



NHTSA

NATIONAL HIGHWAY TRAFFIC SAFETY ADMINISTRATION

NHTSA's THOR-05F Design Update

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Introduction

- NHTSA developed the THOR-05F ATD to better evaluate injury risk of small female adult occupants
 - Alternative to Hybrid-III in frontal crash tests
 - Improved biofidelity and measurement capability
 - More thoroughly evaluate & improve advanced restraint systems
- Initial prototype (3 ATDs) delivered to NHTSA in June 2018



Initial Evaluation - Biofidelity

- BioRanked 14 test modes
- Lower Biorank Score indicates better biofidelity
- Significant improvement over HIII-5th

	THOR-05F	HIII 5 th
	Head	
Average	1.05	1.77
	Neck	
Average	1.11	2.08
	Shoulder	
Average	0.71	2.14
	Thorax	
Average	1.89	4.25
	Abdomen	
Average	1.69	3.36
	Knee-Thigh-Hip	
Average	1.22	2.35
Average BioRank Score	1.28	2.66

Watkins, et al. "Initial Biofidelity Comparison Between THOR-05F and Hybrid-III 5th Percentile Female ATDs". 2022 SAE Government-Industry Meeting.

Initial Evaluation – R&R

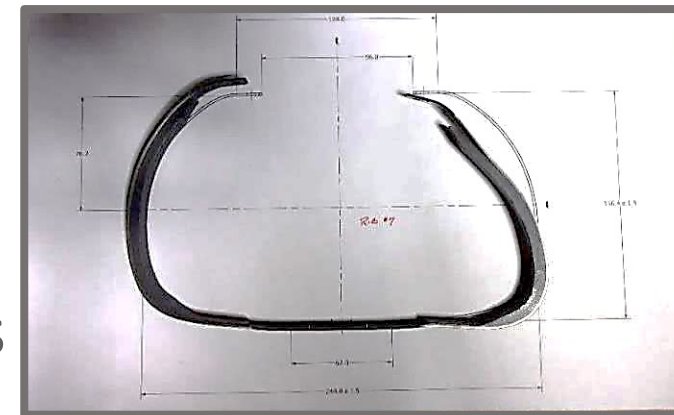
- 360 qualification-type tests performed at VRTC on 3 ATDs (initial design)*
- Minor issues:

Test Mode	Result	Action taken
Face Impact	Performance changes based on total number & time between impacts.	ATD design change to face insert: thermoset honeycomb
Abdomen Impact	Left-to-right differences in APTS response	ATD design change to iDAS housing behind APTS
Upper Leg Impact	Variability in acetabulum force	Test procedure change: increase energy to replicate expected crash loading
Ball-of-Foot Impact	Variability in Fz & My	Test procedure change: specify initial Achilles cable set-up & increase energy

* Hutter, et al. “Status of NHTSA’s THOR-05F Evaluation”. 2020 SAE Government-Industry Meeting.

Initial Evaluation - Durability

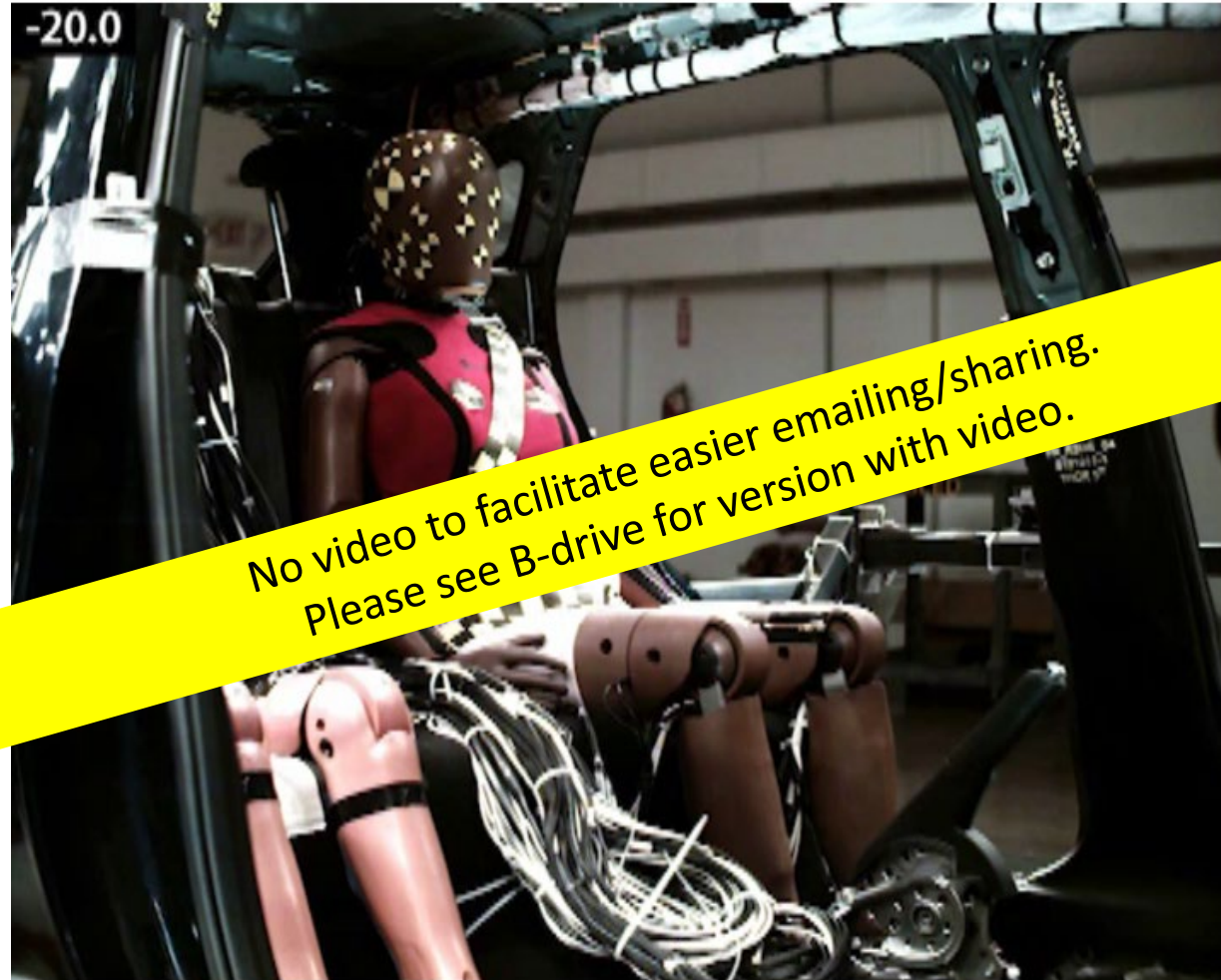
- Durability
 - Full vehicle crash series*
 - THOR-05F: Driver & front passenger
 - 6 frontal vehicle crashes into flat barrier
 - Belted @ 35mph, Unbelted @ 25mph
 - Key results: No ATD durability concerns
 - Rear seat sled**
 - Pulse: 35 mph ΔV , 40 G (similar to NCAP)
 - No load limiter or pretensioner
 - Key results: Severe rib deformation, IR-TRACC failures



* Hutter & Loudon, et al. "Evaluation of THOR-05F in a Full Vehicle Crash Series". 2023 SAE Government-Industry Meeting.

** 2021 NHTSA Research Day. "Female Crash Safety". October 21, 2021.

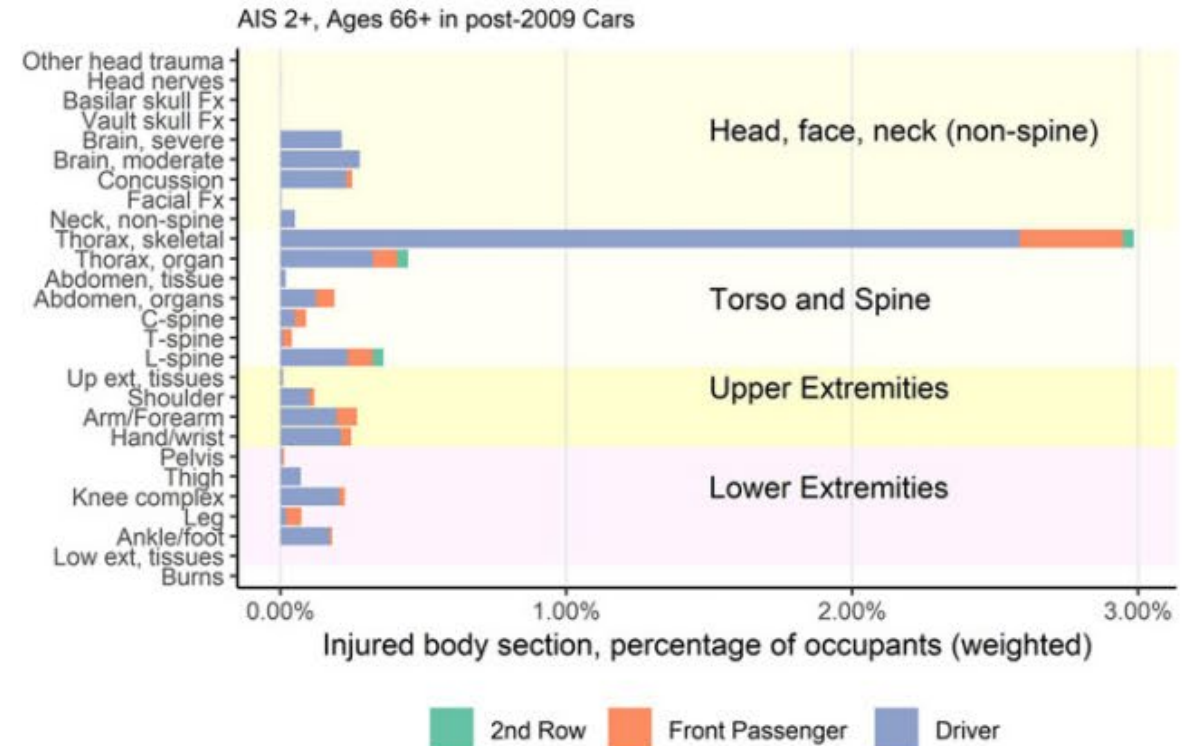
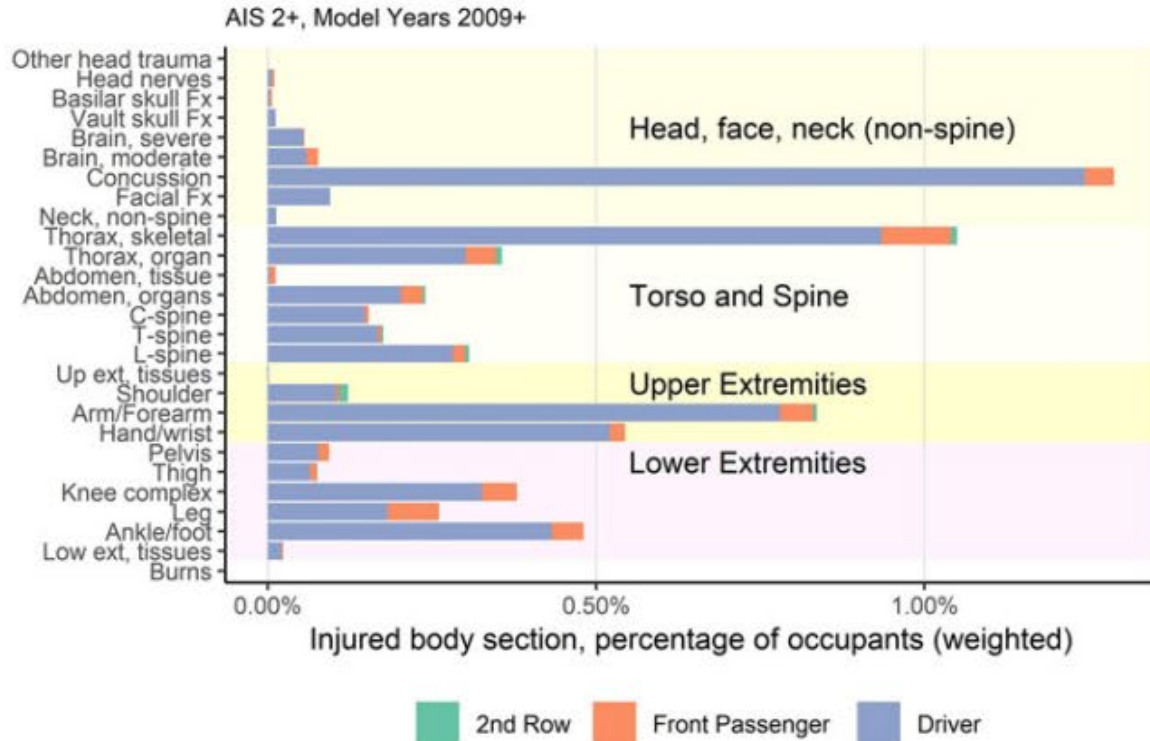
Initial Evaluation – Rear Seat Sled Test



No video to facilitate easier emailing/sharing.
Please see B-drive for version with video.

Area to improve - Thorax

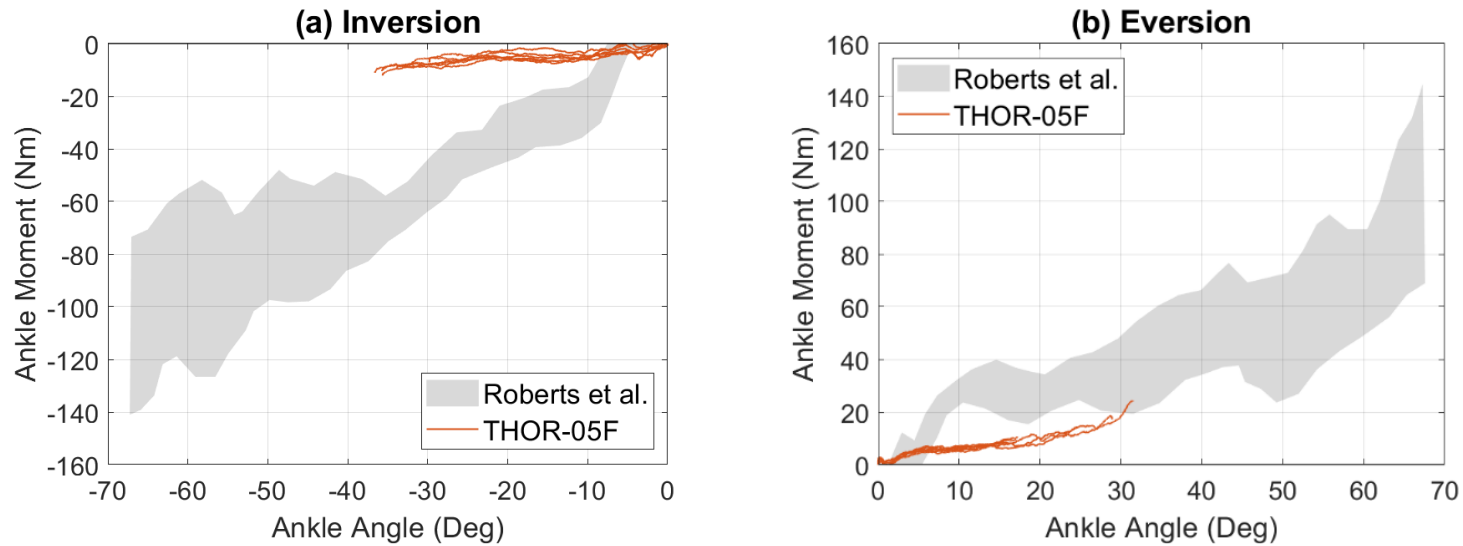
- Address rib & IR-TRACC failures
- Improve durability while maintaining biofidelity
 - Thorax injuries are common in frontal MVCs, especially in older occupants; & females may be at higher risk for injuries like rib fractures*



* Forman et al. "Automobile injury trends in the contemporary fleet: Belted occupants in frontal collisions". TIP 2019, Vol. 20, No. 6: 607-612

Area to improve - Ankle

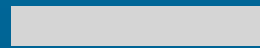
- New small female specific PMHS corridors for inversion & eversion
- Initial THOR-05F ankle design is less stiff than PMHS response



- Need to improve biofidelity
 - Studies suggest female occupants are at higher risk than males for lower extremity injuries.*

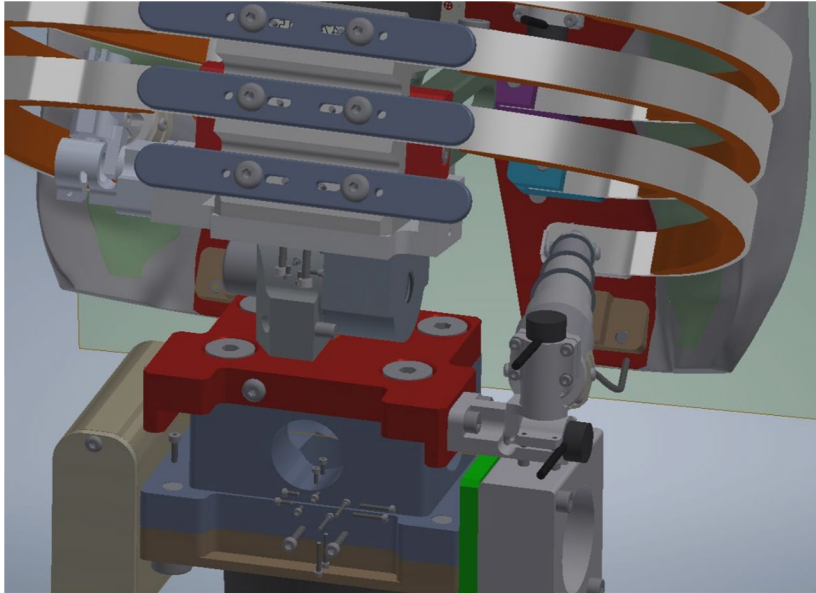
* Forman et al. "Automobile injury trends in the contemporary fleet: Belted occupants in frontal collisions". TIP 2019, Vol. 20, No. 6: 607-612
Craig et al. "Sex-based differences in odds of motor vehicle crash injury outcomes". AAP 2023, In press.

Objective: Provide design & test updates on improved THOR-05F thorax and ankle designs



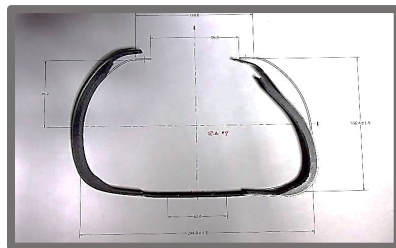
Thorax Design Evolution

Initial Design

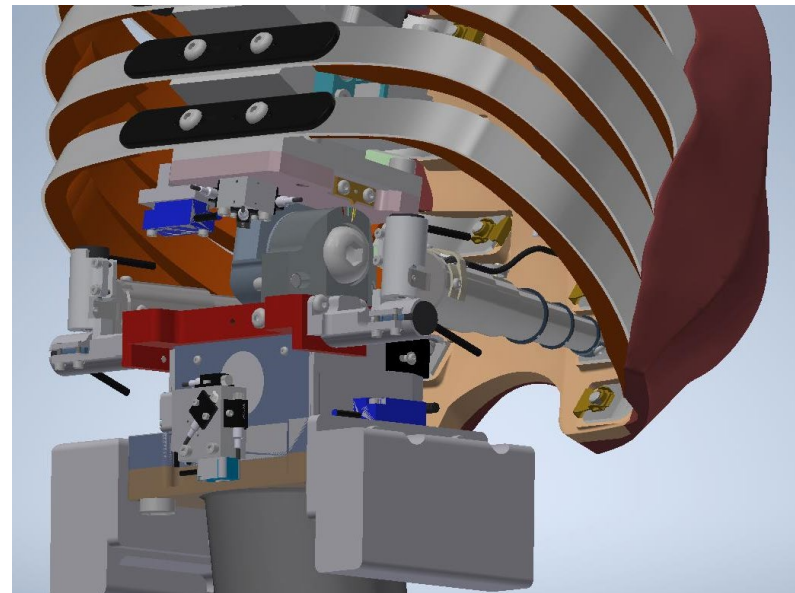


Rear seat sled durability results:

- Deformed ribs
- Broken IR-TRACC (data loss)



HIS Design

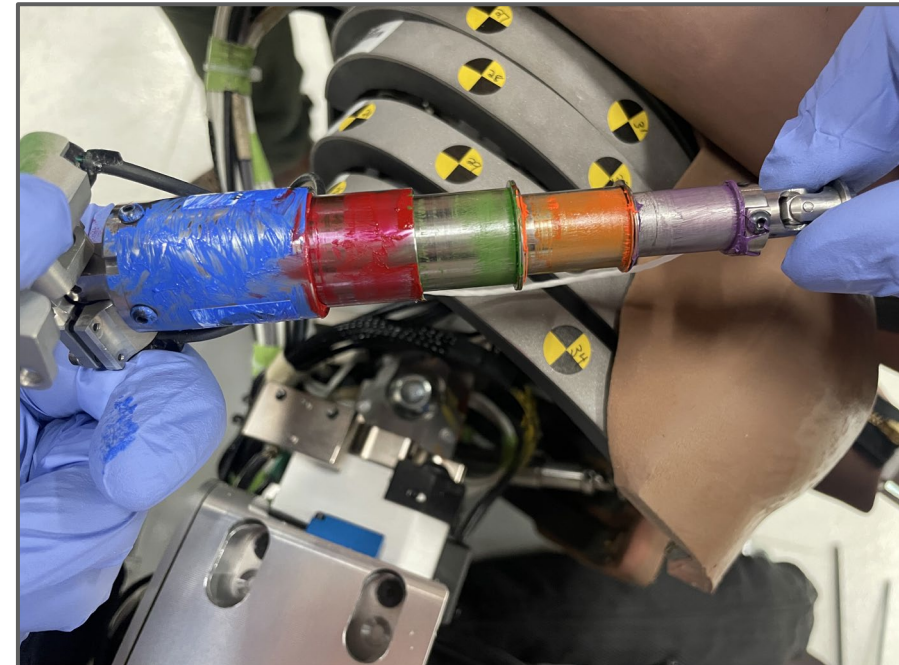


Key changes:

- Rib material change
- Rib geometry change
- Improved lower IR-TRACC brackets

Sled Test of HIS Thorax

- Same as initial test series
 - Rear seat occupant
 - Pulse: 35 mph ΔV , 40 G (similar to NCAP)
 - No load limiter or pretensioner
- 5 trials
- Rib performance monitored with FARO
- Grease paint to determine contact



Rib Evaluation Method

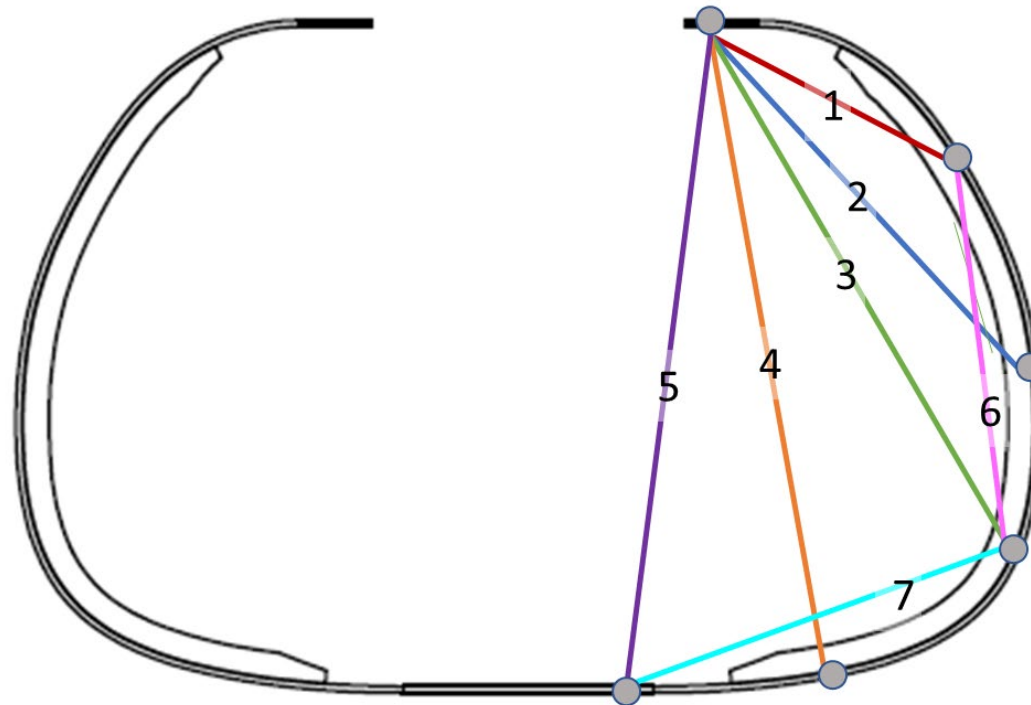
- Needed a method to evaluate rib performance between sled tests.
 - Avoid full tear-down inspection!
- Evaluation procedure:
 - Each ATD was seated on a chair & tilt sensors were recorded.
 - XYZ coordinates of 60 points were measured on ribs 1-7 pre & post-test with the ATD in the same position.
 - Distances between the points were calculated (n=69).
 - Changes between pre-test and post-test distances were monitored.
 - Large change → inspect further for rib deformation



HIS Design: Rib Results

- No significant rib deformation after 5 sled tests
- Maximum change $\leq 3\text{mm}$
 - Attributable to measurement error & small changes in ATD position
- Example: Rib 6R (significant deformation previously)

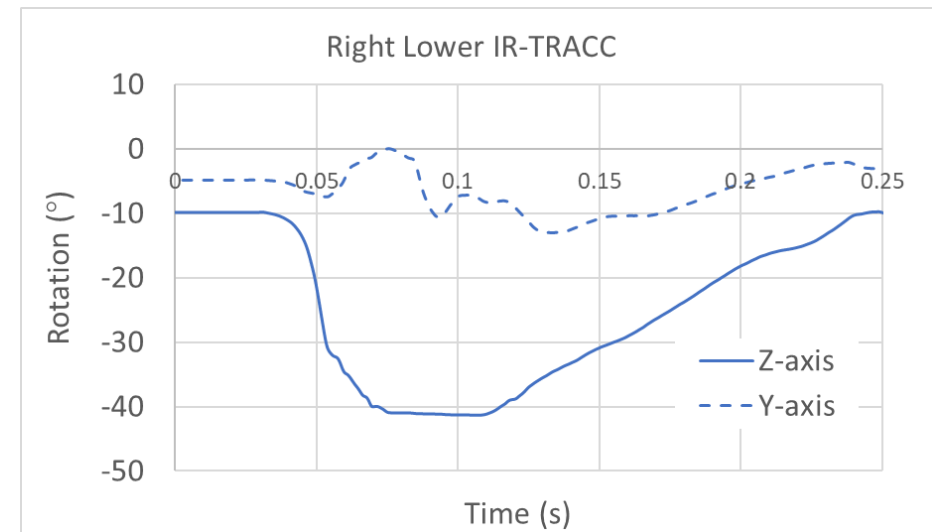
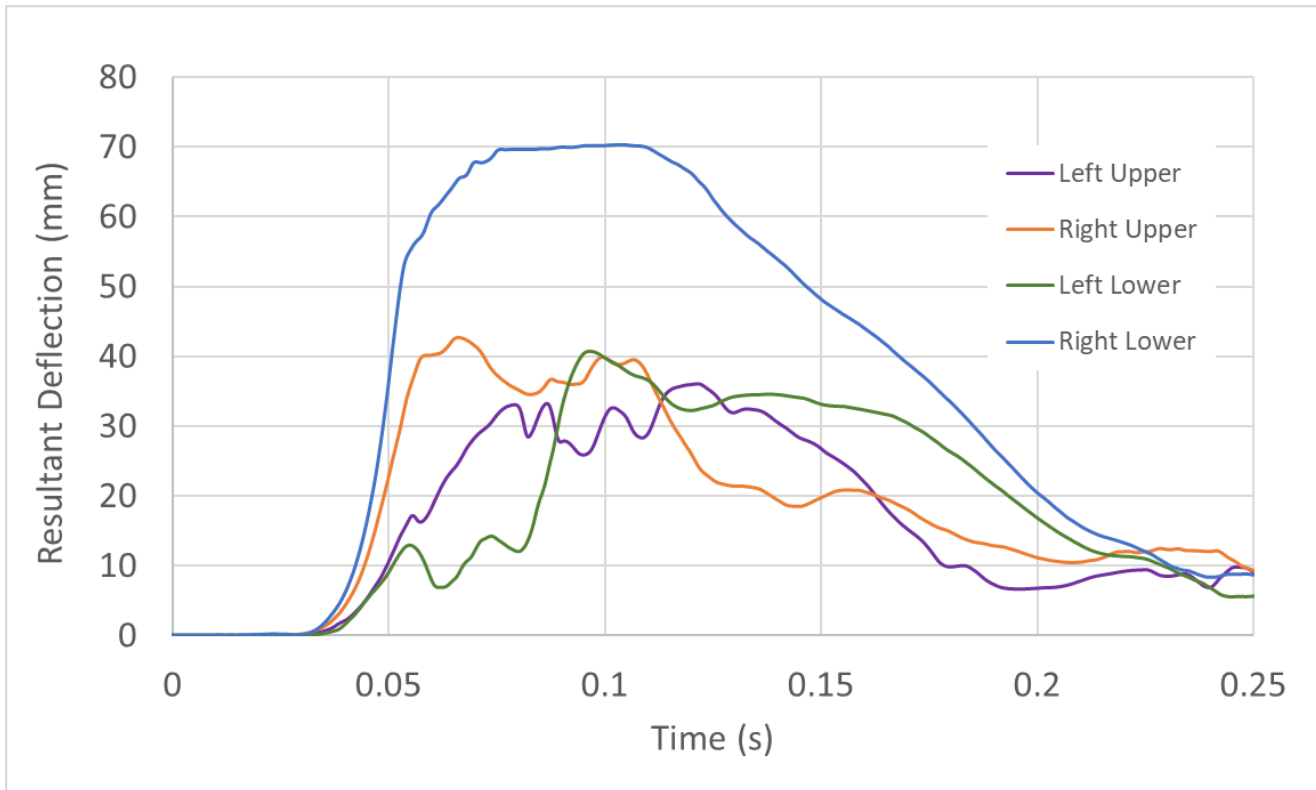
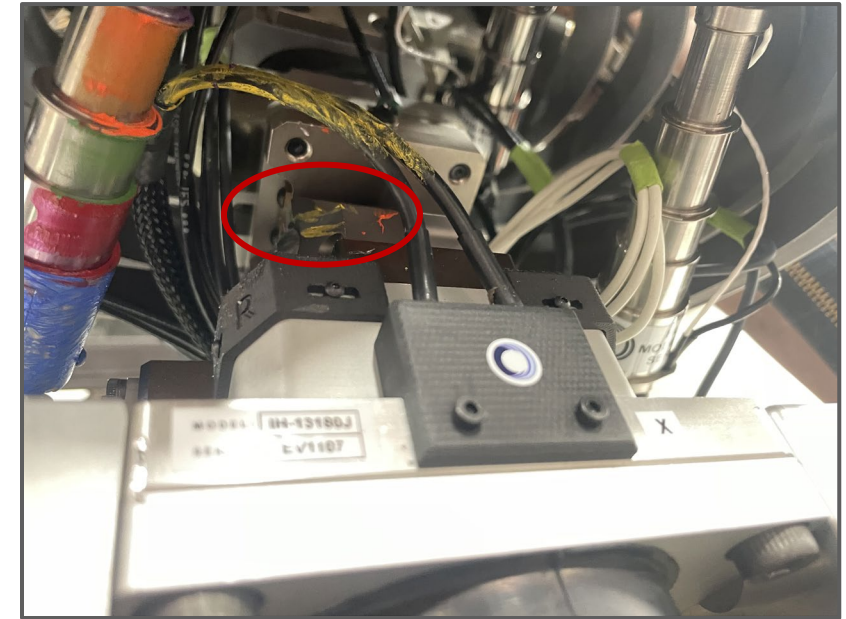
Initial Design:



Distance	Length (mm)		
	Pre-series	Post-series	Difference (post-pre)
1	105.3	105.1	-0.2
2	137.6	137.9	0.3
3	182.7	180.4	-2.2
4	176.3	176.8	0.5
5	184.1	184.2	0.2
6	78.1	78.6	0.5
7	102.1	101.4	-0.7

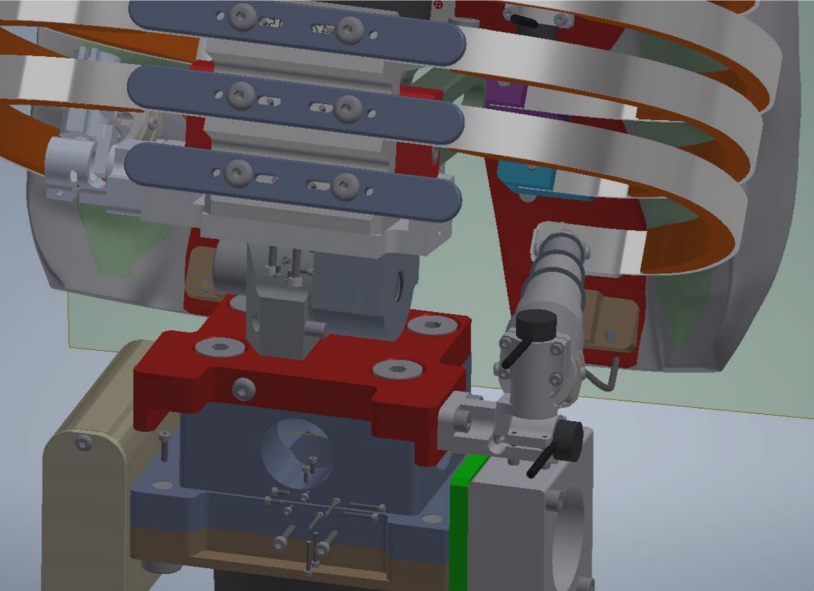
HIS Design: IR-TRACC Results

- No data loss
- Still contact
 - Right lower IR-TRACC rotates about z-axis & contacts spine box



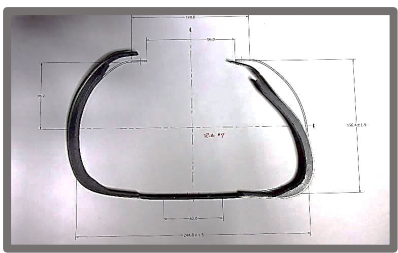
Thorax Design Evolution

Initial Design

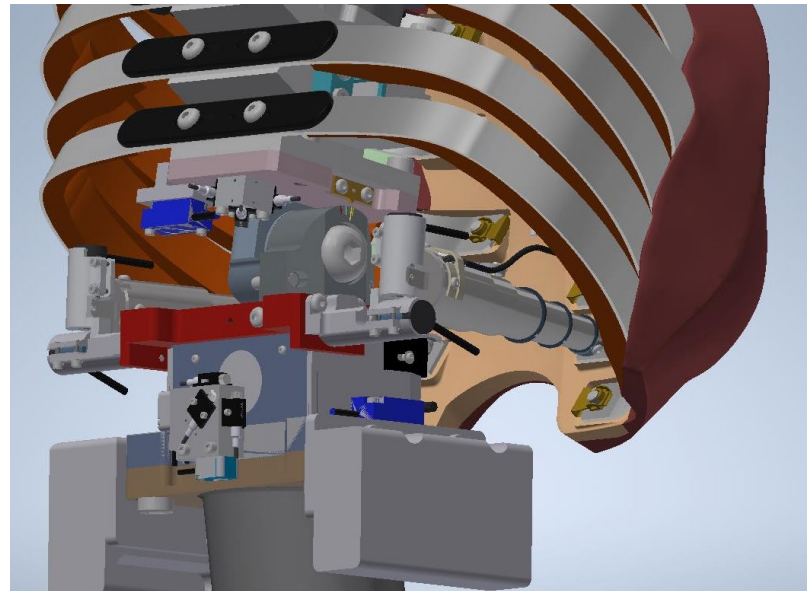


Rear seat sled durability results:

- Deformed ribs
- Broken IR-TRACC (data loss)



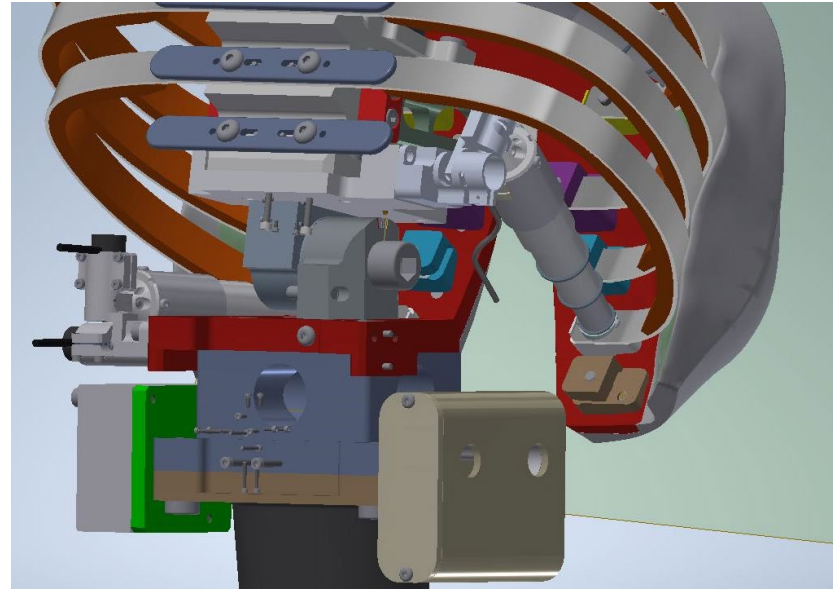
HIS Design



Key changes:

- Rib material change
- Rib geometry change
- Improved lower IR-TRACC brackets

VRTC Design

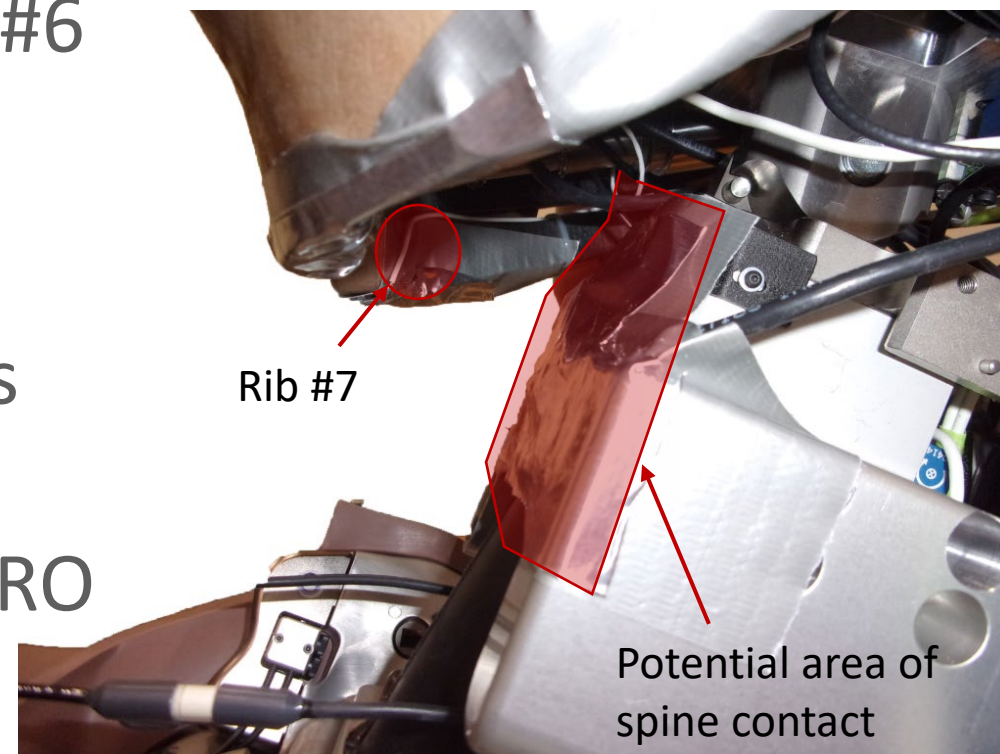


Key changes:

- Relocation of IR-TRACC mounts
 - Superior to thoracic pitch adjustment

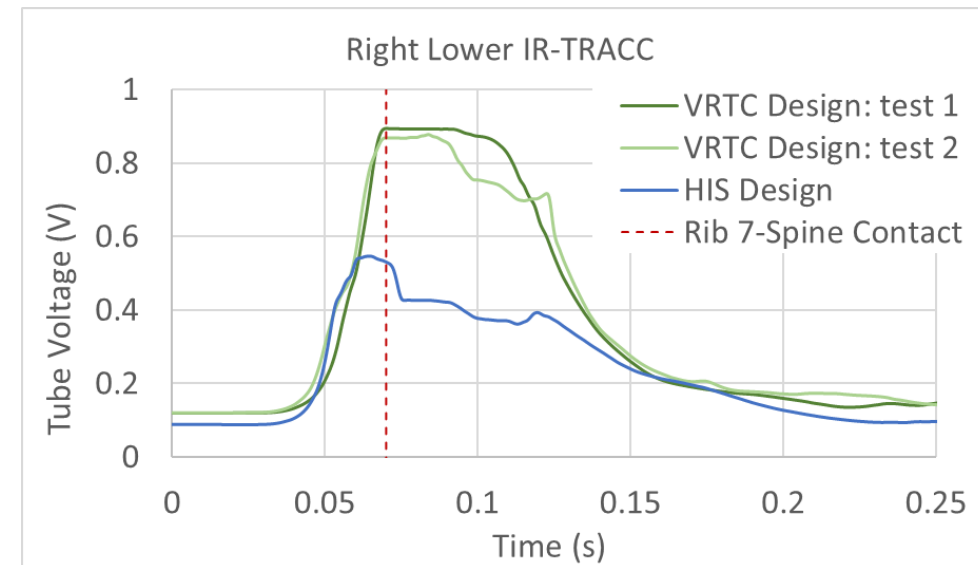
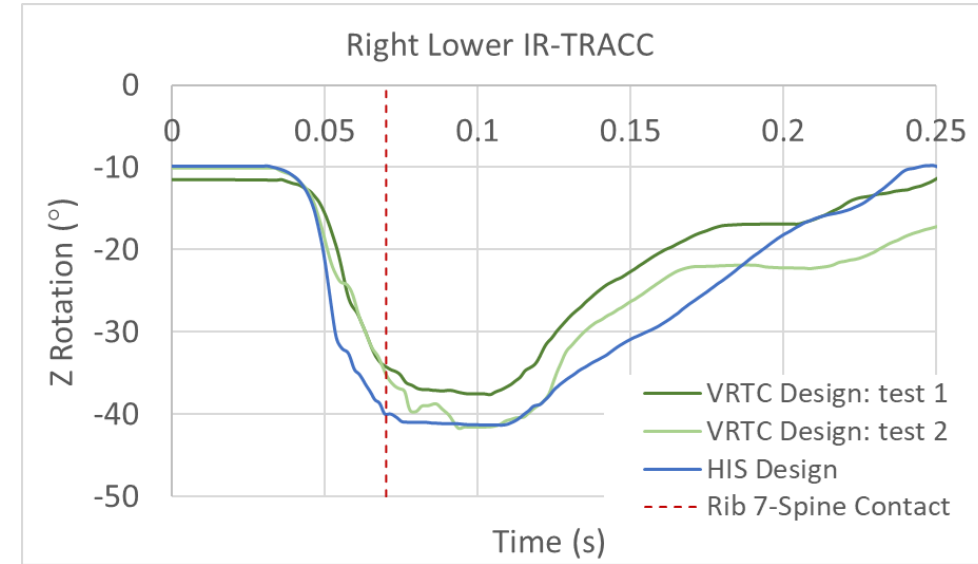
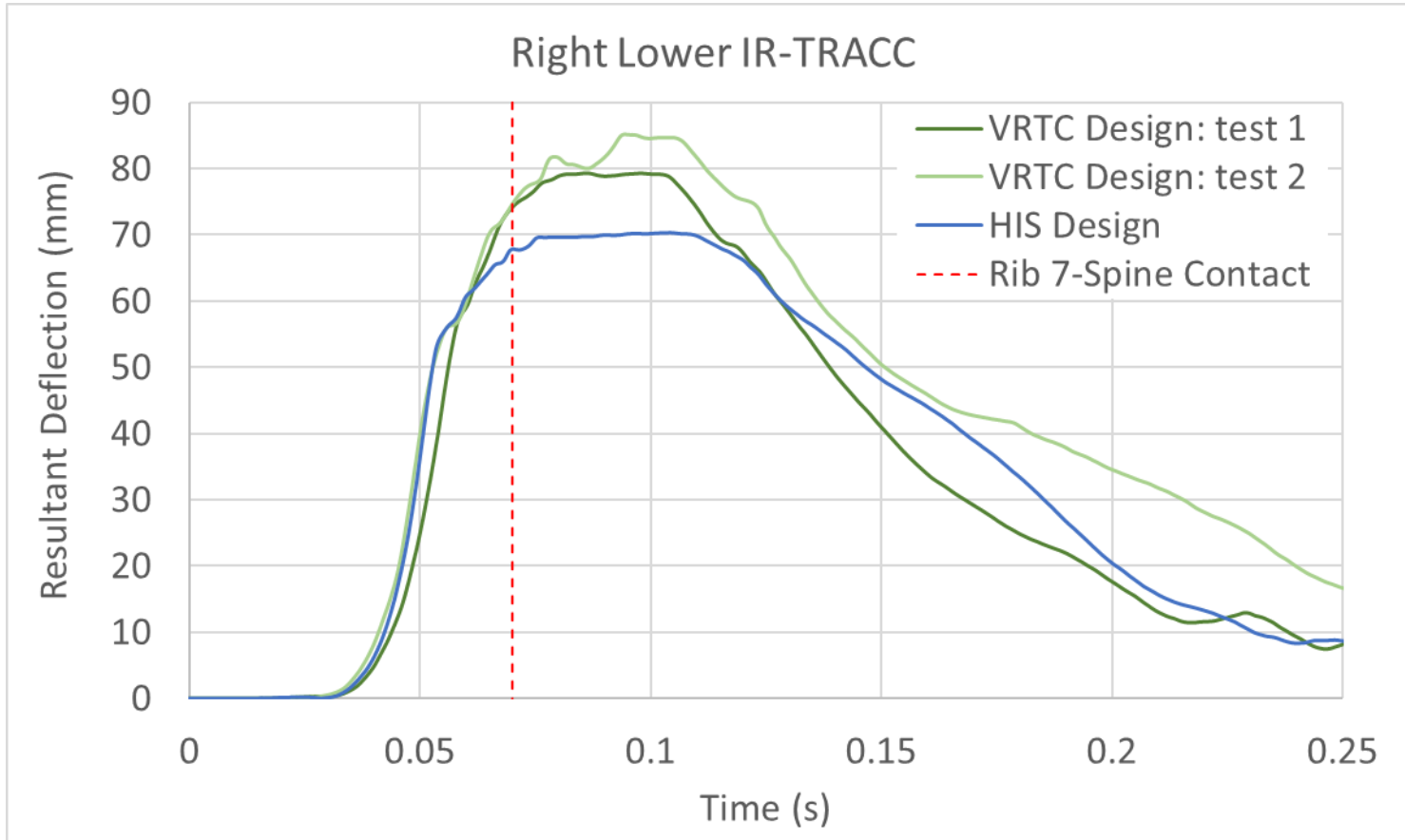
VRTC Thorax Design

- HIS Design with lower IR-TRACC mounts moved superiorly
 - Maintains HIS improved ribs & all other smaller changes*
 - Lower IR-TRACC still attaches to rib #6
- Sled testing of VRTC design
 - Same pulse & buck as previous tests
 - 2 trials
 - Rib deformation monitored with FARO
 - Contact switch on rib 7 & spine box



VRTC Design: Sled Results

- No rib deformation
- Contact between rib 7 & spine around 70 ms
- Lower right IR-TRACC tube bottoms out around 70 ms.

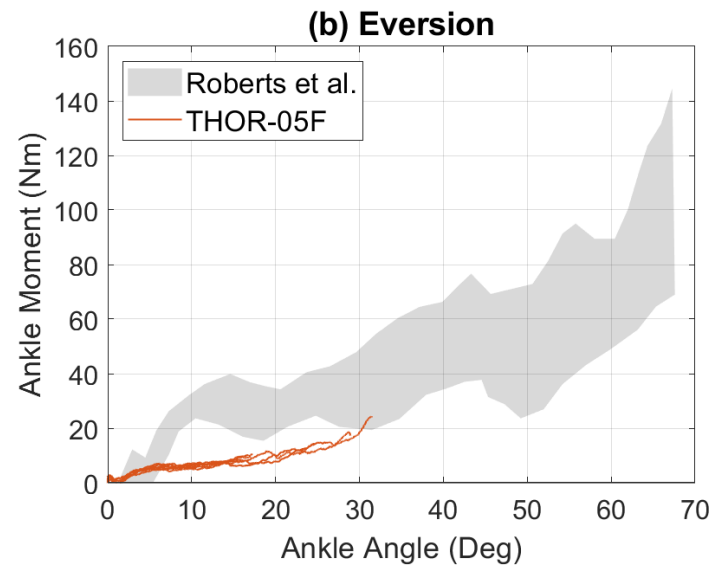
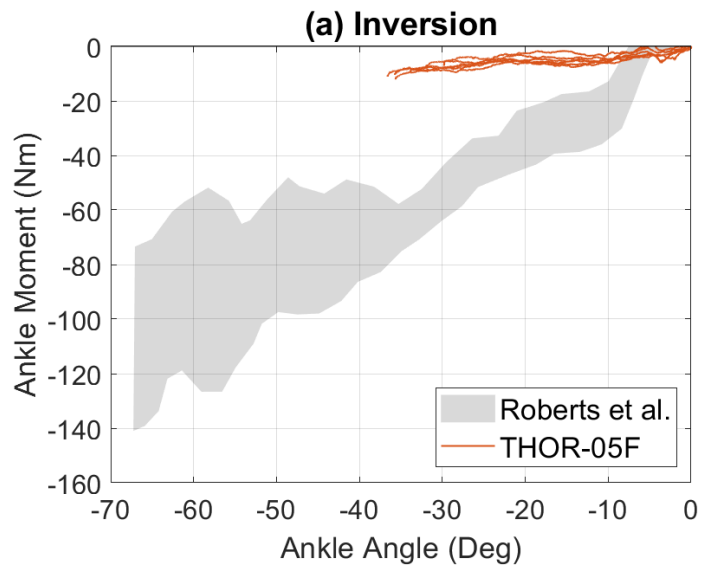
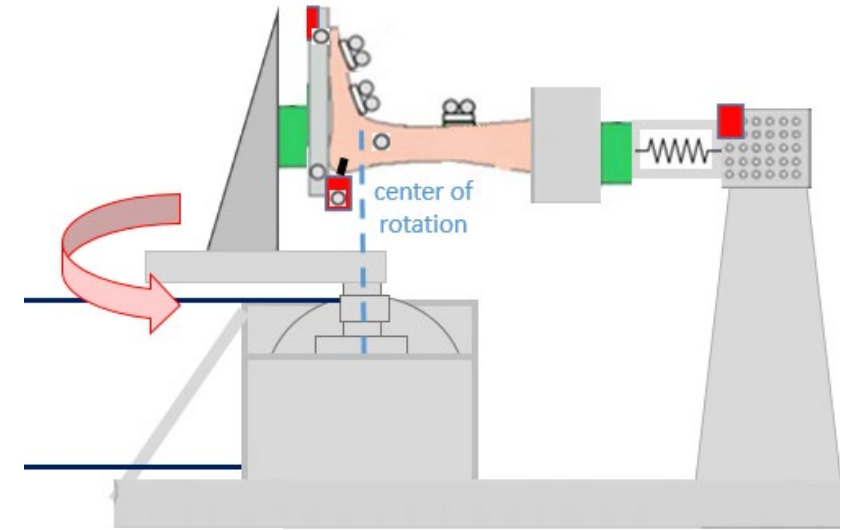


Next Steps for THOR-05F Thorax

- Move forward with the VRTC thorax
 - While the IR-TRACC tube does not fully collapse, this design does not have contact with the spine!
 - Confirming biofidelity and in-house R&R performance
 - Send THOR-05F to outside labs for R&R
- Add bumper to back of rib #7
 - Protect lower IR-TRACCs in severe loading
 - Still can allow for ~75mm of deflection which is likely greater than the injury criteria
 - Minimal effect on performance in less severe environments
- Include all changes in an updated drawing package, qualification manual, & PADI.

THOR-05F Ankle: UVA in/eversion mode

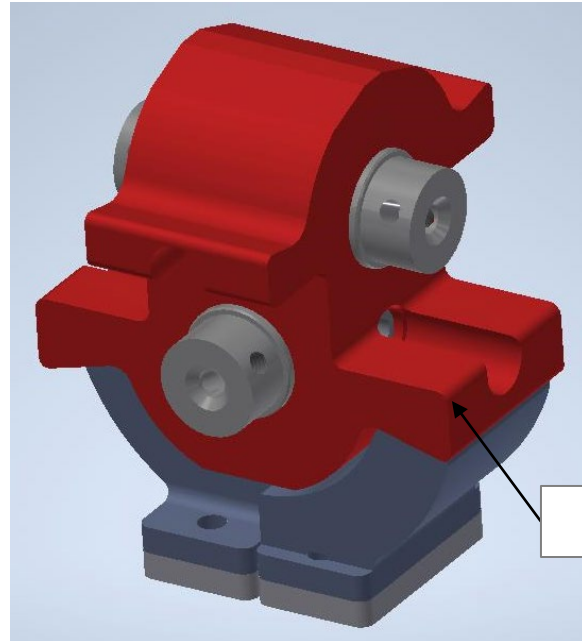
- In/eversion small female PMHS testing performed at UVA
 - Test set-up allows for 70° of rotation at 500°/s
 - 10 specimens tested (shod, 5 inversion, 5 eversion)
 - 2kN axial pre-load
 - Output: Ankle Mx, injury
- Matched pair testing with THOR-05F
 - Original in/eversion stoppers were too soft & had limited RoM



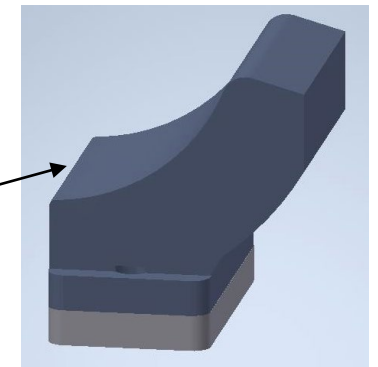
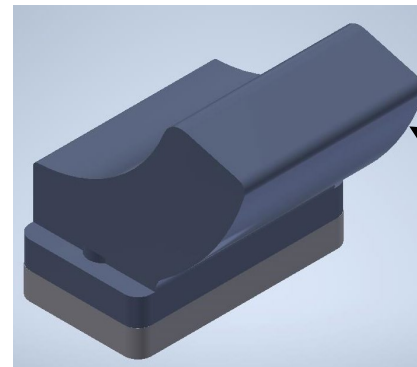
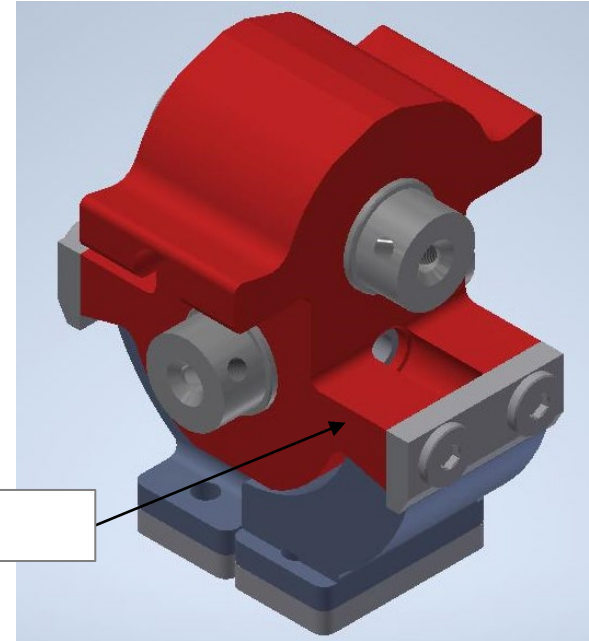
THOR-05F Ankle Design Evolution

- Improve biofidelity
- Geometry change to ankle block
 - Prevents stopper from popping out
- Geometry & material changes to stoppers
 - Varied thickness in x-direction
 - Varied rubber hardness

Initial Design



2nd Gen Design

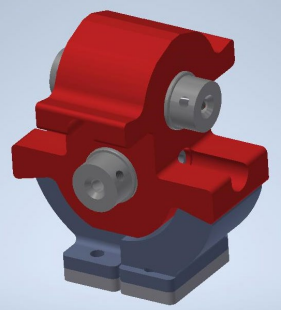


In/eversion stopper

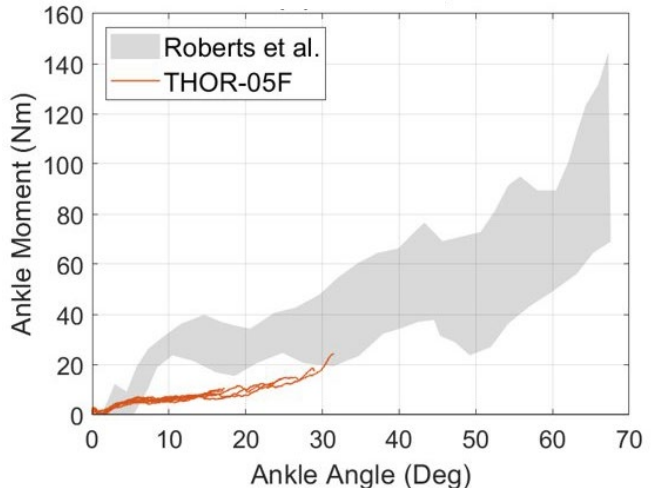
Ankle Testing: 2nd Gen Design

- Sent 7 prototype 2nd Gen stoppers back to UVA in early 2023

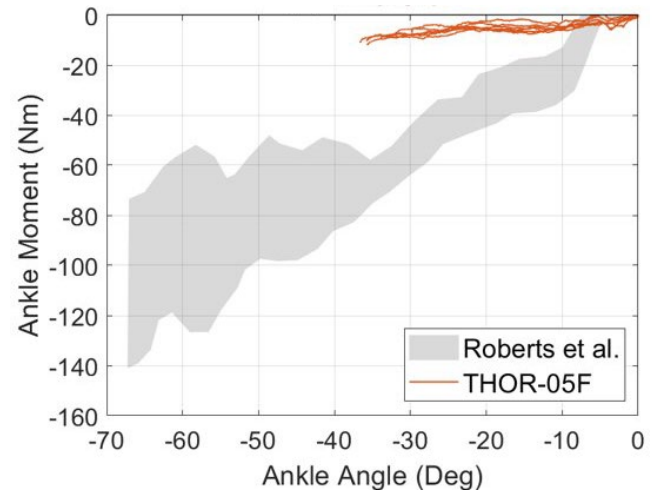
Initial Design



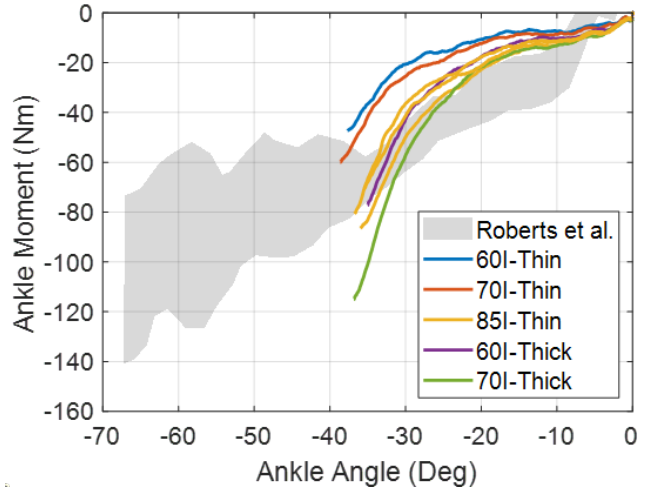
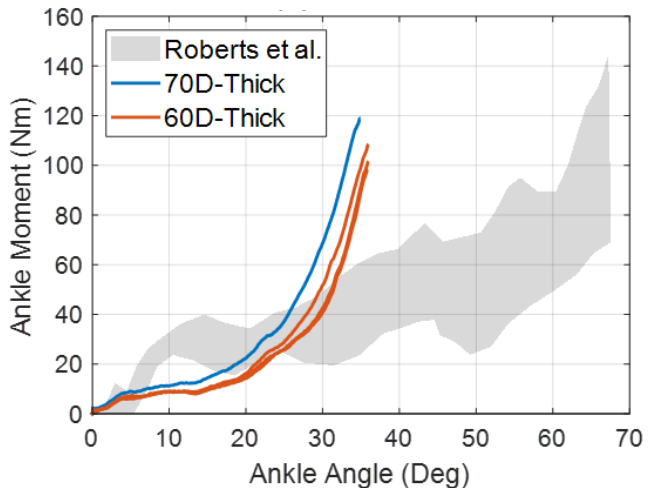
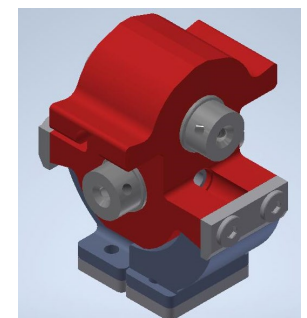
Eversion



Inversion



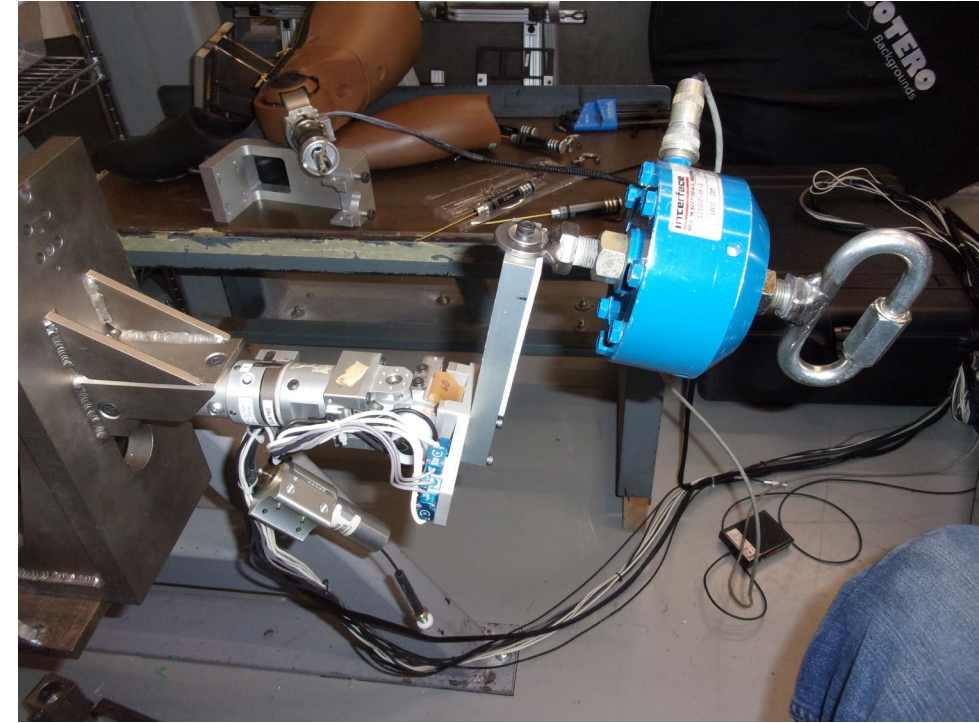
2nd Gen Design



- Better biofidelity than initial design
- Can improve further
- **Need to be able to evaluate at VRTC**

Ankle Testing: 2nd Gen Design

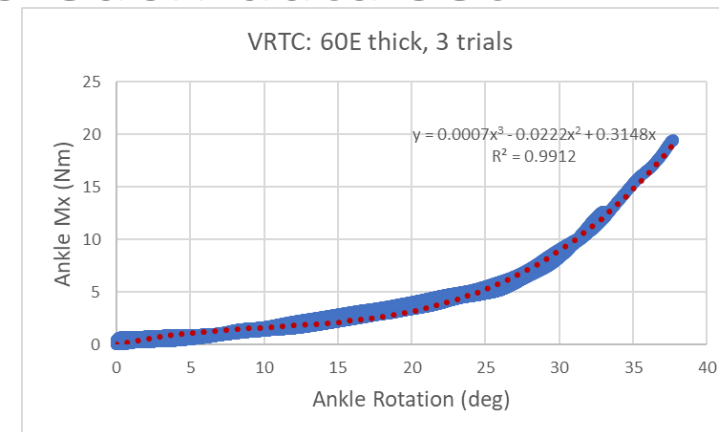
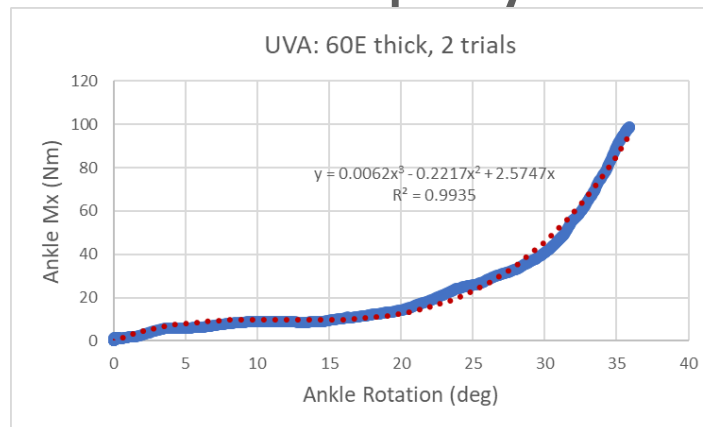
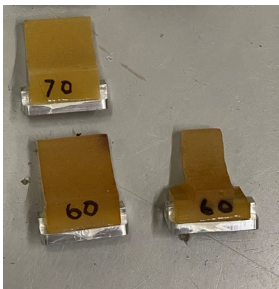
- Can not replicate UVA tests at VRTC
- New VRTC in/eversion test mode
 - Provides quasi-static moment vs angle data
 - Ankle qualification test fixture with extra load cell
 - Quasi-static rotation until full compression of stopper
 - Tested all 7 2nd Gen stoppers



- **Objective:** Develop a transfer function that will predict UVA data for biofidelity analysis
 - Input = VRTC quasi-static data
 - Output = Estimated UVA data

Estimating Biofidelity Response

- For the 7 stoppers, fit a 3rd order polynomial to each data set



Stopper	UVA			
	A	B	C	R ²
60E thick	0.0062	-0.213	2.4766	0.99
70E thick	0.0069	-0.2193	2.6995	0.99
60I thin	0.0025	-0.1039	1.5562	0.99
70I thin	0.0028	-0.1111	1.7138	0.99
85I thin	0.0039	-0.142	2.2659	0.99
60I thick	0.0046	-0.1639	2.2487	0.99
70I thick	0.0056	-0.1919	2.681	0.99

Stopper	VRTC			
	A	B	C	R ²
60E thick	0.0007	-0.0222	0.3148	0.99
70E thick	0.0006	-0.0088	0.2723	0.99
60I thin	0.0005	-0.0196	0.4313	0.99
70I thin	-0.00004	0.0086	0.0579	0.99
85I thin	0.00004	0.009	0.2413	0.96
60I thick	0.00002	0.0076	0.1436	0.99
70I thick	-0.0001	0.0141	0.1703	0.99

$$M = A(r^3) + B(r^2) + Cr$$

M = ankle moment

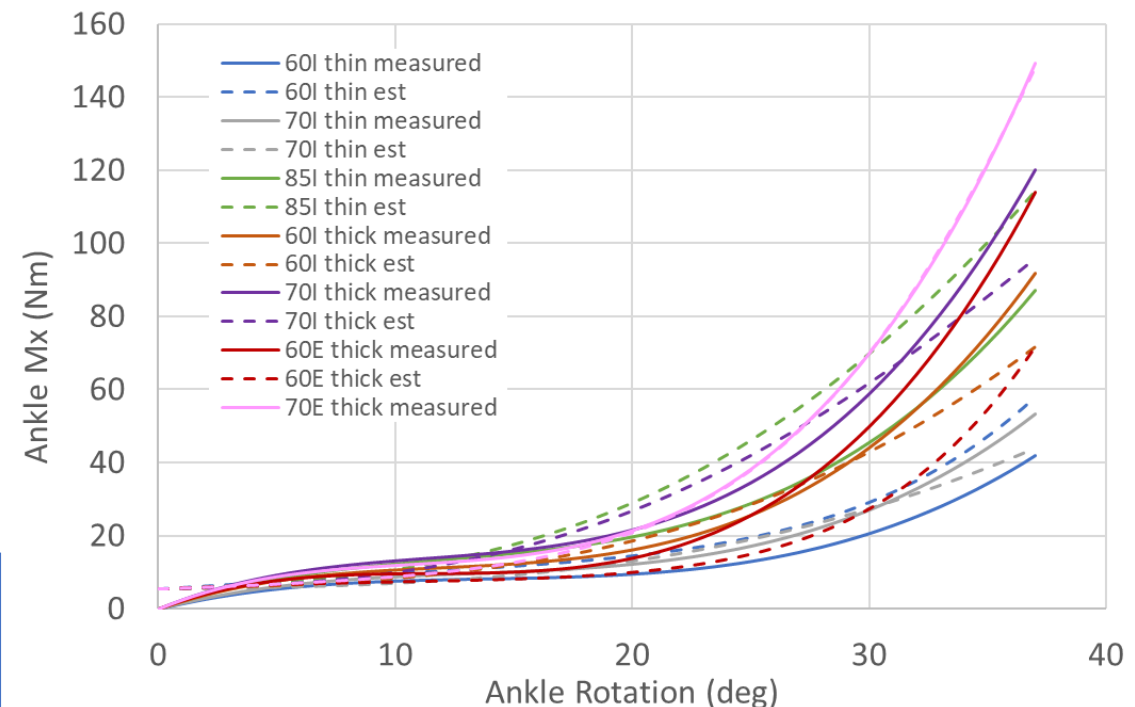
r = ankle rotation

Estimating Biofidelity Response

- Develop a transfer function to estimate UVA response
 - MATLAB design optimization: fminunc
 - Input: polyfit UVA data, polyfit VRTC data, starting point, objective function
 - Objective function: minimizes the sum (n=7) of the RMSE between the actual UVA data & predicted
 - Output: 3rd order solution $M_{UVA_est} = AM_{VTRC}^3 + BM_{VTRC}^2 + CM_{VTRC} + D$
 - Checked solution for 7 different starting points
 - All converged to roughly same solution
 - Evaluated 13,240 potential solutions

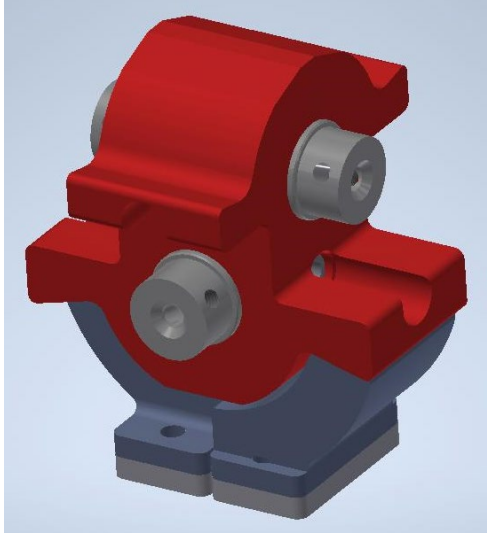
Starting point				Solution				Sum of RSME
A	B	C	D	A	B	C	D	
-0.01138	0.41175	2.93506	2.75045	-0.00351	0.24910	0.77825	5.37857	55.485
-0.00179	0.17958	1.42248	5.43660	-0.00340	0.24420	0.83482	5.22769	55.488
0.01823	-0.11613	2.18175	4.47951	-0.00351	0.24911	0.77821	5.37863	55.485
0.01731	-0.21458	2.81896	4.62945	-0.00351	0.24911	0.77821	5.37866	55.485
0.00559	0.00242	1.65198	1.82039	-0.00351	0.24910	0.77825	5.37851	55.485
0.04403	-0.44366	3.33298	3.57836	-0.00351	0.24910	0.77825	5.37857	55.485
0.00707	-0.10922	2.36946	3.84740	-0.00352	0.24912	0.77812	5.37877	55.485

$$M_{UVA_est} = -0.0035M_{VTRC}^3 + 0.2484M_{VTRC}^2 + 0.7863M_{VTRC} + 5.357$$

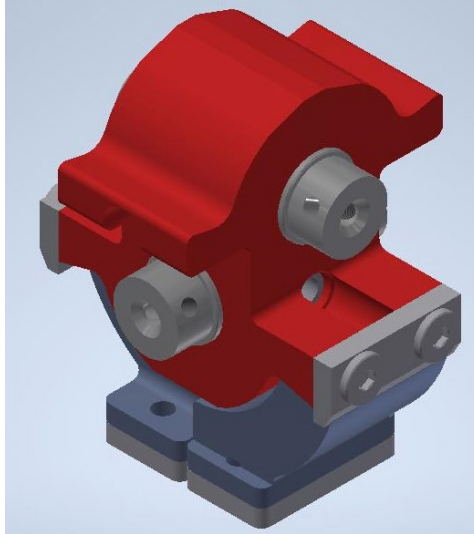


THOR-05F Ankle Design Evolution

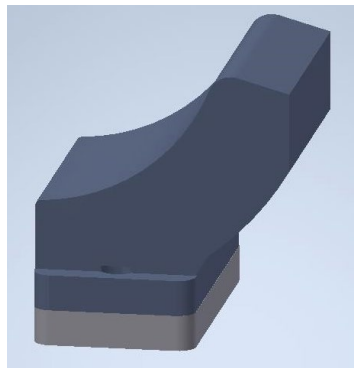
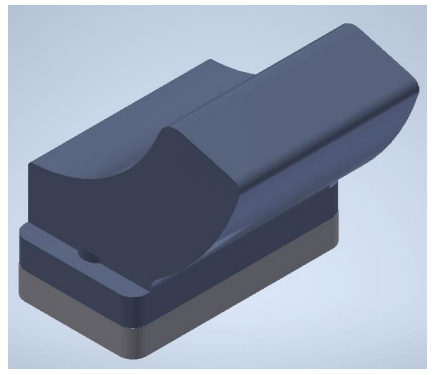
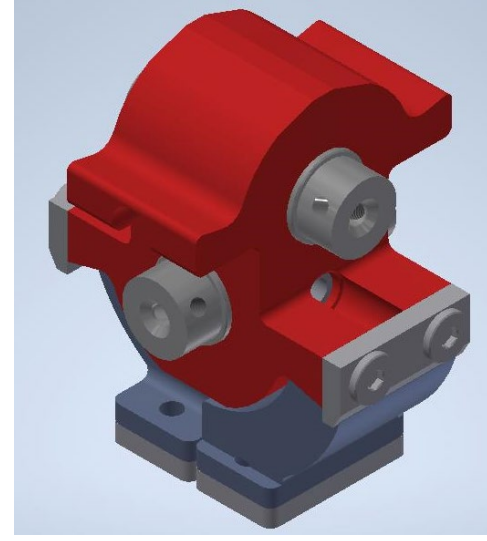
Initial Design



2nd Gen Design



3rd Gen Design

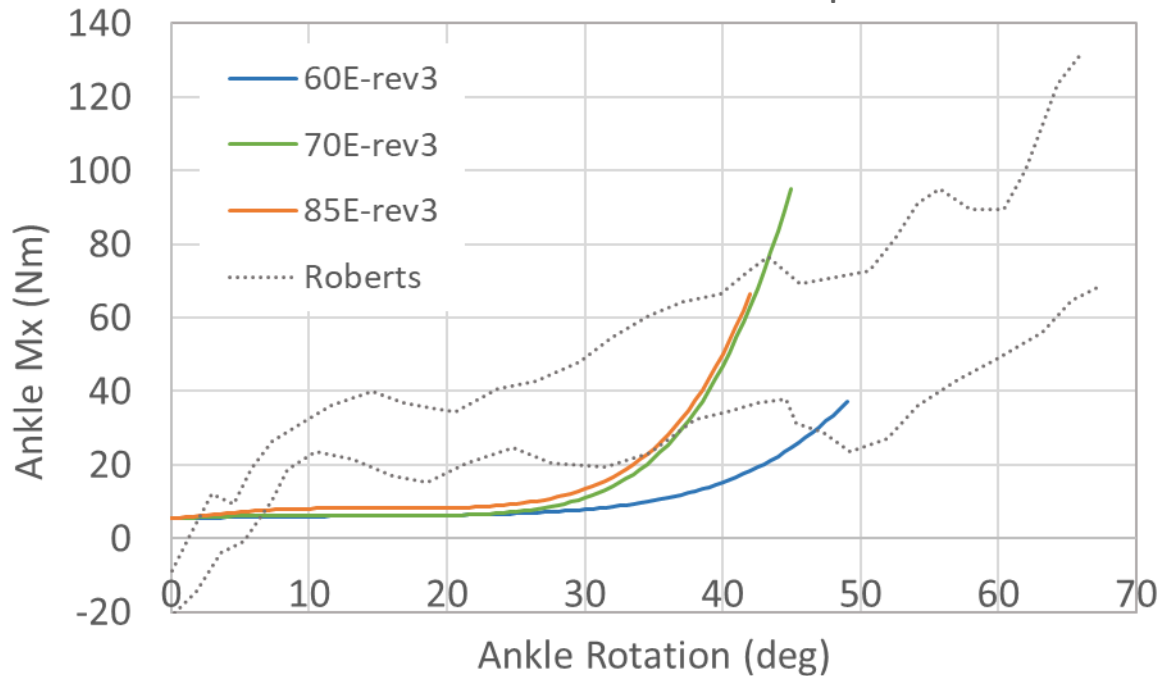


- Allows for more in/eversion rotation
- Maintains high terminal stiffness
- Fabricated 3 3rd gen stoppers
 - varied rubber hardness

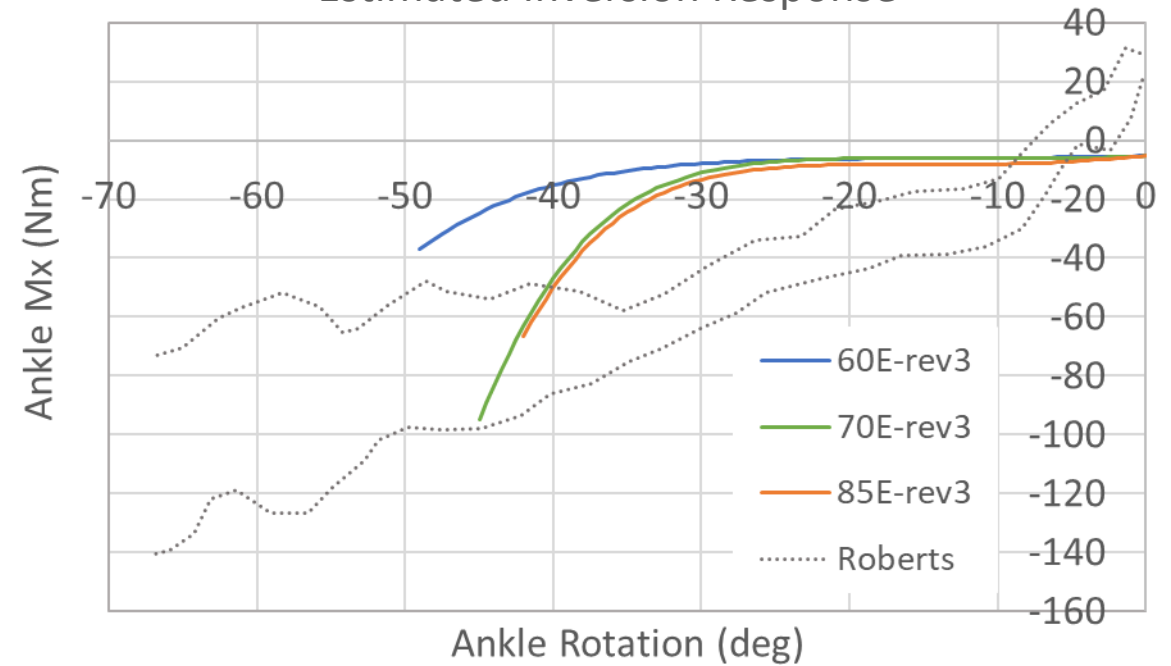
Ankle: Estimated Biofidelity Response

- Apply best transformation to VRTC quasi-static data from new stoppers
- Provides estimate of UVA test data (biofidelity corridors available)

Estimated Eversion Response



Estimated Inversion Response



- 3rd gen stoppers have larger rotation range compared to 2nd gen
- Ideally, initial stiffness should be higher

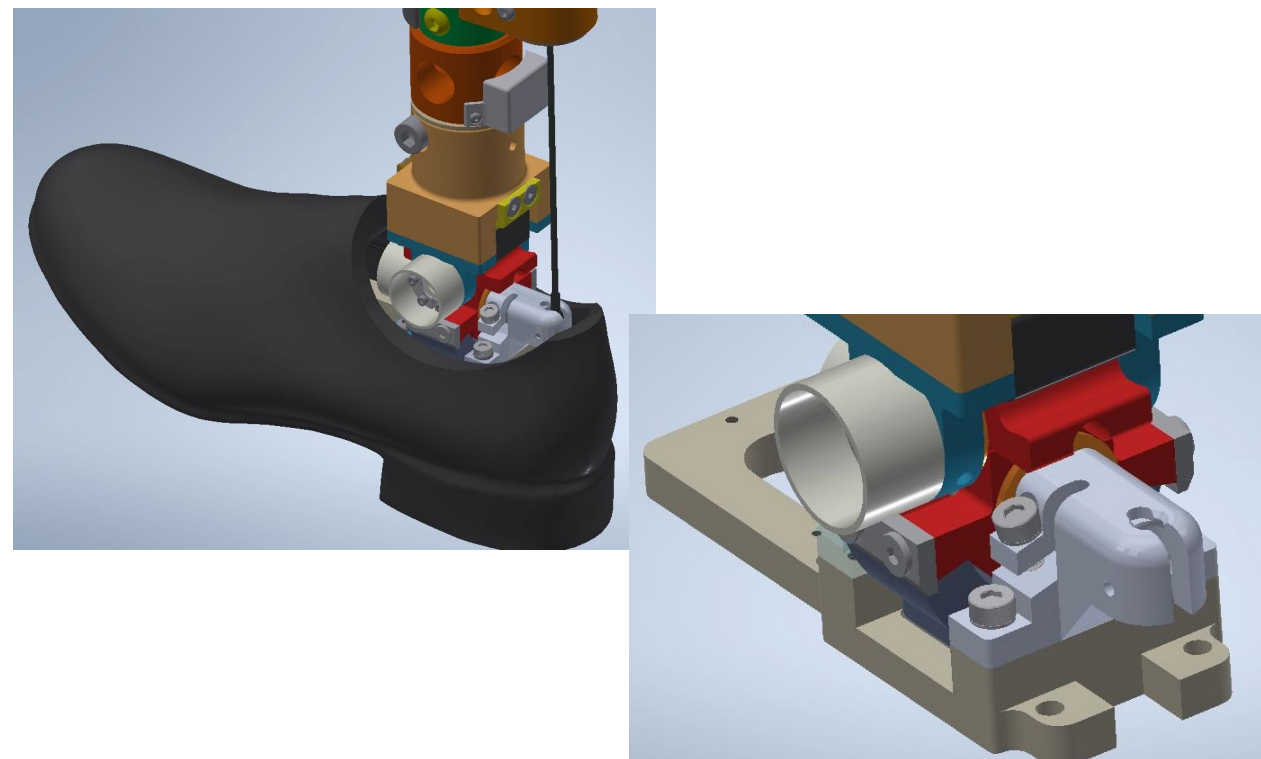
Next Steps for THOR-05F Ankle

- Investigating design change to Achilles Cable Retainer.
 - Increase initial stiffness
- Developing a dynamic test at VRTC that may better correlate to UVA test mode.
- Include all changes in an updated drawing package, qualification manual, & PADI.

Original Design



New Design



- THOR-05F thorax and ankle designs have been significantly improved.
- Continued assessment of the VRTC thorax design
 - Thorax biofidelity
 - R&R at VRTC and outside labs
- Prototyping new ankle parts to evaluate in early 2024
 - Biofidelity, increased energy durability, & R&R
- Documentation is being drafted for the NPRM
 - Drawing package, PADI, qualification manual, injury criteria report, & seating procedures
- Additional crash and sled tests