From Lab to The Literal Field: Custom-Fit, 3D-Printed Medical Devices And Wearable Sports Gear

Michael Zabala

Auburn Alumni Engineering Council Endowed
Associate Professor Mechanical Engineering
Director, Auburn University Biomechanical Engineering Lab

AUBURN
UNIVERSITY

BIOMECHANICAL
ENGINEERING LAB

E-mail: zabalme@auburn.edu

Outline

- AUBE Lab

- Auburn Football Connection

- Extension of Technology out of Auburn

- Media Coverage

- The Process (3D Scan to 3D Print)

- Sports, Medical, Military Application

- Lab-based Testing

- Field-based Testing

AUBE (Biomechanics) Lab

- 900 sq. ft. (32 ft. x 30 ft.)
- Vicon motion capture system
  - 10 Vantage V5 Wide Optics cameras
- 2 AMTI Ground-Embedded Force Plates
- Delsys Trigno wireless EMG/IMU sensors
- Creaform Go!SCAN 20
- 2 Raise3D 3D Printers
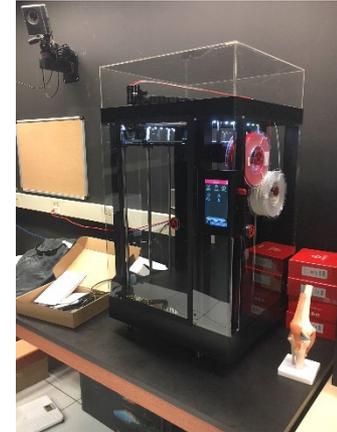
AUBE Lab/Auburn Football

- My neighbor in 2019: Robbie Stewart, Head Athletic Trainer for Football

- Call regarding injured wide receiver
  - Anthony Schwartz

- Can you help?

Yes!

3D Scan to 3D Print

- Creaform Go!Scan20: $30,000
- Raise3D 3D Printer
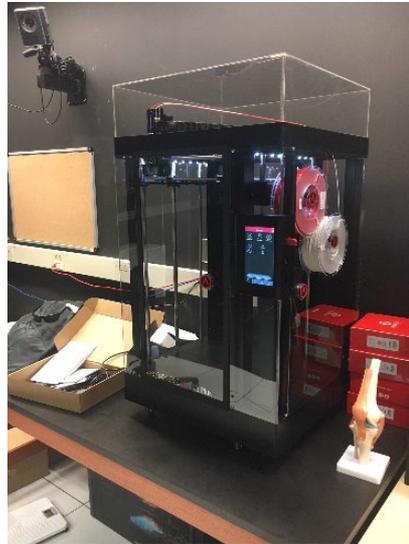
Extension of Technology

- West Virginia University
- Call regarding injured wide receiver
- Can you help?

Yes!

ESPN

Source: ESPN

The Process
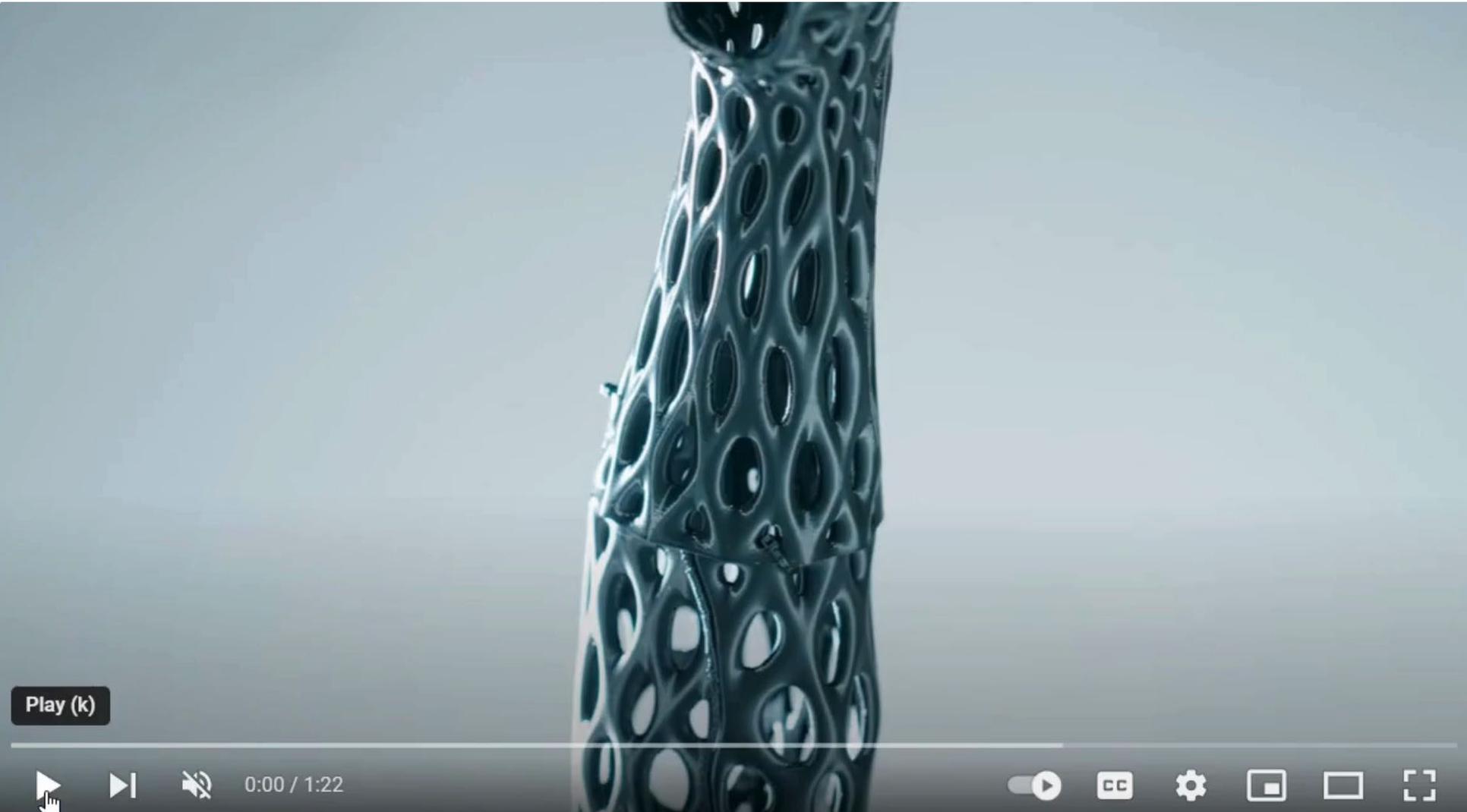
Sports Application

- Dozens of Division 1 Athletics Programs

- Multiple NFL Teams

- Major League Baseball (MLB)

- Major League Soccer
  - Including custom-fit shin guards worn during 2022 World Cup (Qatar)

Medical Application

- Casts, braces, pads, etc.
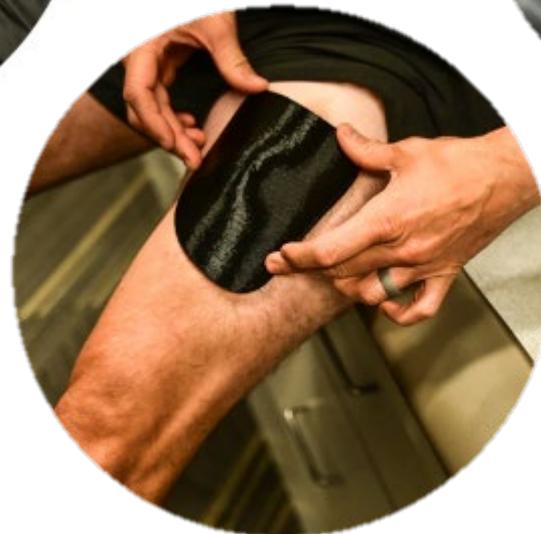
DOD Application

- Submitted for multiple grants from various agencies

- Improve system for use by DOD in various forms

Army

Marines

Navy

Air Force

USSOCOM

Lab/Field Testing

Impact Testing 1st Session

Effect of padding, print interruption

- Body Opponent Bag (BOB®) shoulder scan obtained using proprietary smartphone app

- 3mm thick PLA custom shoulder guard made

- Each guard was positioned on Shockshield®-draped concrete shoulder model

- Impactor designed to match NFL linebacker tackler momentum[1]

  - 6 foot drop height required

1. N. Yoganandan, F.A. Pintar, J. Zhang, J.L. Baisden. *Physical properties of the human head: mass, center of gravity and moment of inertia*. J Biomech, 42 (9) (2009), pp. 1177-1192

Impact Testing 1ˢᵗ Session

Effect of padding, print interruption

- Tested three test conditions
  - No padding, 9 kg impactor
  - No padding, interrupted print (24 hrs), 9 kg impactor
  - EVA foam padding, 9 kg impactor

- Vicon® motion capture system recorded the velocity of the helmet through impact and two AMTI® force plates recorded the impact force

- Hypothesized that for each guard, a break would occur after the first impact and on or before the tenth impact

Impact Testing 1st Session

Effect of padding, print interruption
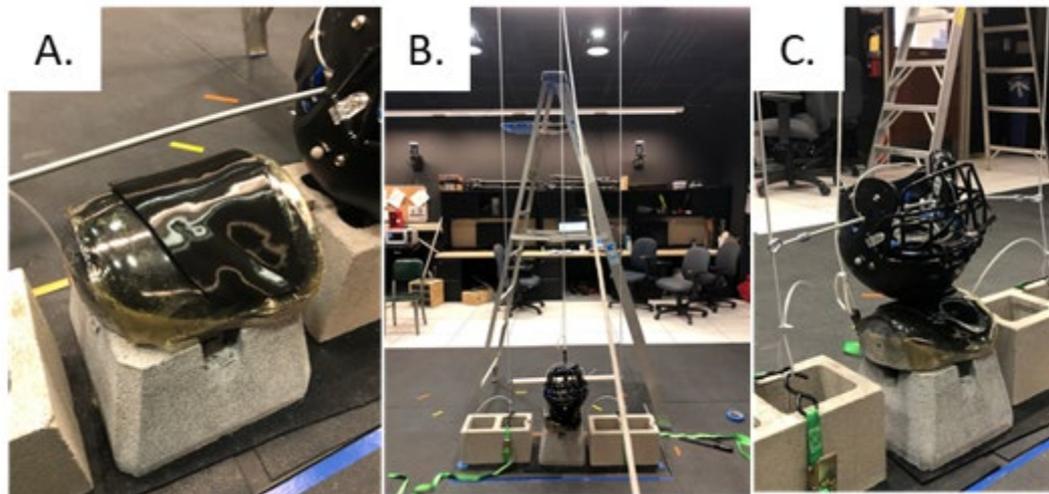
Figure #. A.) 3D printed guard on BOB® replica shoulder. B,C.) Test rig.

Impact Testing (1) - Results

Effect of padding, print interruption

	Average Impact Force (lb)	Average Velocity (mph)	Avereage Momentum (kg m/s)	Break Occurred
No Padding	1656.72	11.62	46.63	NO BREAK
Interrupted, No Padding	2029.39	11.84	47.53	10th Trial
3mm EVA Foam Padding	1749.23	11.84	47.53	NO BREAK
3mm EVA Foam Padding (with increased mass)	2036.65	11.91	57.46	17th Trial*

Table 1. *This guard was impacted 10 times with a total helmet mass of 9 kg, then impacted seven more times with a helmet mass of 10.8 kg until a break occurred. On the 17th impact both the guard and the helmet broke.

Impact Testing 2nd Session

Effect of print material, presence of holes

- Body Opponent Bag (BOB®) shoulder scan obtained using proprietary smartphone app

- Used to produce seven guards:
  - 1. Formlabs® Durable resin, solid, printed via stereolithography (SLA)
  - 2. Formlabs® Durable resin, holed, SLA
  - 3. Formlabs® Tough resin, solid, SLA
  - 4. Formlabs® Tough resin, holed, SLA
  - 5. Hatchbox® PLA, solid, FDM
  - 6. Hatchbox® PLA, holed, FDM
  - 7. Raise3D® PLA, solid, FDM

Impact Testing 2nd Session

Effect of print material, presence of holes

- Each guard was positioned on the Shockshield®-draped concrete shoulder model

- Impacted repeatedly with the 9 kg weighted football helmet dropped six feet from the tower

- Vicon® motion capture system recorded the velocity of the helmet through impact and two AMTI® force plates recorded the impact force

- Hypothesized that for each guard, a break would occur after the first impact and on or before the tenth impact

Impact Testing 2nd Session

Effect of print material, presence of holes

Figure #. Testing Guards (Top Row L-R: Formlabs® Durable resin, solid; Formlabs® Durable resin, holed; Formlabs® Tough resin, solid; Formlabs® Tough resin, holed; Bottom Row L-R: Hatchbox® PLA, solid; Hatchbox® PLA, holed; Raise3D® PLA, solid)

Impact Testing (2) - Results

Effect of print material, presence of holes

Guard	Average Impact Force (lb)	Average Velocity (mph)	Average Momentum (kg m/s)	Break Occurred
Formlabs® Durable, solid	1564.06	12.09	48.54	NO BREAK
Formlabs® Durable, holed	1609.97	12.01	48.20	NO BREAK
Formlabs® Tough, solid	1400.86	11.99	48.15	NO BREAK
Formlabs® Tough, holed	1458.51	12.09	48.53	3rd Trial
Hatchbox® PLA, solid	1512.82	12.09	48.55	NO BREAK
Hatchbox® PLA, holed	1495.34	12.08	48.51	5th Trial
Raise3D® PLA, solid	1788.80	12.12	48.65	2nd Trial

Table 2. Summary of impact testing results.

Ballistics Testing

- Custom-made (patent pending) compression shirt was placed on a Body Opponent Bag (BOB)®

- 3D scan of the right pectoral area/pocket of BOB was performed using the proprietary smartphone scanning app

- Virtual model of a 3 mm armor plate that contours that of BOB's right chest

- 3D print the armor plate on an EOS M280 (Material=Titanium Ti64, Finish=Basic, with kiln stress relief)

Ballistics Testing
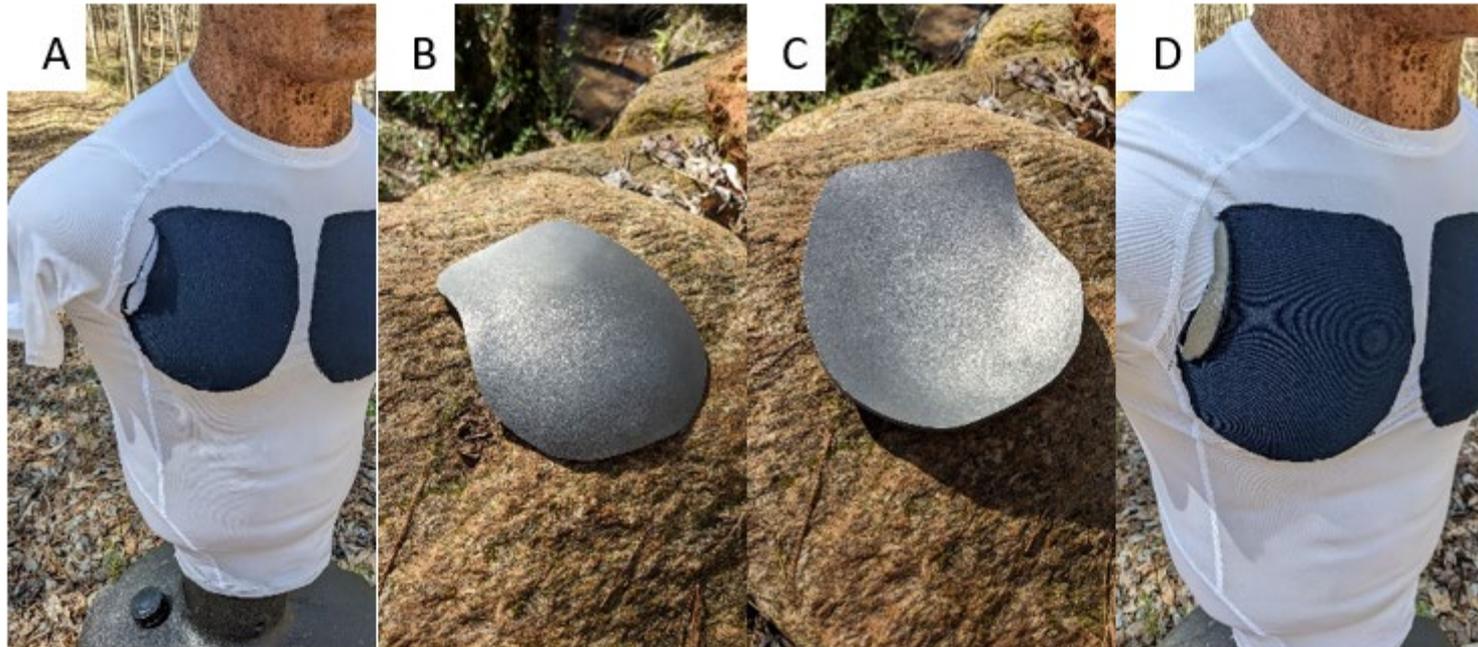
Figure #. Custom-made compression shirt (A) and corresponding custom-fit Titanium armor plate (B, C). Armor plate inserted into pocket (D).

Ballistics Testing Projectiles

- .22 Long Rifle (round nose)

- 9 mm pistol (full metal jacket, round nose)

- .223 (pointed soft point)

Ballistics Testing - Results

- .22 Long Rifle – effective at stopping

- 9 mm pistol – effective at stopping

- .223 – ineffective at stopping

- Concerns with shrapnel
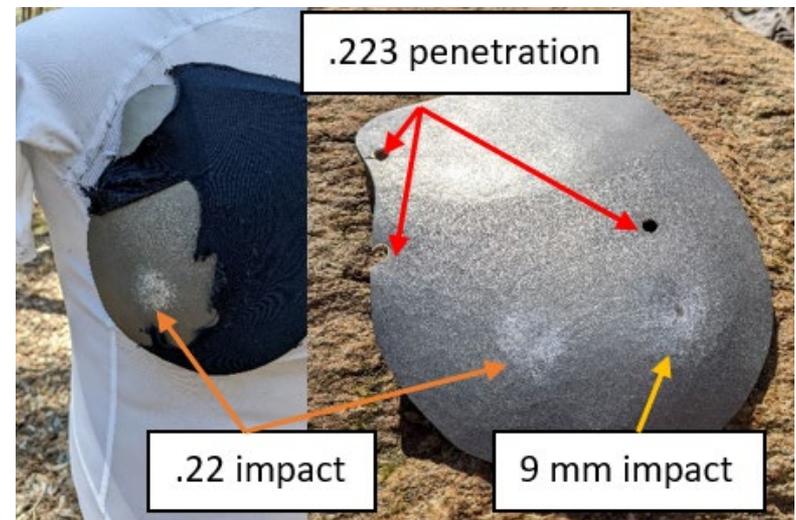
Thank you!

Michael Zabala, PhD

Auburn Alumni Engineering Council Endowed
Associate Professor
Mechanical Engineering

AUBURN
UNIVERSITY

BIOMECHANICAL
ENGINEERING LAB

E-mail: zabalme@auburn.edu