Comparison of Lower Leg Responses Using Hybrid III, THOR-50M, and THUMS in Simulated Test Conditions

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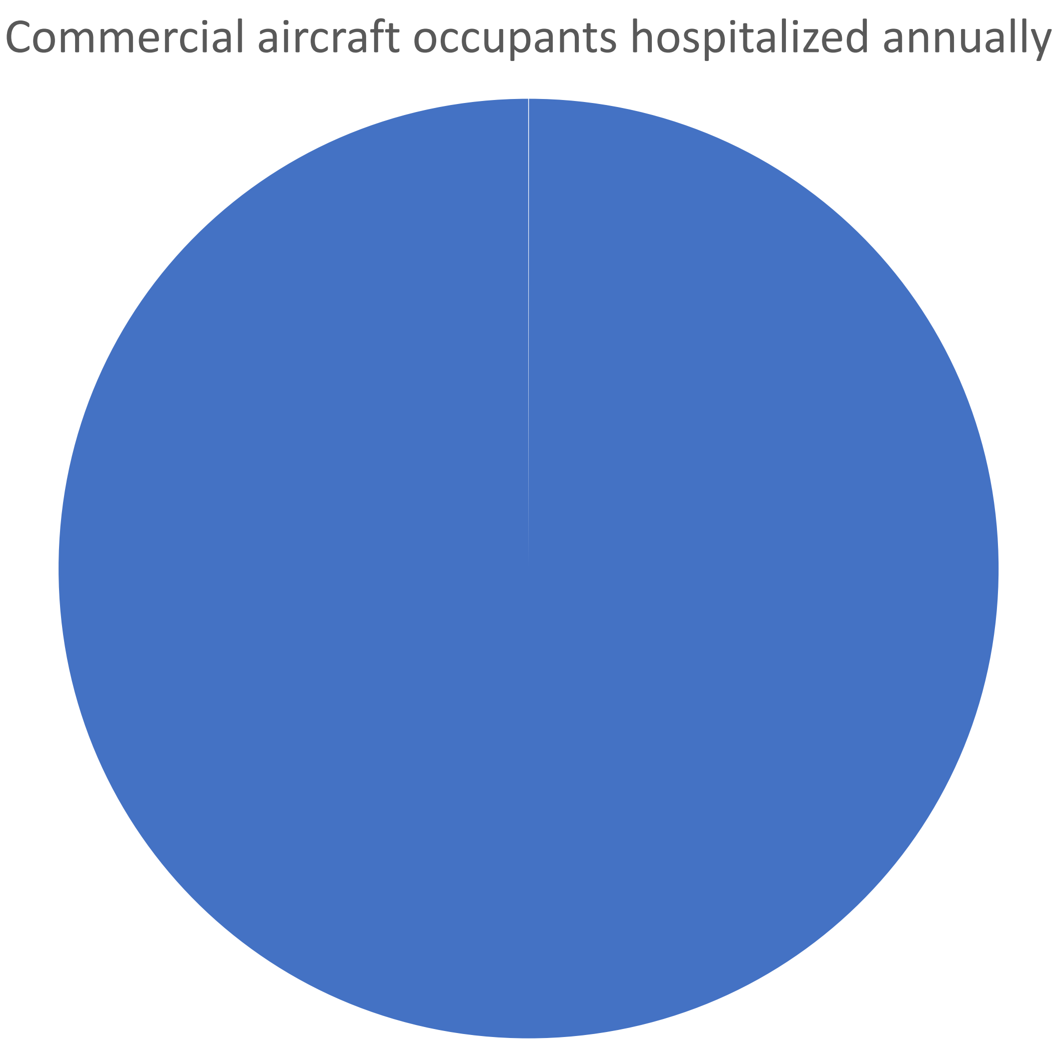
Background

- Hospital data



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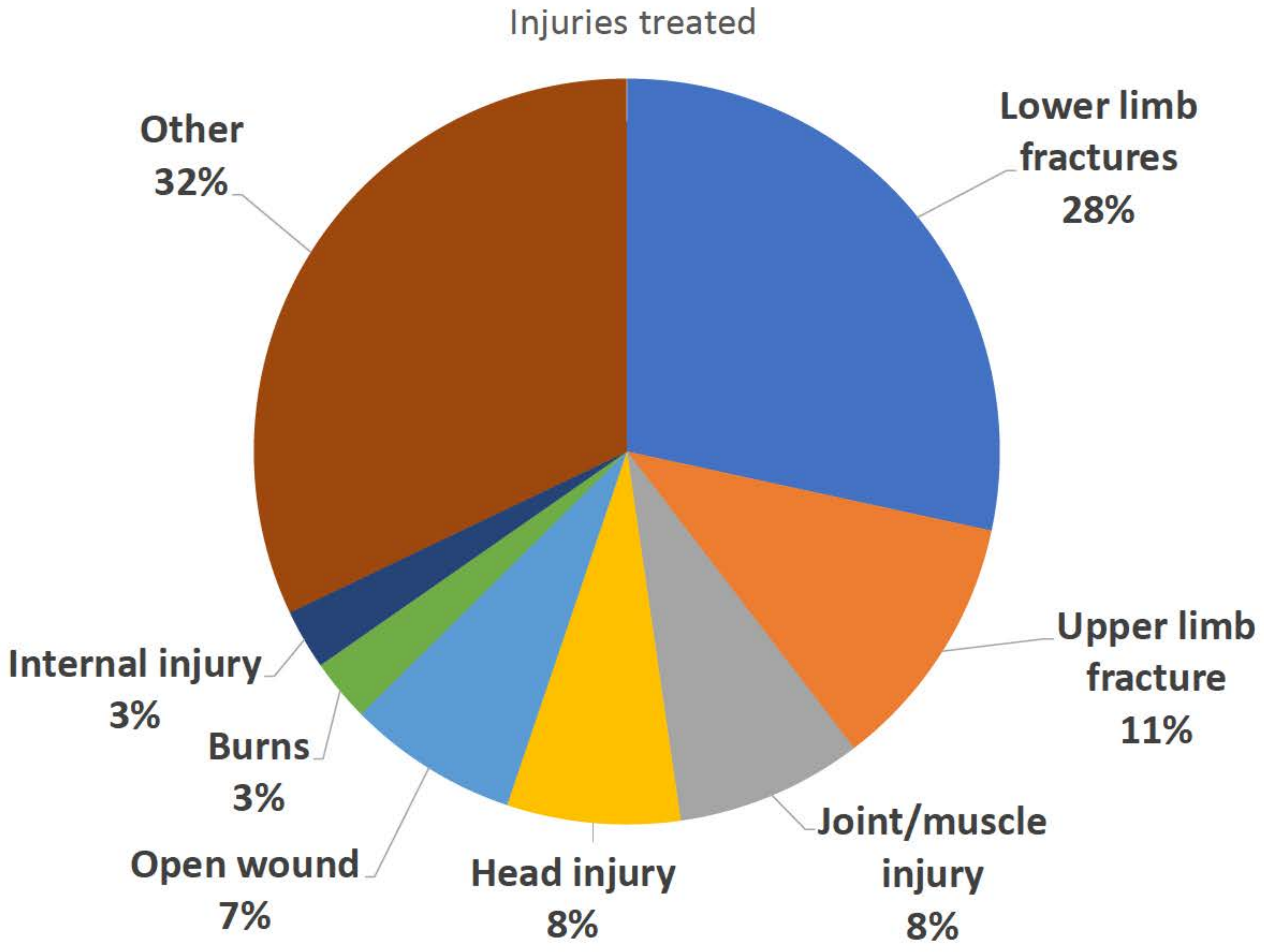

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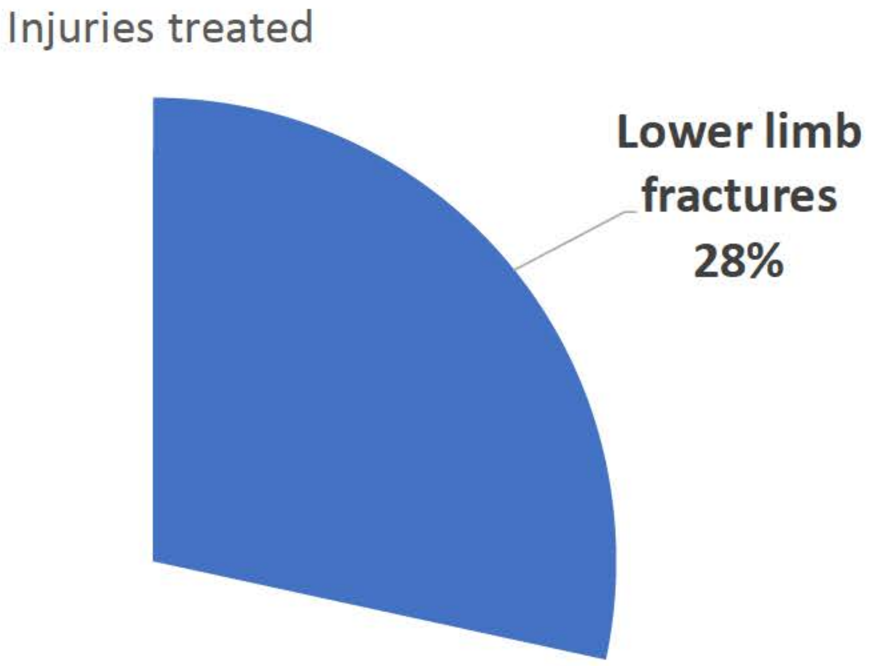
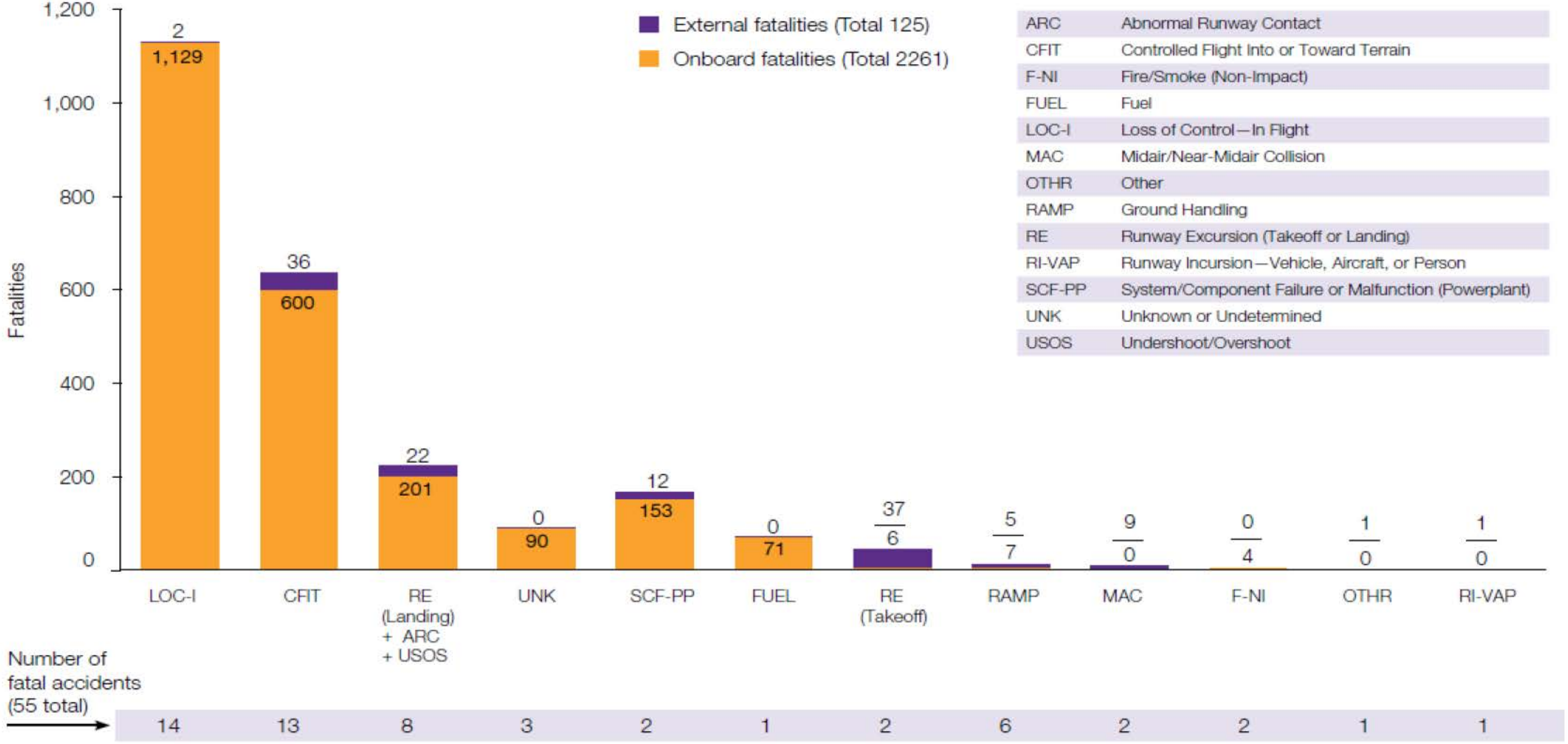


- 820 Fracture of neck of femur
- 821 Fracture of other and unspecified parts of femur
- 822 Fracture of patella
- 823 Fracture of tibia and fibula
- 824 Fracture of ankle
- 825 Fracture of one or more tarsal and metatarsal bones
- 826 Fracture of one or more phalanges of foot
- 827 Other multiple and ill-defined fractures of lower limb
- 828 Multiple fractures involving both lower limbs lower with upper limb and lower limb(s) with rib(s) and sternum
- 829 Fracture of unspecified bones

Baker, S., et al., Aviation-Related Injury Morbidity and Mortality: Data from U.S. Health Information Systems, Aviat Space Environ Med. 2009 December; 80(12):1001-1005.

Fatalities by CICTT Aviation Occurrence Categories

Fatal Accidents | Worldwide Commercial Jet Fleet | 2008 through 2017



ARC	Abnormal Runway Contact
CFIT	Controlled Flight Into or Toward Terrain
F-NI	Fire/Smoke (Non-Impact)
FUEL	Fuel
LOC-I	Loss of Control—In Flight
MAC	Midair/Near-Midair Collision
OTHR	Other
RAMP	Ground Handling
RE	Runway Excursion (Takeoff or Landing)
RI-VAP	Runway Incursion—Vehicle, Aircraft, or Person
SCF-PP	System/Component Failure or Malfunction (Powerplant)
UNK	Unknown or Undetermined
USOS	Undershoot/Overshoot

Boeing, "Statistical Summary of Commercial Jet Airplane Accidents Worldwide Operations", 1959 – 2017, 2017.

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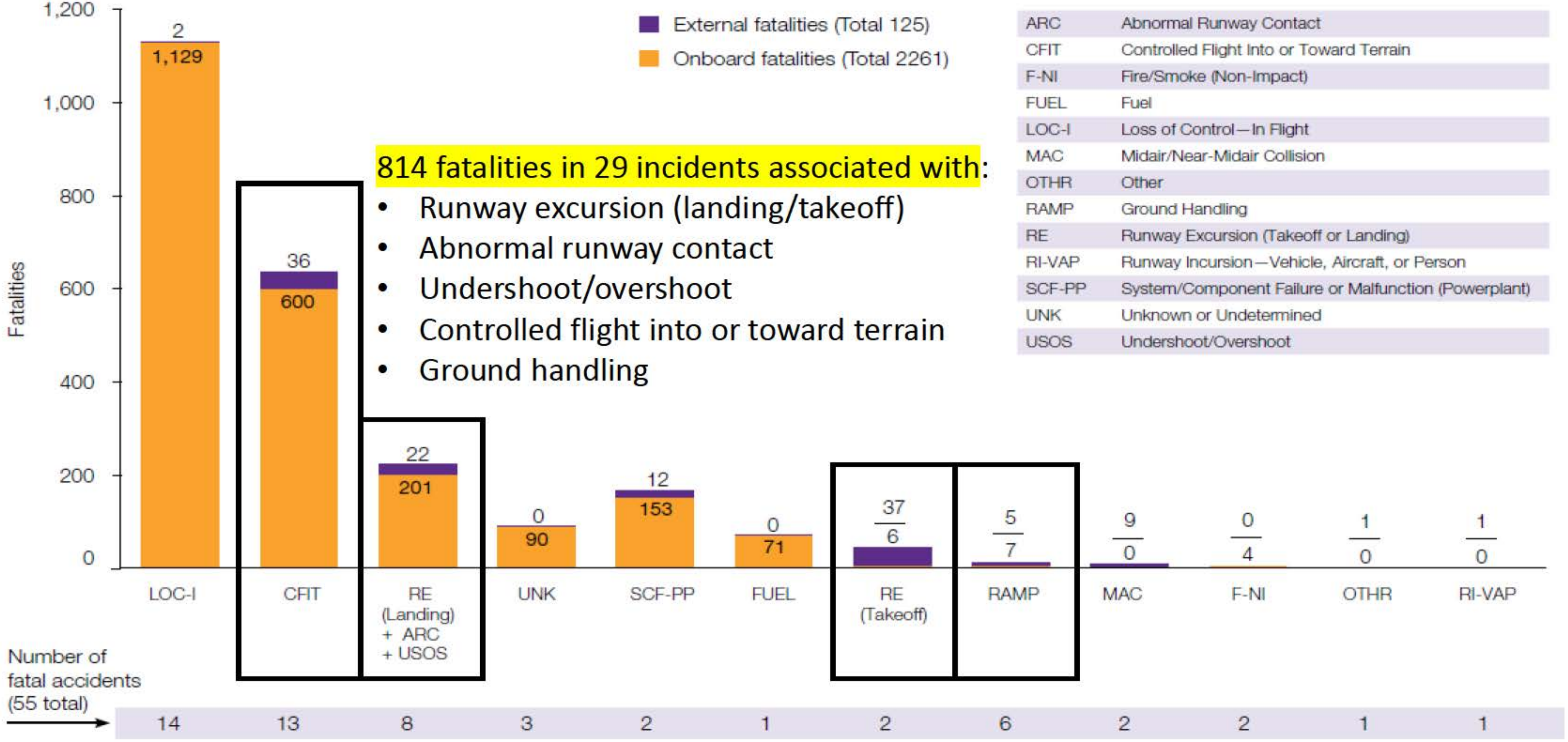

814 fatalities in 29 incidents associated with:

- Runway excursion (landing/takeoff)
- Abnormal runway contact
- Undershoot/overshoot
- Controlled flight into or toward terrain
- Ground handling

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What is a serious injury?

- ICAO and NTSB Definitions (paraphrased)
  - Requires > 48 hr hospitalization
  - Results in bone fracture
  - Causes severe hemorrhage, nerve, muscle, or tendon damage
  - Internal organ injury
  - >2nd degree burns over >5% of body
  - Exposure to infectious substance or radiation

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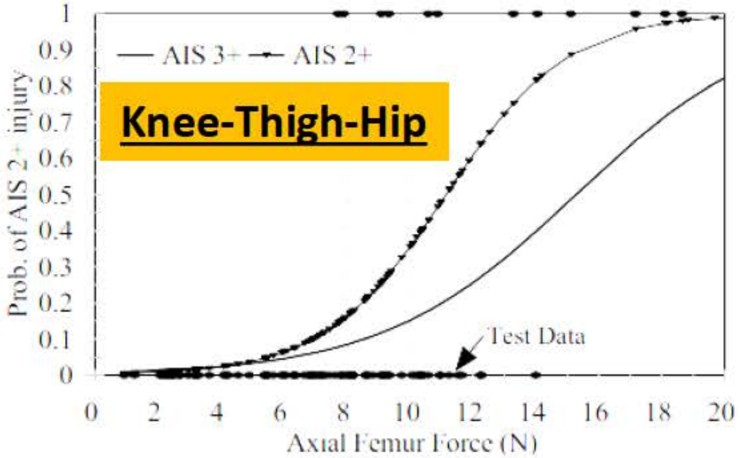
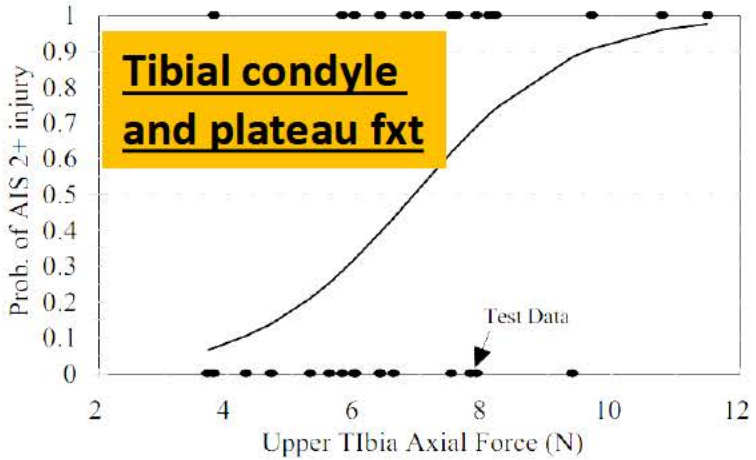
Serious leg injury?

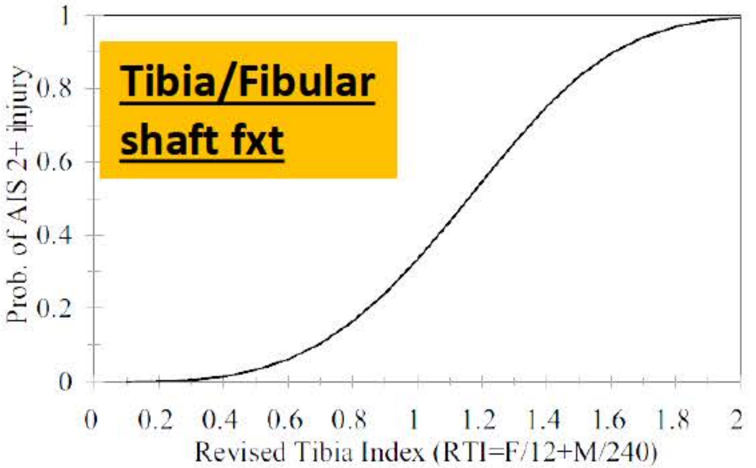
- Results in bone fracture
- Causes severe hemorrhage, nerve, muscle, or tendon damage

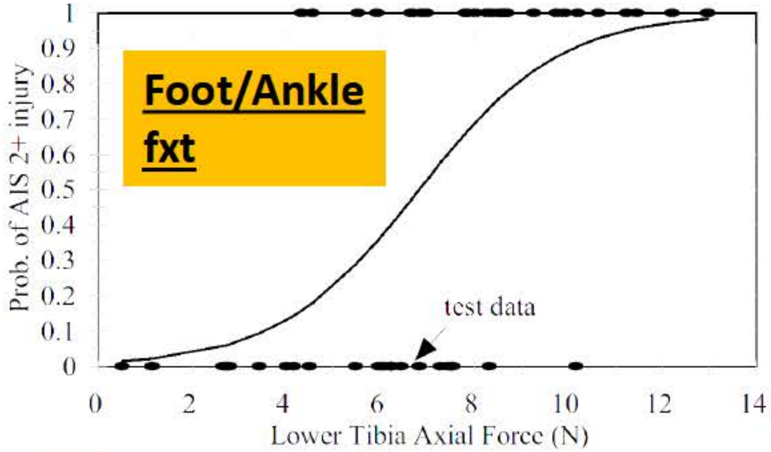
- Blunt impact
  - Fractures, dislocations, crush injuries
  - Muscle/Connective tissue damage
- Sharp edge/point
  - Lacerations, hemorrhage

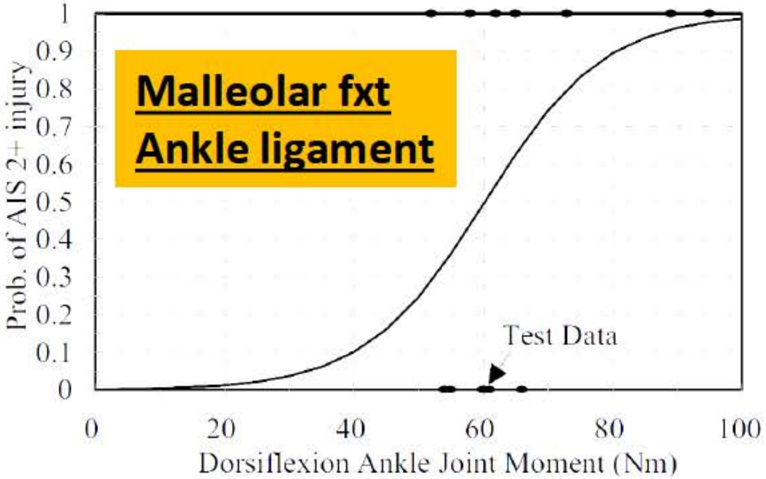
Injury Risk Curves

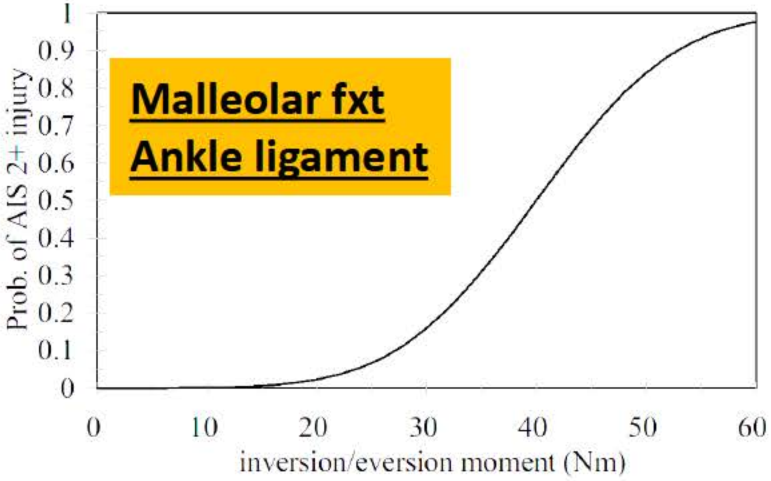












Kuppa, Shashi M., Jiangping Wang, Mark Haffner and Rolf H. Eppinger. "LOWER EXTREMITY INJURIES AND ASSOCIATED INJURY CRITERIA." International Conference on the Enhanced Safety of Vehicles (2001).

Summary of Lower Extremity Injury Criteria

Body Region	Percent AIS 2+ injury	Percent LLI	Injury Criteria	50th pcntile male 25% prob. of injury limit	5th percentile adult female		95th percentile adult male	
					scale factor	injury limit	scale factor	injury limit
Hip	12.2%	24.3%	axial femur force	9040 N	$\lambda_F=\lambda_{x\text{-femur}}^2=0.85^2=0.72$	6510 N	$\lambda_F=\lambda_{x\text{-femur}}^2=1.08^2=1.17$	10580 N
Femur	9.4%	10.7%						
knee	33.1%	6.9%						
Knee ligament	0.5%	0.8%	Tibia/fibula relative translation	15 mm	$\lambda_T=(0.85+0.85)/2=0.85$	13 mm	$\lambda_T=(1.08+1.09)/2=1.09$	16.5 mm
Tibia Plateau	7.1%	8.2%	Proximal tibia axial force	5.6 kN	$\lambda_F=\lambda_{x\text{-tibia}}^2=0.85^2=0.72$	4.0 kN	$\lambda_F=\lambda_{x\text{-tibia}}^2=1.09^2=1.2$	6.7 kN
Tibia/fibula shaft	4.5%	8.1%	Revised Tibia Index $F/F_c+M/M_c<0.9$	F_c=12 kN M_c=240 Nm	$\lambda_F=\lambda_{x\text{-tibia}}^2=0.72$ $\lambda_M=\lambda_{x\text{-tibia}}^3=0.61$	F_c=8.64 kN M_c=146 Nm	$\lambda_F=\lambda_{x\text{-tibia}}^2=1.2$ $\lambda_M=\lambda_{x\text{-tibia}}^3=1.3$	F_c=14.4 kN M_c=312 Nm
ankle+calcaneus	3.3%	3.7%	Distal tibia axial force	5.2 kN	$\lambda_F=\lambda_{x\text{-tibia}}^2=0.72$	3.75 kN	$\lambda_F=\lambda_{x\text{-tibia}}^2=1.2$	6.25 kN
midfoot	10.0%	10.8%						
ankle malleolus	19.9%	26.5%	dorsiflexion moment	50 Nm	$\lambda_M=\lambda_{x\text{-ankle}}^3=0.85^3=0.61$	31 Nm	$\lambda_M=\lambda_{x\text{-ankle}}^3=1.3$	65 Nm
			Xversion moment	33 Nm	$\lambda_M=\lambda_{x\text{-ankle}}^3=0.61$	20 Nm	$\lambda_M=\lambda_{x\text{-ankle}}^3=1.3$	43 Nm

Kuppa, Shashi M., Jiangping Wang, Mark Haffner and Rolf H. Eppinger. "LOWER EXTREMITY INJURIES AND ASSOCIATED INJURY CRITERIA." International Conference on the Enhanced Safety of Vehicles (2001).

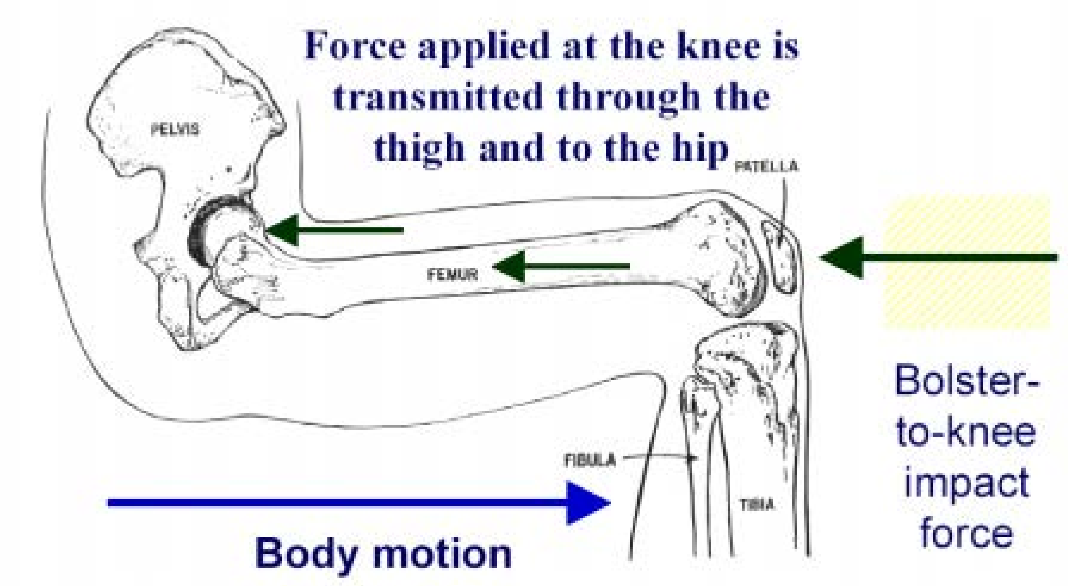
Example IARV (Star Rating)– Lower Limb

Table 1
Injury Parameter Cutoff Values Associated with Possible Injury Protection Ratings

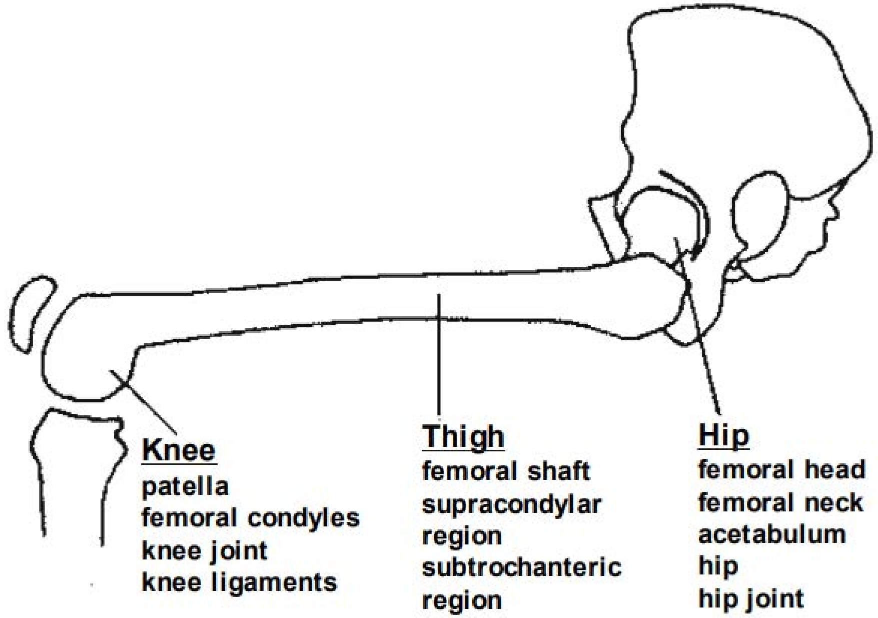
Body Region	Parameter	IARV	Good – Acceptable	Acceptable – Marginal	Marginal – Poor
Leg and foot, left and right	Femur axial force (kN)**	–9.1	–7.3	–9.1	–10.9
	Tibia-femur displacement (mm)	–15	–12	–15	–18
	Tibia index (upper, lower)	1.00	0.80	1.00	1.20
	Tibia axial force (kN)	–8.0	–4.0	–6.0	–8.0
	Foot acceleration (g)	150	150	200	260

Mechanisms of Injury - KTH

- Most common lower limb injury in vehicle crashes
  - 55% of AIS 2+; 42% life years lost to injury
    - Kuppa, Shashi M., Jiangping Wang, Mark Haffner and Rolf H. Eppinger. "LOWER EXTREMITY INJURIES AND ASSOCIATED INJURY CRITERIA." International Conference on the Enhanced Safety of Vehicles (2001).



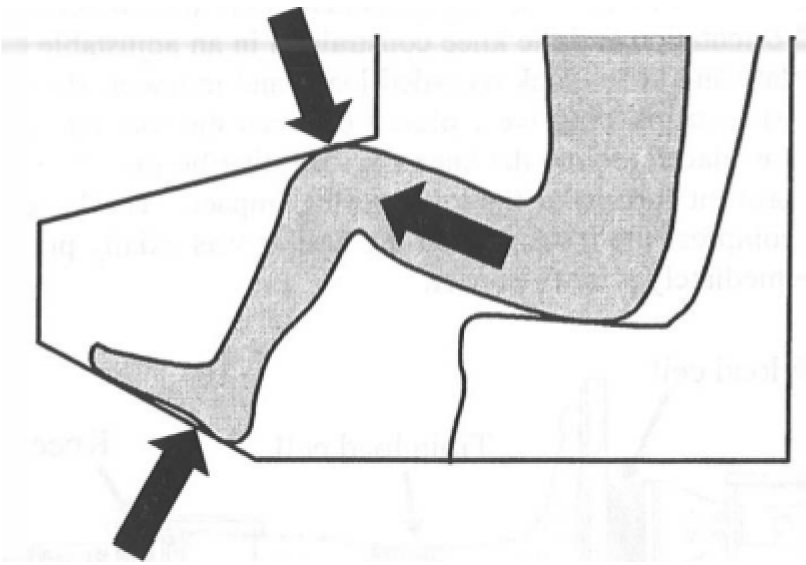
Silvestri, C., Development and Validation of a Knee-Thigh-Hip LSDYNA Model of a 50th Percentile Male, PHD Thesis, Worcester Polytechnic Institute, 2008



Kuppa, S., Fessahaie, O., An Overview of Knee-Thigh-Hip Injuries in Frontal Crashes in the United States

Mechanisms of Injury – Tibial Plateau

- Most severe lower limb injury in vehicle crashes
  - Long-term impairment, poor outcome
  - Often associated with foot/ankle fracture
    - Funk, J., et al., Experimentally Produced Tibial Plateau Fractures, IRCOBI 2000



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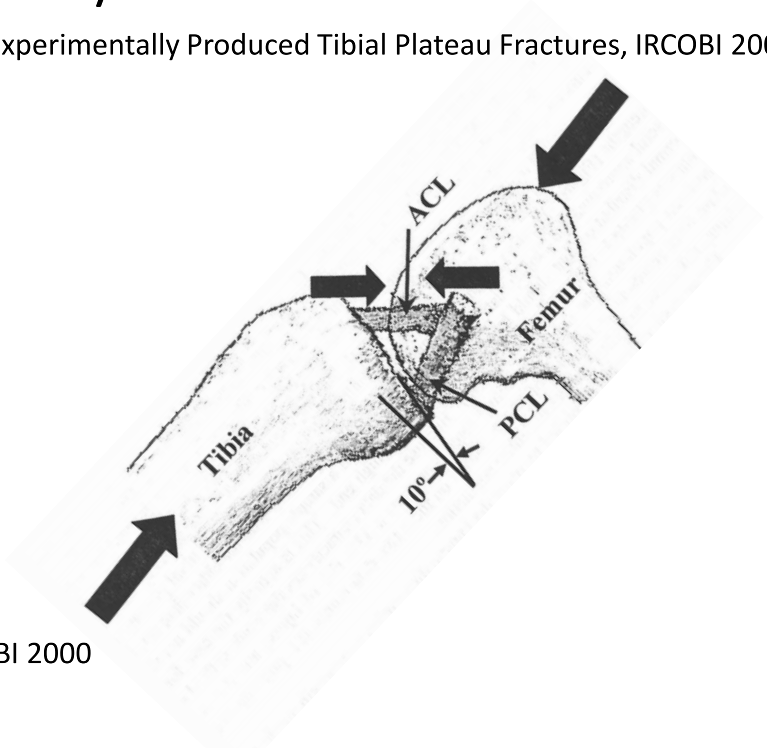
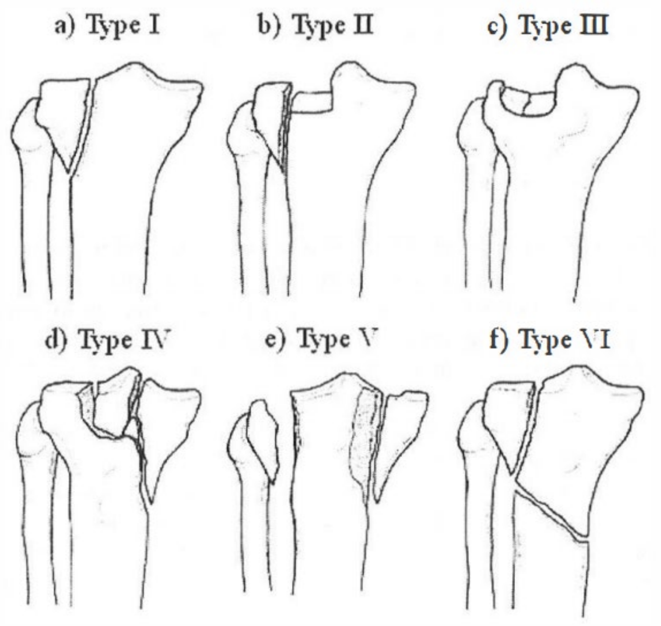
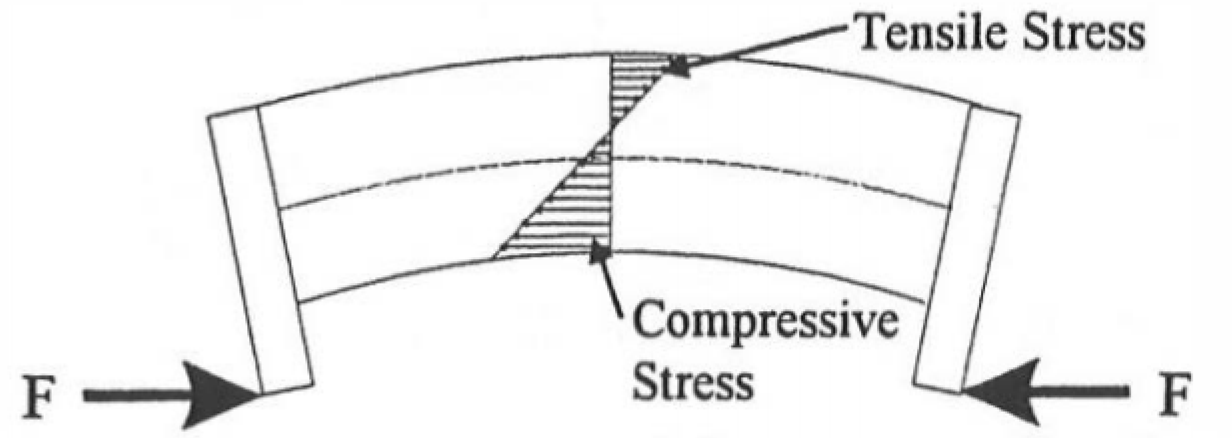




Schatzker, J., McBroom, R., Bruce, D., "The Tibia Plateau Fracture: The Toronto Experience 1 968-1 975," Clinical Orthopaedics and Related Research," Vol. 138, pp. 94-1 04, 1 979.

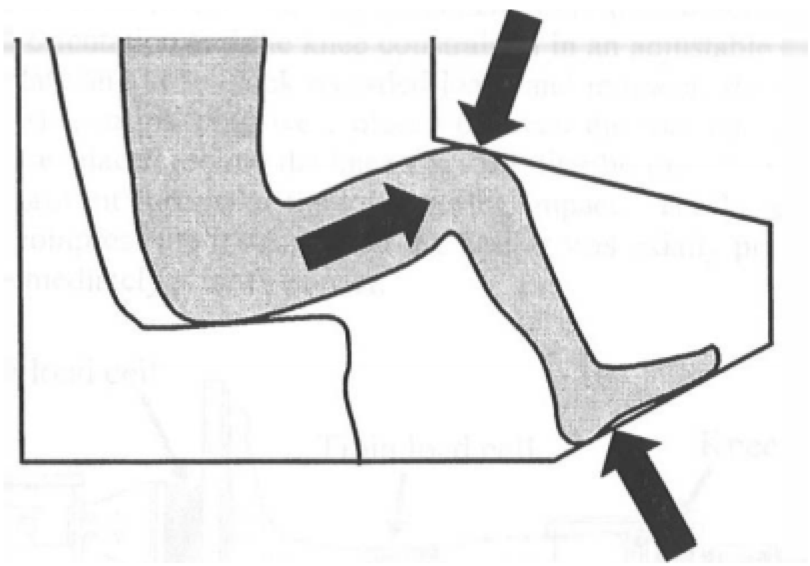
Mechanisms of Injury – Tibia/Fibula Shaft

- Less frequent, less severe in vehicle crashes



Mechanisms of Injury – Foot/Ankle

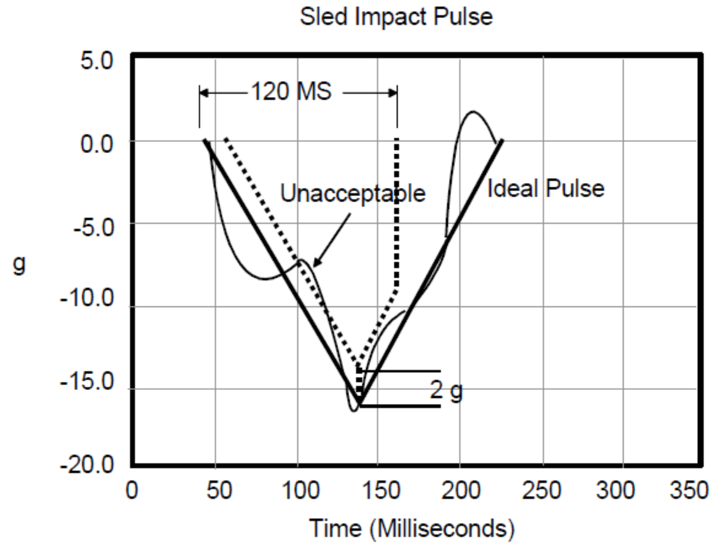
- Less frequent, less severe in vehicle crashes
  - Long-term impairment, poor outcome
  - Often associated with foot/ankle fracture
    - Funk, J., et al., Experimentally Produced Tibial Plateau Fractures, IRCOBI 2000



Funk, J., et al., Experimentally Produced Tibial Plateau Fractures, IRCOBI 2000

Methods

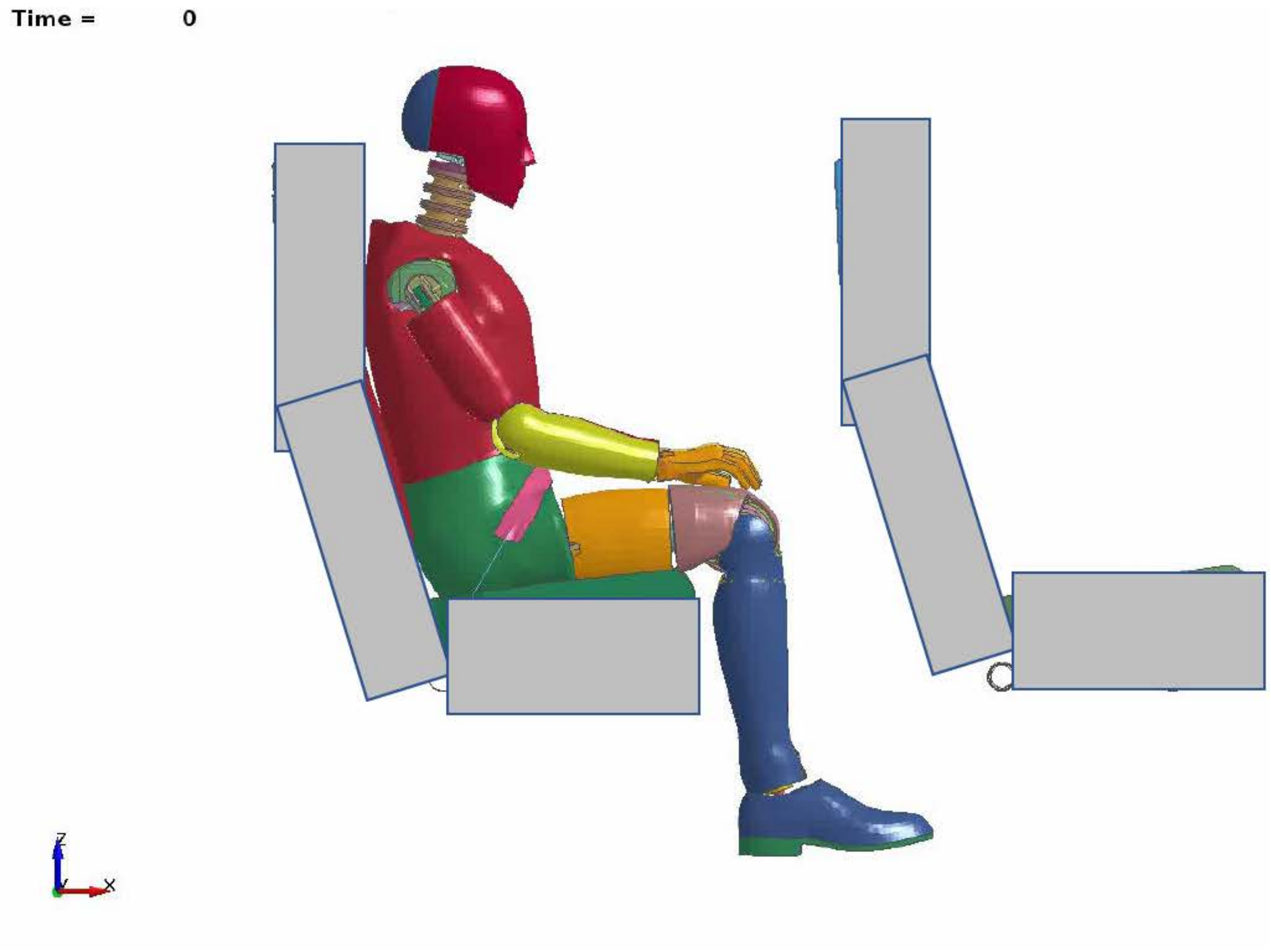
- Finite Element Analysis (LS-DYNA)
- Validated model
  - Hybrid III 50th
  - THOR 50M
  - THUMS
- FAA Frontal Impact Test
  - Production seat
  - Validated against test
  - 36” pitch
  - Foam seat and seatback



Methods

- Initial settling of dummy
- Tighten belt (~75 mm)
- Apply deceleration pulse

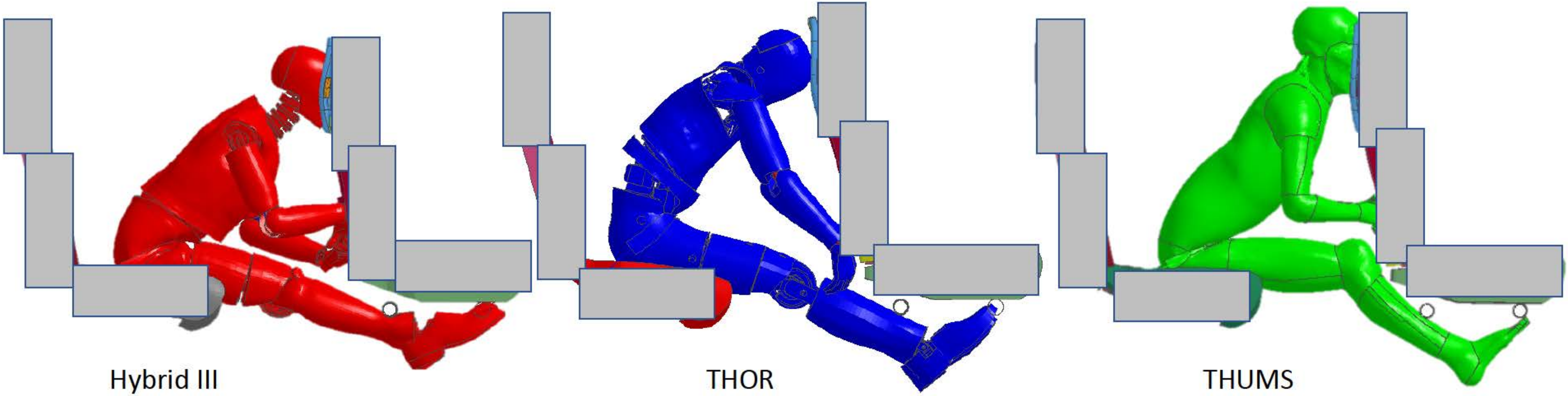
*FE model of production seat used, but hidden for proprietary reasons



Results

*FE model of production seat used, but hidden for proprietary reasons

- Different Kinematics
  - Tibia contact location, knee and pelvis excursion, head contact



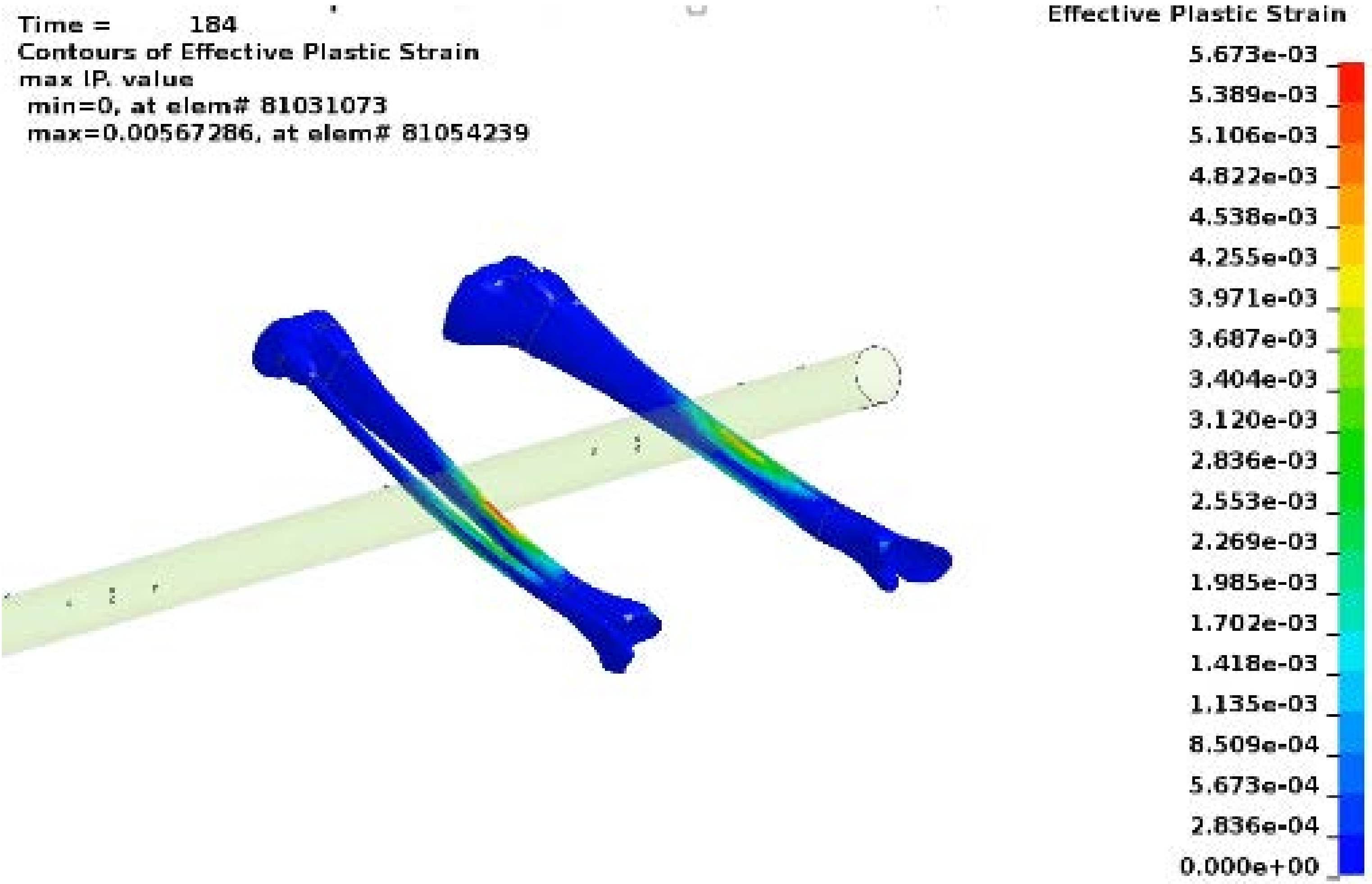
Hybrid III THOR THUMS

Results

- Tibia impact velocity

	Average relative Impact Velocities	
Surrogate	Horizontal (m/s)	Vertical (m/s)
Hybrid III	2.5	2.5
THOR 50M	2	5
THUMS	6.5	3

Results – Tibia Strain



Results - Summary

Injury Mechanism	Loading scenario
KTH – axial femur load	Knee to Seatback?
Tibial plateau fracture	Floor loading + seat engagement
Tibia fracture	Shin to seat support
Foot/Ankle fracture	Foot to seat support? Floor loading?

Results - Pending

- Effect of
  - Floor motion
  - Seat Pitch / Knee to seatback
  - Brace Position
  - Activated musculature for HBM
  - Out of position
  - “Real World” impact conditions
  - Varying stature/age/gender/etc.
  - Belt-fit/position
  - ….

Discussion

- Greater lower limb excursion for THUMS
- Faster and earlier tibia-seat impact for THUMS and THOR over H3
- THUMS tibia impact is above injury threshold
- Knee-seatback interaction for THUMS
  - Would increase at lower seat pitch layouts, greater occupant statute/weight
- Kinematics different for all surrogates
- Lower belt forces for THUMS

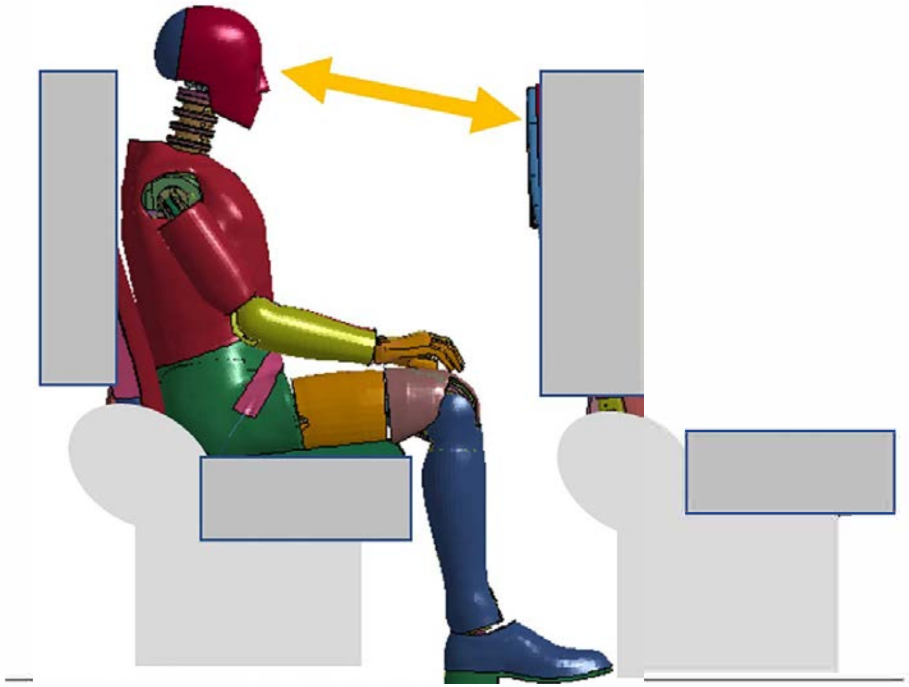
Discussion

- Most injury mechanisms not replicated
  - Floor deformation
  - Occupant positioning/bracing
  - Vertical component
- Benefit from integrated impact scenarios (fuselage damage + seat performance)
- The effects of vertical and forward impact would exacerbate submarining which would increase risk of lower extremity injury

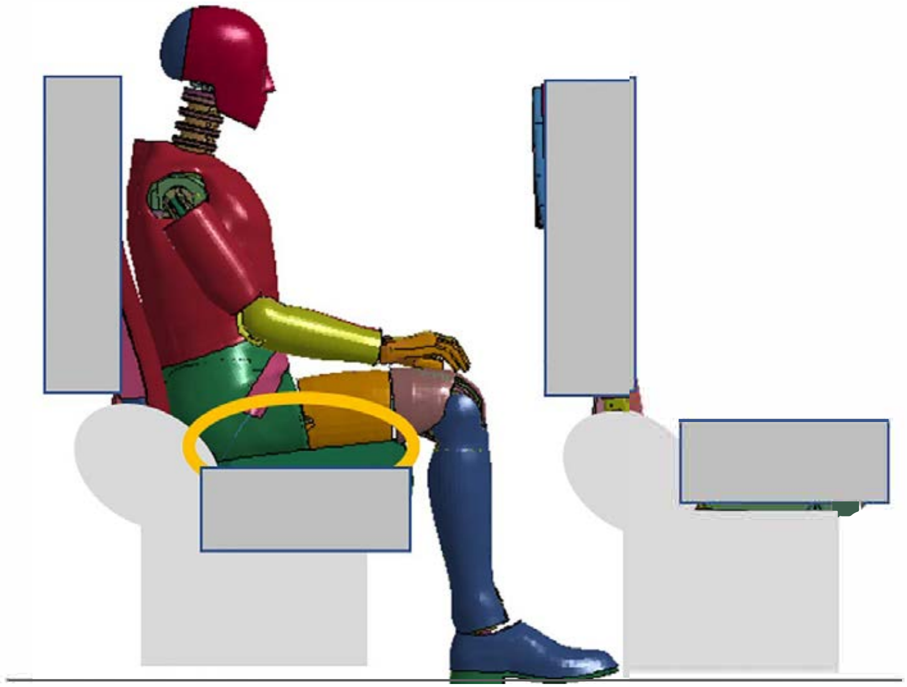
Discussion – Additional Information

- Effect of friction on injury response – 20-50% difference

Head-to-Seatback Friction



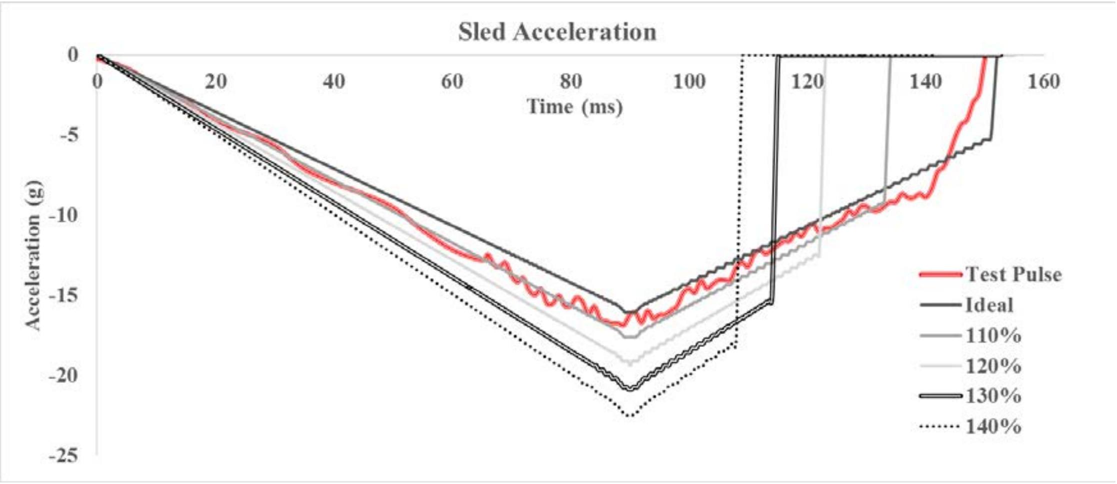
ATD-to-Launch Seat Friction

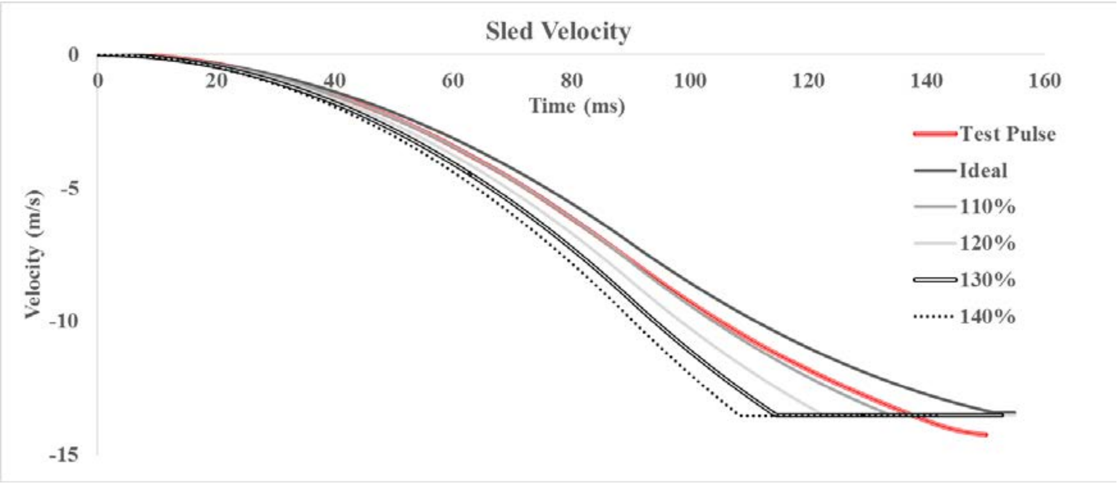


Friedman, K., Mattos, G., et al., Potential effects of friction on injury measures computed in aircraft seat HIC analysis testing, SAE Aerotech Conference, 2017-01-2054

Discussion – Additional Information

- Effect of deceleration on injury response – 20-75% difference





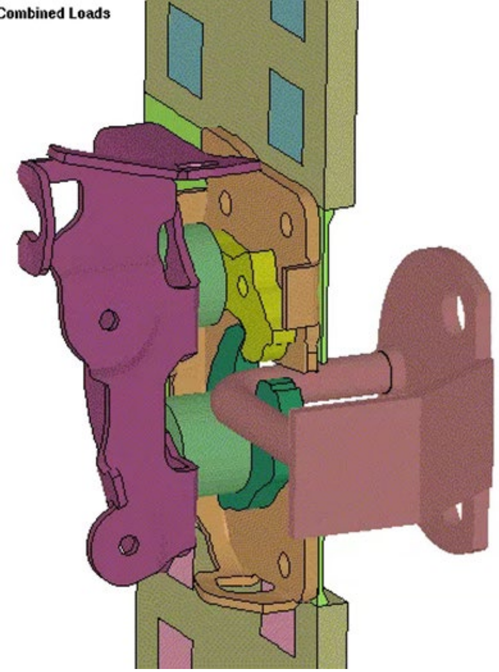
Friedman, K., Mattos, G., et al., Potential effects of deceleration pulse variations on injury measures computed in aircraft seat HIC analysis testing, SAE Aerotech Conference, 2017-01-2052,

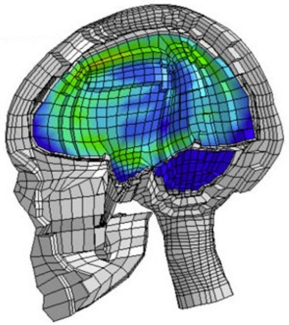
Conclusions

- Lower limb injury is frequent in aircraft crashes
- Forward sled impacts (dynamic seat test) demonstrate that lower limb injury is potentially masked with the use of ATDs over HBMs
  - Due to differences in kinematics and injury measure capability
- Existing forward sled impact scenario likely not representative of many lower limb injury scenarios
- The use of virtual testing in combination with physical testing is likely the way forward
- Field data is vital to ensure effective designs/countermeasures

Future work

- Performance based evaluations
  - Apply impact scenarios to fuselage
  - Identify a ‘safety envelope’
    - IARVs
- Injury Data Expansion
  - More information about injuries





Thank you for your time

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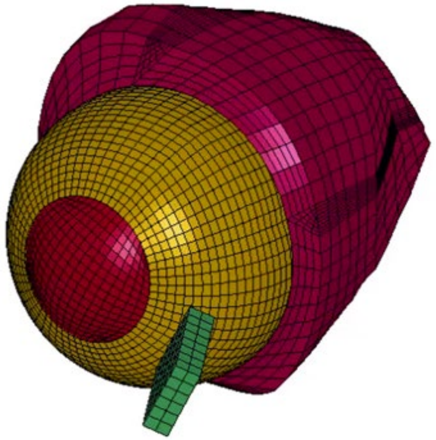

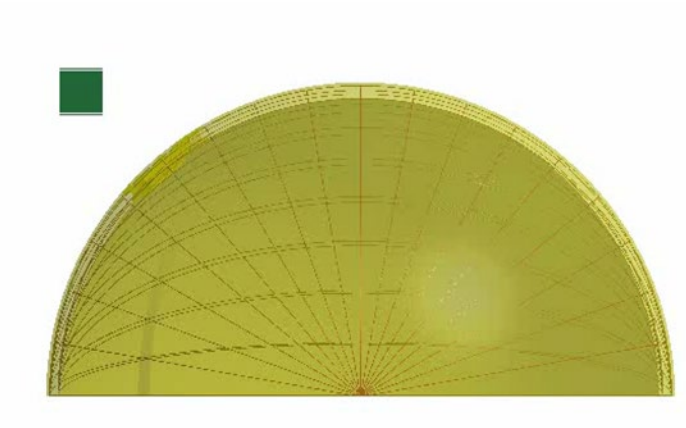

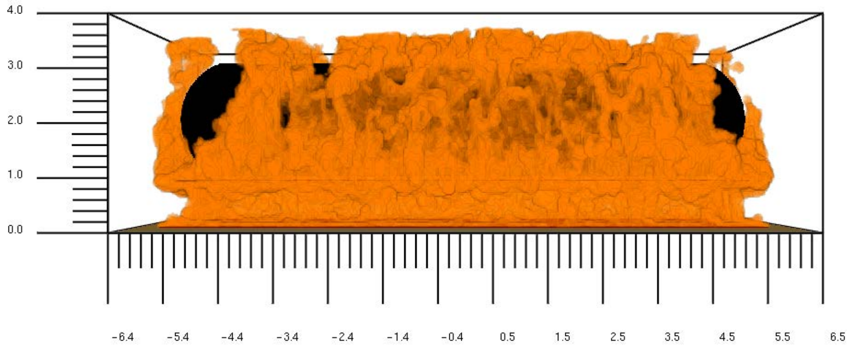

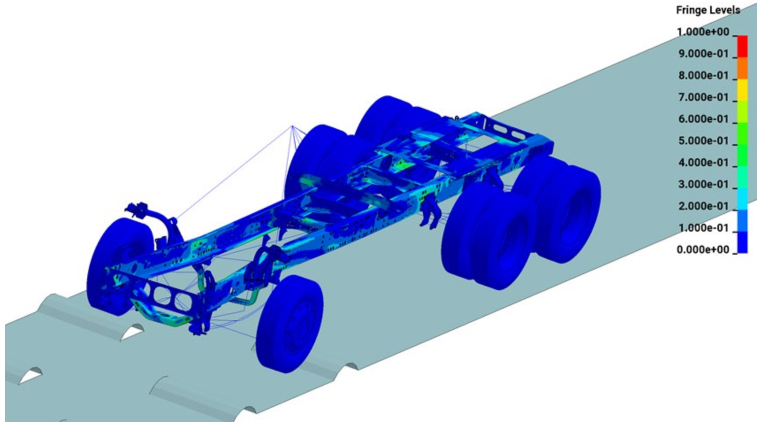

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