NHTSA

NATIONAL HIGHWAY TRAFFIC SAFETY ADMINISTRATION

Large Omnidirectional Child (LODC) ATD Seating Evaluation

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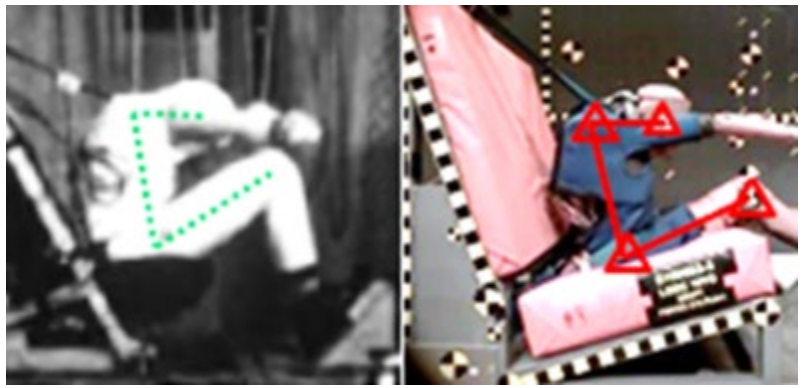
Background

- Large Omnidirectional Child (LODC) ATD
- HIII-10C is currently the best tool for evaluating large belt-positioning booster seats (FMVSS 213).
- LODC was developed by NHTSA to continue biofidelity improvements of the HIII-10C ATD, which was adopted into CFR 49 Part 572.
  - Mitigates chin-chest contact issues
  - Measures abdominal loading & identifies submarining
  - Upper torso flexion consistent with human response



Body Region	LODC	HIII-10C
Head	0.61	1.81
Neck	1.57	2.73
Cervicothoracic	1.35	1.83
Thorax	1.84	5.50
Abdomen	0.66	1.61
OVERALL ATD	**1.21**	**2.70**

Lower BioRank scores = More Biofidelic

Source: Stammen et al. SAE Technical Paper (No. 2016-22-0017) : "The large omnidirectional child (LODC) ATD: biofidelity comparison with the hybrid III 10 year old ".

Head has inertial properties & impact response matching pediatric data

Chest deflection measured by non-contact laser device

Shoulders and thorax reflect pediatric anatomy and mimic pediatric response

Biofidelic, instrumented abdomen to measure belt-induced loading

Anthropometry matches actual seated child data

Neck can elongate and allow for free Z axis rotation; response matching pediatric data

Flexible cervicothoracic & thoracic spine for more biofidelic head trajectory and neck loads

Background - Anthropometry

- The LODC ATD is designed to represent a 9 – 11 year old child, with a stature matching the HIII-10C, but detailed anthropometry matching 10 year old seated volunteer model data from Reed et al. (2006, 2009).
- This includes a 90 degree spine angle with tilted pelvis.

Overlay of LODC with UMTRI Childshape model (www.childshape.org)

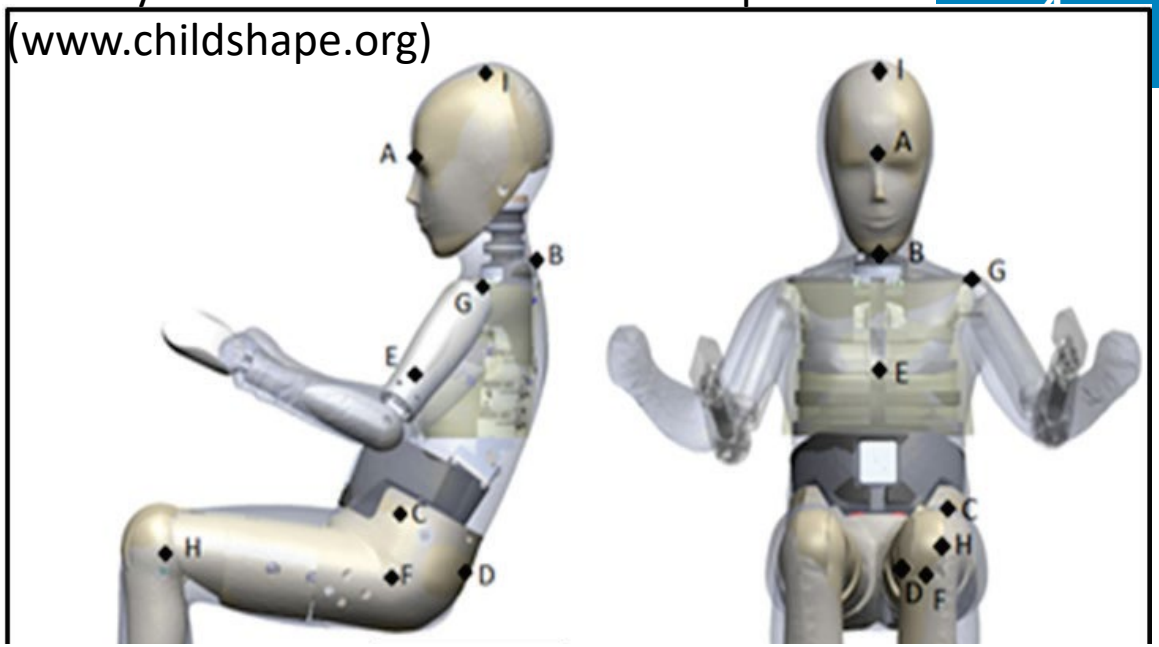


Table 2. Comparison of external dimensions and segment masses

Parameter	LODC	HIII-10C	Childshape model	9-11YO Volunteer Data from Reed et al (2006)	9-11YO CDC Growth Charts (50th Percentile, 2000)***
Mass, overall (kg)	34.6	35.2	---	36.1 ± 5.7	28.5 – 37.0
Mass, head (kg)	3.56	3.73	---	---	---
Mass, neck (kg)	0.53	0.80	---	---	---
Mass, upper torso (kg)	6.62	8.15	---	---	---
Mass, lower torso (kg)	10.12	8.72	---	---	---
Body mass index (kg/m^2)	20	20	20	18.1 ± 2.4	16.2 – 17.5
Stature (mm)*	1300	1300	1300	1413 ± 58.6	1330 - 1440
Seated height (mm)**	679	716	684	692 ± 5.7	---
Erect Sitting Height / Stature	0.55	0.586	0.55	0.52 ± 0.01	---
Shoulder width (mm)	340	315	343	---	---
Shoulder height (mm)	390	395	394	---	---
Chest depth (mm)	188	165	185	---	---
Chest circumference (mm)	755	704	720	---	---
Abdomen depth (mm)	182	186	196	---	---

*LODC stature was designed to be the same as the HIII-10C stature; both dummies have short legs in comparison to volunteers but matching seated height; **Calculated as Seated Height = Erect Sitting Height * COS(20 deg), where 20 degrees is the recline angle; ***Range is combined boys and girls 50th percentile values from age 9 - 11

Source: Stammen et al. /Stapp Car Crash Journal Vol 60 Nov 2016 "The Large Omnidirectional Child (LODC) ATD: Biofidelity Comparison with the Hybrid III 10 Year Old".

Background

- UMTRI Human Study; Reed et al 2006*
  - The Reed study was used to quantify “slouching” by examining the differences between postures selected and standard seating postures by 62 children representing 6-to-10 year-olds with a body mass from 18 to 48 kg.
- The study was conducted using a vehicle seat with and without a booster, with the seat back angle set to 19°, 23° and 27°.
- Data from the study was analyzed to quantify hip and head locations and pelvis and head angles for both sitter-selected and standardized postures to develop a sense of how children were sitting.
  - In reviewing the data, occupants with similar stature of the LODC were analyzed
    - LODC pelvis angle at approximately 35° produced more head level results and decreased the tibia angles similar to children in the Reed study.

Source: Reed et al. /Stapp Car Crash Journal Vol 50 Nov 2006 “Improved Positioning Procedures for 6YO and 10YO ATDs Based on Child Occupant Postures”

Previous Seating Work

- During the development of the LODC, the dummy was assessed on the proposed FMVSS No. 213 bench and in the rear seat of a 2016 Chevrolet Malibu (with and without a booster).
- Initial seating procedure:
  - The dummy was pulled forward at the pelvis until the knees bent over the edge of the cushion.
    - This was used based on the dummy design and to maintain a vertical spine. At the time the tilt sensors were not being used and the H-point was not recorded.
  - Issues identified when using dummy on other platforms:
    - Where do you determine when to stop pulling the dummy forward?
    - Where do you bend the legs over the seat cushion and how far do you push them back on the cushion? Do the knees need to be a 90 degree angle?
    - The flexible spine can have the dummy in a variety of locations and pelvic angles.

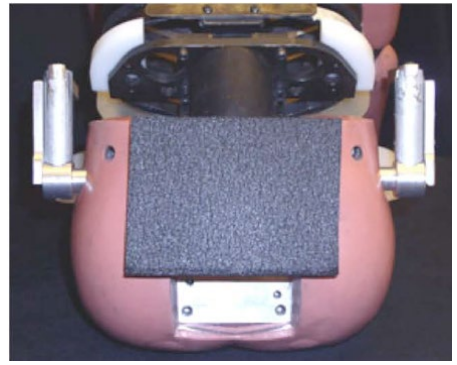
Objective: Development of the LODC Seating Procedure:

Goals

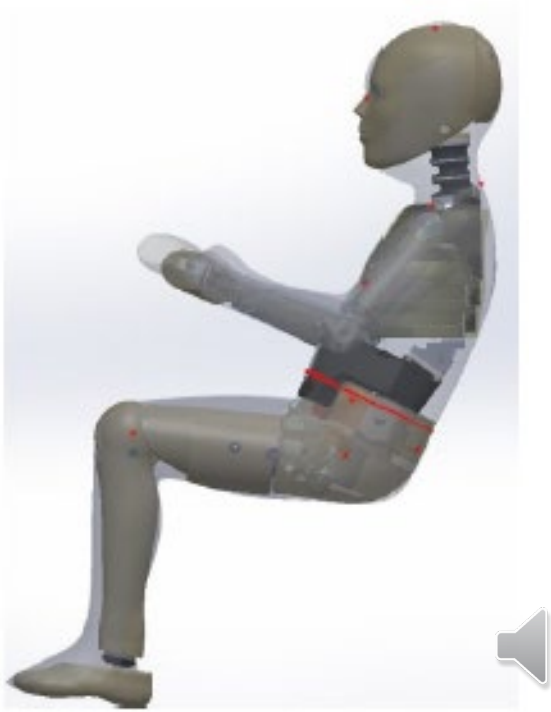
- Develop a seating procedure that represents how children sit.
- Develop a repeatable, unambiguous procedure that positions the dummy in a repeatable, reproducible method.
  - Utilize H-point location and tilt sensors
- Develop the procedure for use on the proposed FMVSS No. 213 bench but also for future use in vehicle rear seat environments.

Hybrid III 10YO versus LODC

On FMVSS No. 213 proposed bench



- Current Hybrid III 10YO is used in FMVSS No. 213 in booster and harnessed seats.
- A pelvis pad must be used on the back side of the Hybrid III 10YO when in a booster to place the dummy in correct orientation with the seatback/CRS back
- There are no tilt sensors in the Hybrid III 10YO, so the dummy could sit at a variety of angles.
  - Not required measurement in FMVSS 213
- The LODC utilizes tilt sensors in the head and pelvis.
- The LODC pelvis was designed to eliminate the need for the pelvis pad.
- The pelvic angle of the LODC is similar to UMTRI human study.
  - The pelvis was developed to represent a more human like slouched pelvis.



LODC/HIII-10C Seating Procedure Comparison

HIII-10C – FMVSS No. 213

- Seat Full Rearward
- If adjustable seat back adjusted 25° using SAEJ826 Manikin
- Head Restraint Full Down/Full Rear
- Center ATD in seat position with rear of pelvis parallel to seat back slid rearward until pelvis positioning pad and seat back have minimal contact
- Press rearward at pelvis with 40lbf using force gauge
- Press rearward at chest with 40lbf using force gauge
- Rotate the arms of the dummy down so that they make contact to CRS or seat.
- Bend the knees until the back of the lower legs are in minimal contact with the Seat
- Legs are spaced 220mm ± 10mm
- Soles of feet perpendicular to the centerline of the lower leg

* 10YO was also seated with the Head Rest adjusted to the full up position if there was interaction

CW_1 = LODC – FMVSS No. 213

- Seat Full Rearward
- If adjustable seat back adjusted 25° using SAEJ826 Manikin
- Head Restraint Full Down/Full Rear
- Center ATD in eat position with rear of pelvis parallel to seat back slid rearward until pelvis and seat back have minimal contact
- Press rearward at pelvis with 40lbf using force gauge
- Press rearward at chest with 40lbf using force gauge
- Rotate the arms of the dummy down so that they make contact to CRS or seat.
- Bend the knees until the back of the lower legs are in minimal contact with the Seat
- Legs are spaced 220mm ± 10mm
- Soles of feet perpendicular to the centerline of the lower leg

* Further adjustments can be made here if needed (neck angle, head restraint position).

CW_2 = LODC – Hip Angle at 35°

- Seat Full Rearward
- If adjustable seat back adjusted 25° using SAEJ826 Manikin
- Head Restraint Full Down/Full Rear
- Center ATD in seat; adjust the pelvis to approximately 35° and slide rearward until pelvis and seat back make minimal contact
- Adjust head restraint up if there is interaction
- Adjusted neck to level head if needed (can adjust head restraint to lowest position if possible)
- Verify the pelvis angle is 35°
- Rotate the arms of the dummy down so that they make contact to CRS or seat.
- Bend the knees until the back of the lower legs are in minimal contact with the seat
- Legs are spaced 220mm ± 10mm
- Soles of feet perpendicular to the centerline of the lower leg

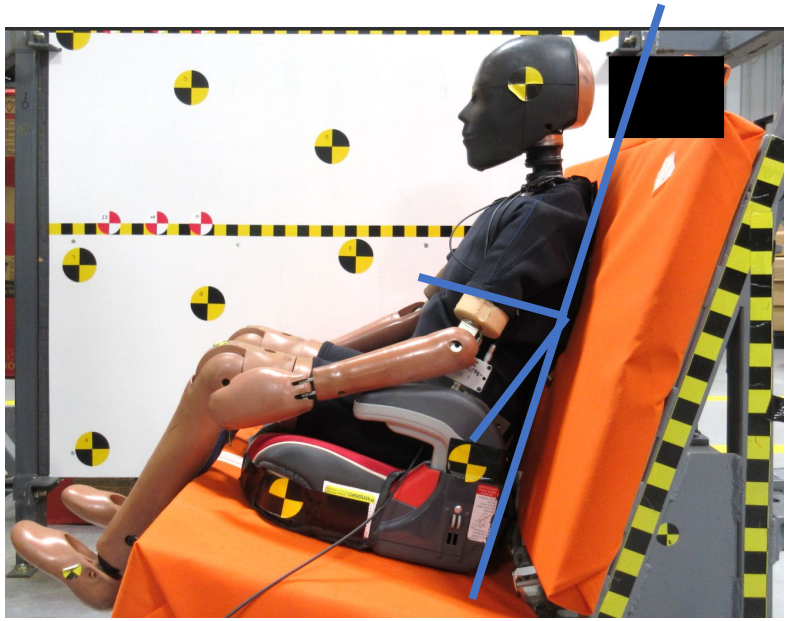
*Neither the 10YO or the LODCs' legs were able to extended when placing into the seat due to front seat or dash interaction

Graco TurboBooster

On proposed FMVSS 213 bench

HIII-10C, 213 Seating

LODC, CW_1,
Neck Adjusted



LODC, CW_2,

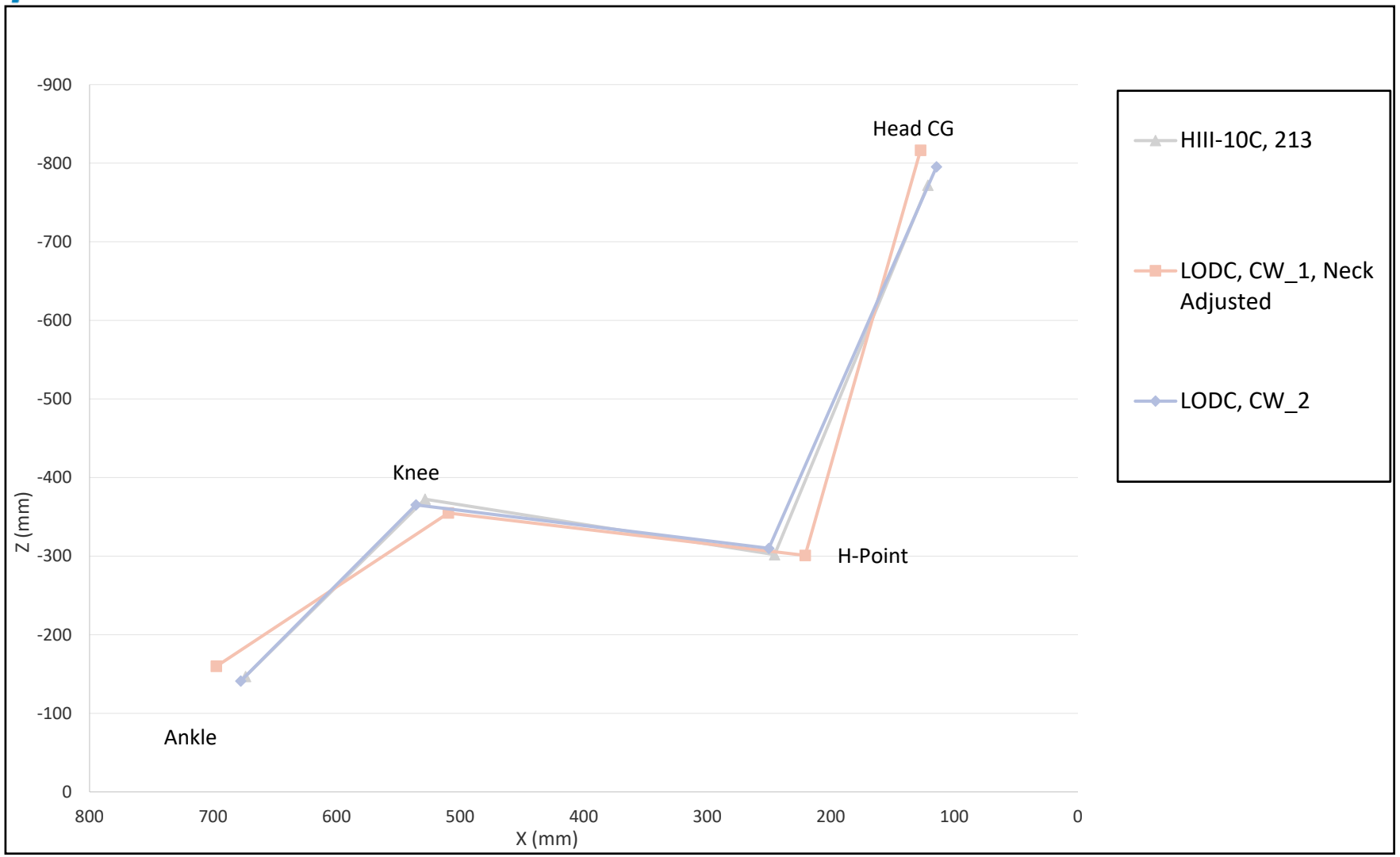
LODC Seating

Hybrid III seating used by LODC: Initial investigation

- Using the current Hybrid III 10YO seating procedure on the LODC (CW_1)
  - Forces the pelvis in a more upright position
    - Head more forward with spine not vertical
    - Head and neck typically have to be adjusted to make head level.
- Using a refined seating procedure with pelvic angle of 35 degree (CW_2)
  - It allows the top edge of the pelvis to make contact with the seatback and allows the spine to be in-line with the head and neck.
  - The legs hang comfortably over the edge of the booster seat - no ambiguity of where to let them fall over the edge

FMVSS No. 213 Bench Seating

On proposed bench

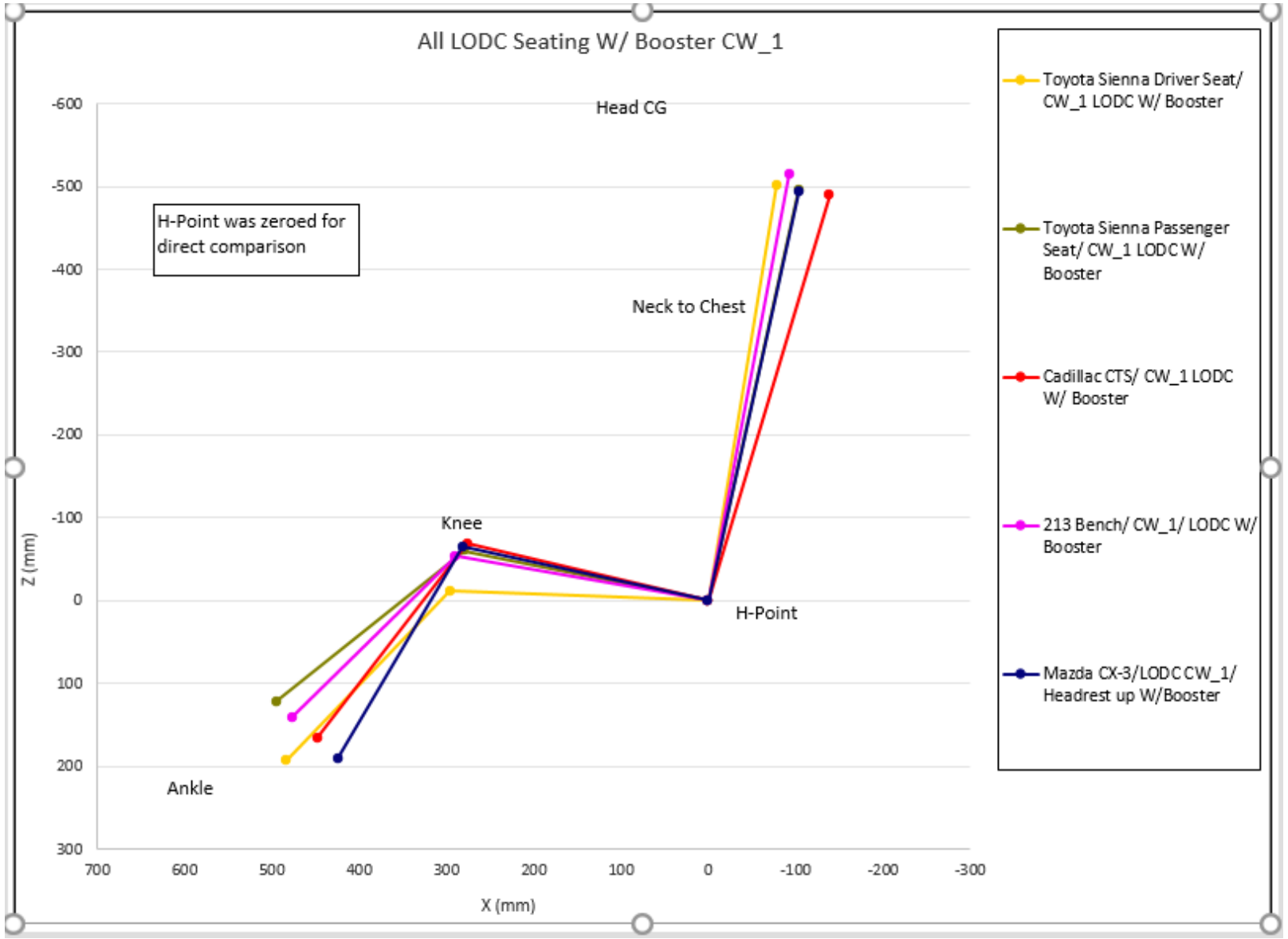


Initial Seating in Vehicles

- Does CW_1 or CW_2 positioning work better in rear seats of vehicles?
- Vehicles with different seat pan lengths were evaluated.
- Graco TurboBooster was used

Vehicle	Seat Position	Seat Pan Length in Millimeters	Seat Back Height in Millimeters	Seat Pan Angle in Degrees	Seat Back Angle in Degrees
2014 Toyota Sienna	Driver	518	610	5.8°	23.6°
2014 Toyota Sienna	2nd row/driver side	503	606	19°	24.9°
2011 Cadillac CTS	Rear Passenger/ Driver side	487	644	6.7°	26.2°
FMVSS 213 Proposed Bench	N/A	435	635	15°	20°
2017 Mazda CX-3	Rear Passenger/ Driver side	430	615	11.1°	22.3°

CW_1 LODC Seating



Toyota Sienna, CW_1, Driver Seat, LODC, Booster		
Tilt Sensors	x (°)	y (°)
Head	0.2	-7.8
T6	-0.4	-3.6
T12	-1.2	-2.6
Pelvis	-0.6	27.6

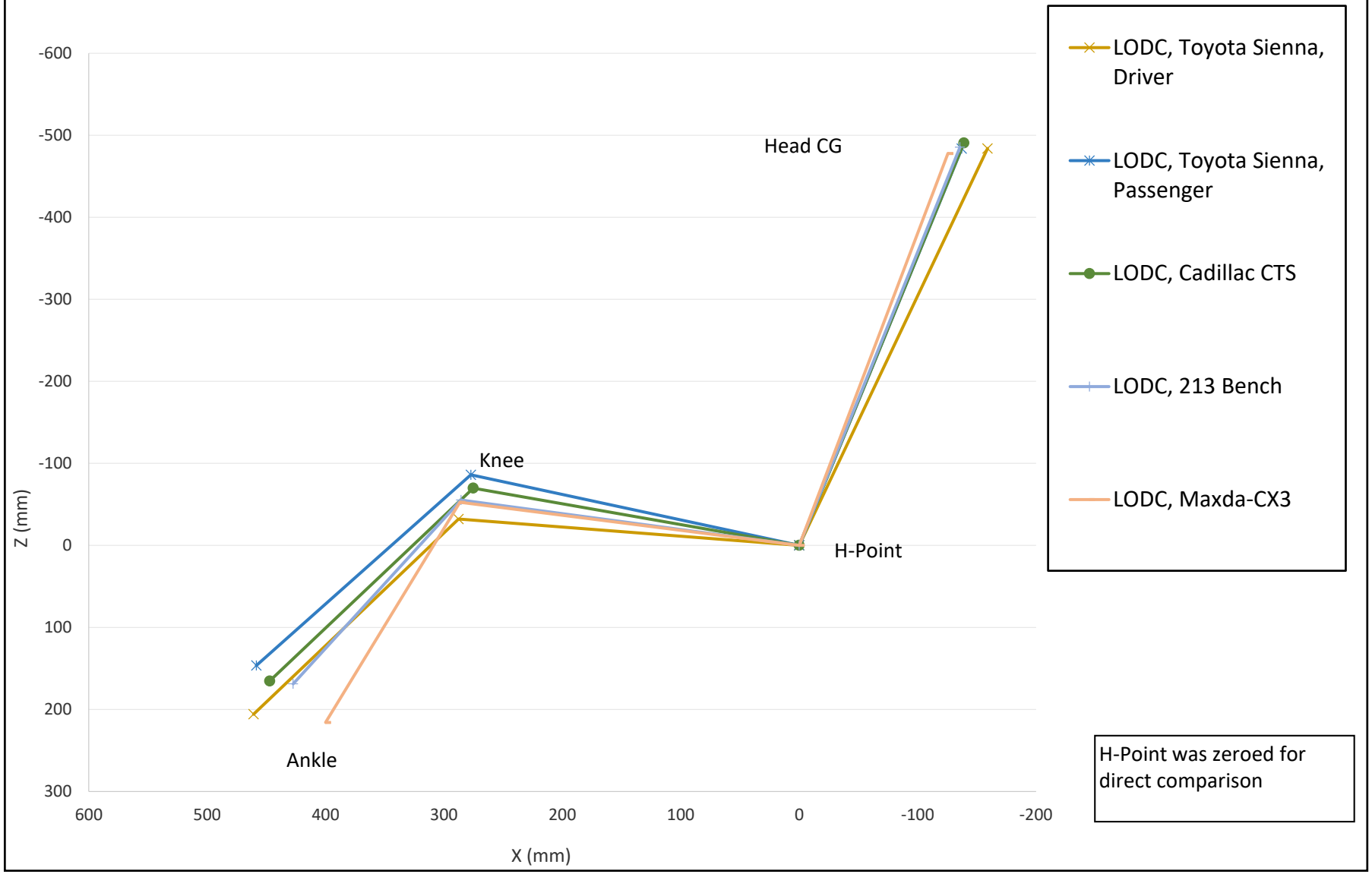
213 Bench, CW_1,LODC, Booster		
Tilt Sensors	x (°)	y (°)
Head	-0.1	-11.7
T6	-1	-8.4
T12	-1.6	-7.5
Pelvis	-0.2	24.8

Toyota Sienna, CW_1, Rear Passenger Seat, LODC, Booster		
Tilt Sensors	x (°)	y (°)
Head	1.2	-5.6
T6	0.1	-2.2
T12	-0.4	-1.1
Pelvis	0.2	30.1

Mazda CX-3, CW_1, Rear Passenger Seat, LODC, Booster, Head restraint Down		
Tilt Sensors	x (°)	y (°)
Head	0.1	-12.6
T6	-3.9	-7.4
T12		
Pelvis	0	29

Cadillac CTS, CW_1, Rear Passenger Seat, LODC, Booster		
Tilt Sensors	X(°)	Y(°)
Head	0.2	-1.2
T6	-1.8	0.3
T12		
Pelvis	-0.5	35

CW_2 LODC Seating



H-Point was zeroed for direct comparison

Toyota Sienna, Driver Seat, CW_2, LODC, W/ Booster, HP set at 35°		
Tilt Sensors	x (°)	y (°)
Head	0.1	2.2
T6	-0.9	4.7
T12	-	-
Pelvis	0	35

213 Bench, CW_2, LODC, W/ Booster, HP set at 35°		
Tilt Sensors	x (°)	y (°)
Head	0.3	0.8
T6	-0.5	3.2
T12	-	-
Pelvis	0.4	35.1

Toyota Sienna, Passenger Seat, CW_2, LODC, W/ Booster, HP set at 35°		
Tilt Sensors	x (°)	y (°)
Head	0.2	-3
T6	-1.3	1.4
T12	-	-
Pelvis	-0.5	34.9

Mazda CX-3, CW_2, LODC, W/ Booster, HP set at 35°		
Tilt Sensors	x (°)	y (°)
Head	0.2	-5.7
T6	-0.4	0.5
T12	-	-
Pelvis	-2.1	35

Cadillac CTS, CW_2, LODC, W/ Booster, HP set at 35°		
Tilt Sensors	x (°)	y (°)
Head	0.2	-1.2
T6	-2.0	0.3
T12	-	-
Pelvis	-1	35

This Method Showed The Most Consistency:

CW_2 LODC Seating

213 Bench, LODC, CW_2, With Graco Turbo Booster, Hip-Point set at 35°

Mazda CX-3, LODC, CW_2, Passenger Seat, With Graco Turbo Booster, Hip Point set at 35°

Initial Results

Graco Turbo Booster

- CW_1:
  - Pelvis is placed in more upright position which makes the dummy unstable.
  - CW_1 position typically placed the legs extended out more, and knees were over booster; making it difficult to bend over the edge of the booster.
  - Head was typically more forward.
  - Head and neck had to be adjusted to get head/neck level.
- CW_2:
  - By placing pelvis at 35 degrees the dummy fell into place typically and easily
  - No additional head/neck adjustments needed; head and neck were aligned with the spine.

Seating Position Evaluation

CW_2 Test Matrix in Vehicles and Proposed FMVSS No. 213 Bench

- Multiple rear seats with varying
  - Seat pan lengths
  - Seat back angles
  - Seat back heights
- Multiple booster/belt positioning seats
  - Seats chosen based on overall height of boosting
    - Graco TurboBooster (3)
    - Harmony Youth (3)
    - Graco Turbo Grow (3)
    - MiFold (3)*
- Repeats on each position

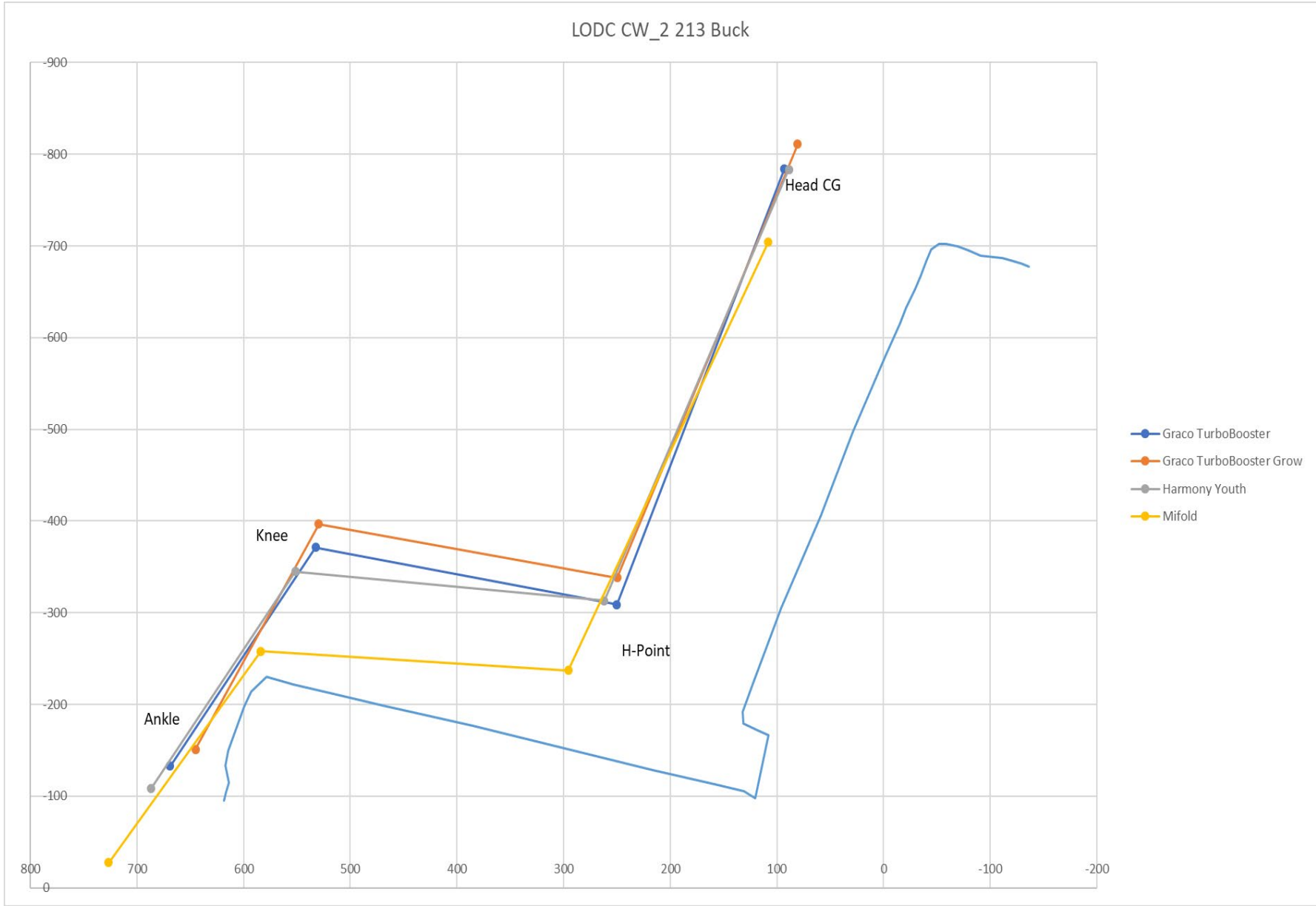
*While the Mifold may not be a “booster” under FMVSS No. 213, it was used in this study as it had features, such as a very low profile and different belt routing, that were of interest to this research project.

Test Matrix

- All CW_2 seating positioning
- OSCAR vehicle seat according to SAE J826
- Front seat is positioned at mid position

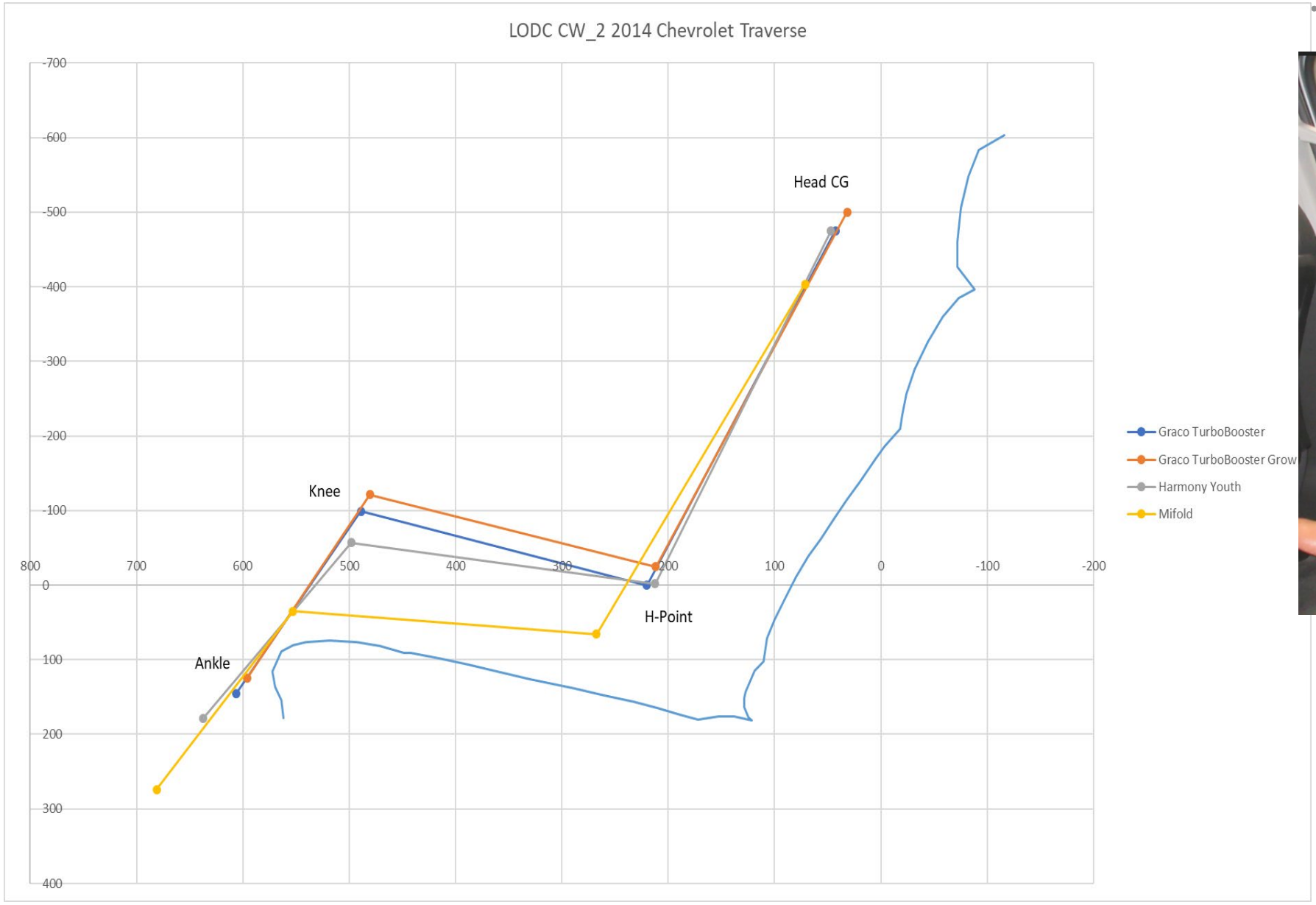
Vehicle	Vehicle Size	Seat Pan Length (millimeters)	Seat Back Height (millimeters)	Seat Pan Angle	Seat Back Angle
Proposed FMVSS No. 213 Bench	Average Rear Seat	435	635	15°	20°
2020 Ford Ranger	Compact Truck	408	608	8°	0°
2011 Chevrolet Traverse	SUV	446	620	19°	Adjustable set at 25°
2020 Hyundai Veloster	Compact Car	460	668	19°	25°
2010 Toyota Yaris	Compact Car	468	489	8°	19°
2011 Cadillac CTS	Mid-Size Car	487	644	7°	26°
2014 Toyota Sienna	Mini Van	503	606	19°	25°
2010 Toyota Yaris (Front Seat)	Compact Car	515	625	11°	19°

213 Buck



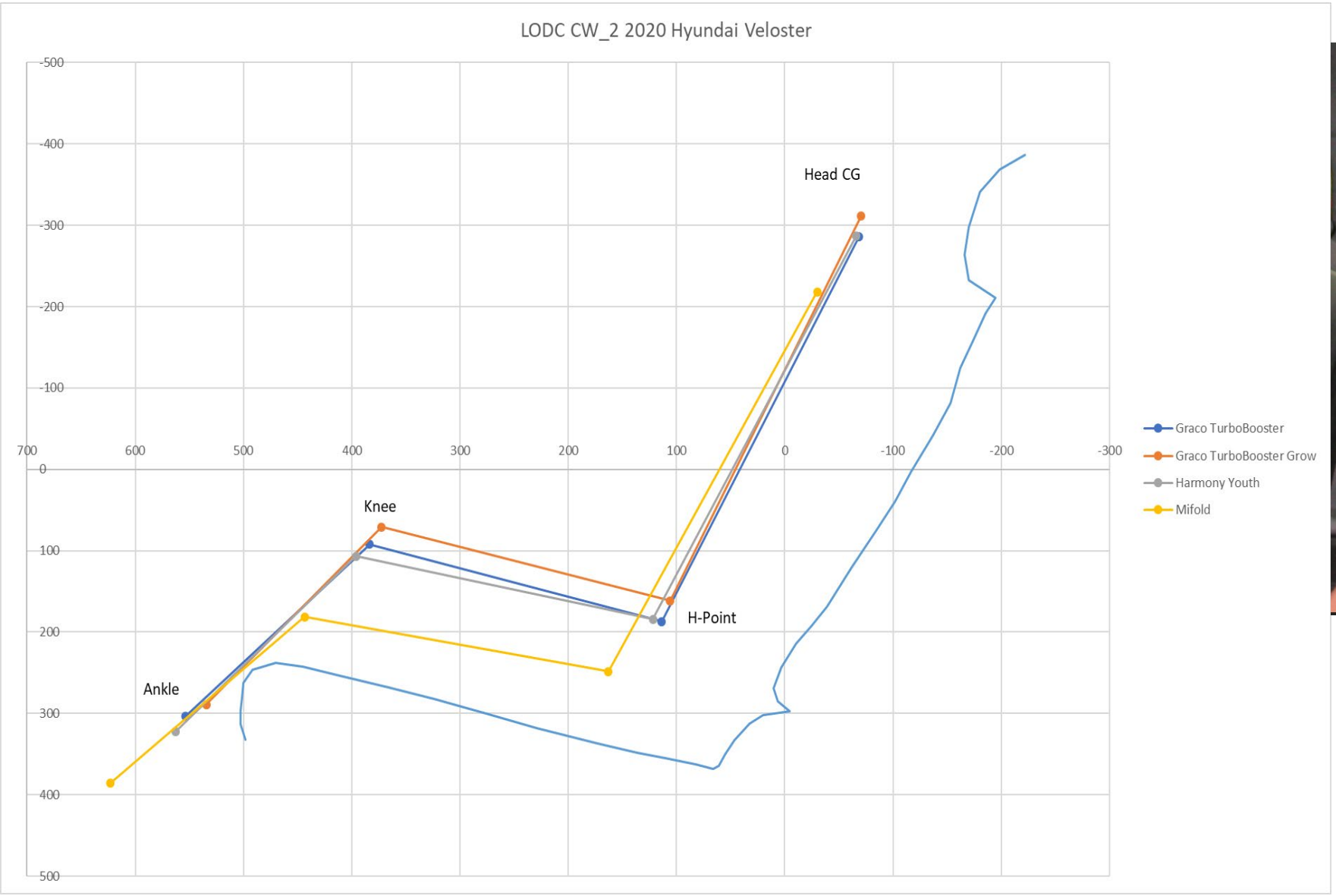
Seat Pan Length	435 mm
Seatback Angle	20°
Torso Recline Angle Max	22°
Torso Recline Angle Min	17°
Tibia Angle Max	34°
Tibia Angle Min	18°

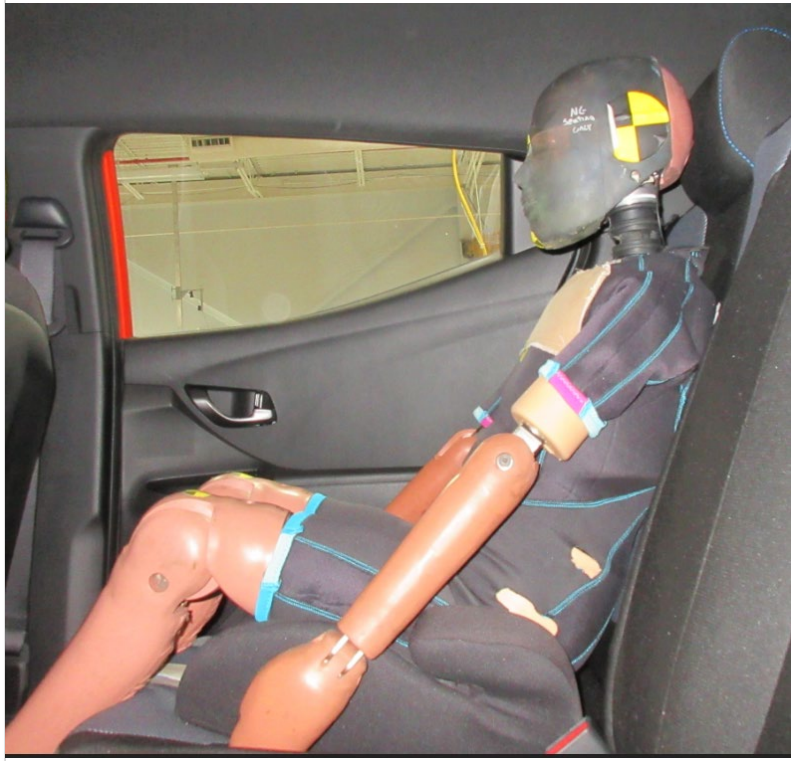
2014 Chevrolet Traverse



Seat Pan Length	446 mm
Seatback Angle	25°
Torso Recline Angle Max	23°
Torso Recline Angle Min	19°
Tibia Angle Max	32°
Tibia Angle Min	24°

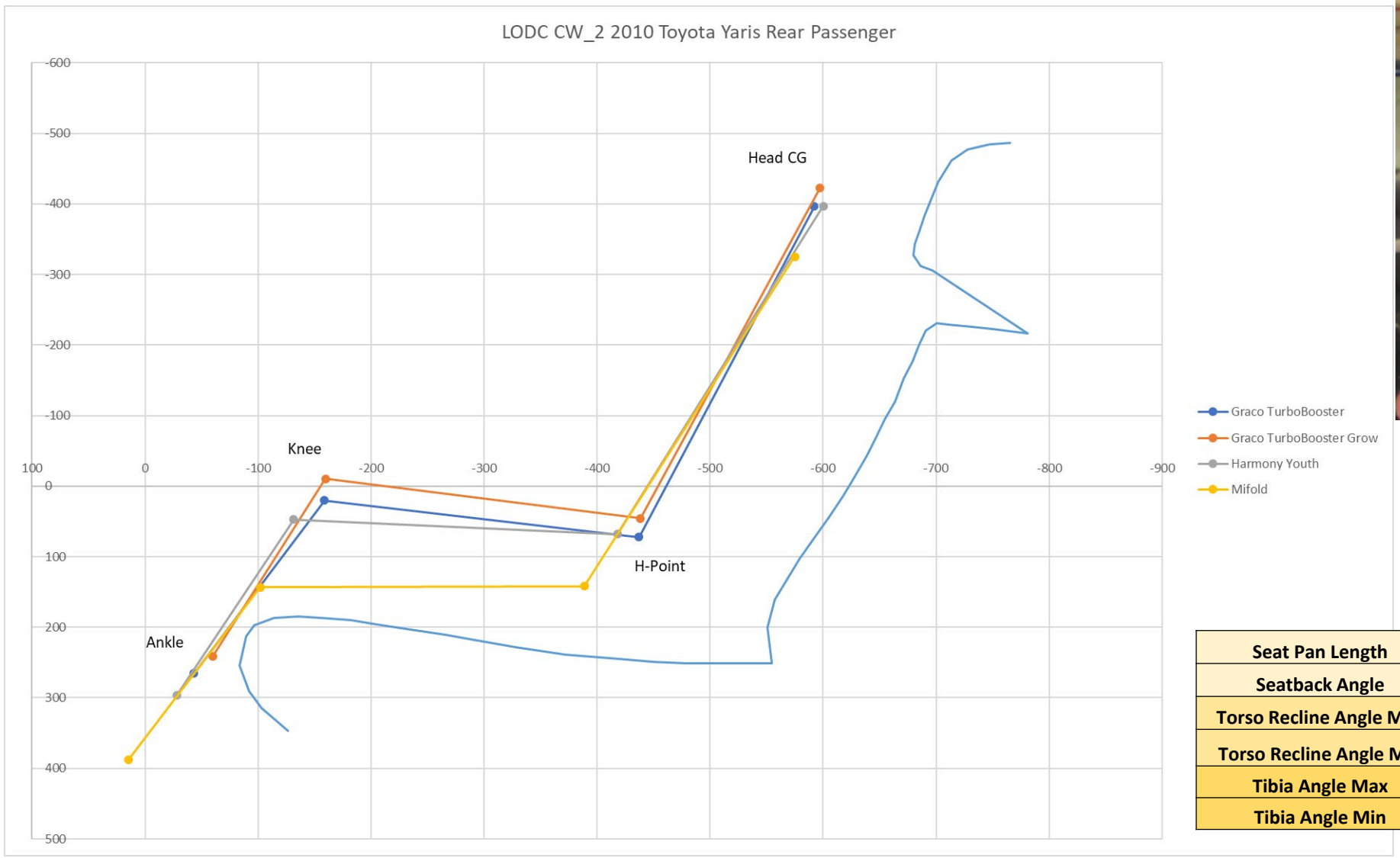
2020 Hyundai Veloster





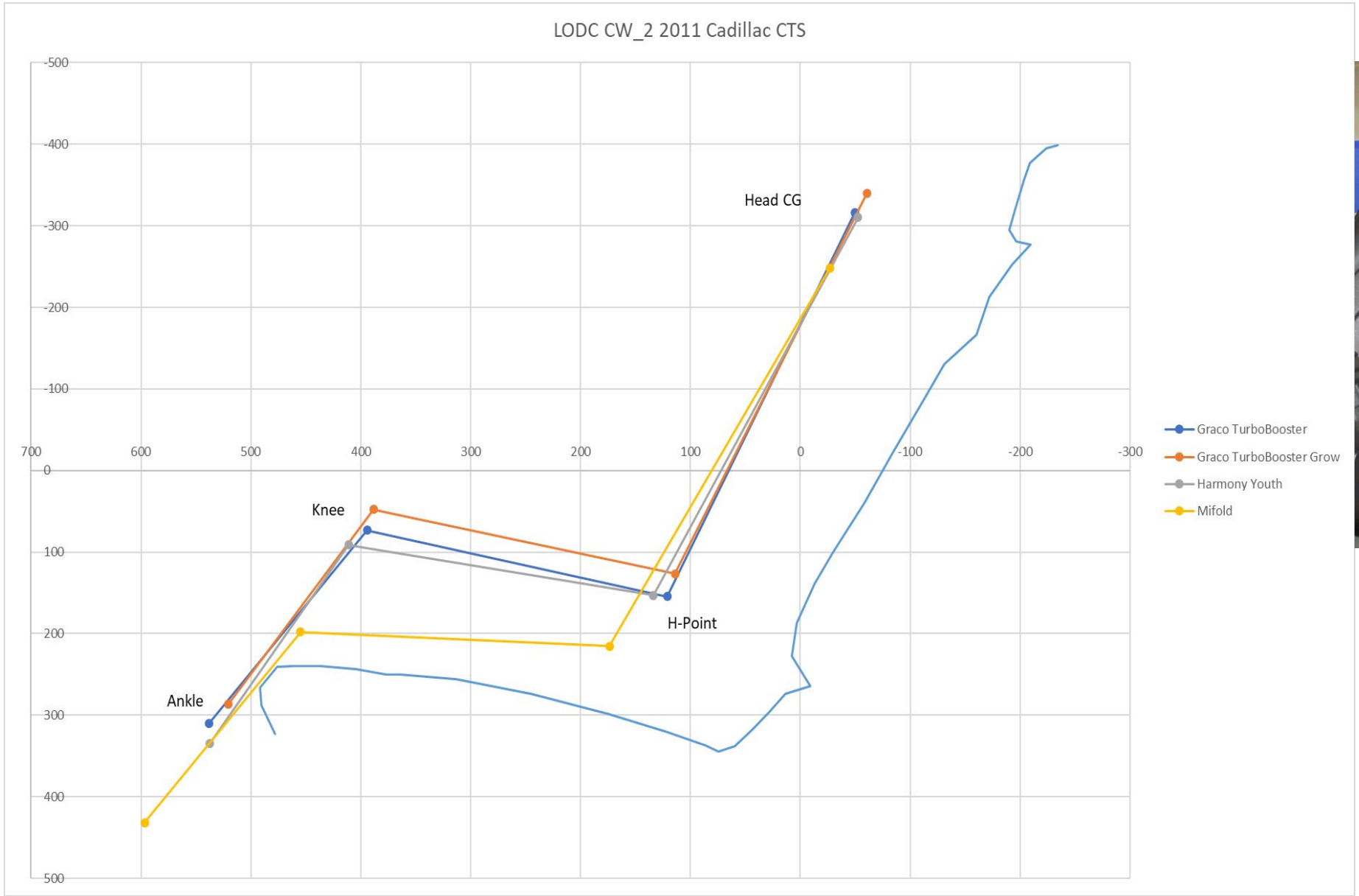
Seat Pan Length	460 mm
Seatback Angle	25°
Torso Recline Angle Max	24°
Torso Recline Angle Min	20°
Tibia Angle Max	43°
Tibia Angle Min	36°

2010 Toyota Yaris Rear Passenger



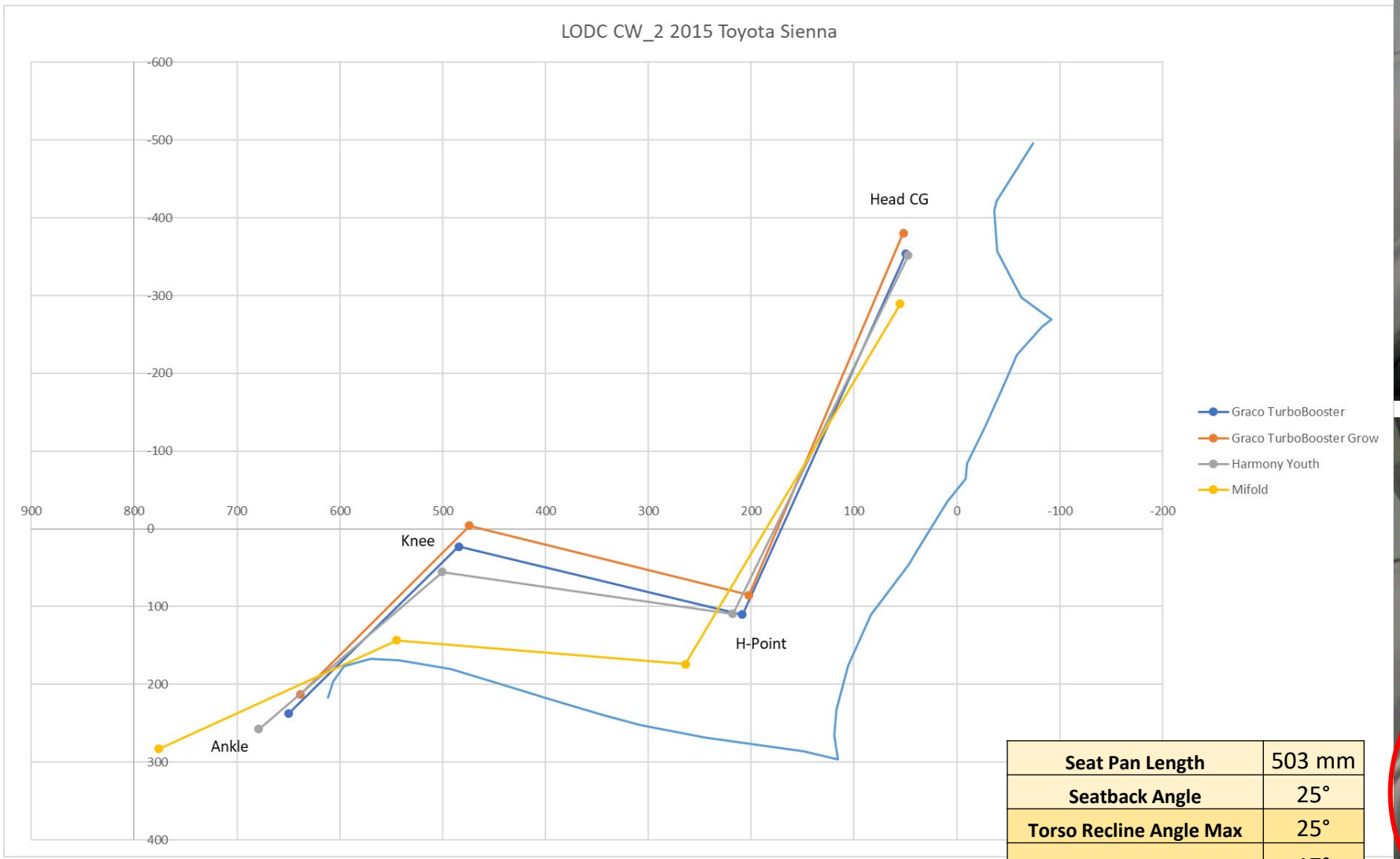
Seat Pan Length	468 mm
Seatback Angle	8°
Torso Recline Angle Max	24°
Torso Recline Angle Min	17°
Tibia Angle Max	27°
Tibia Angle Min	16°

2011 Cadillac CTS



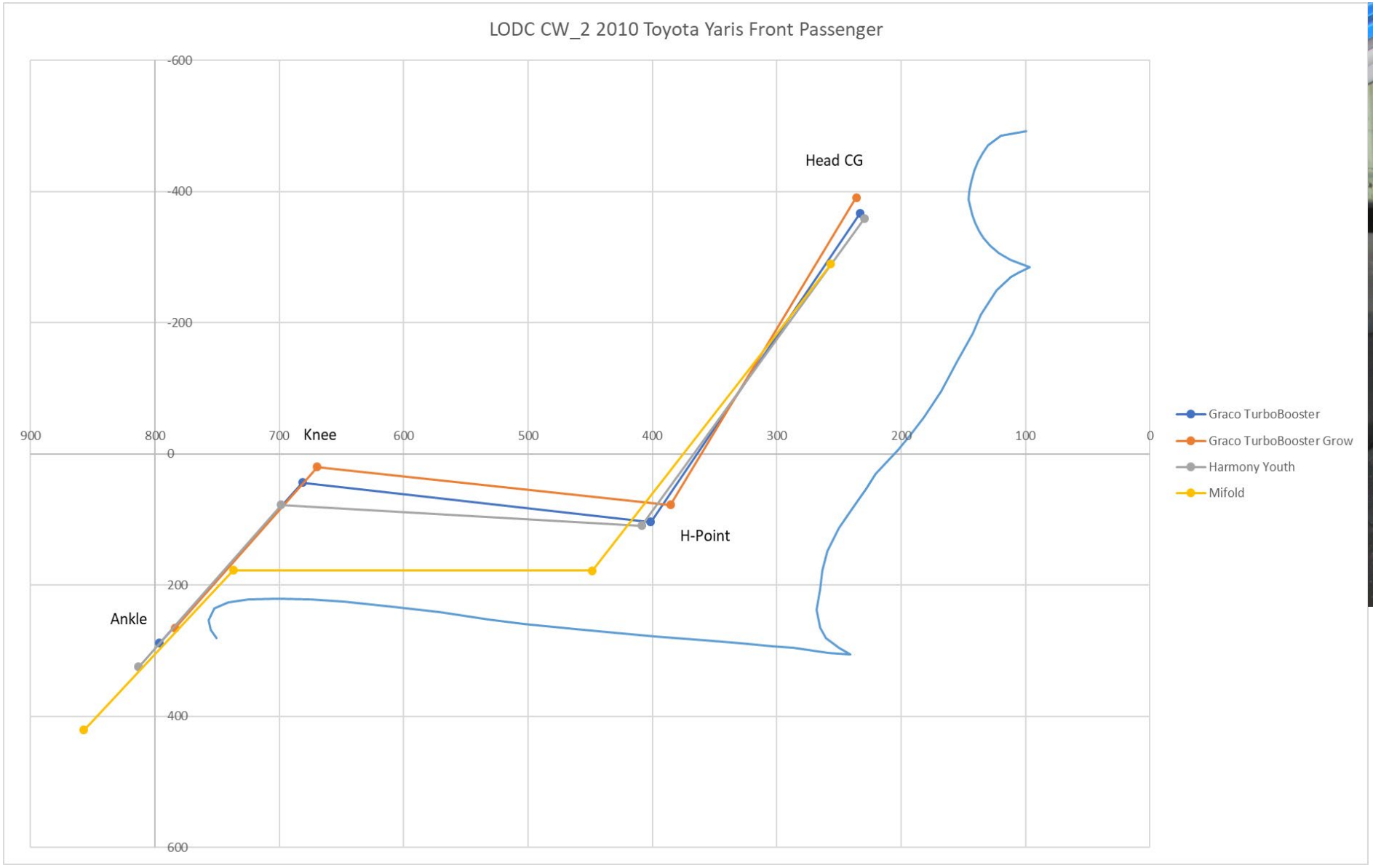
Seat Pan Length	487 mm
Seatback Angle	26°
Torso Recline Angle Max	23°
Torso Recline Angle Min	18°
Tibia Angle Max	36°
Tibia Angle Min	26°

2015 Toyota Sienna



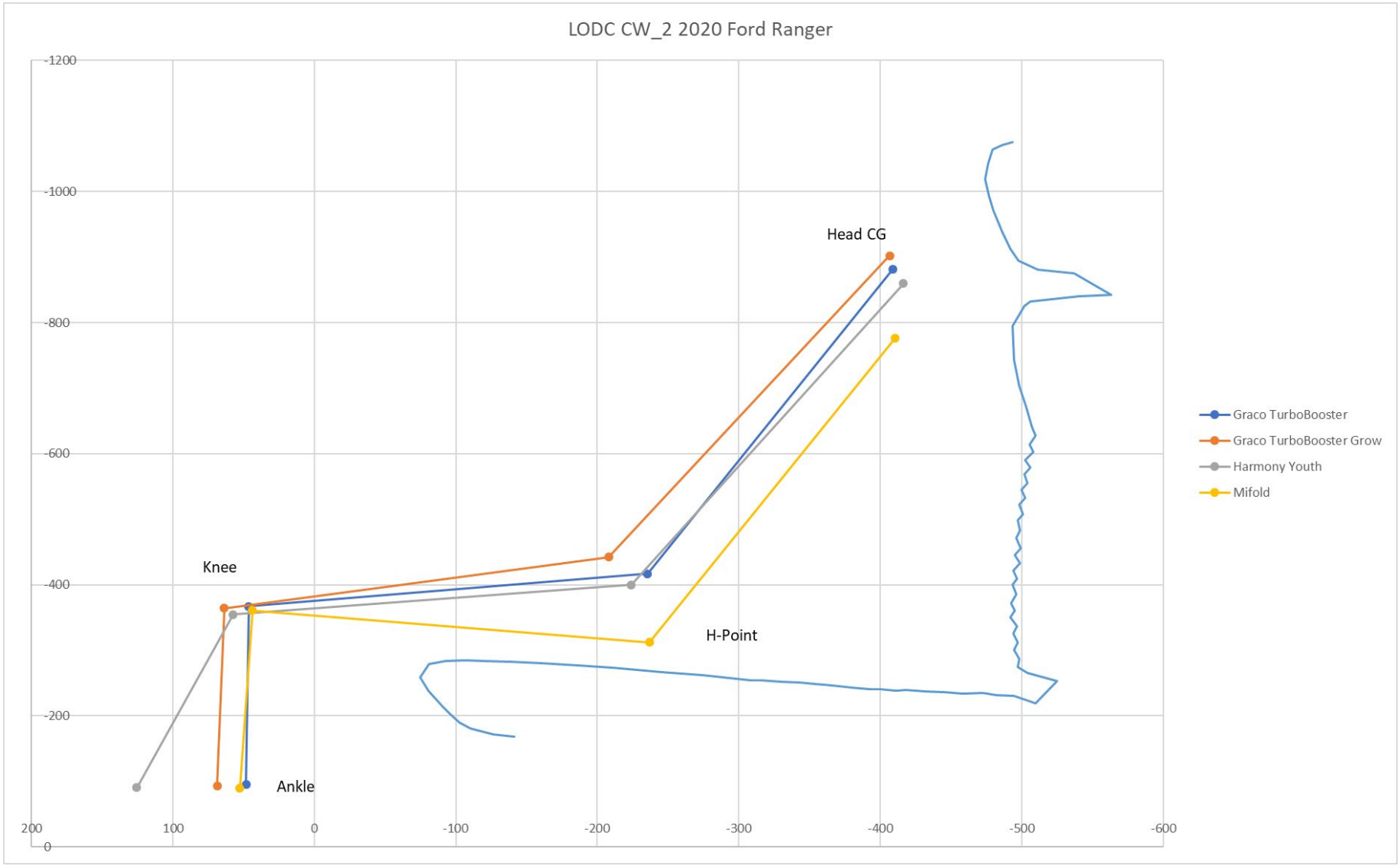
Seat Pan Length	503 mm
Seatback Angle	25°
Torso Recline Angle Max	25°
Torso Recline Angle Min	17°
Tibia Angle Max	63°
Tibia Angle Min	37°

2010 Toyota Yaris Front Passenger



Seat Pan Length	515 mm
Seatback Angle	19°
Torso Recline Angle Max	23°
Torso Recline Angle Min	17°
Tibia Angle Max	31°
Tibia Angle Min	23°

2020 Ford Ranger



Seat Pan Length	408 mm
Seatback Angle	0°
Torso Recline Angle Max	24°
Torso Recline Angle Min	19°
Tibia Angle Max	15°
Tibia Angle Min	-3°

Observations

- Generally, each seat was repeatable in each vehicle
  - Repeated up to 3 times with one technician; some seats had additional repeats with a different technician
  - The variety of variables in the different vehicle platforms and limited data set did not allow us to draw a conclusion about the effects of the seat lengths and angles
- The average torso recline angle was 21.8° with the test bench being 20° degrees
- The average tibia angle was 28° degrees, same as the proposed test bench
  - There were some seat combinations that allowed the legs to be more horizontal
    - Toyota Sienna and Hyundai Veloster

			Calculated Torso Angles (Calculated from Hip Point to Had CG)			
	Seat Pan Length (mm)	Seatback Angle (deg)	Max (deg)	Min (deg)	Stand. Dev.	Average (deg)
Proposed FMVSS 213 Bench	435	20	22	17	1	20
2014 Chevrolet Traverse	446	25	23	19	1	21
2020 Hyundai Veloster	460	25	24	20	1	22
2010 Toyota Yaris (Rear)	468	8	24	17	2	20
2011 Cadillac CTS	487	26	23	18	1	21
2015 Toyota Sienna	503	25	25	17	2	20
2010 Toyota Yaris (Front)	515	19	23	17	2	20
2020 Ford Ranger	408	0	24	19	1	22
	Average					21.8

			Calculated Tibia Angles (Calculated from Outer Knee center to Outboard Ankle)			
	Seat Pan Length (mm)	Seatback Angle (deg)	Max (deg)	Min (deg)	Stand. Dev.	Average (deg)
Proposed FMVSS 213 Bench	435	20	34	18	4	28
2014 Chevrolet Traverse	446	25	32	24	3	27
2020 Hyundai Veloster	460	25	43	36	2	39
2010 Toyota Yaris (Rear)	468	8	27	16	3	24
2011 Cadillac CTS	487	26	36	26	3	30
2015 Toyota Sienna	503	25	63	37	9	43
2010 Toyota Yaris (Front)	515	19	31	23	2	25
2020 Ford Ranger	408	0	15	-3	6	4
	Average					27.53

Observations Continued

2020 Ford Ranger

- This vehicle had a more upright seat back angle (0 degrees) and a shallow seat pan length (408 mm)
- The CW_2 seating procedure did not work as well in this configuration
  - By placing the pelvis at 35 degrees, it forced the dummy's pelvis to be far away from seatback and allowed the dummy's knees to be bent at 90 degrees with the feet touching the floor.
  - Further investigation is planned on how to handle upright seatbacks using the LODC and the CW_2 seating procedure

CW_2
Pelvis: 35°; Head:-4.0°

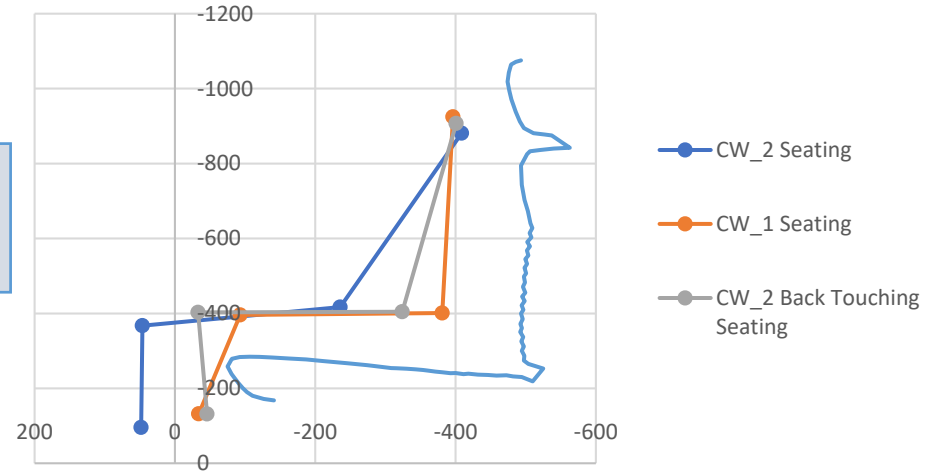
CW_1
Pelvis: 10.3°; Head:-1.8°

Back Aligned with SB
Pelvis: 27°; Head:-4.5°

2020 Ford Ranger Additional Seatings

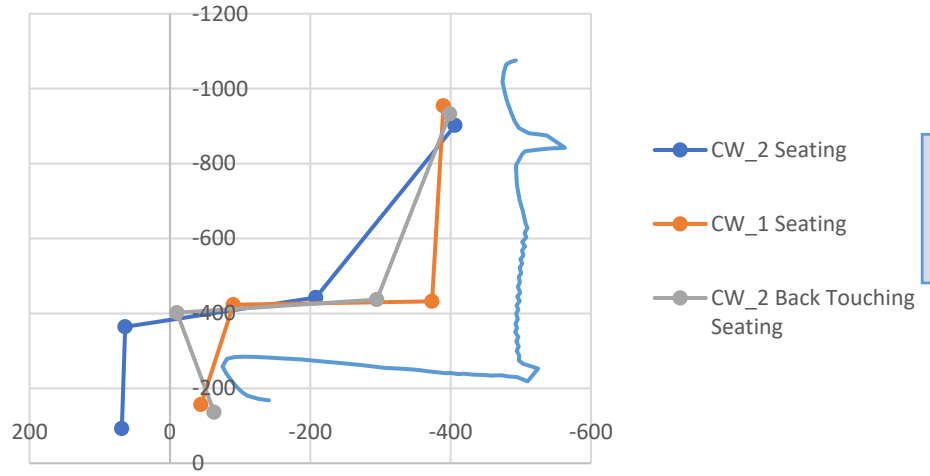
2020 Ford Ranger Graco TurboBooster

CW_2 Pelvic Angle: 34.4°
CW_1 Pelvic Angle: 12.6°
Back Touching Pelvic Angle: 24.2°



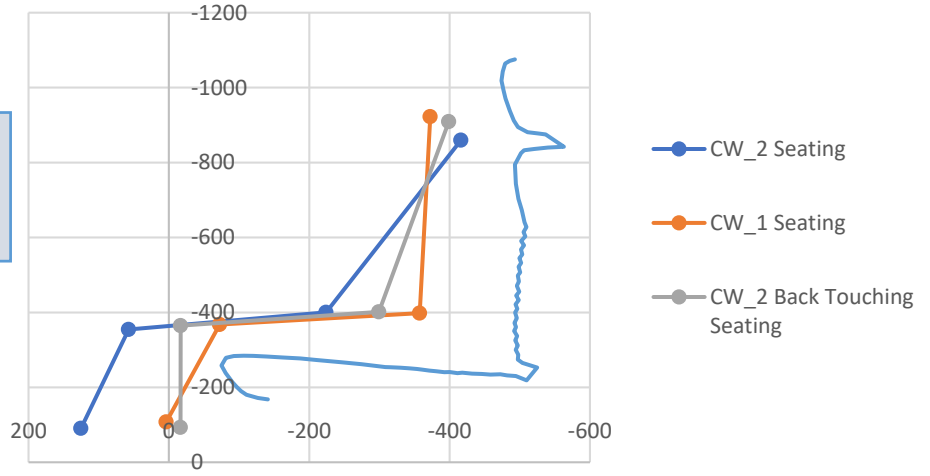
2020 Ford Ranger Graco TurboBooster Grow

CW_2 Pelvic Angle: 34.5°
CW_1 Pelvic Angle: 10.3°
Back Touching Pelvic Angle: 27.1°



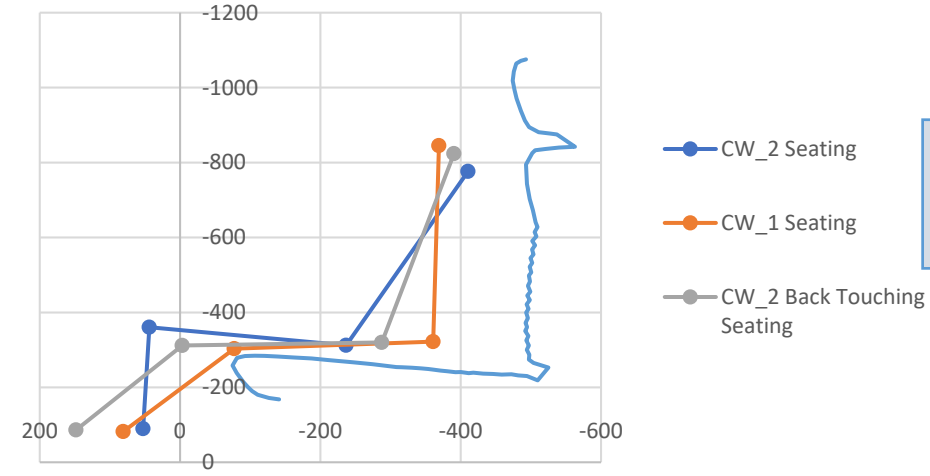
2020 Ford Ranger Harmony Youth

CW_2 Pelvic Angle: 35.1°
CW_1 Pelvic Angle: 9.0°
Back Touching Pelvic Angle: 20.8°



2020 Ford Ranger Mifold

CW_2 Pelvic Angle: 34.9°
CW_1 Pelvic Angle: 8.8°
Back Touching Pelvic Angle: 21.4°



Next Steps

- Conduct additional test evaluation without booster seats in similar rear seat environments.
  - Further development of the seating procedure to address the upright seat back angle, high tibia angles, and use without a booster
  - Can the CW_2 be used for the no booster environment?
  - Additional analysis to compare to the current Hybrid III 10YO dummy in the proposed FMVSS 213 test conditions
- Perform dynamic tests on proposed FMVSS No. 213 bench.
- Conduct additional dynamic crash research with the LODC in rear seat environment to assess kinematics of rear occupants.

Thanks for your attention

Any questions on the seating procedure

contact Allison Louden at

Allison.Louden@dot.gov 937-666-4511 ext 280

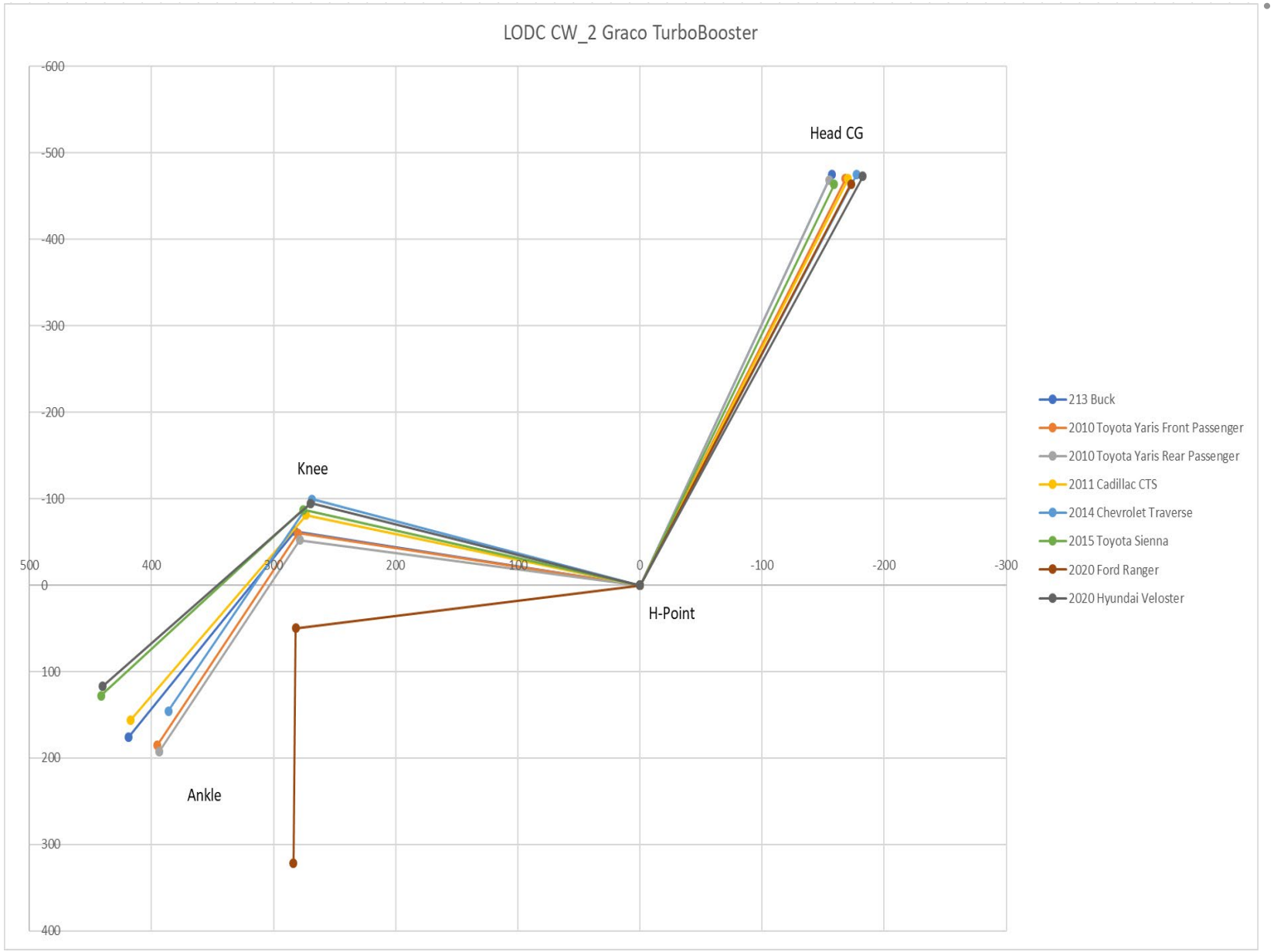
Any questions on the LODC updates

contact Jason Stammen at

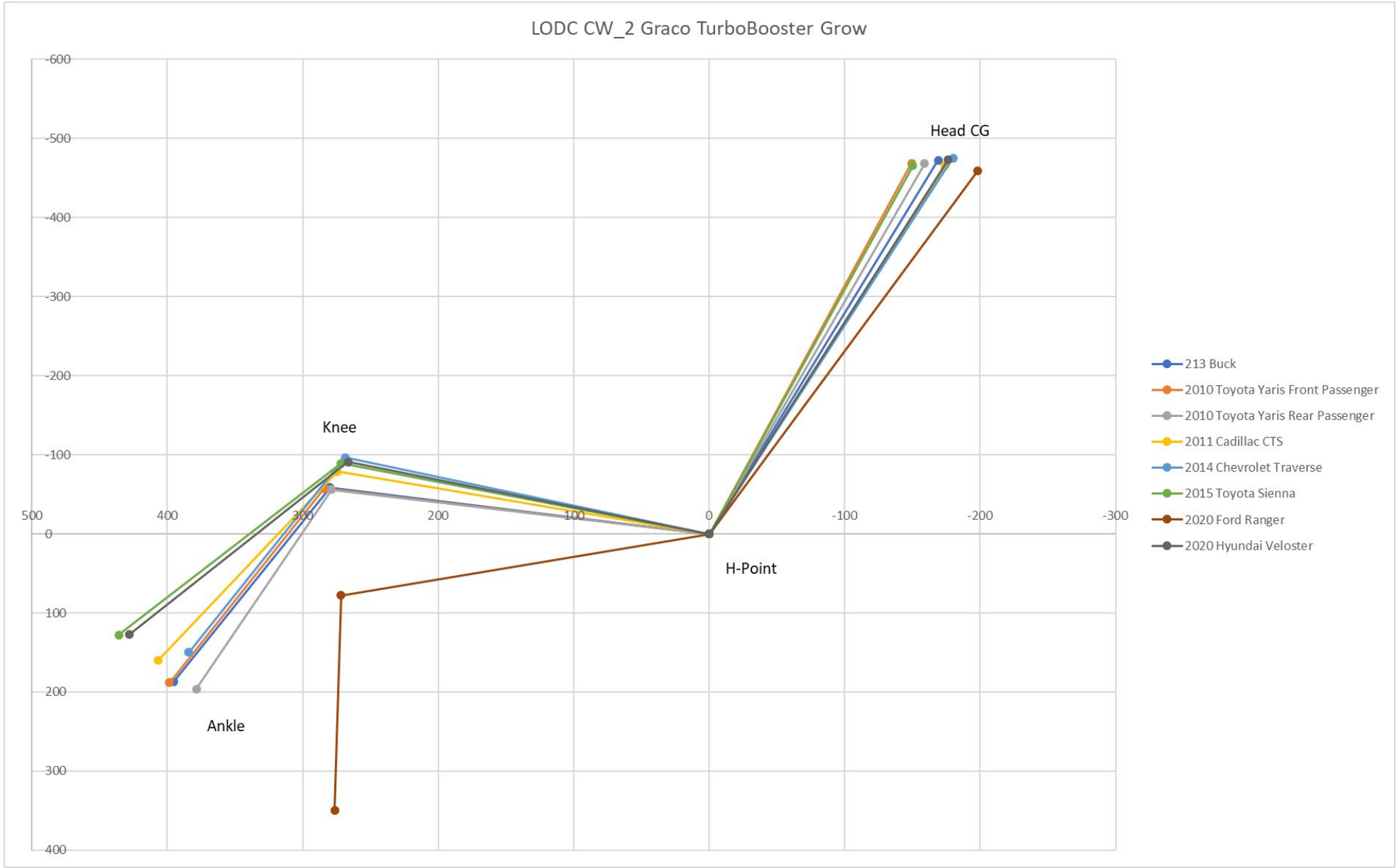
Jason.Stammen@dot.gov 937-666-4511 ext 219

Hip Pocket

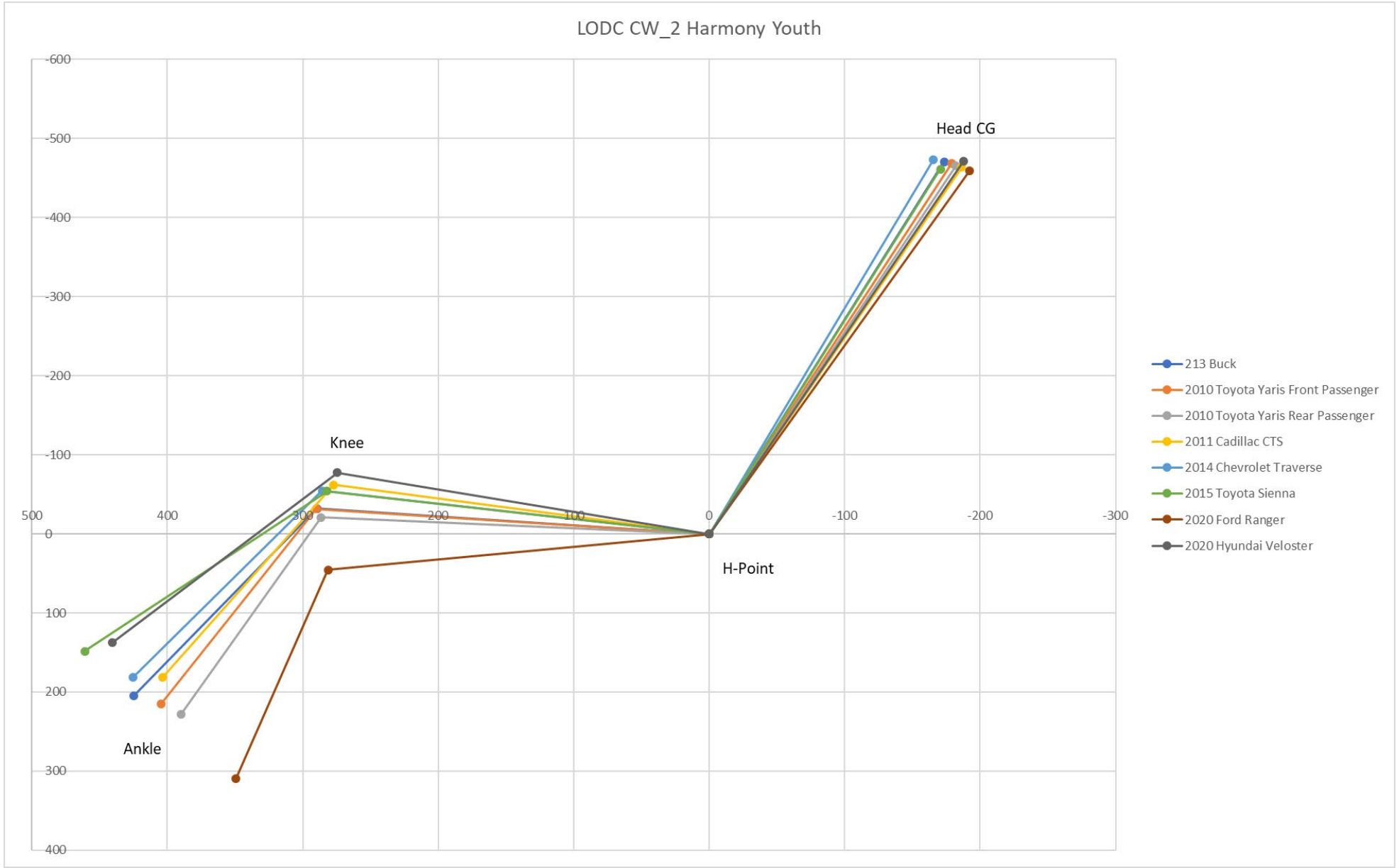
Graco TurboBooster



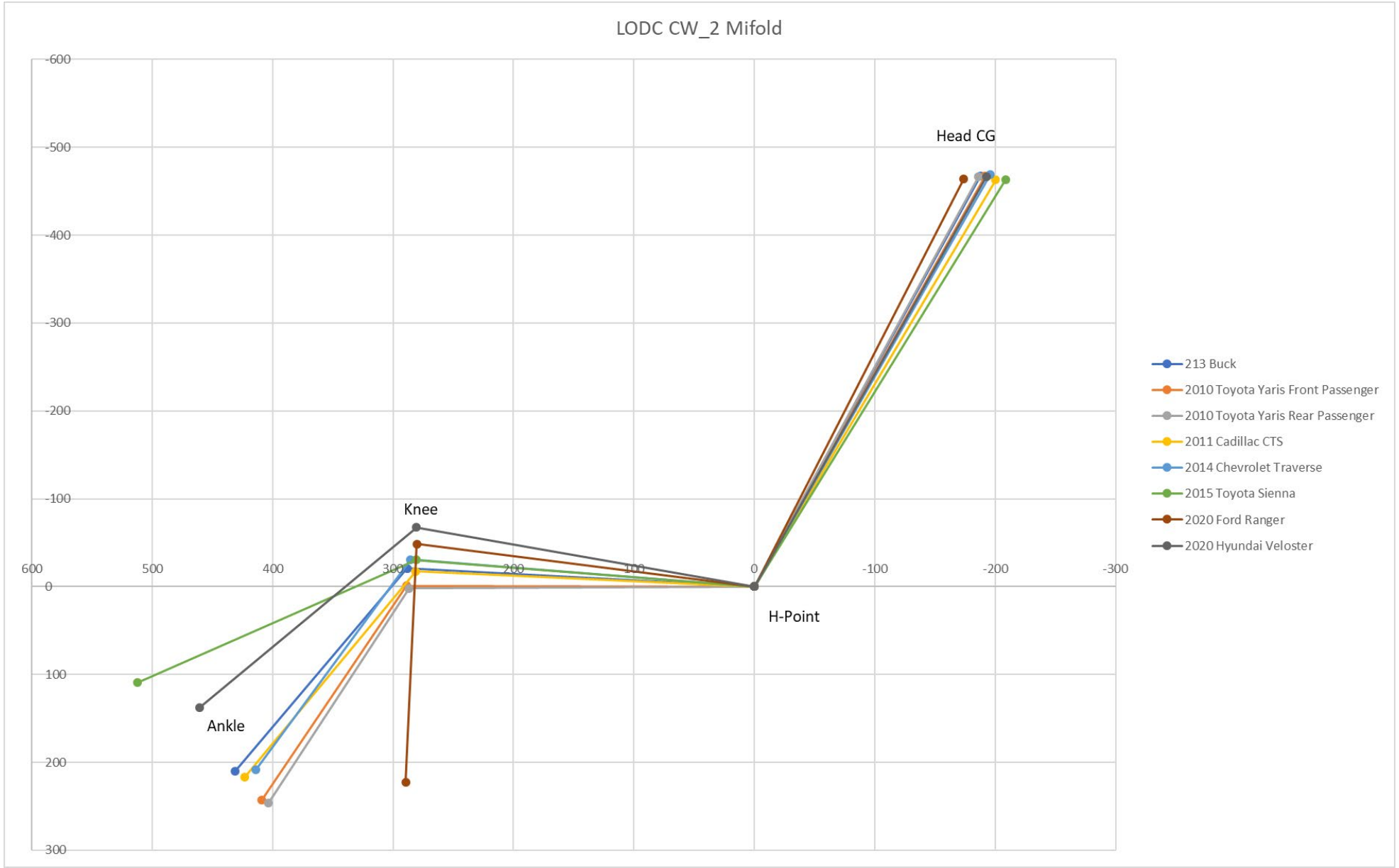
Graco TurboBooster Grow



Harmony Youth



Mifold


LODC CW_2 Mifold
-600
-500
-400
-300
-200
-100
0
100
200
300
600
500
400
300
200
100
0
-100
-200
-300
Head CG
Knee
H-Point
Ankle
213 Buck
2010 Toyota Yaris Front Passenger
2010 Toyota Yaris Rear Passenger
2011 Cadillac CTS
2014 Chevrolet Traverse
2015 Toyota Sienna
2020 Ford Ranger
2020 Hyundai Veloster