UVa
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Injury Criteria and Numerical Modeling for High Speed Craft

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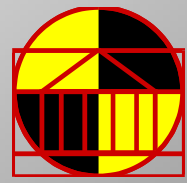


Overview

Mk V SOC

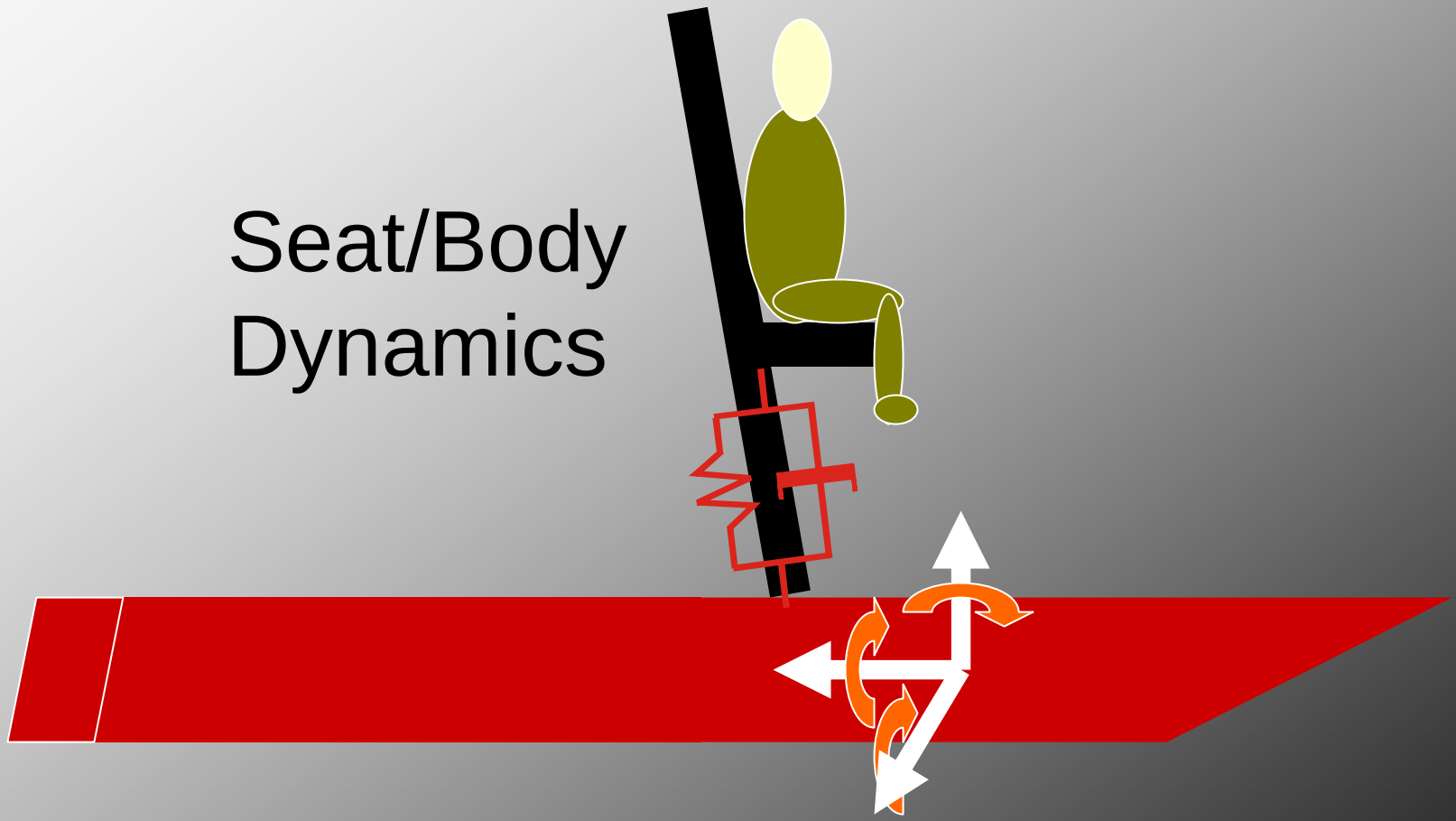
Scope

- Prevention of Human Injury Should Be Included In the *Initial* Design Process
- Example: Automobile Impact Protection
  - Incorporated into initial design (Numerical Models)
  - Tested Using
    - Objective criteria (Head, Thorax, Femur Injury)
    - Established test protocol (Sled, Automobile Impact Tests)
  - Outcome checked using epidemiology (FARS, NASS)
  - The human is always part of the system
- Problem with High Speed Craft:

  No Fully Suitable Injury Criterion

Human Dynamics Modeling

Seat/Body Dynamics

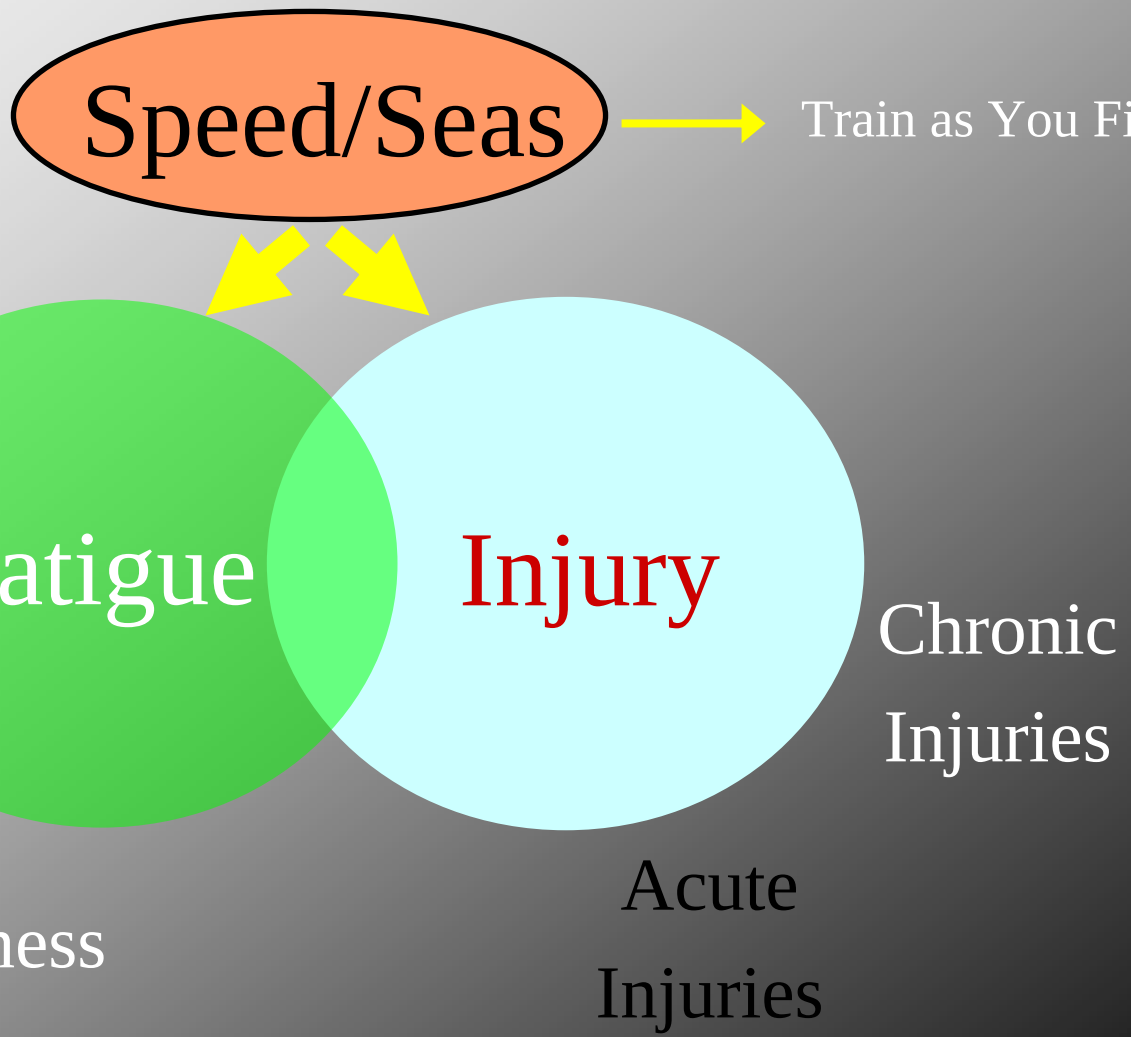


Hull/Deck Dynamics

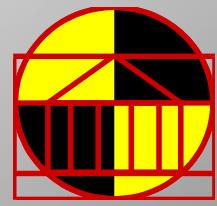
Framework

- Need => Validated Tools and Objective Measures of Goodness
- Robust Injury Model
  - Suitable for situation
- Numerical Models
  - Developing specifications, Initial craft design
  - Countermeasure development, Evaluation of procedures
- Experimental Validation
  - Evaluation of craft, numerical models
- Epidemiological Tracking
  - Injury investigations
  - Evaluation of injury models

Injury Issues



Other Considerations

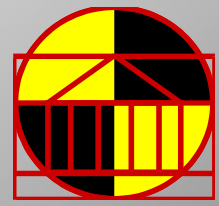


- Acute Injuries
  - Loss of personnel during rehabilitation
  - Potential immediate decrease in mission effectiveness
- Chronic Injuries
  - Pain, morale, loss of personnel during rehab
  - Long term consequences, costs
- Human Factors – Fatigue, Comfort, Workflow
  - Potentially long missions
  - Need for operators to remain mobile
- Additional Equipment
  - Night Vision/Helmet – Head mounted mass problem

Self Reported Injury Survey

- Example Epidemiological Study – Ensign *et al* (2000) NHRC
- Prevalence of Injury
  - 65% of SBU Operators Report At Least One Injury
  - Distribution of Injuries
    - Lower back, neck and upper back
    - Knee, Shoulder, Ankle
- Most Serious Injuries
  - Trauma
  - Fracture
  - **Intervertebral disc problems – particularly prominent**
- Impact of Injuries
  - 33% reported some limitations on mission performance
  - 44% reported limited duty days associated with injury

Injuries in High Speed Boat Operators: Anecdotal Findings (*Bass et al - 2000*)



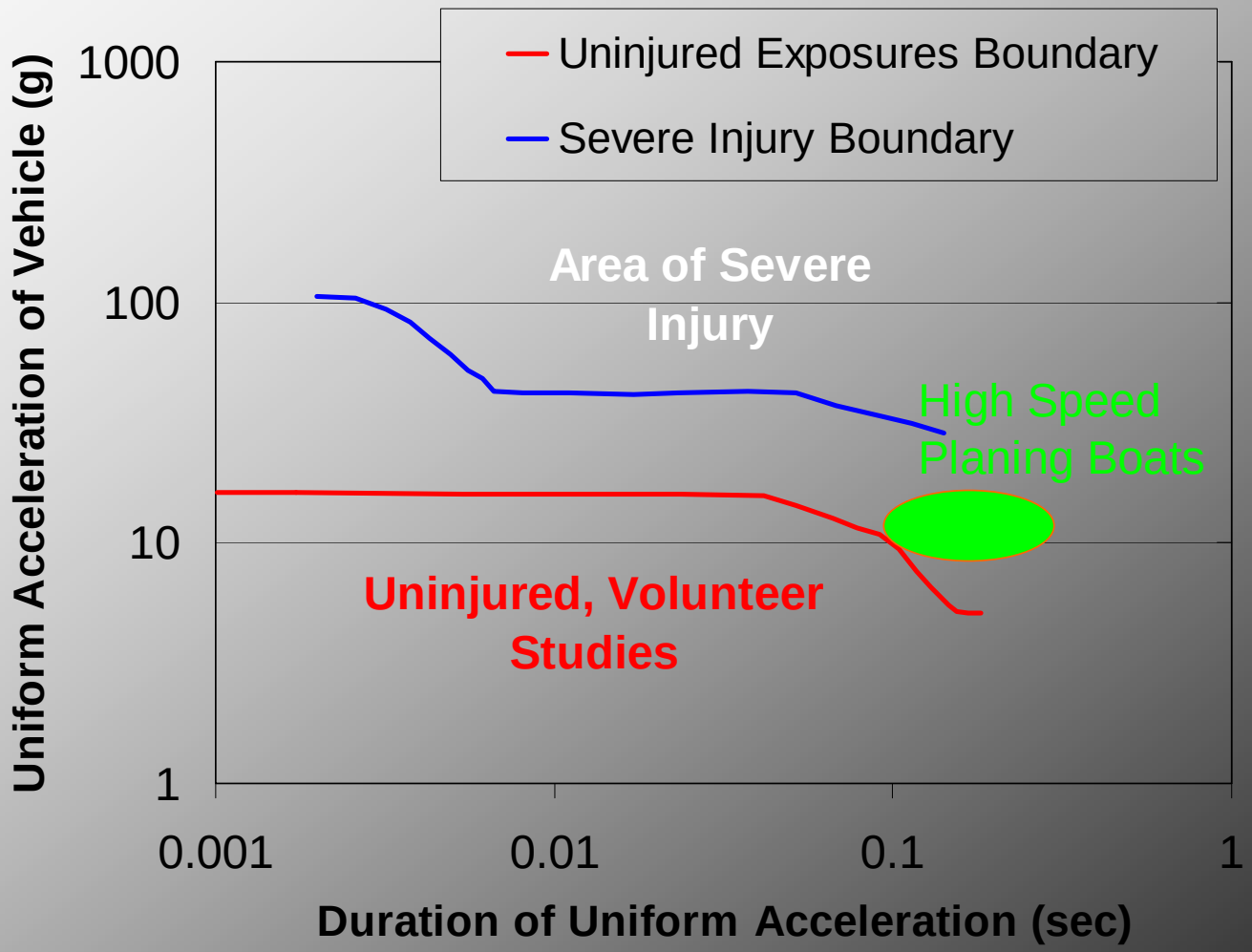
- No Reported Coccyx Injuries => No Lower Spine Blunt Impact Injuries
- Acute injuries
  - Often associated with momentary inattention to wave state
  - Irregular wave approach
- Chronic injuries not specifically associated with impact event
  - Often identified with an acute injury
- One Operator – Lower Spine Disc Herniation
  - 3200 mg ibuprofen daily – self medicated!

Biomechanics

Current Injury Criteria

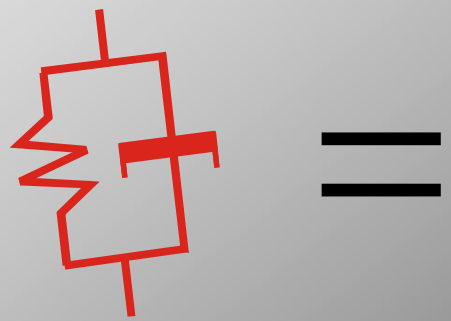
- Focus on ‘Biomechanical’ Criteria
  - Not ISO-2631 pt. 1, VDV etc
- Many – Often Acceleration Based
  - Surrogate for applied force
- None Are Completely Applicable to this Problem
  - Complex postures
  - Long term repeated/complex loading
- Often Outside the Range of Applicability

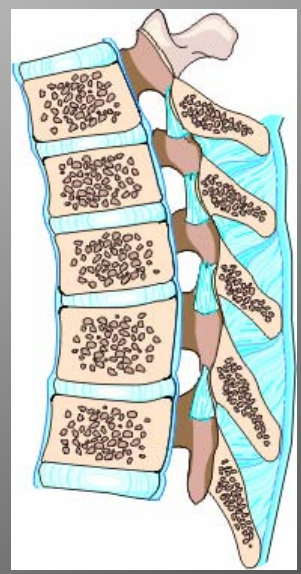
Ejection Seats – Single Impact



Displacement Response Index (DRI)

- Simple Lumped Mass Model, Ejection Injuries [Payne-1975]
- Compressive Loading => Compressive Fracture



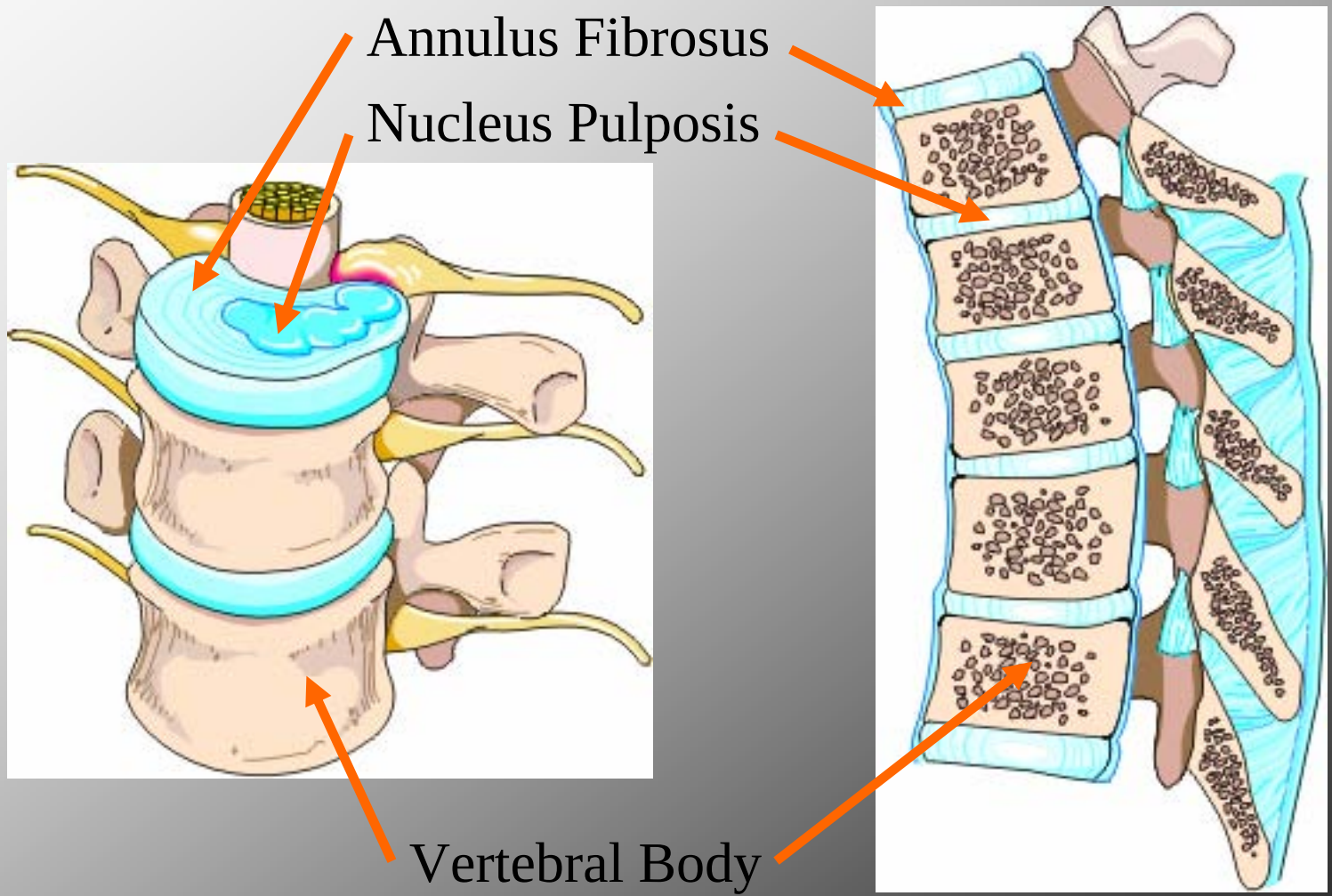


- WEDIM (Peterson-1996)
- Limited Usefulness
  - Does not account for repetitive loading
    (Extension not validated for n > 4 impacts)
  - Based on compressive spinal fracture
  - Columnar spinal loading
  - Does not account for complex postures

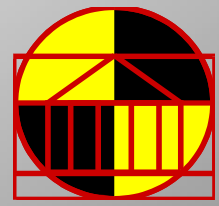
Army Repeated Jolt Standard

- Basis of New ISO-2631.5 (Alem-2002)
  - 3D – x, y, z lumbar acceleration
- Predominantly Compressive Loading
  - Limited to +/- 4 g
- Likely the ‘Best’ Option Available
  - Accounts for repetitive loading
  - Columnar spinal loading
  - Does not account for complex postures/complex modes of motion
  - Neural net dynamics model
  - **Based on spinal fracture**

Lumbar Spine Biomechanics



Lumbar Spine Biomechanics



- Experimental Models – Difficult to Fail in Compression
  - Rate Sensitive (Tsai, *et. al.* – 1998)
    - o Increased Loading Rate => Increased Injury
  - Minor damage to vertebral body increases loading (Adams *et. al.* – 2000)
  - Lateral motions – higher interdisc stress (Dolan-2001)
  - *Repeated flexion/extension with small compression may cause herniation (Callaghan et. al. – 2001)*

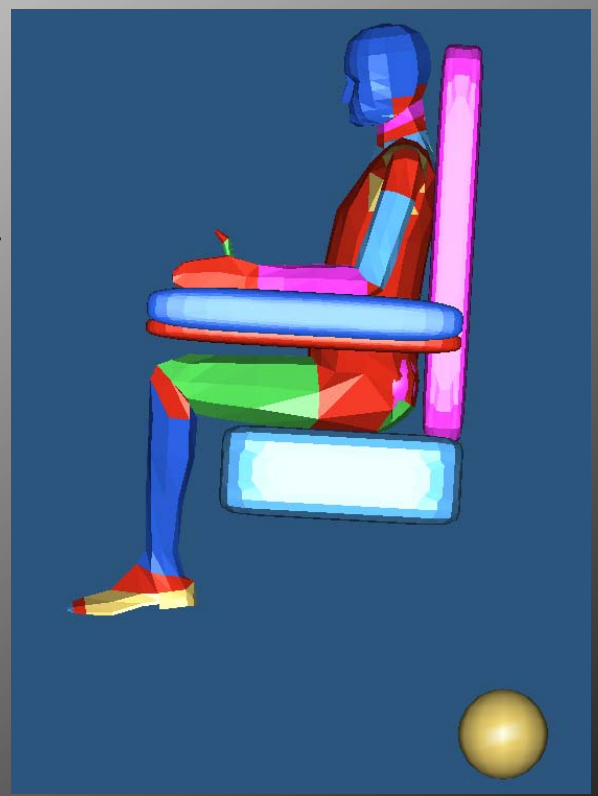
Summary

- No Perfectly Suitable ‘Biomechanical’ Model for Repeated Low-Level Impact
  - All based on gross body acceleration or spinal fracture
- Need: Material Fatigue Model of Intervertebral Disc Failure
  - Need to Incorporate Flexion/Extension and Lateral Motions into the Model

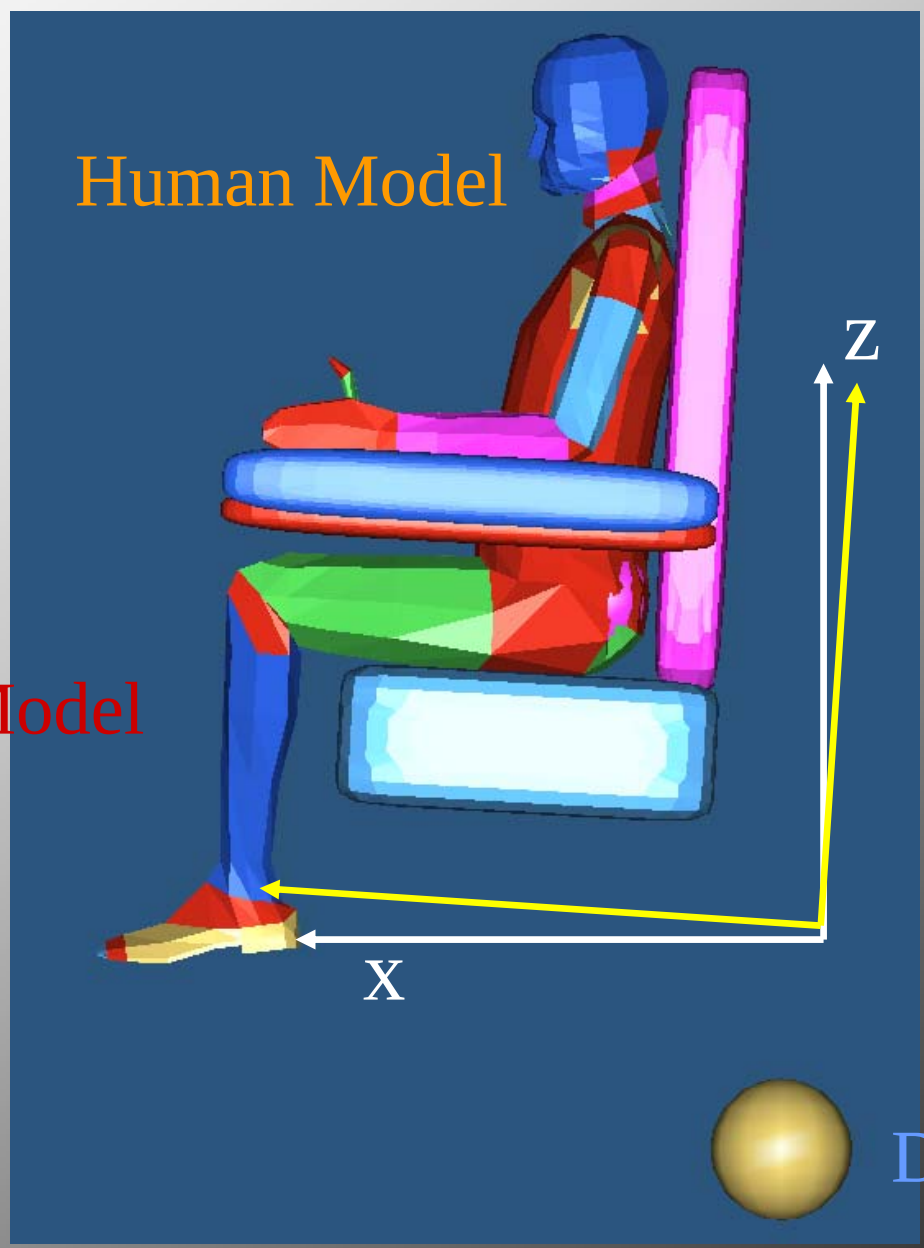
Madymo Model

Overview: Madymo Human Model (MAthmatical DYnamic MOdel)

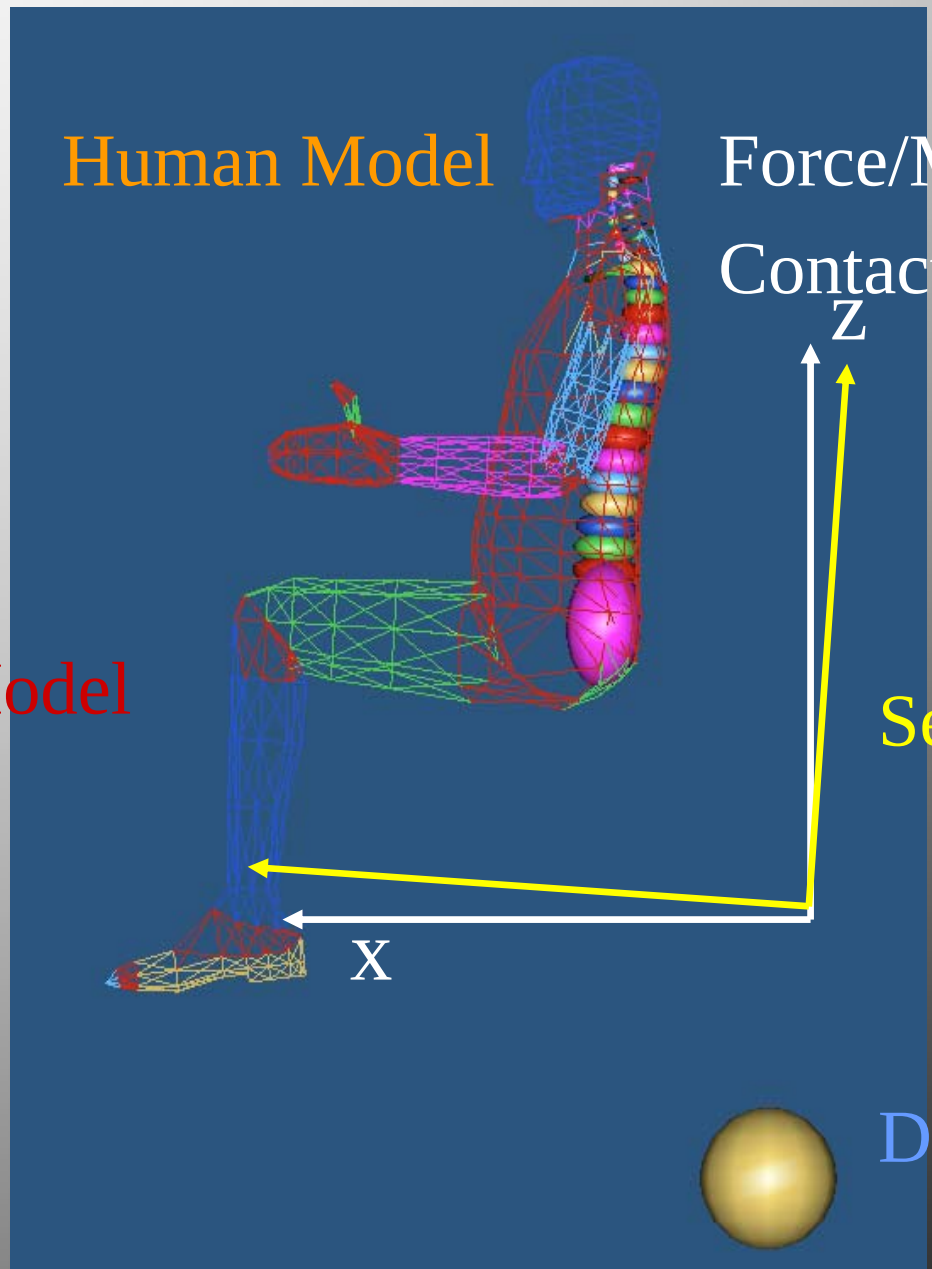
- Simulates dynamic behavior of physical systems
- Validated using vehicle collisions and injury assessment data
- Outputs
  - Force, moment, disp., vel., accel.
  - Injury parameters



Madymo Human Model



Madymo Human Model



Validation Dataset – Mk V Data

- Validation Dataset – 6DOF Data from Sea Trials (January 2002, Peterson, *et al*)
- Four Impacts Chosen – Range of Conditions
  - Intense vertical/horizontal impact loads, lateral, torsion
  - May be repeated over long periods of time
  - Two similar to range of ISO 2631.5 – two outside

Validation Dataset

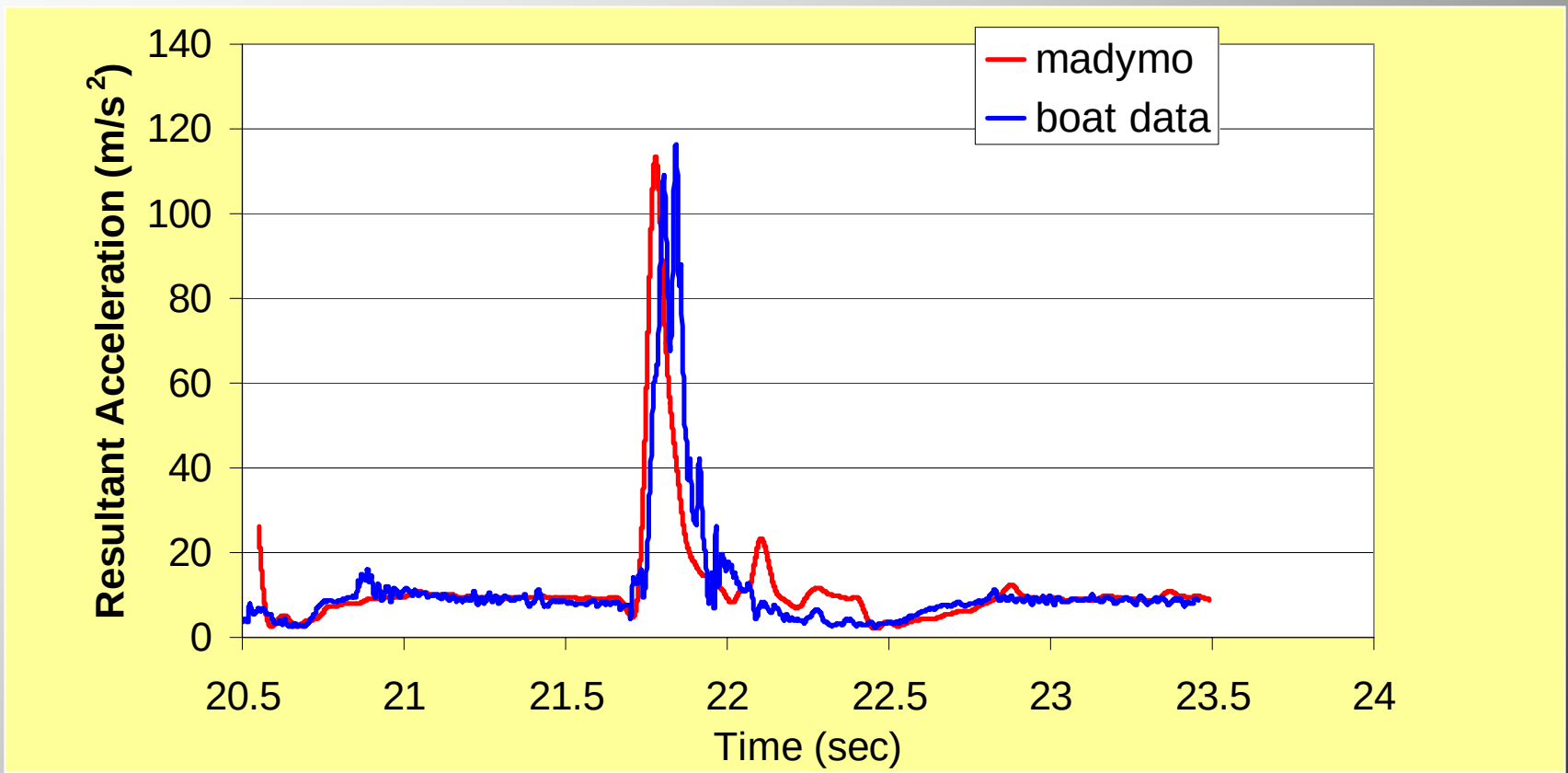
Validation Dataset

- Select Validation Datasets for Range of Dynamics
  - Seated Reasonably Erect
  - Limited Use of Shoulders
  - Varying Impacts
    - Large heave (~10 g)
    - Medium heave (~4 g)
    - Small heave (~2 g)
    - Large heave with rotation (~10 g, max rotation)
- Boat/Human Body Measurements
  - Deck/Seat
  - Hip/Back/Head

Large Heave – Night – Single Impact

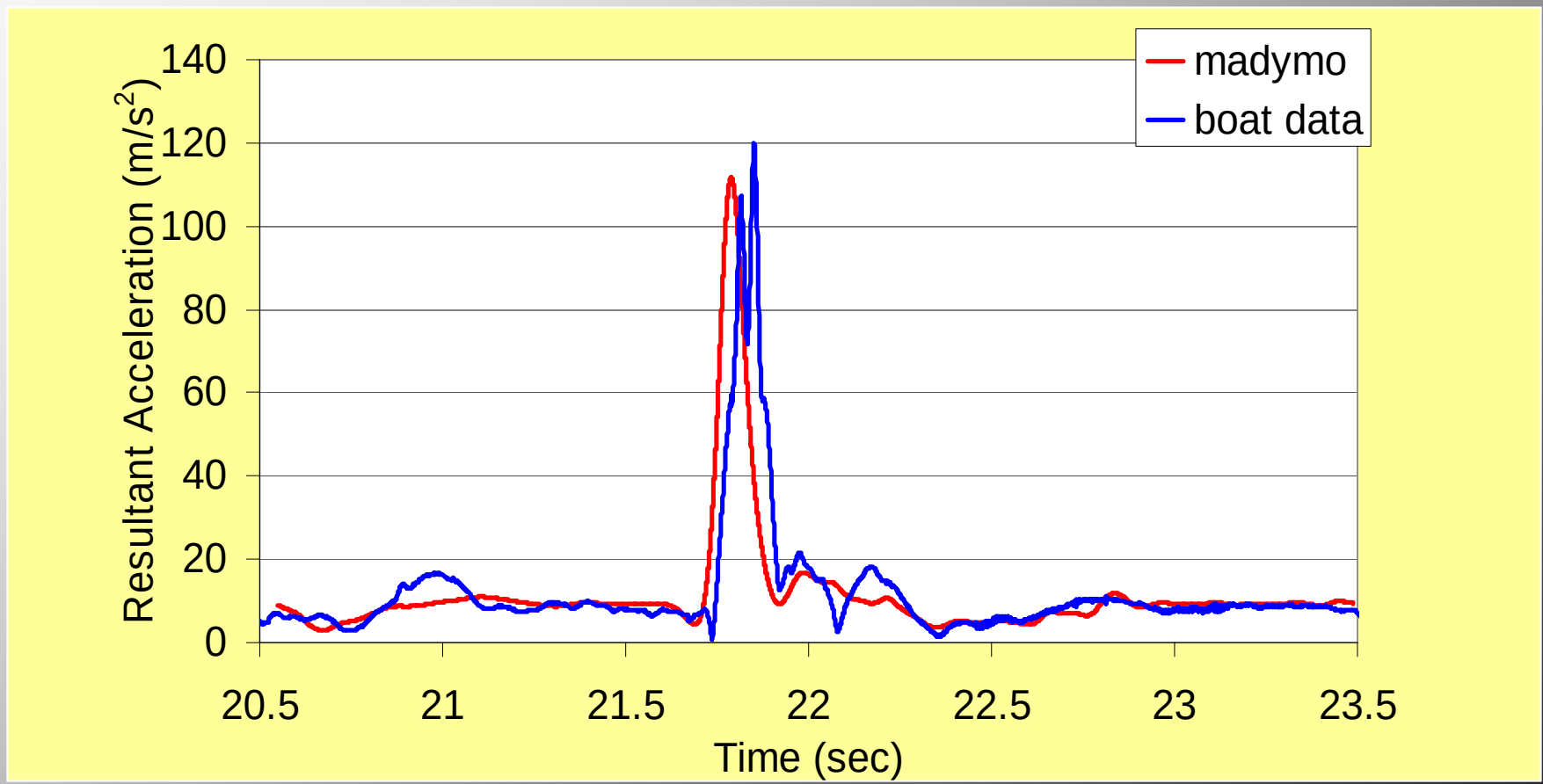
Madymo Simulation

Compare Experiment with Model Output Dynamics (Lumbar Spine)



‘Good’ = Peaks within 10%,
Impulse within 10% of Experimental Values

Large Pulse - Head CG Accel.



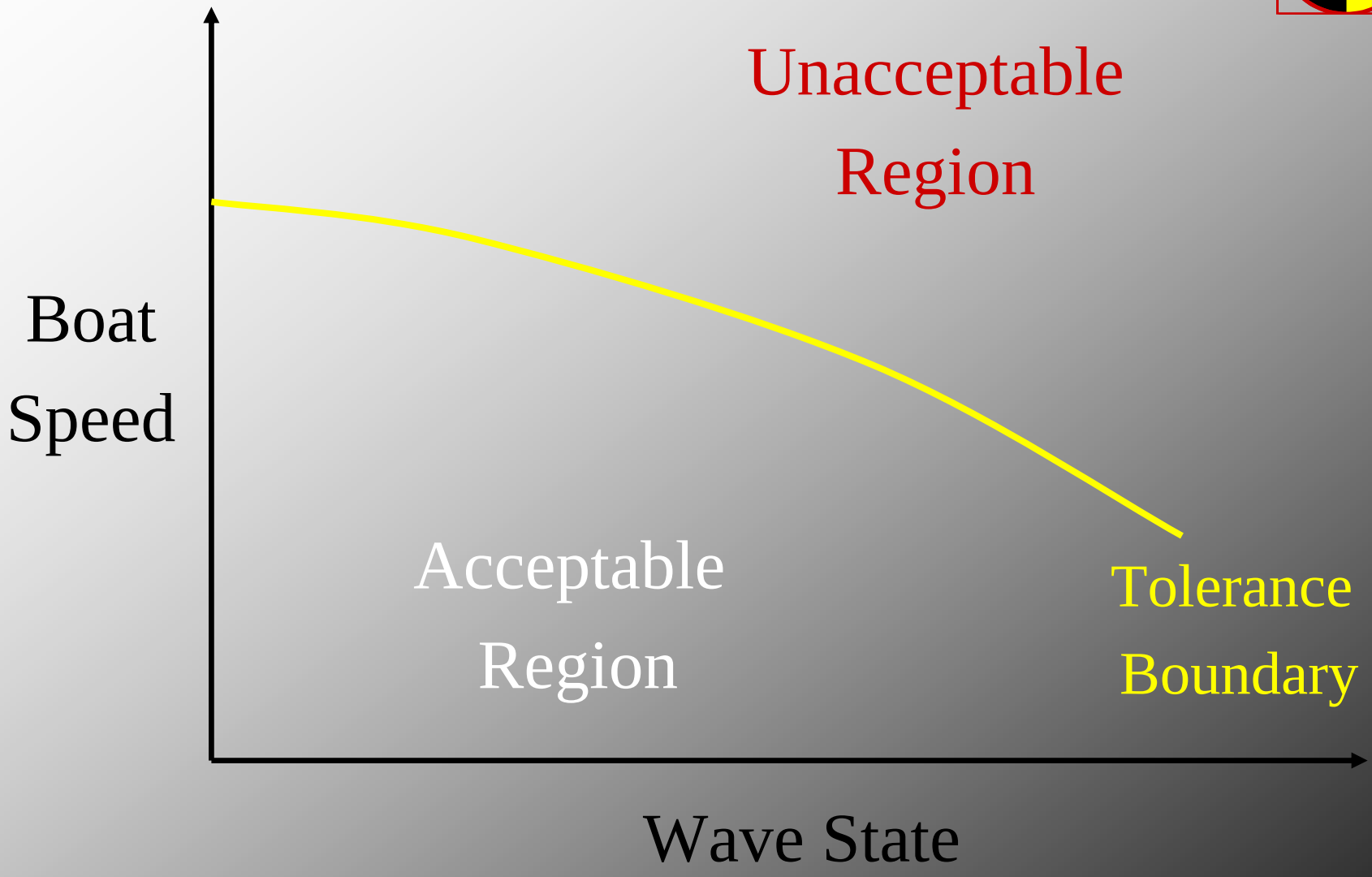
Madymo ‘Metamodel’

- ‘Validated Model’
- Develop ‘Metamodel’
  - Run validated Madymo model for range of inputs
  - Deck inputs => Human injury output
  - Rapid calculation
- Metamodel Used to Evaluate Injury In:
  - Computational boat model
  - Tank test boat model
  - Experimental boat

Validation Dataset Caveat

- Not Sensitive to Pitch-Related Motions
  - Appear to be relatively small
  - Related to relatively high velocity, relatively low sea state?
- Relative contribution of pitch vs. translational velocity
  - *Repeated flexion/extension with small compression may cause herniation (Callaghan et. al. – 2001)*

Effect of Pitch



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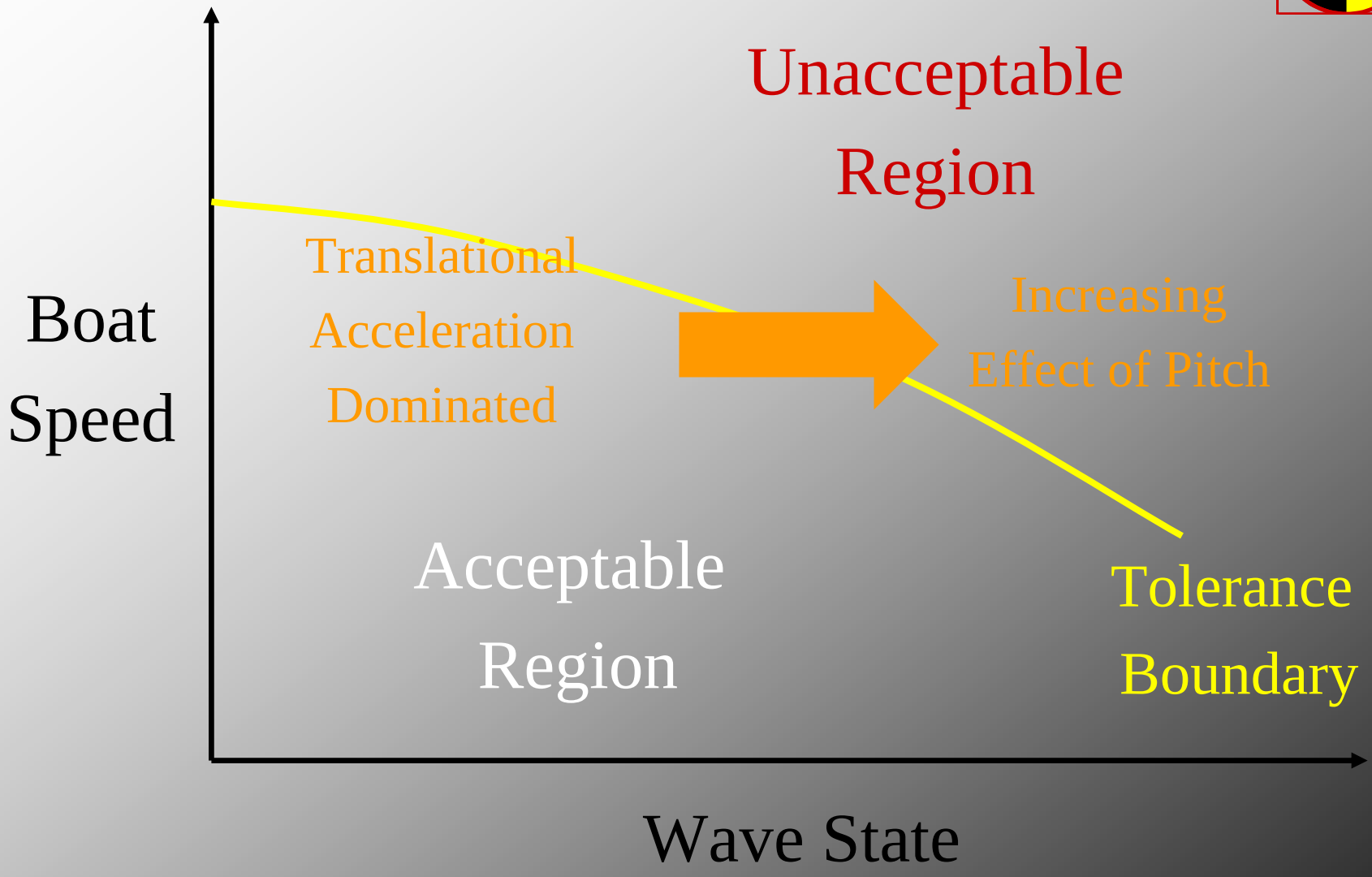
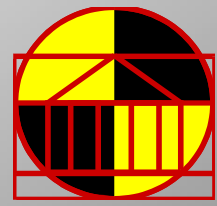


Uses and Limitations

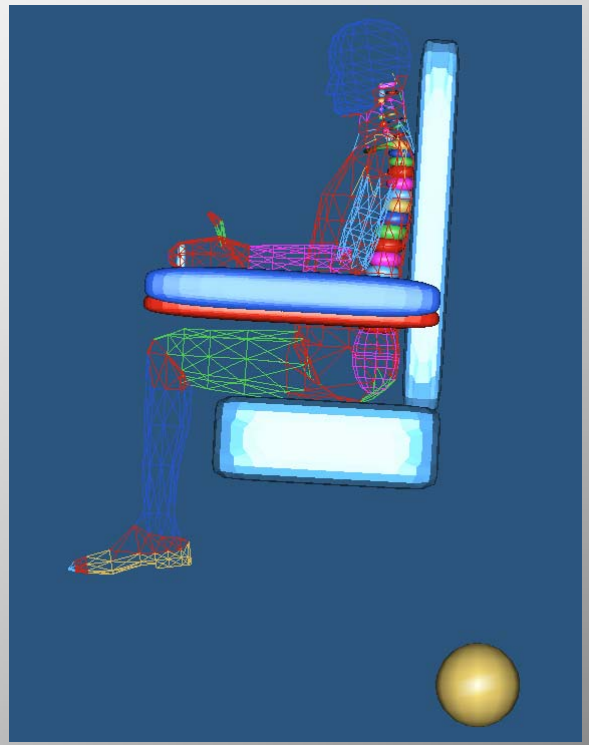


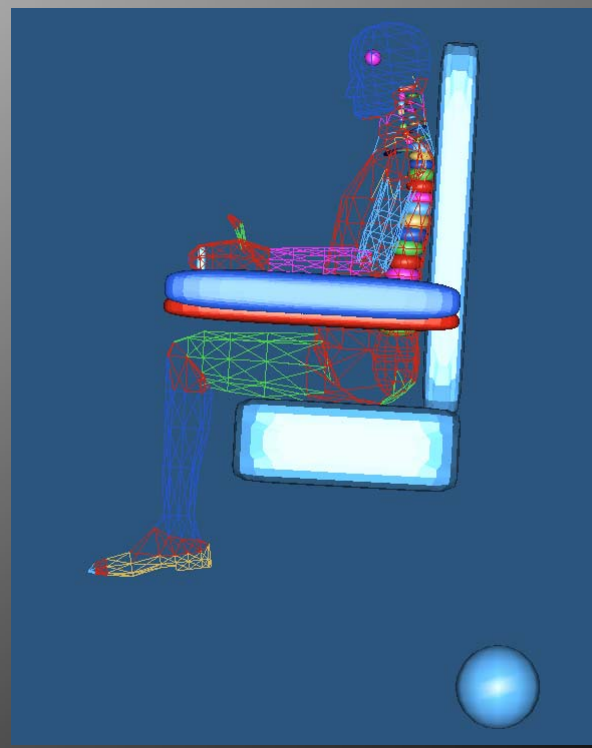
- Calculation of injury in design/construction/deployment phases of boat lifetime, e.g.:
  - Explore seats/belts/countermeasures
  - Incorporate into naval architecture codes
- Limitations
  - Only as good as validation studies
  - Local moments and forces approximate
  - Significant limitation of the injury model
    - Not based on injuries identified in epidemiological studies

Example: Exploratory Study

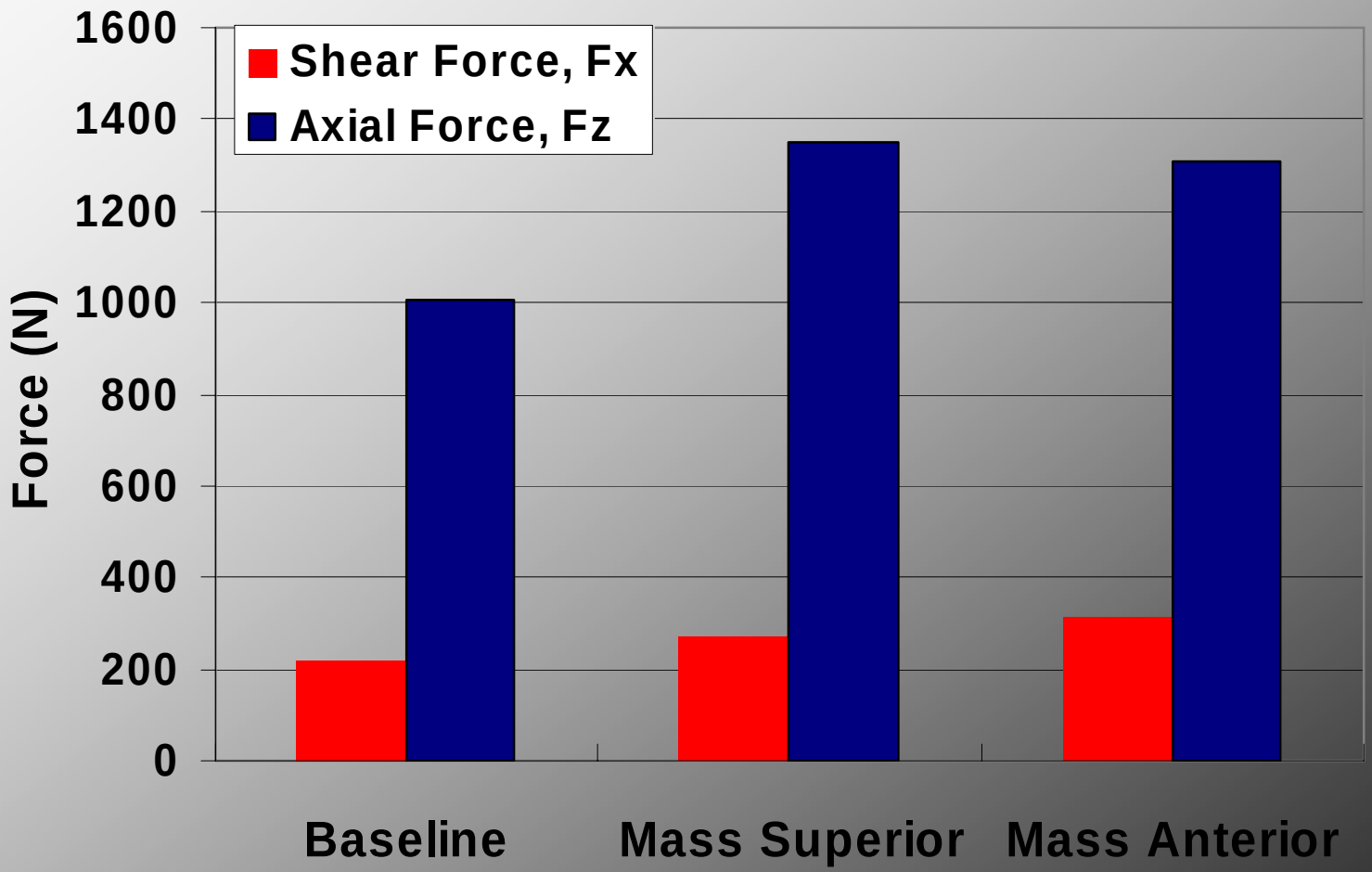
Head Supported Mass (HSM)

- No Mass
- 1.75 kg at 52 mm Superior to Head CG
- 1.75 kg at 17 mm Anterior, 49 mm Superior

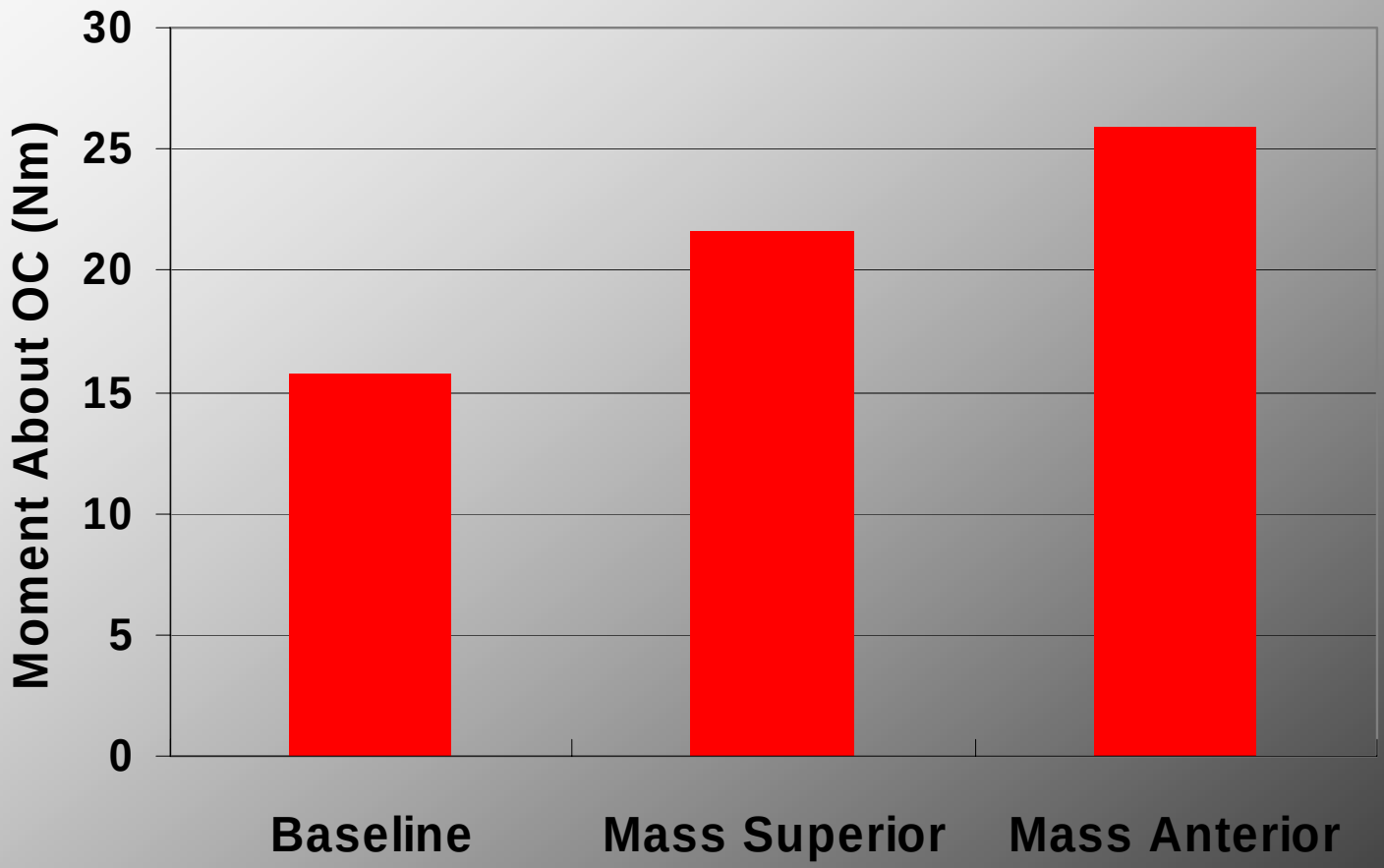




Effect of HSM on Neck



Effect of HSM on Neck



Injury Criterion for Flexion: 190 Nm

Current Work

- Validate Using Current Datasets
  - Higher sea states
  - More rotation
- Validate Against Dummy Data in High Speed Craft
- Develop Madymo ‘Metamodel’
  - Fast calculation code for parameter studies

Summary

- No Current Injury Model is Fully Applicable
- Framework
  - Robust injury model needed!
  - Numerical modeling
    - Evaluation of concepts, countermeasures, etc.
    - Development of specifications
  - Experimental verification/validation
    - Volunteer experimental studies
    - Mechanical performance characterization
  - Epidemiological tracking

Acknowledgements

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Source

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