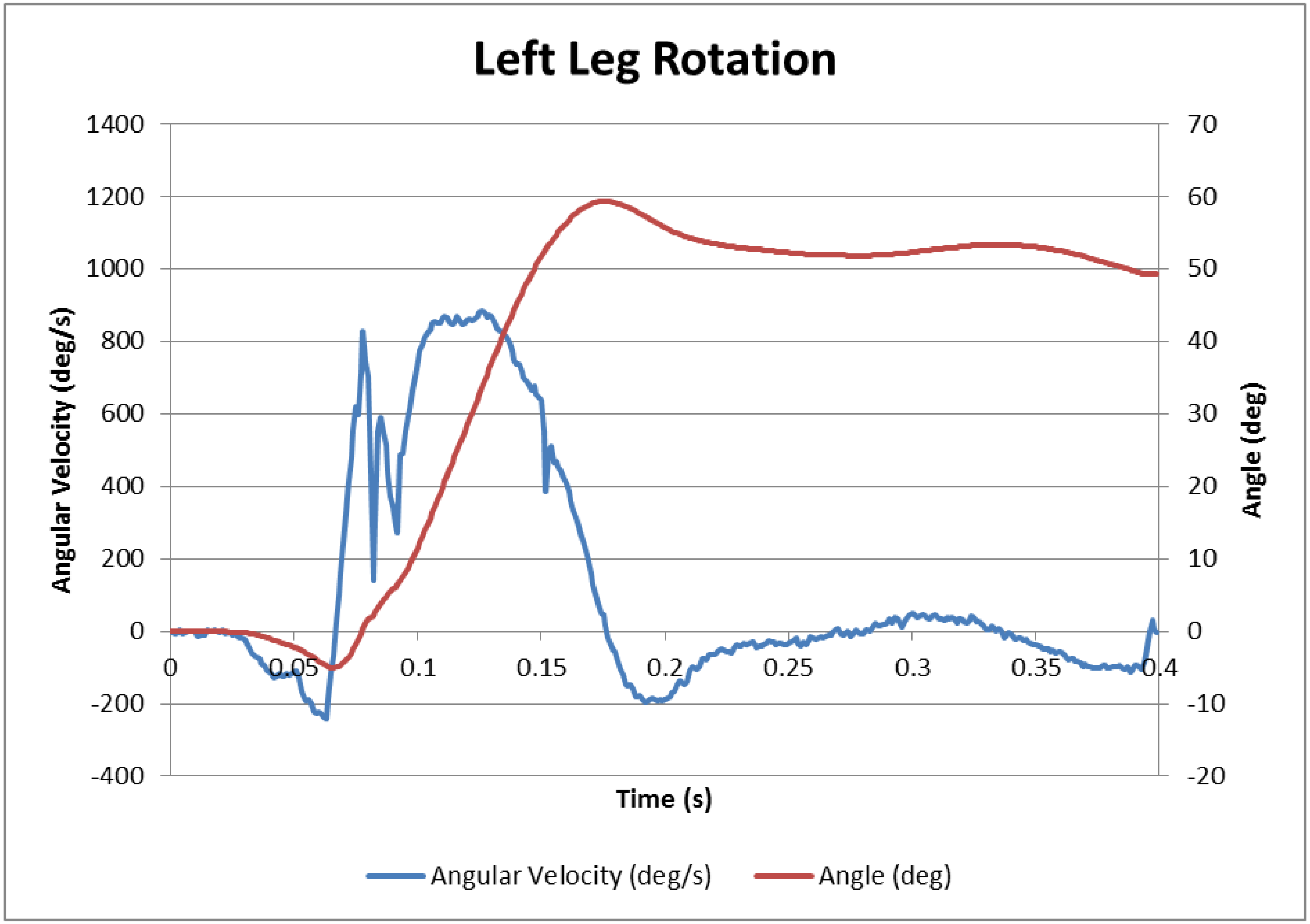
Left photo from Robert Huculak (NIAR)

Airbag Threshold Tests

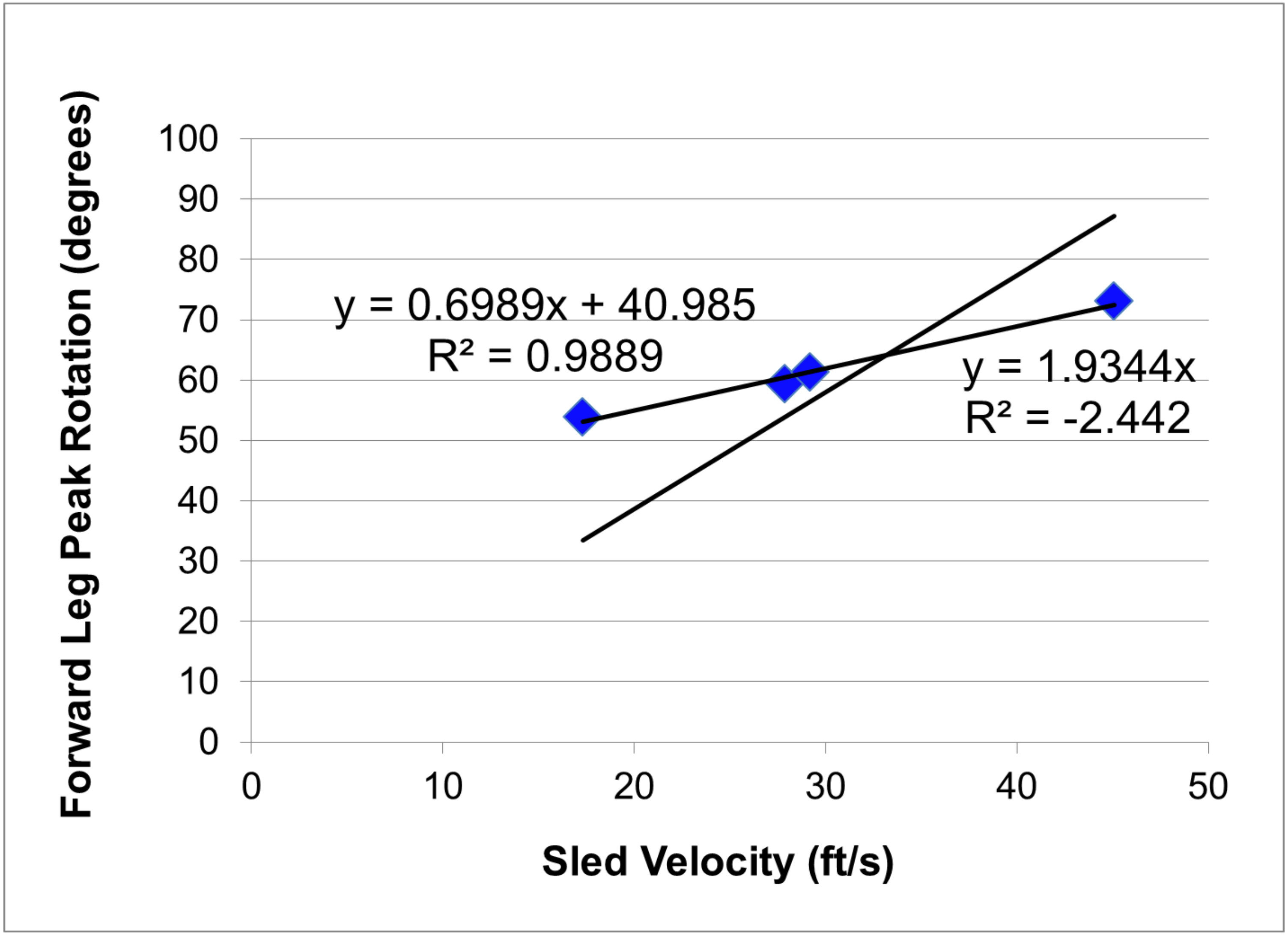
Pulse	Limit	Research Pulse	“Duration” Pulse	“Slope” Pulse
Test Number		A16031	A16033	A16032
Peak G's		11.3	9.9	9.7
Average G's		7.76	4.73	4.93
Velocity (ft/s)		27.9	29.2	17.3
Shoulder Strap Load (lb)	1750	1109	1011	542
Max Shoulder Belt Payout (in)		0.8	0.55	0.55
Upper Rib Deflection (in)	1.73	0.00	0.00	0.02
Middle Rib Deflection (in)	1.73	0.05	0.03	0.07
Lower Rib Deflection (in)	1.73	0.38	0.47	0.31
Sum Abdominal Force (lb)	562	151	178	91
Pubic Symphysis Force (lb)	1350	347	267	228
Upper Neck Tension (lb)	405	*558*	*463*	233
Upper Neck Compression (lb)	405	1	1	1
Upper Neck Bending Mx (in-lb)	1018	485/-350	477/-255	394/-293
Upper Neck Shear Fxy (lb)	186	*201*	181	145
Left Leg Rotation (degrees) *	35	*59*	*61*	*54*
Right Leg Rotation (degrees) *	35	*62*	*61*	*53*
T1 Ay (g)		33	31	18
Upper Rib Ay (g)		33	34	19
Middle Rib Ay (g)		29	30	16
Lower Rib Ay (g)		43	41	26
Pelvic Ay (g)		28	21	23
Center Belt Anchor Force (lb)		537	431	401
Trailing Belt Anchor Force (lb)		1057	960	599

*Red denotes value exceeds the limit

Leg Rotation



Leg Rotation



Leg Rebound Response

- The lack of biofidelity of the ES-2re hip rotation stiffness means low energy can still create high rotation during rebound.
- The maximum femur rotation angle limit may not be applicable to the legs during their rebound as long as the method of mitigation does not return excessive energy to the legs.
- This applies to both the full 16g test and any threshold tests.

Trailing Leg Flail Limit Assessment

- Femur limit is based on an angle known to be non-injurious for the average person i.e. the normal range of hip motion.
- The source of that limit cites the same angles for both internal and external hip rotation.
- In feedback from industry, it has been noted that the ATD legs can cross in the 10° yaw test and there is a belief that the normal range of human motion is actually greater for external rotation than for internal rotation.

Trailing Leg Flail Limit Assessment

- **However, the “leg crossing movement” cited as the basis for this observation actually involves hip motion in multiple axes (flexion, abduction, and external rotation), rather than the single axis motion limited in the policy.**
- **During the loading phase of a lateral impact, it is unknown whether the hip joint of the trailing leg would exhibit these additional degrees of freedom.**
- **Before a change in the external rotation limit is considered, more information is needed.**

Submarining

- **Occupant retention and support requirements in PS-ANM-25-03-R1are:**
  - g. Occupant (ES-2re ATD) retention: The pelvic restraint must remain on the ES-2re ATD's pelvis during the impact and rebound phases of the test. The upper-torso restraint straps (if present) must remain on the ATD's shoulder during the impact.
  - h. Occupant (ES-2re ATD) support: (1) Pelvis excursion: The load-bearing portion of the bottom of the ATD pelvis must not translate beyond the edges of its seat's bottom seat-cushion supporting structure.
- **In some development tests, the lap belt was partially bearing on the ATD abdomen during rebound (a position currently prohibited).**
- **For the reviewed development tests, by the time the lap belt moves up off the pelvis during rebound, the belt loads had dropped significantly.**

Submarining

- **Post Mortem Human Subjects (PMHS) dynamically tested with a loop of seat belt webbing centered on the front of the abdomen.**
- **The applied loads that produced injury ranged from 920 lb to 2170 lb.**
- **The loads that produced no injuries were mostly between 625 lb and 1285 lb, although one no injury test was as high as 2260 lb.**

Submarining

- **ES-2re has an abdominal injury criteria based on the sum of the force applied to three load cells mounted under the abdomen on the leading side of the ATD [562 lbs].**
  - Intended to measure lateral contact forces with adjacent structures (e.g. an armrest).
- **500 lb loop load applied laterally would produce a reaction force in the ES-2re abdomen that is in the same range as the 562 lb abdominal load limit defined in the side-facing seat policy.**
- **Since the lap belt could load areas of the abdomen that are not directly over the load cells, using the output of those cells to assess the risk of belt induced injury is not adequate.**

Submarining

- **250 lb lap belt tension limit (one half of a 500 lb loop load) would be in line with the 562 lb ES-2re contact force limit and be conservative with respect to lowest injury point (920 lb loop load) from the PMHS test data.**

Submarining

Three things are needed for this evaluation:

1. **a clear indication of when the belt moves above the pelvis,**
2. **a measurement of the belt tension during the time when the belt moves above the pelvis,**
3. **useful video and belt load data must be recorded until significant ATD rebound motion stops.**

Submarining

Observations

- **For airbag threshold tests, any input acceleration that produces energy below the 28.5 ft/s test case should not result in serious leg injury and therefore the 35° leg rotation limit could be exempted for these tests.**
- **The maximum femur rotation angle limit should only apply to the loading phase as long as the method of mitigation does not return excessive energy to the legs during rebound.**

Observations

- **Unless further research suggests otherwise, the femur rotation limit should be applied to both the leading and trailing legs.**
- **Calculating leg rotation using angular rate sensor data in accordance with SAE AS 8049/1B could be an acceptable method to derive this parameter.**

Observations

- **Belt contact forces are not likely to cause serious injury if the pelvic restraint slides off the pelvis during the rebound phase of the impact if the tension in that strap is less than 250 lb.**
- **Additional research should be conducted to support definition of a standard threshold pulse shape and duration, however, the applicant should continue to define the installation specific peak G.**

Acknowledgment

Co-authors:

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Federal Aviation Administration

Restraints provided by AmSafe Corp. Commercial Aviation

Reference

A report containing the details of this project will be published as an Office of Aviation Medicine Report available at: https://www.faa.gov/data_research/research/med_humanfacs/oamtechreports/

Moorcroft D, Taylor A, DeWeese R. "*Supplemental Injury Risk Considerations for Aircraft Side-Facing Seat Certification*", Washington DC: Department of Transportation /Federal Aviation Administration; In Press