

The Virtual Soldier Research Program

Background

History

Physics-based

Strength

Applications

An Integrated Human

Open architecture





Virtual Soldier Research Program

Biomechanics of Soft Tissue

National Adv
Driving Simu



Reliability &
Systems

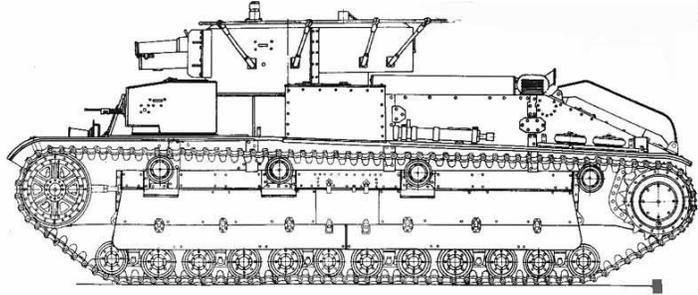
search

RSPS

Advanced Manufacturing



Why the Virtual Soldier?



Physical
prototypes



Engineering Analysis



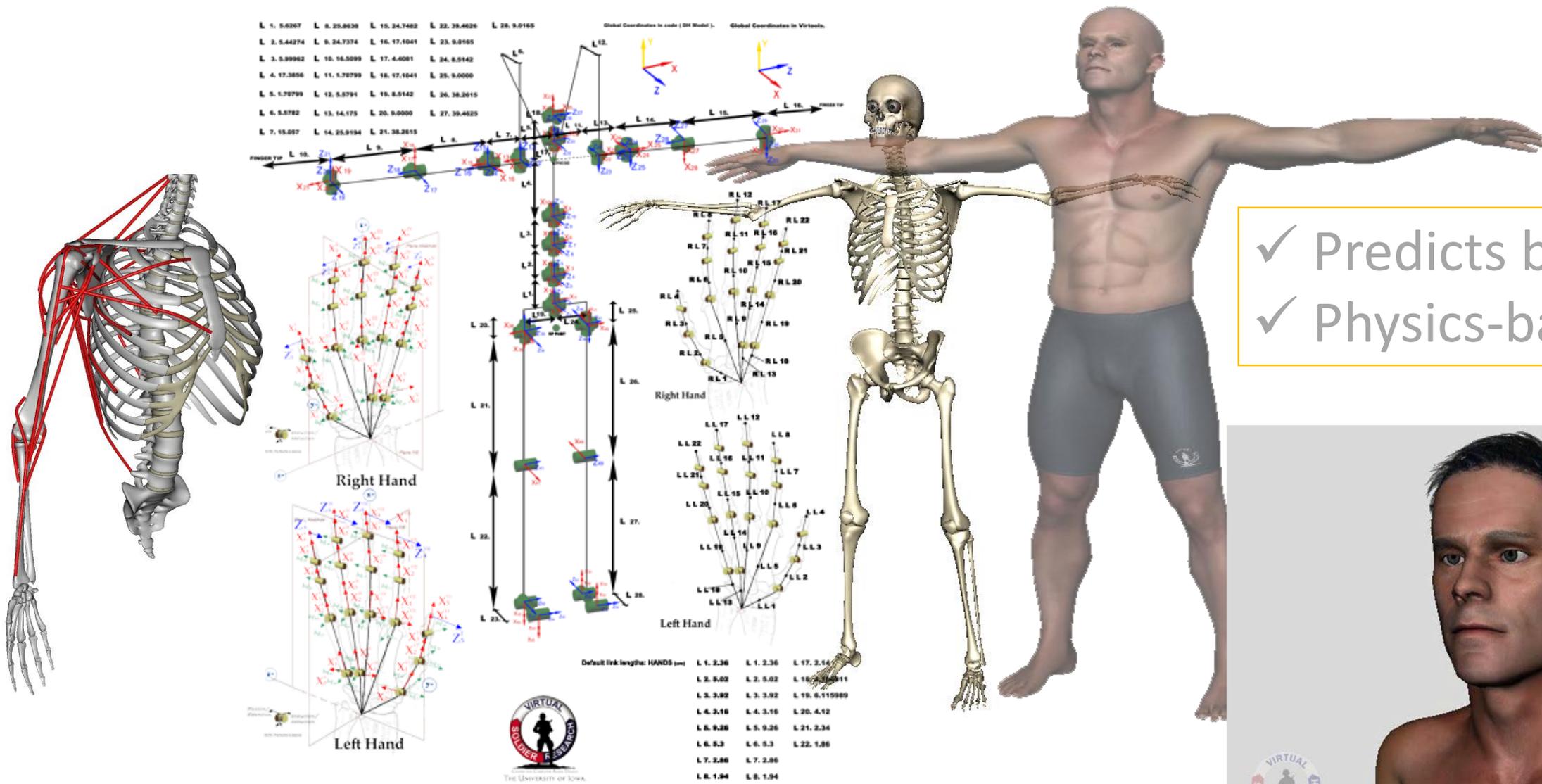
Stress
Vibration
Sound
Structural
Aerodynamics
Thermal
Fluid
Power



Virtual Soldier



The Santos[®] Model



- ✓ Predicts behavior
- ✓ Physics-based



Optimization based kinematics

Objective:

Minimize $F(\mathbf{q})$ e.g., Energy

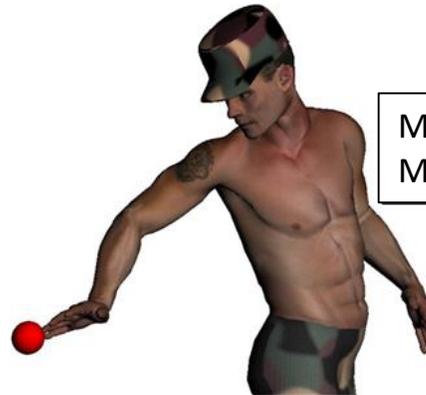
Find: DOF(\mathbf{q})

Constraints:

- Range of motion
- Distance to target
- Physical constraints

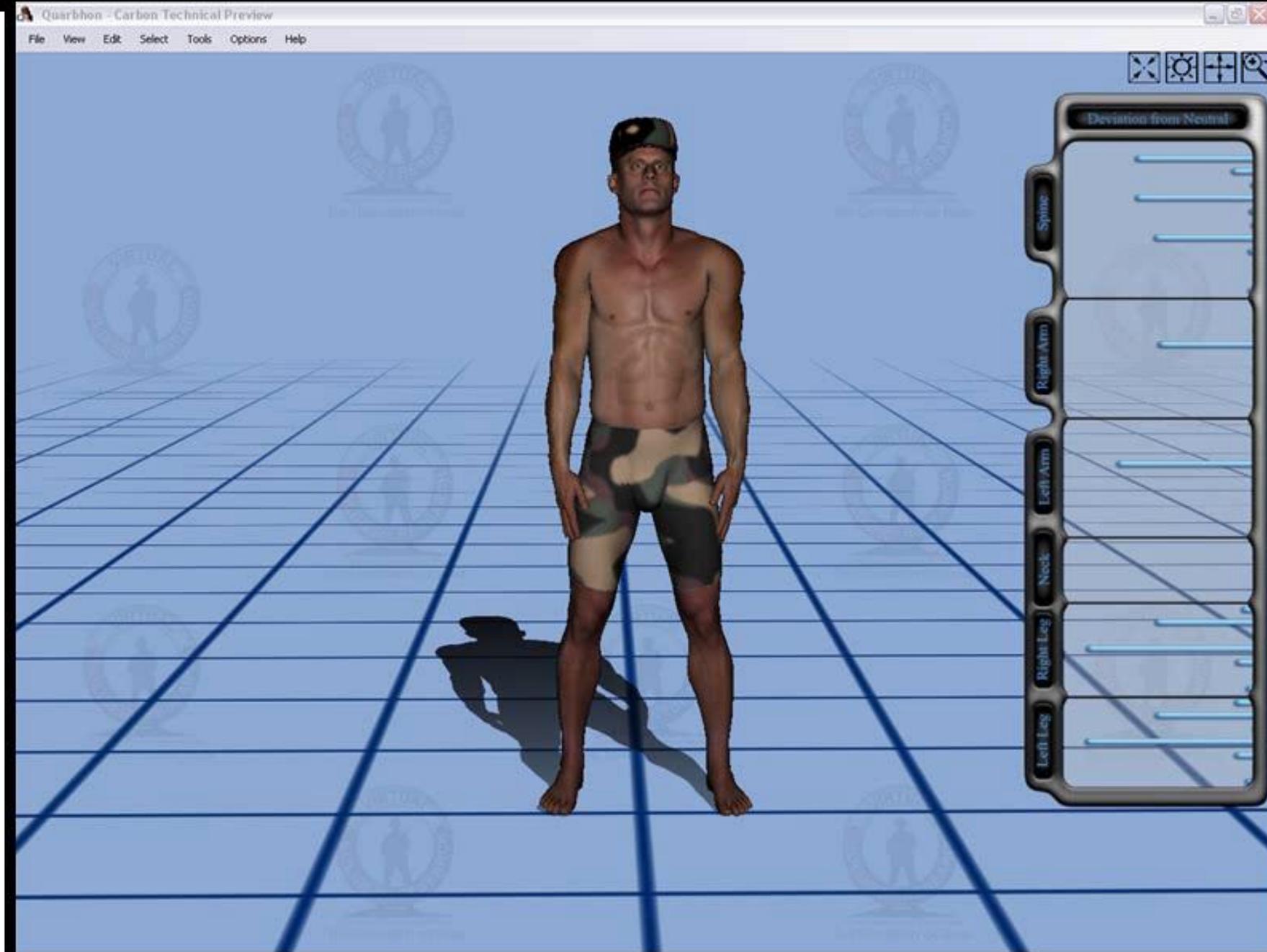


Minimize
Distance



Minimize Distance
Maximize Vision

In 2004/2005



Physics – Dynamics

Objective:

Minimize $F(\mathbf{q})$ e.g., Energy

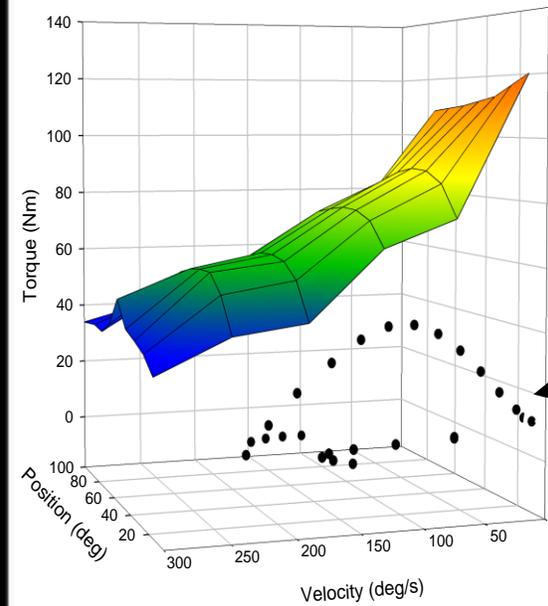
Find: DOF(\mathbf{q})

Constraints:

- Range of motion
- Distance to target
- Physical constraints
- **Equations of Motion (Newton's Laws)**



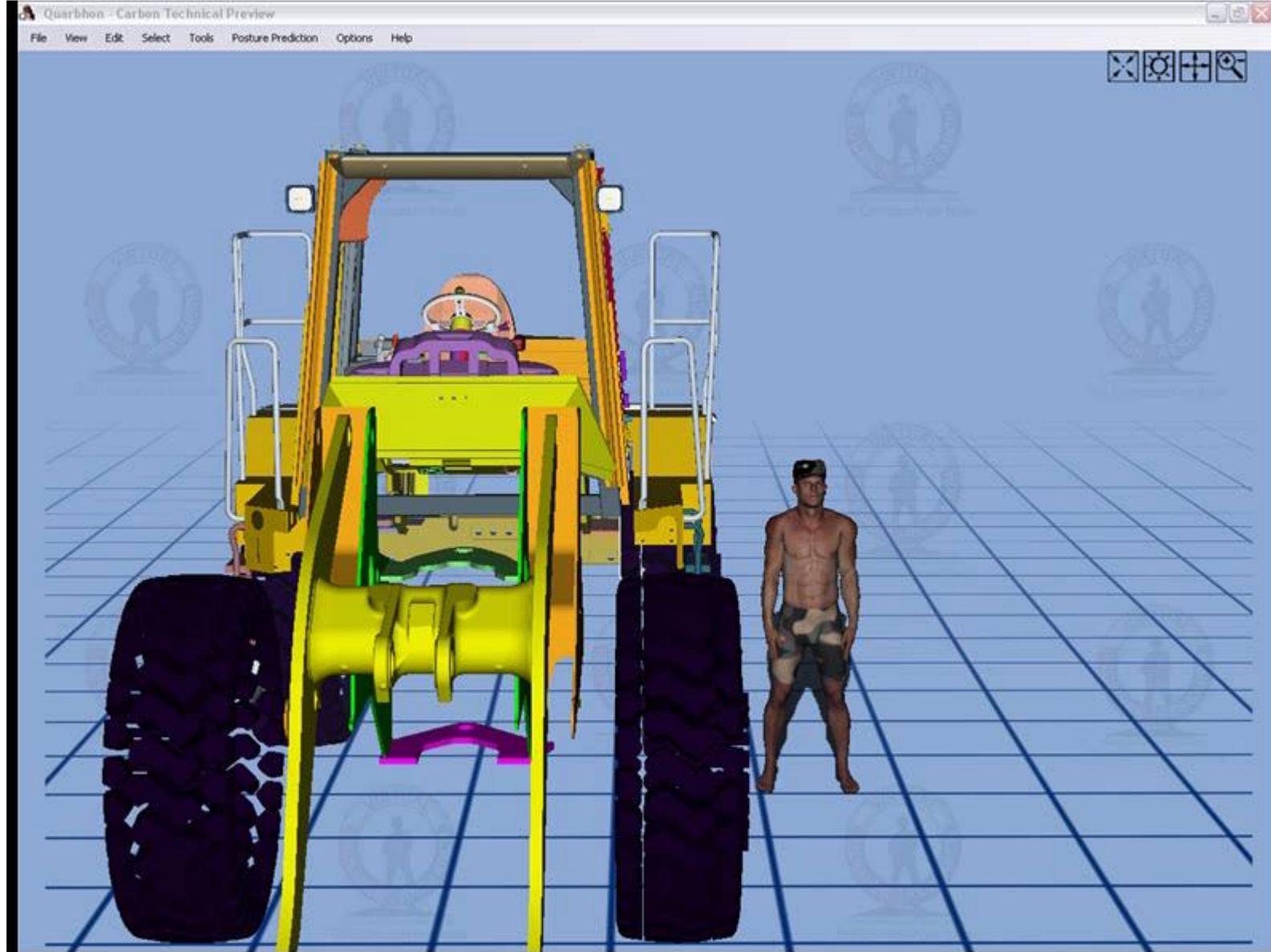
Understanding limits of Human Strengths



gait with 40 lb
backpack
knee joint
50% strength

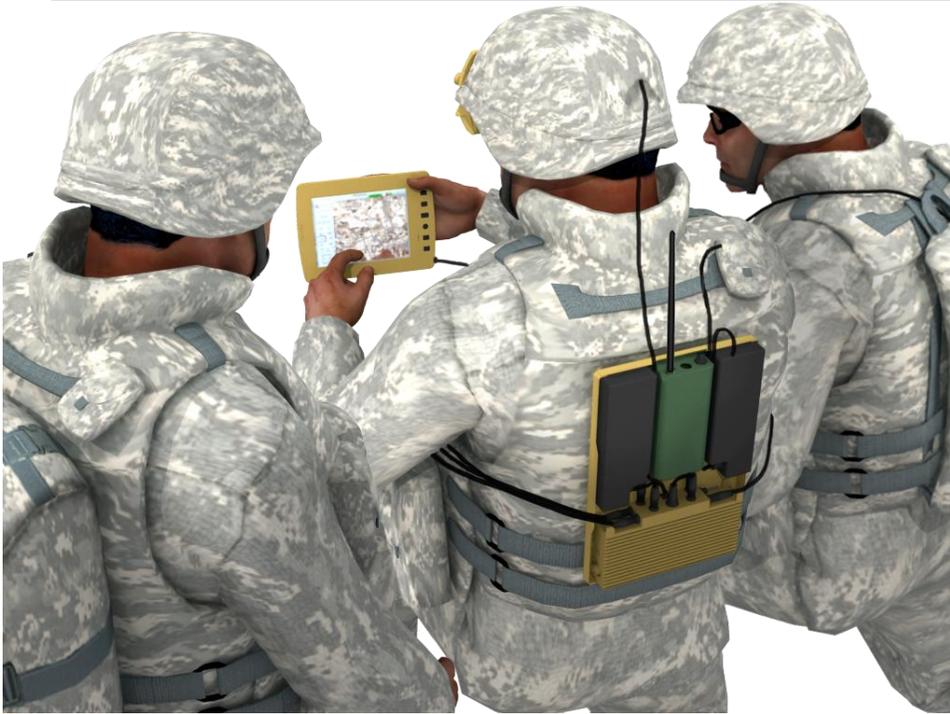


Stability -ZMP



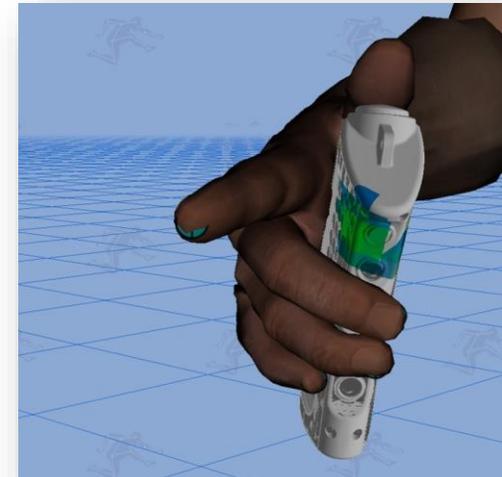
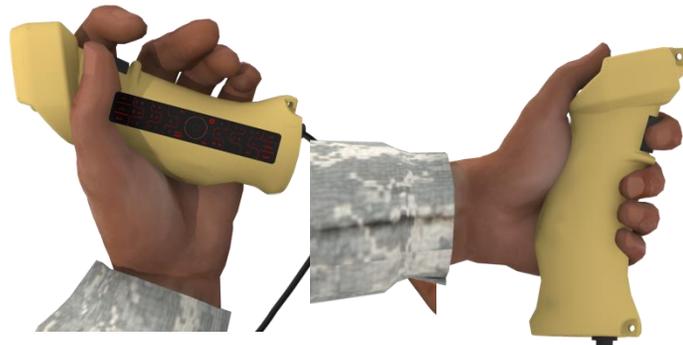
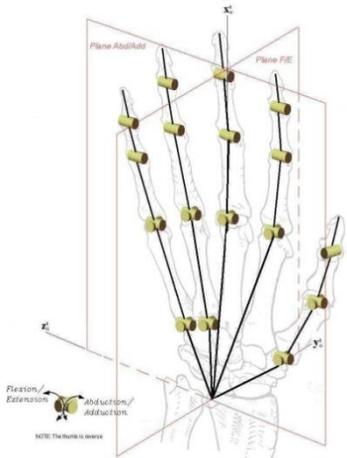
Stability analysis

Hand model

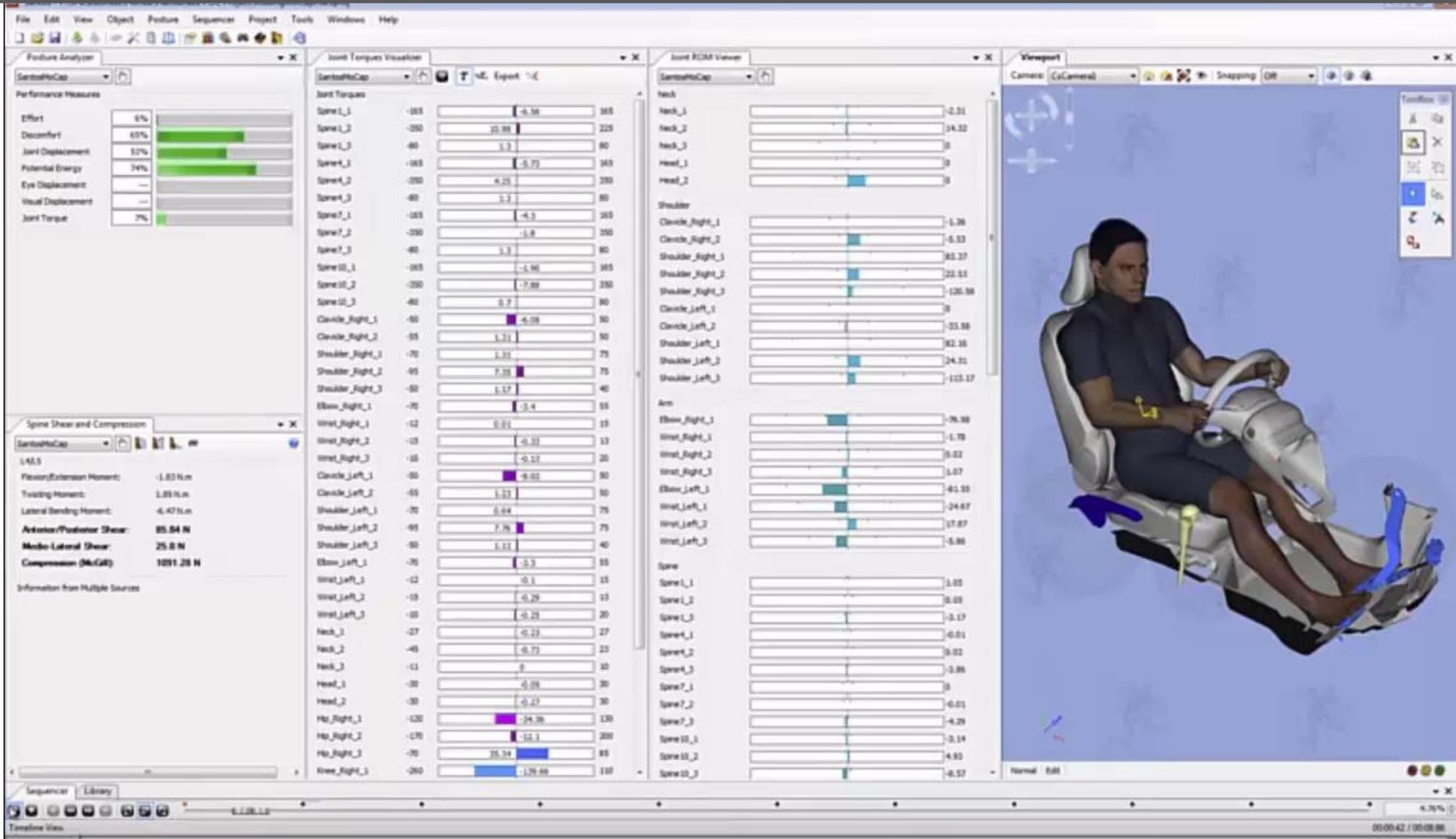


Hand

- 9.1. General Capabilities
 - 9.1.1. 25-DOF model
 - 9.1.2. Literature-based joint limits/range of motion (ROM)
 - 9.1.3. Variable ROM
 - 9.1.4. Flex-joint utility (auto finger range of motion)
 - 9.1.5. Carpel Tunnel risk calculator
 - 9.1.6. Force-torque calculator
 - 9.1.7. Hand Posture Prediction
- 9.2. Zone Differentiation
- 9.3. Grasping
 - 9.3.1. Manual hand morphing
 - 9.3.2. Precision grasping
 - 9.3.3. Power grasping



Analysis: strength, joint range of motion, spine shear and compression





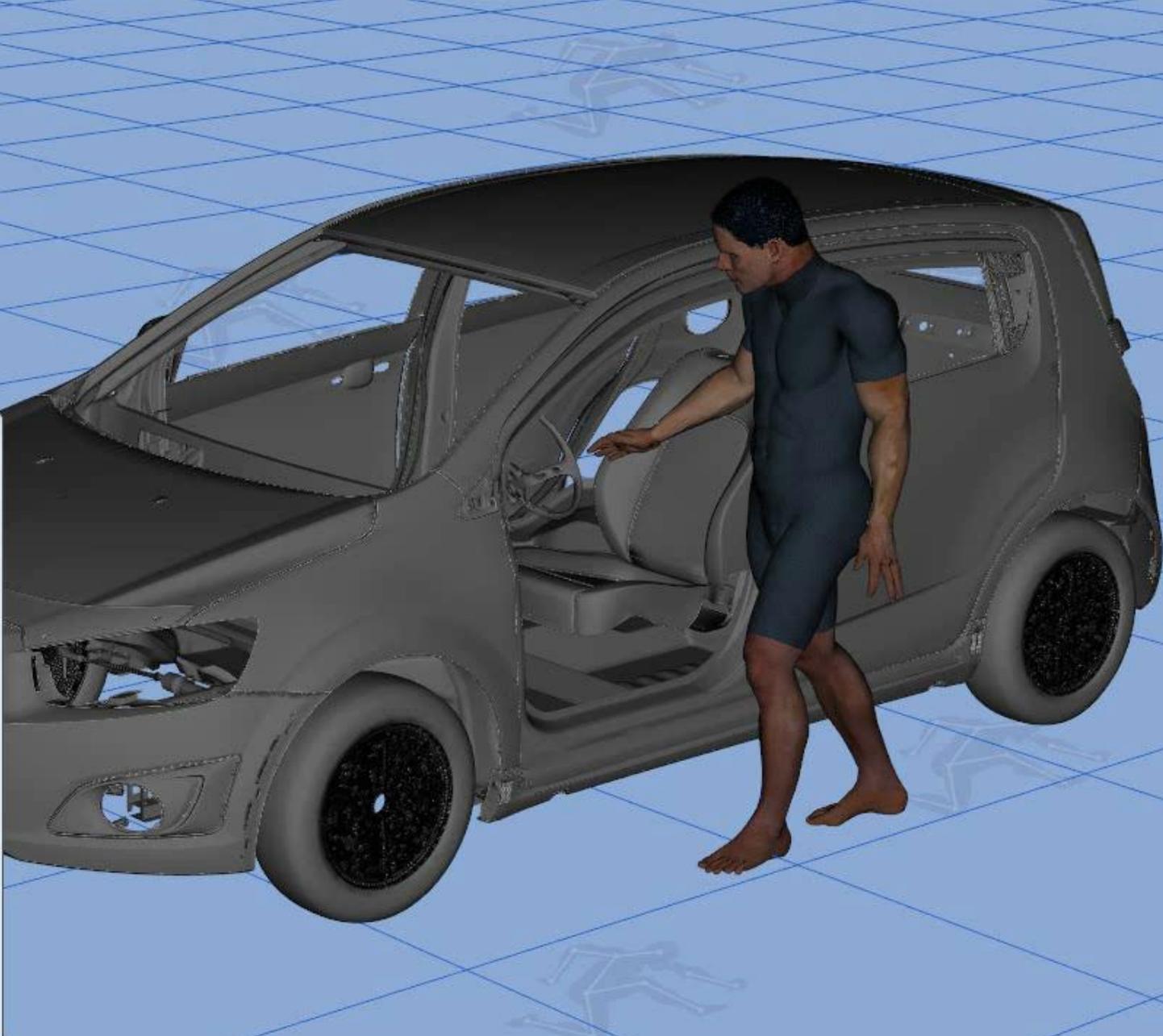
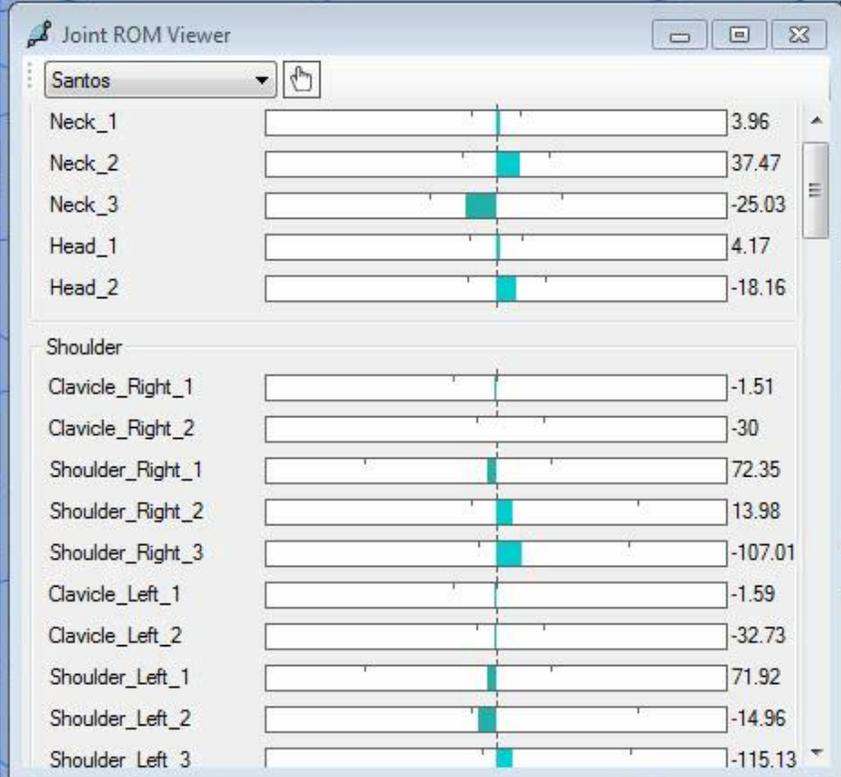
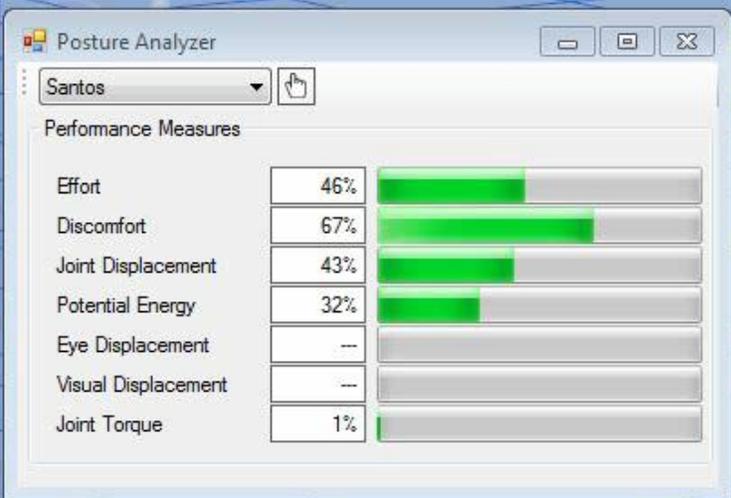
Santos has Biomechanics & Physiology



U.S. ARMY MEDICAL DEPARTMENT
BROOKE ARMY MEDICAL CENTER



Egress-Ingress Analysis



Volumetric Encumbrance

Santos

Intersect armor throughout animation

Voxel radius: 0.22480

Accuracy (Frames per Second): 50.000%

Include Avatar skin intersection (slow)

Run

Visualize

Show Filled

Show Encumbered

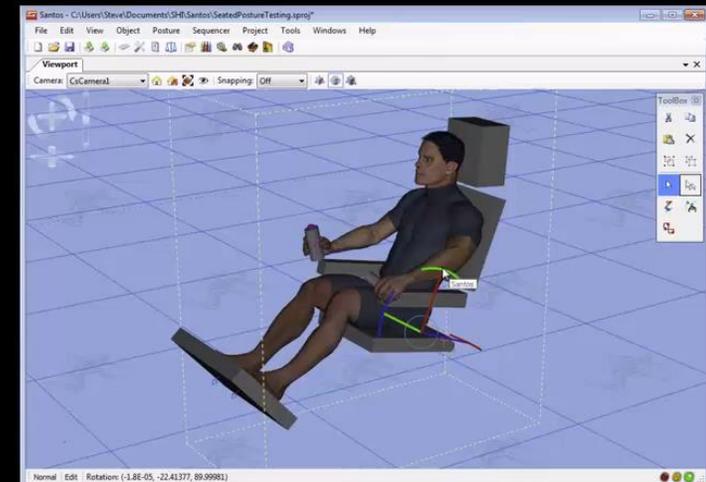
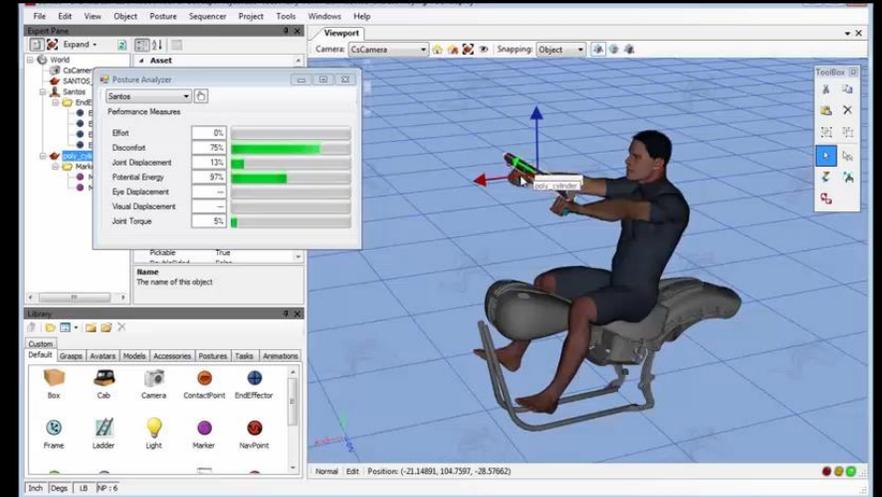
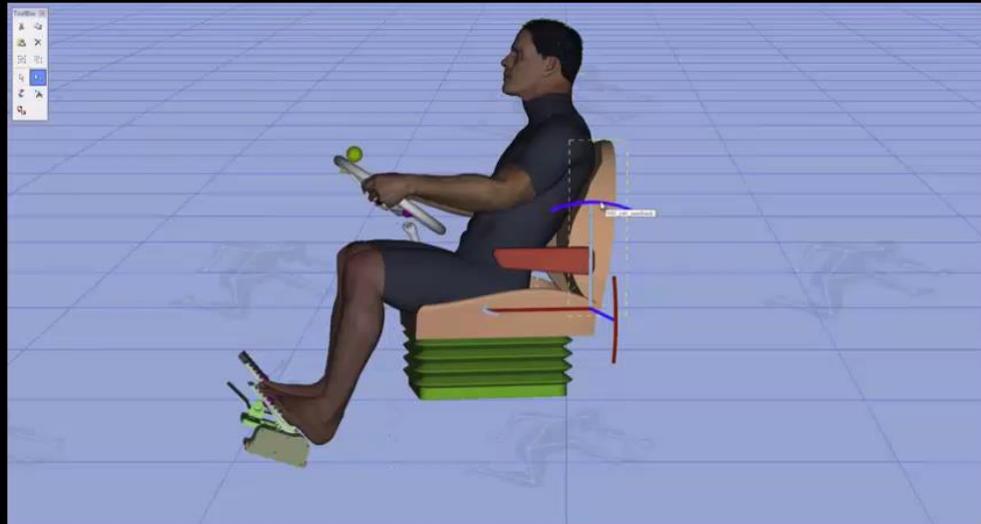
Load as model...

Show Armor

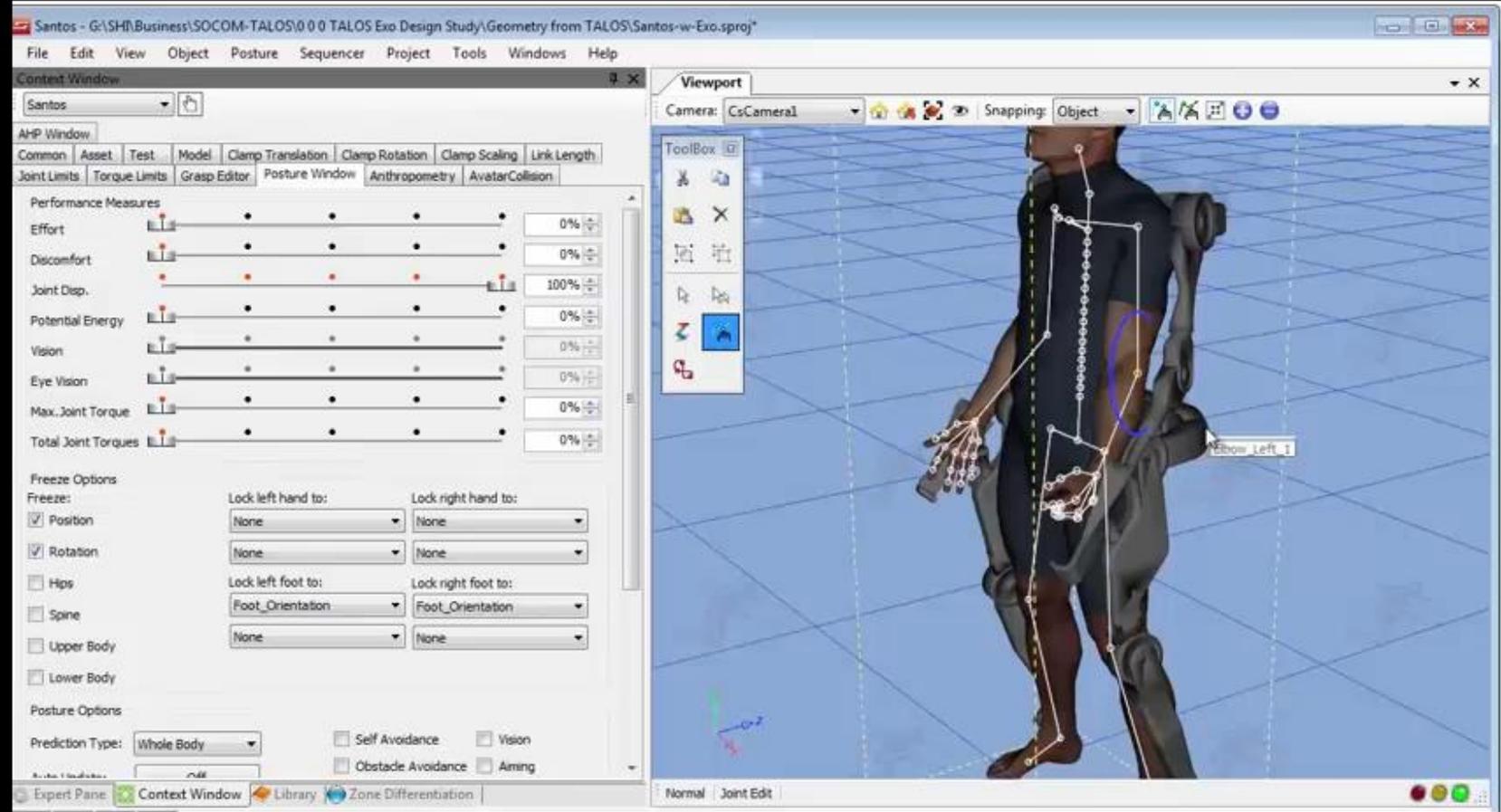
Hide Armor



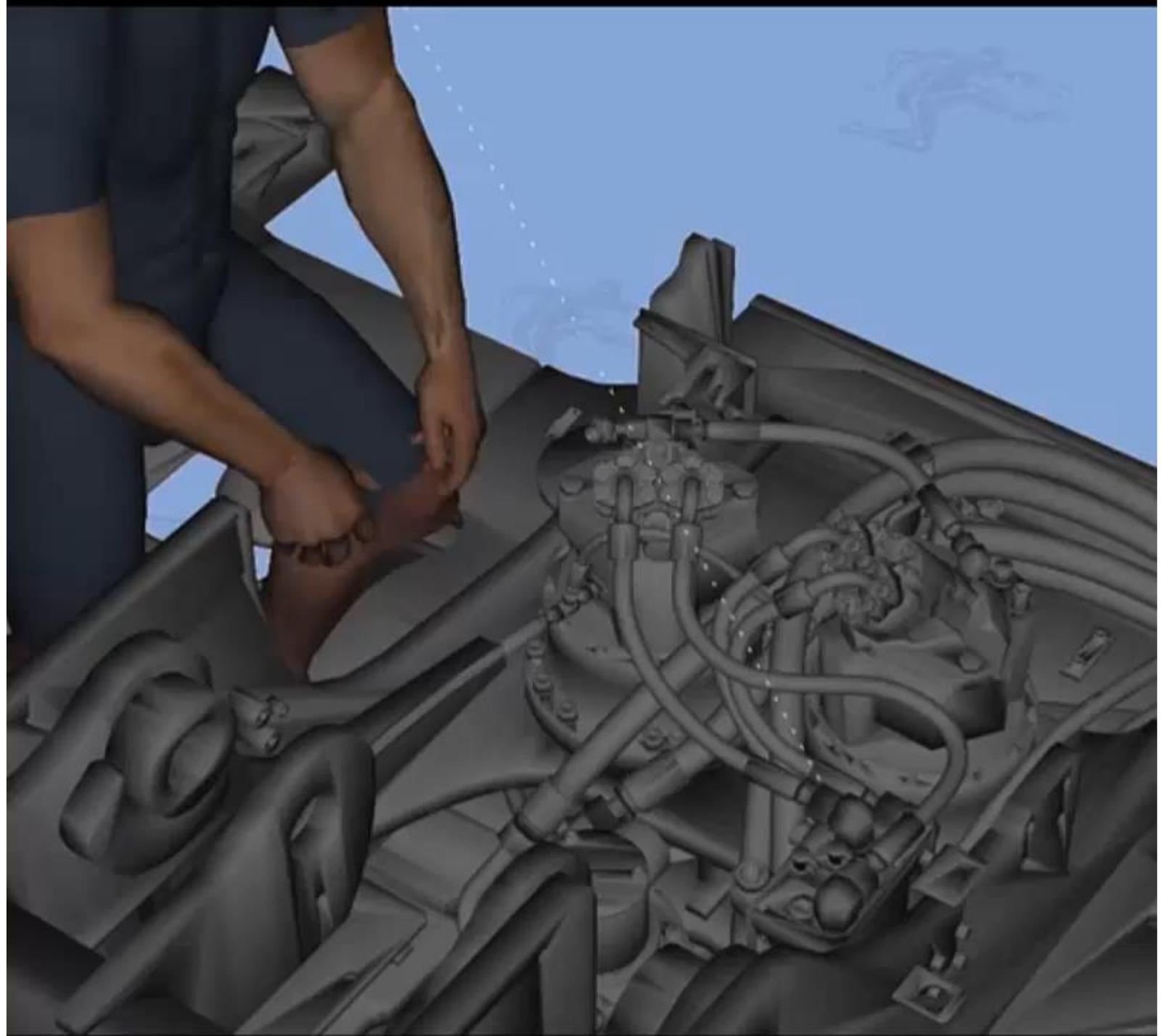
Seat and Cab design

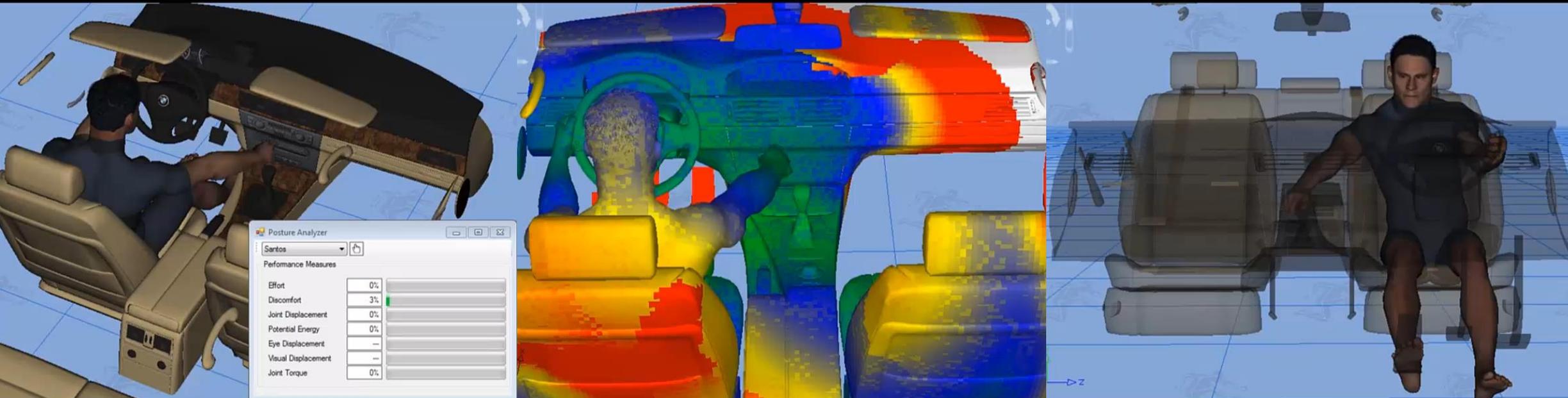


Analysis of function, form, and fit



Reach, Vision, and Collision Detection





Posture Analyzer

Santos

Performance Measures

Effort	0%
Discomfort	3%
Joint Displacement	0%
Potential Energy	0%
Eye Displacement	—
Visual Displacement	—
Joint Torque	0%

Joint ROM Viewer

Santos

Neck		
Neck_1		-0.04
Neck_2		35.01
Neck_3		-0.37
Head		
Head_1		-0.01
Head_2		-28.15
Shoulder		
Clavicle_Right_1		-0.14
Clavicle_Right_2		-29.34
Shoulder_Right_1		89.57
Shoulder_Right_2		17.29
Shoulder_Right_3		-156.86
Clavicle_Left_1		-0.8
Clavicle_Left_2		-29.87
Shoulder_Left_1		67.74
Shoulder_Left_2		0.91
Shoulder_Left_3		-132.38
Arm		
Elbow_Right_1		80.57
Wrist_Right_1		6.6
Wrist_Right_2		23.98
Wrist_Right_3		-14.57
Elbow_Left_1		-78.23
Wrist_Left_1		1.49
Wrist_Left_2		-9.63
Wrist_Left_3		16.05

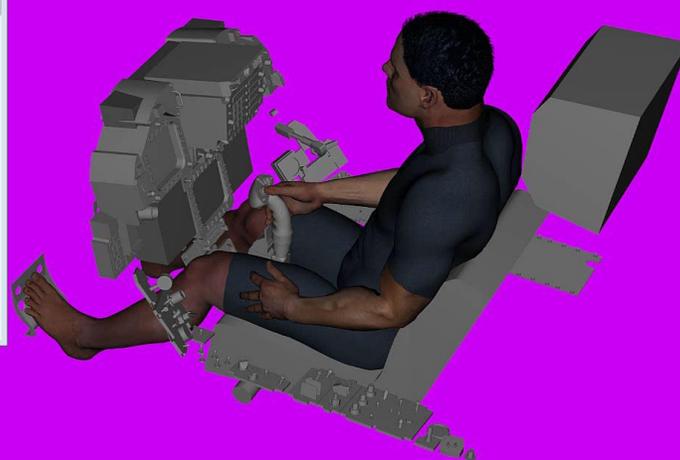
Static Fatigue

Santos

Reference

60 min : 00 sec

- Upper Extremities
 - Clavicles
 - Shoulder
 - Left
 - Extension: 60 min : 00 sec
 - Flexion: 46 min : 03 sec
 - Abduction: 60 min : 00 sec
 - Adduction: 60 min : 00 sec
 - Internal Rotation: 60 min : 00 sec
 - External Rotation: 60 min : 00 sec
 - Right
 - Extension: 60 min : 00 sec
 - Flexion: 30 min : 59 sec
 - Abduction: 60 min : 00 sec
 - Adduction: 50 min : 36 sec
 - Internal Rotation: 60 min : 00 sec
 - External Rotation: 60 min : 00 sec



Posture Analyzer

Santos

Performance Measures

Effort	0%
Discomfort	50%
Joint Displacement	12%
Potential Energy	17%
Eye Displacement	—
Visual Displacement	—
Joint Torque	8%

HF Analysis Tools

Human Variability



- Anthropometry
- Weight
- Body type
- Strength
- Fatigue

Soldier Lethality

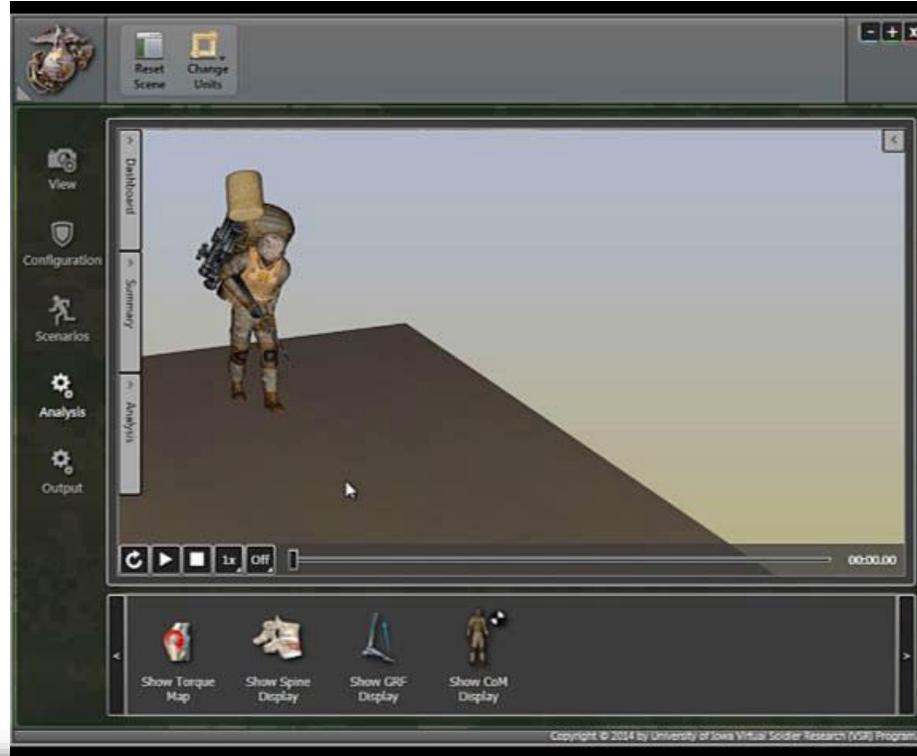
- Operational effectiveness
- Individual load configuration
- Weight distribution on squad
- Human performance
- Mobility
- Survivability, PPE, and vulnerability
- Soldier/Squad specific

mobility versus protection versus lethality

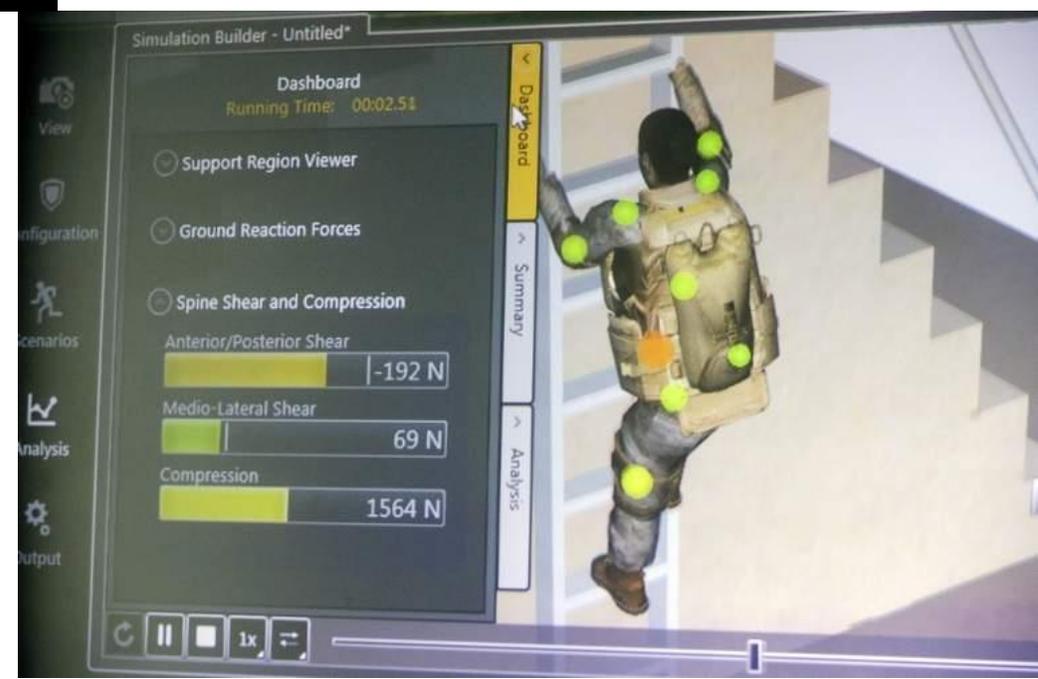




Warrior Performance



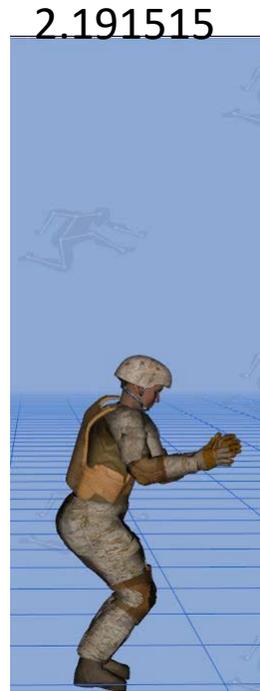
- Effects of Load
- Effects of gravity
- Muscle fatigue
- Muscle strength
- Clothing restrictions
- Terrain
- Energy expenditure



Conduct trade off analysis

The screenshot displays a virtual simulation environment. At the top, there is a toolbar with a Marine Corps emblem, 'Reset Scene', 'Change Units', and 'Help' buttons. A central window shows a soldier with a large backpack and rifle standing on a set of stairs. To the left of the window is a sidebar menu with icons for 'View', 'Avatars', 'Configuration', 'Scenarios', and 'Output'. Below the window is a video player interface with playback controls and a '1x speed' indicator. At the bottom, a control panel features six icons for movement actions: 'Stair Ascend', 'Stair Descend', 'Stair Ascend Steep', 'Stair Descend Steep', 'Vertical Jump', and 'Ladder Climb'. A tooltip 'Click and hold on right side for navigation' is visible over the speed control.

Sophia
60 kg



Jenny
51 kg



Injury, blast, internal organs



Survivability Analysis



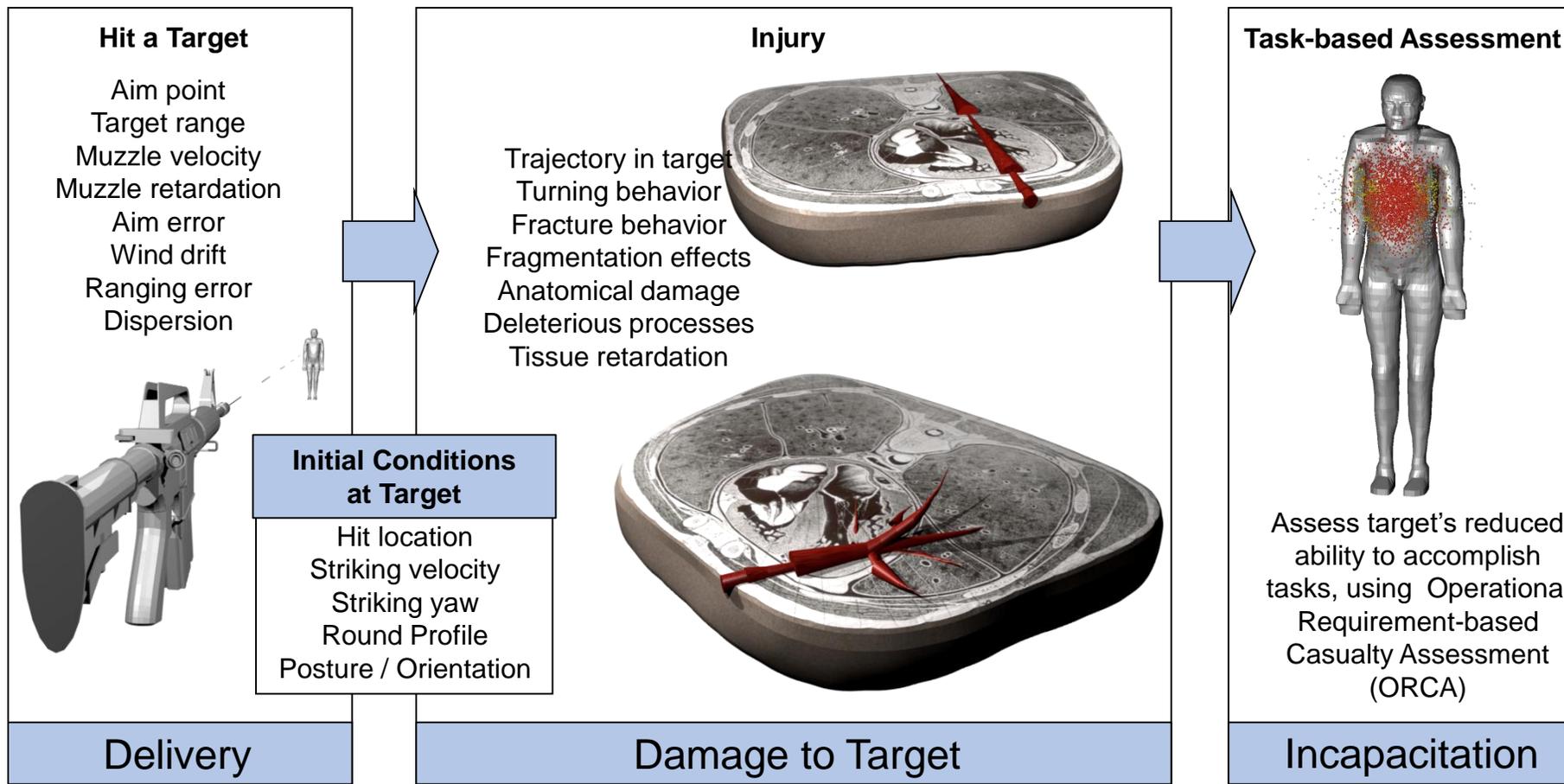
MUVES – simulates various threats against personnel with armor. It is a stochastic, component level survivability, lethality, and vulnerability (SLV) software suite. Simulates direct and indirect fire munitions against vehicles and personnel with armor





U.S. ARMY
RDECOM

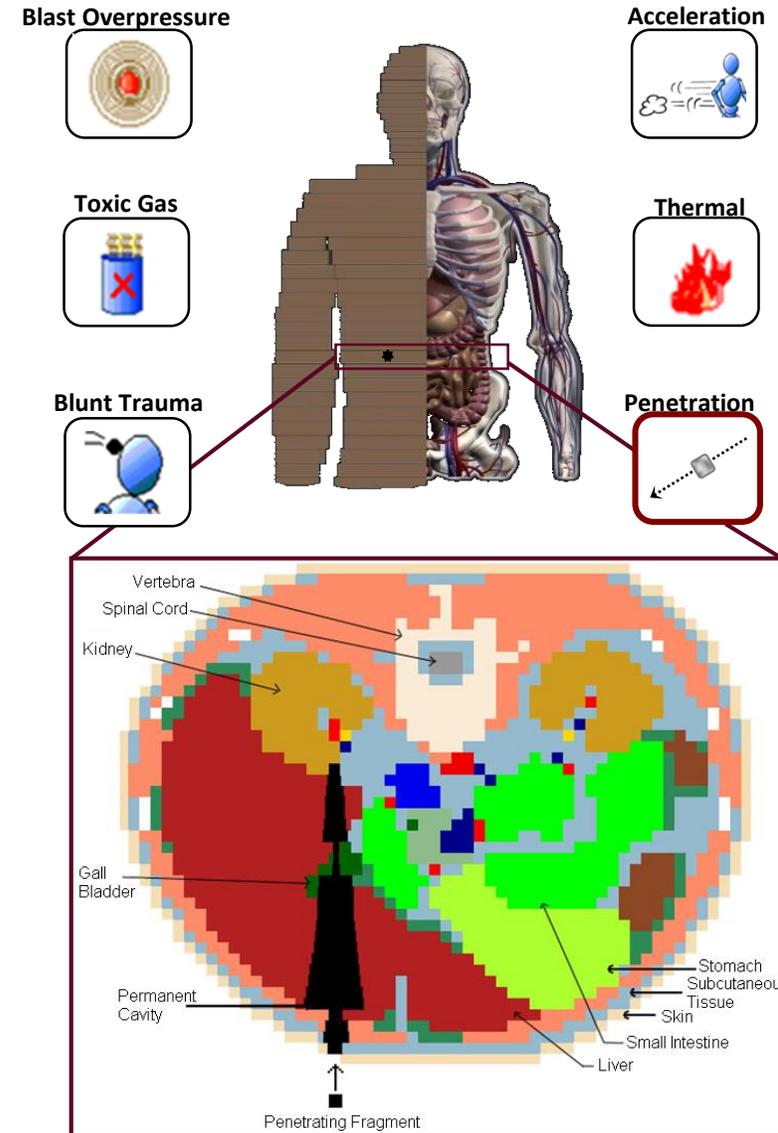
Static-Dynamic Framework **ARL**



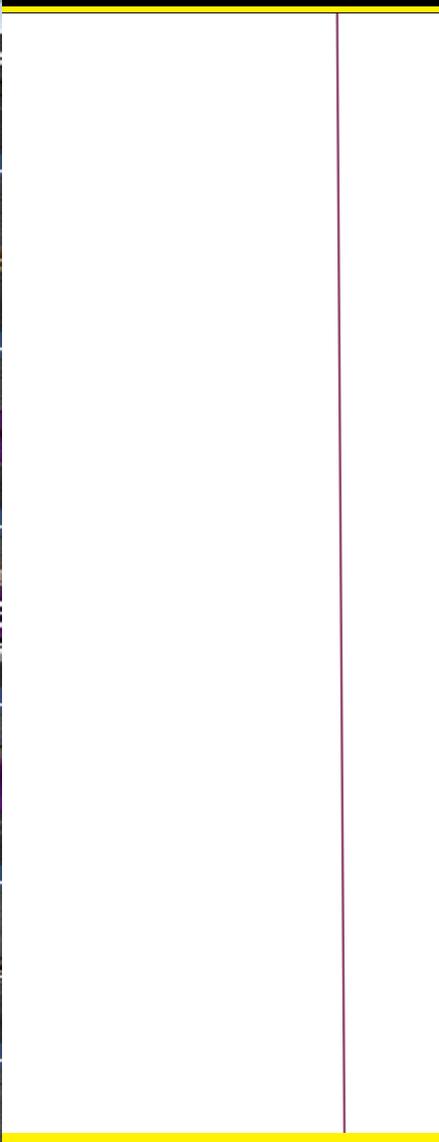
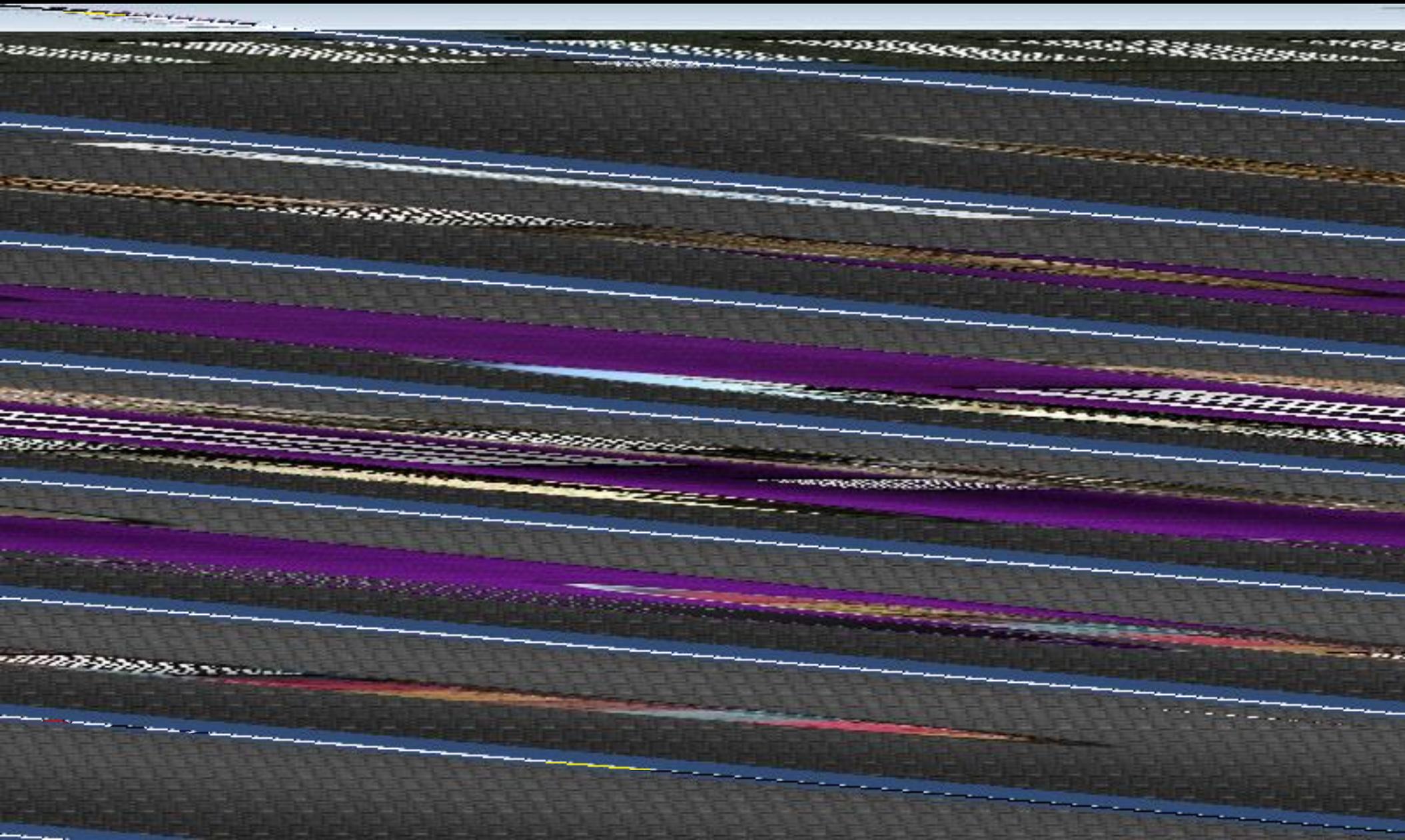
ORCA – a high-resolution computerized human vulnerability model that is used to assess the impact of various casualty-causing insults on personnel. Insults include penetration, blast effects and thermal effects

ORCA:

- Is the DoD's high-resolution computerized human vulnerability model that is used to assess the impact of various casualty-causing insults on personnel.
- Calculates injury severity trauma metrics that may be used to characterize both an individual injury as well as multiple injuries to a single person.
- Assesses the impact of various casualty-causing mechanisms on the ability of military personnel to perform battlefield tasks.
- Considers the operational tasks that personnel must perform, and determines the extent to which penetration and other battlefield insults degrade the ability to perform these tasks.
- May be used to provide medical and operational casualty data of the human system.



Lighten The Load



- **Mobility**

(RoM, weight, speed, agility, recovery, extended load carriage)



Mobility versus weight versus protection

Range of Motion



Warrior Configuration - test1.sproj

Total Equipment Inventory: 84.92 Pounds

Name	Quantity	Weight
Total By Group		
Clothing:	10	9.83
Equipment:	7	75.09
Extra Items:	0	0
Clothing		
Elbow Pad (L)	1	0.5
USMC Boot (L)	1	2.05
Elbow Pad (R)	1	0.5
EFCE Pants	1	2.2
Frog Glove (L)	1	0.165
USMC Boot (R)	1	2.05
Frog Glove (R)	1	0.165
EFCE Shirt	1	1.2
Knee Pad (R)	1	0.5
Knee Pad (L)	1	0.5
Equipment		
IMTV Vest L	1	14.37
ECH Helmet M	1	3.06
M18 Smoke Grenade	1	2
M67 Frag Grenade	2	4
USMC Main Pack (1/2)	1	36.5
M249 saw	1	15.16
Extra Items (Empty List)		

Warrior Specs Santos

Height: 1.82 m

Weight: 258.64 lb

Warrior: 173.72
Gear: 75.09
Pack: 36.5
Clothing: 9.83

Bounding Box

Height: 0.71 m
Width: 1.72 m
Depth: 1.87 m

Cocoon Volume

Total: 0.74 m³
Avatar: 0.55 m³
Pack: 0.18 m³

Navigation Bar: Joint Torque Map, Eye Relief, Aiming Envelope, Spine Shear Compression, Discomfort, Support Region, Reaction Forces, Center of Mass, Cocoon, Bounding Box, Avatar Visibility, Collision Tracking

Recovery

The screenshot displays a virtual soldier simulation interface. At the top, a toolbar includes icons for Open File, Save File, Reset Scene, Change Units, Show Alerts, Create Log, Cmd Window, and View Help. The main window is titled "Extended Load Carriage - Untitled*" and features a central 3D model of a soldier in desert camouflage holding a rifle. To the left of the model is a "Thermal" panel with "USARIEM Recommendations" and "Environmental Factors". To the right is an "Inputs" panel with terrain, slope, speed, and gear load settings. A bottom toolbar contains playback controls and a timeline. A bottom menu shows various terrain and environment presets.

Thermal

USARIEM Recommendations

- Max Work 300 min
- Max Water 0.3 qt/hr
- Work Rest Cycle 60 min
- Work Rest Cycle Water 0 qt/hr
- Rest Water 0.2 qt/hr
- Heat Casualty 0.44 %
- Estimated Recovery 7.7 min

Environmental Factors

- Time of Day Dawn
- Temperature 21.1 °C
- Relative Humidity 76.77 %
- Wind Speed 8.63 m/s
- Mean Radiant Temp 64.7 °C
- Altitude 455 m
- ICLO Parameter 0.47

Inputs

Fitness First Class

Max VO₂ 67.08 mL/kg/min

Terrain Dirt Road

Dirt Road

Slope 0°

Flat

Speed 1.12 m/s

Slow

Gear Load 7.86 kg

Default Desert Summer Desert Winter Tundra Tundra Extreme Temperate Plains Temperate Plains Hot Temperate Plains Cool Rain Forest

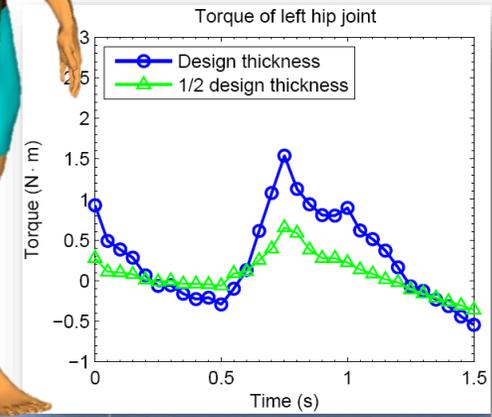
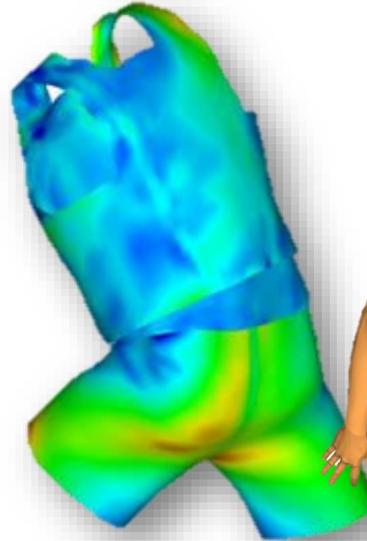
Optimization for dynamics EXE 'StrideWalkingWithWeapon_LeftLeading.exe' succeeded after 1 evaluation(s). Copyright © 2015 by University of Iowa Virtual Soldier Research (

Survivability

Armor (PPE), cover and concealment



Biomechanical Effects of PPE Soft Armor & Clothing



Viewport Camera: CsCamera Snapping: Off

Joint Torques Visualizer

Santos

Joint	100%	Value	100%
Spine1_1	100%	2.74%	100%
Spine1_2	100%	-19.06%	100%
Spine1_3	100%	-0.92%	100%
Spine4_1	100%	3.06%	100%
Spine4_2	100%	-16.81%	100%
Spine4_3	100%	-1.22%	100%
Spine7_1	100%	3.16%	100%
Spine7_2	100%	-14.69%	100%
Spine7_3	100%	-1.17%	100%
Spine10_1	100%	3.11%	100%
Spine10_2	100%	-12.67%	100%
Spine10_3	100%	-0.71%	100%
Clavicle_Right_1	100%	-9.38%	100%
Clavicle_Right_2	100%	-6.02%	100%
Shoulder_Right_1	100%	5.12%	100%
Shoulder_Right_2	100%	9.18%	100%
Shoulder_Right_3	100%	7.04%	100%
Elbow_Right_1	100%	-10.49%	100%

Posture Analyzer

Santos

Performance Measures

Effort	59%
Discomfort	82%
Joint Displacement	54%
Potential Energy	45%
Eye Displacement	---
Visual Displacement	---
Joint Torque	1%

ZMP Viewer

Santos

ZMP

Center of Mass (COM) Data

Santos

Neck_1	-6.72
Neck_2	2.86
Neck_3	6.47
Head_1	-0.27
Head_2	-26.74
Shoulder	
Clavicle_Right_1	1.49
Clavicle_Right_2	-11.4
Shoulder_Right_1	81.24
Shoulder_Right_2	44.44
Shoulder_Right_3	-149.99
Clavicle_Left_1	-4.68
Clavicle_Left_2	-15.24
Shoulder_Left_1	89.98
Shoulder_Left_2	24.76
Shoulder_Left_3	-119.78
Arm	

22.63%

ZMP distance measures

ZMP Stability Margin

Distance to Nearest Segment: 0.275999993085861. Inside Foot Support Region (FSR):

00:09.40 / 00:41.54

Intellectual Property

- All IP is owned by the University of Iowa
(The **Bayh–Dole Act** or Patent and Trademark Law Amendments **Act** (Pub. L. 96-517, December 12, 1980))

Open Architecture

- API and Scripting

Validation & Verification

- Significant work at various organizations

An Integrated Approach

Puppeteer™

Use Motion Capture
Change Camera
 In Place (Anchored) Animation
Toggle Nodes
Toggle Edges
Slow Motion
Use Depth of Field
Use Shadows
Reload Scene

Idle
Walk
Run
Jump
Dive
Dance 1
Dance 2

Select an Animation to Play
1 - GUI On/Off | 2 - Transparency On/Off

- Arms
- Cartilage
- FacialMuscles
- DeepMuscles
- Bones
- Legs
- Ligaments
- NeckMuscles
- SpineDiscs
- TorsoMuscles

Virtual Humans

- Hand signals
- Training procedures
- Enemy combatants



Scenario Generation



Santos can make a difference

Trade off analysis

What if scenarios

Survivability/Mobility Assessment

Scalable: soldier to battalion

Reduction of cost & time to acquisition

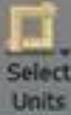


Human Simulation Systems

- **Santos** - Overall M&S environment
- **GruntSim** - Mobility, human performance, equipment, evaluation, soldier
- **Lighten the Load (LTL)** - soldier squad, equipment, load, distribution
- **Ektimo** - Mobility, survivability, PPE
- **MALUM** - Injury prediction, human performance, soldier squad
- **Santos-R & Puppeteer** - Posture/movement simulation and muscles
- **SimBioSys** - Physiology simulation

Thank you!





View

Avatars

Equipment

Postures

Output

Inventory Manager



Armor



Armor Attachments



Backpacks



Backpack Attachments



Helmets



Helmet Attachments



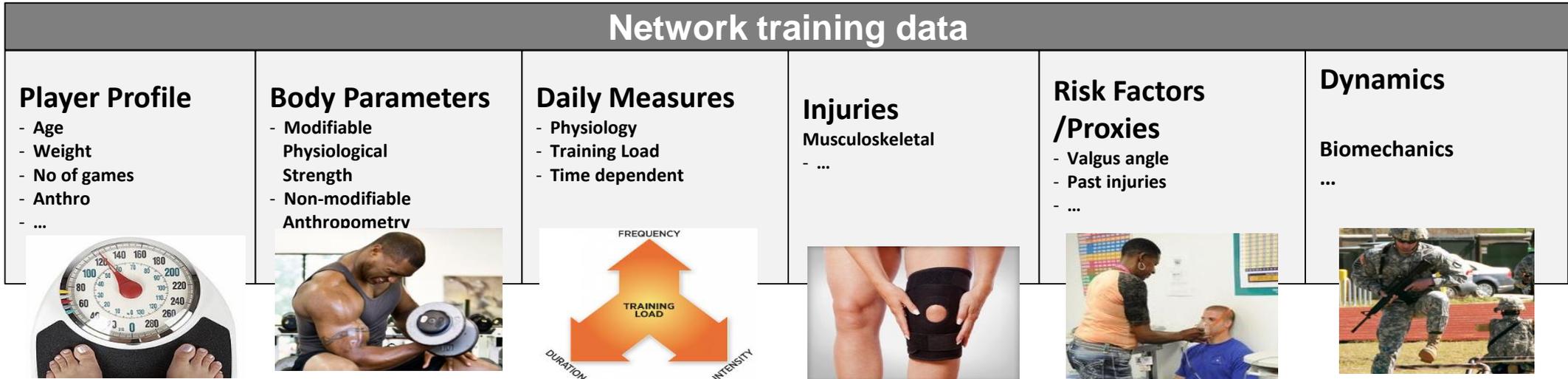
More

Variations in Soldiers



Male Avatar Statistics			
Avatars	Height	Weight	Strength Percentile
Santos	6 ft. 1 in	173.72 lbs.	90 %
220 Male	5 ft. 7 in	160.94 lbs.	80 %
508 Male	5 ft. 7 in	143.52 lbs.	75%
530 Male	6 ft. 3 in	244.93 lbs.	90%
601 Male	6 ft. 2 in	155.43 lbs.	80%
1719 Male	5 ft. 11 in	177.91 lbs.	85%
1953 Male	5 ft. 7 in	195.11 lbs.	80%
2033 Male	6 ft. 3 in	217.82 lbs.	90%
2459 Male	5 ft. 4 in	122.14 lbs.	75%

Load Confi



- Subject 1**
- Age
 - Gender
 - Weight
 - Strength
 - Flexibility
 - Physiology
 - Expected Training Load
 - Past injuries
 - FMS
 - Proxies



Propensity for Injury

Physiological performance

Biomechanical performance

Time to failure

DASHBOARD

BODY TEMPERATURE 98.2 F	HEART RATE 110 BPM	INJURY TYPE L Knee-ACL
CHOLESTEROL: 300 NORMAL TRIGLYCERIDES: 90 LOW HDL: 40 RIGHT LDL: 180	BLOOD PRESSURE 120 80 72	BLOOD GLUCOSE 100 mg/dL

Adaptation

Strengthening & Conditioning



Training



U.S.ARMY

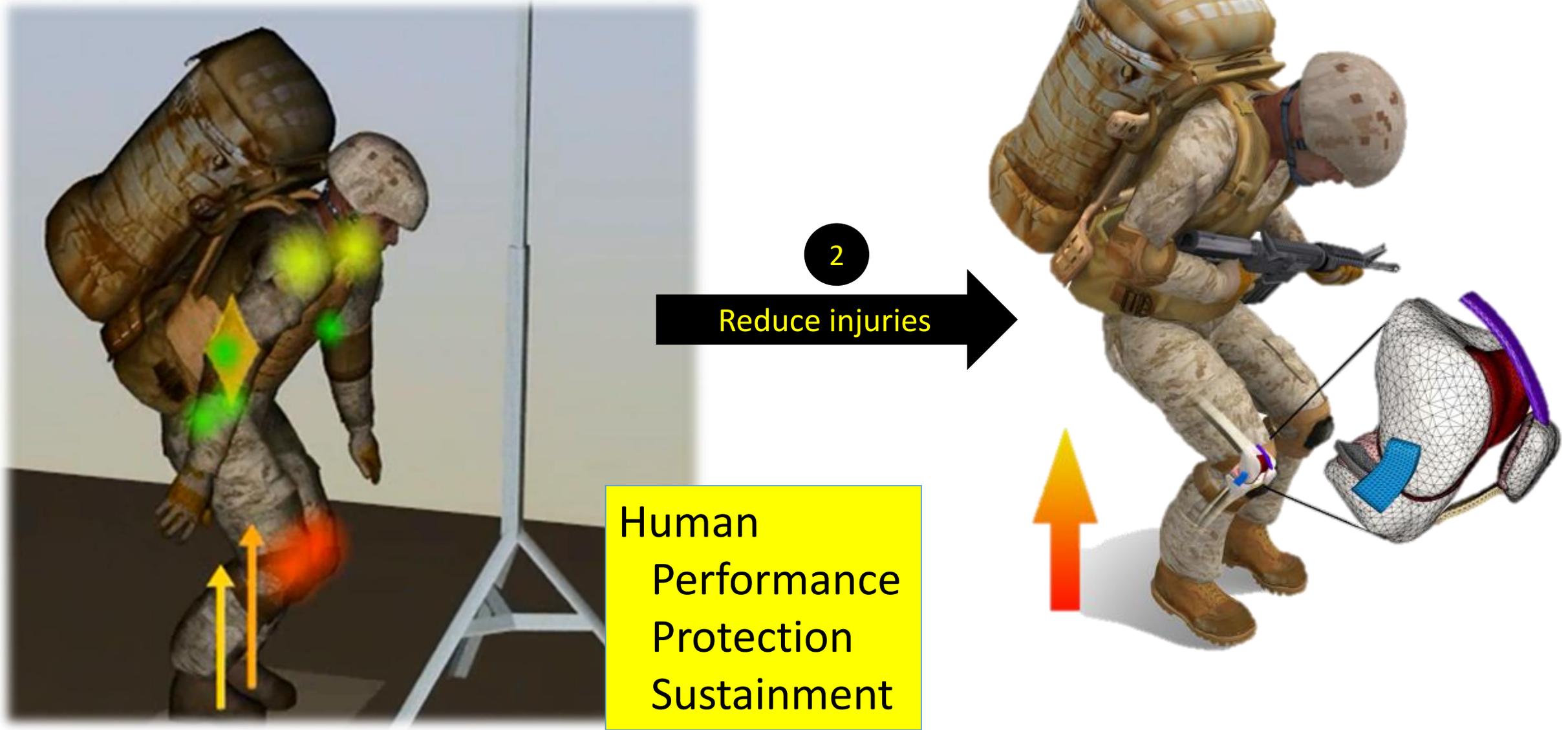


Synthetic Training Environment

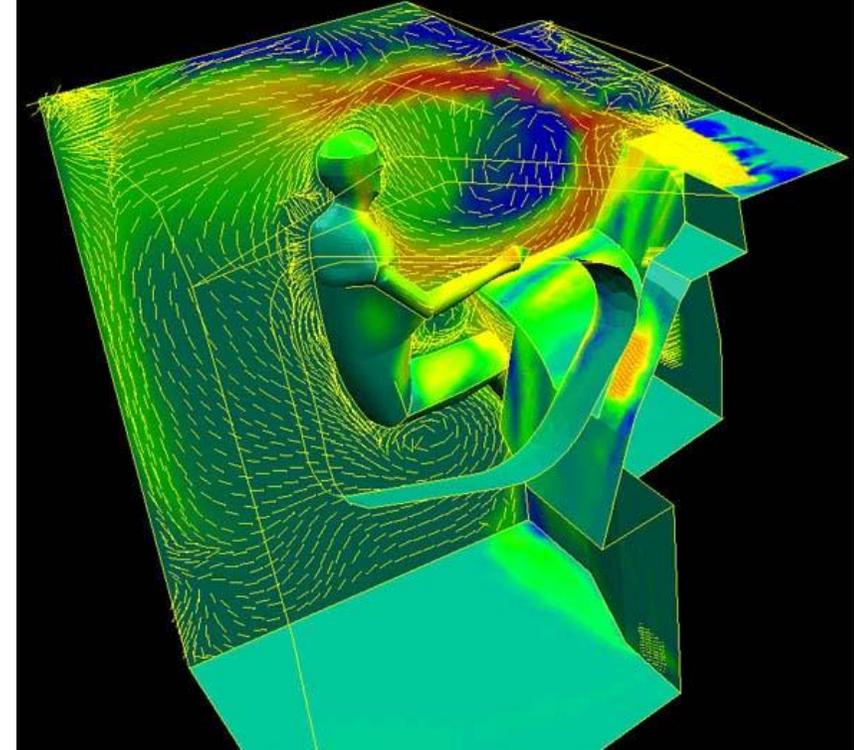


Human simulation can reduce injuries

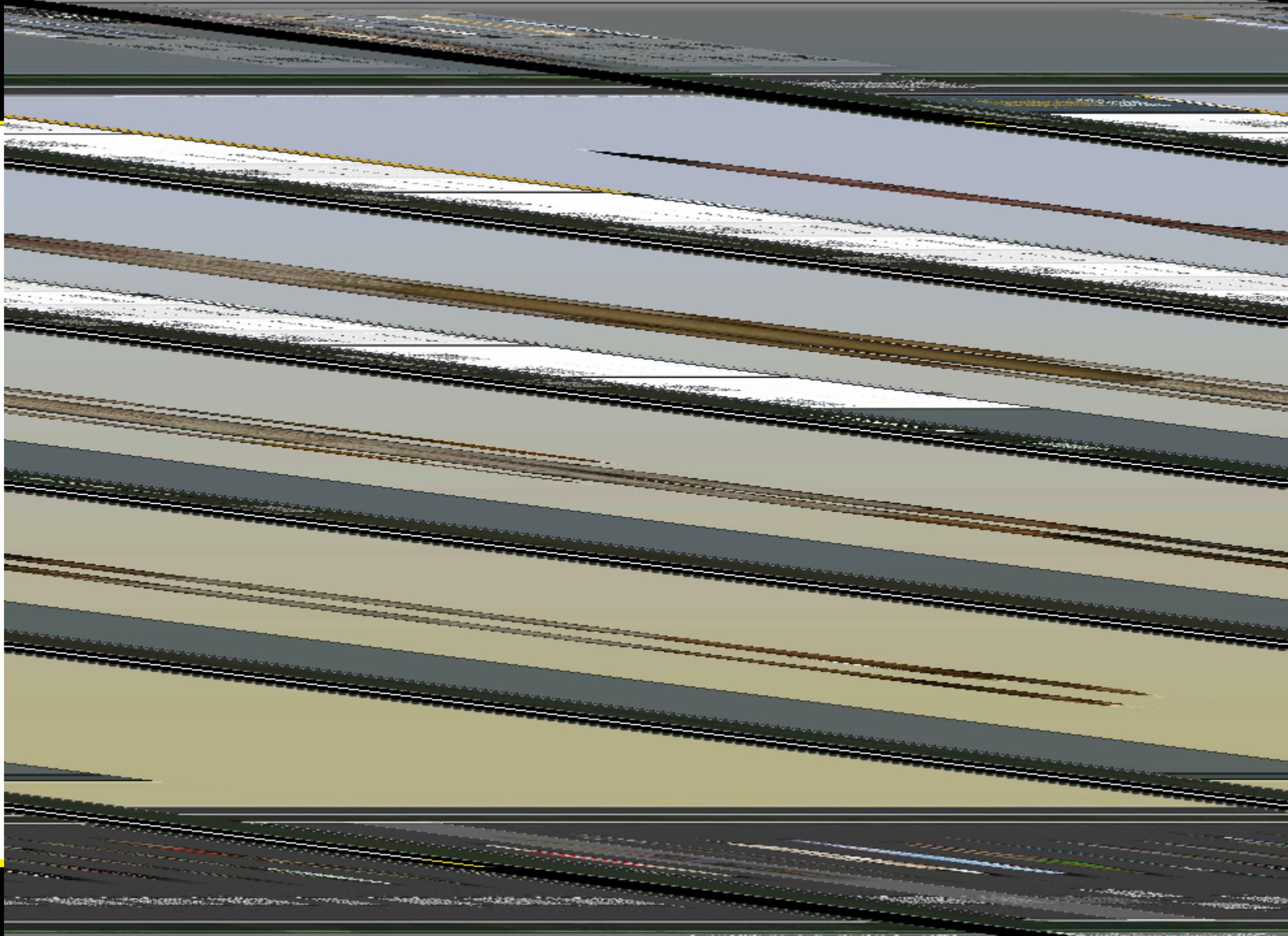
- Majority of injuries (~ 86.5%) are non-battle injuries.
- In 2006 (Hauret, et al.) reported 743,547 MSK injuries



Thermal Considerations



Experiment with new weapons



Anthropometry is

