

# Spacesuit Sizing by Multivariate Simulation: Case Study for Liquid Cooling and Ventilation Garment

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# Spacesuit Liquid Cooling and Ventilation Garment (LCVG)

- Liquid Cooling and Ventilation Garment (LCVG) is a form-fitting under-garment worn inside of the spacesuit
- LCVG functions as a microclimate conditioning system to maintain the core body temperature during extra-vehicular activity (EVA)
- Chilled water is supplied from the portable life support system (PLSS), then circulated through 300-foot flexible tubes woven throughout the mesh
- LCVG also has ventilation ducts for nitrogen purge. Moist air also drawn through the ducts from the wearer's extremities to minimize dampness



# Background and Aims

## Background

- The next-generation government reference design spacesuit xEMU has been developed for microgravity and Lunar missions
- Re-design of the LCVG requires an improved sizing optimized for the current and future NASA crewmember population characteristics
- For example, previous NASA standards for the International Space Station defined the crew population by the 5<sup>th</sup> percentile female to 95<sup>th</sup> percentile male body measurements
- However, the new NASA standards enhanced the ranges to 1<sup>st</sup> percentile female to 99<sup>th</sup> percentile male body measurements to ensure 90% of the crew population can be accommodated

NASA STD 3001

Critical Dimension	Application Example	Minimal Clothing	
		Min (cm, (in))	Max (cm, (in))
Stature, Standing <sup>3</sup>	Maximum vertical clearance	148.6 (58.5)	194.6 (76.6)
Sitting Height <sup>2</sup>	Vertical seating clearance	77.7 (30.6)	101.3 (39.9)
Eye Height, Sitting <sup>2</sup>	Placement of panels to be within line-of-sight	66.5 (26.2)	88.9 (35.0)
Acromial Height, Sitting <sup>2</sup>	Top of seatback	49.5 (19.5)	68.1 (26.8)
Thigh Clearance, Sitting	Placement of objects that may be overlap (panels, control wheel, etc.)	13.0 (5.1)	20.1 (7.9)
Knee Height, Sitting	Height of panels in front of subject	45.5 (17.9)	63.5 (25.0)
Popliteal Height, Sitting	Height of seat pan	33.0 (13.0)	50.0 (19.7)
Wrist Height, Sitting (with arm to the side)	Downward reach of subject	39.6 (15.6)	54.6 (21.5)
Biacromial Breadth	Placement of restraint straps	32.3 (12.7)	44.5 (17.5)
Bideltoid Breadth	Width of seatback	37.8 (14.9)	56.1 (22.1)
Forearm-Forearm breadth	Side clearance envelope, possible seatback width	38.9 (15.3)	66.0 (26.0)
Hip Breadth, Sitting <sup>1</sup>	Width of seat pan	31.5 (12.4)	46.5 (18.3)
Buttock-Popliteal Length, Sitting	Length of seat pan	42.2 (16.6)	57.2 (22.5)
Buttock-Knee Length, Sitting	Placement of panels in front of subject	58.1 (22.9)	76.2 (30.0)

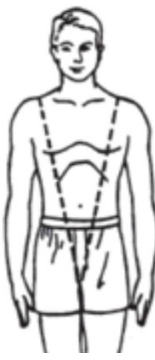
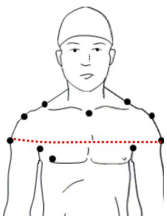

1<sup>st</sup> percentiles

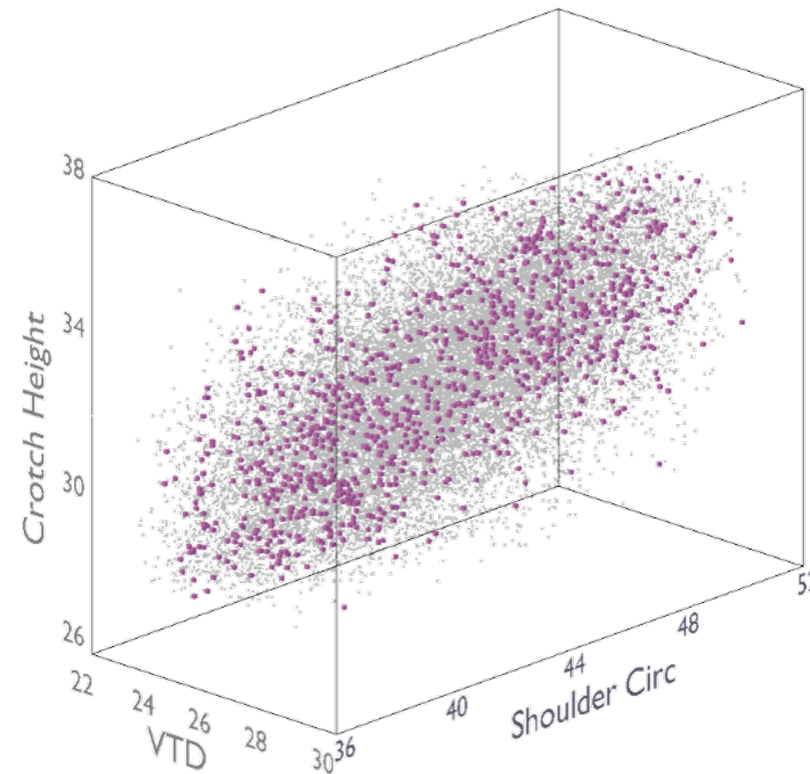
99<sup>th</sup> percentiles



# Crew Population Definition

- Vertical Trunk Diameter (VTD), Shoulder Circumference (ShC) and Crotch Height (CrH) were selected for critical body measurements for LCVG sizing for the crew population
- The US Army Anthropometric Survey (ANSUR 1988) was used for reference data.
- A dense pseudo-sample population was synthetically generated using a multivariate normal probability function
- Minimum (1<sup>st</sup> percentile female) and maximum (99<sup>th</sup> percentile male) measurements were used to truncate the samples

	Vertical Trunk Diameter	Shoulder Circ.	Crotch Height
Min	22.2"	35.6"	26.2"
Max	29.9"	52.7"	37.7"
			



■ ANSUR Original Data    ● Synthetic Pseudo-Data

# Fit Scoring Scheme

- A fit scoring scheme was built on the decades of suit fit check data and subject test records with NASA for Shuttle EMU suit
- The outcome served as data points highly correlated with fitting and sizing of crew population
- The new scheme was able to leverage the EMU scoring system, as the xEMU LCVG is similar in shape and fabric characteristics

Unit: Inches

Wearer VTD - LCVG VTD =	<-2	-2	-1	0	>0				
<b>X Score</b> =	0	4	8	10	0				
Wearer ShC - LCVG ShC =	<-2	-2	-1	0	1	2	3	>3	
<b>Y Score</b> =	0	4	8	10	8	6	4	0	
Wearer CrH - LCVG CrH =	<-2	-2	-1	0	1	2	3	4	>4
<b>Z Score</b> =	0	5	8	10	8	10	8	4	0

Total Fit Score = **X Score** + **Y Score** + **Z Score**

A total fit score 30: maximum score (10+10+10)

22-29: "good fit",

20-21: "acceptable fit"

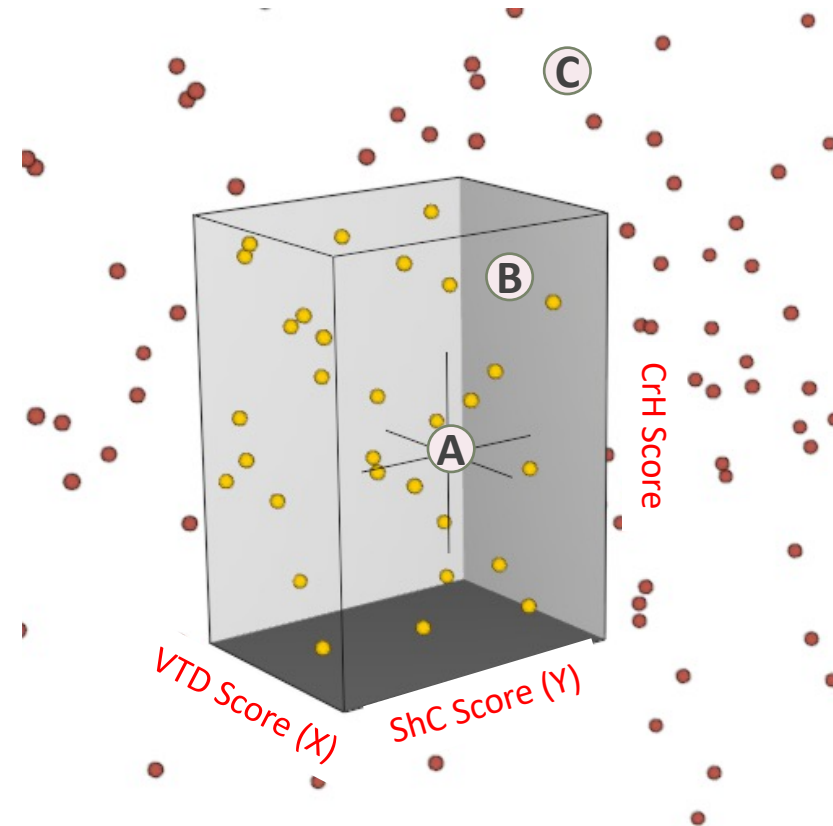
1-19: : "fit"

0: "non-fit"



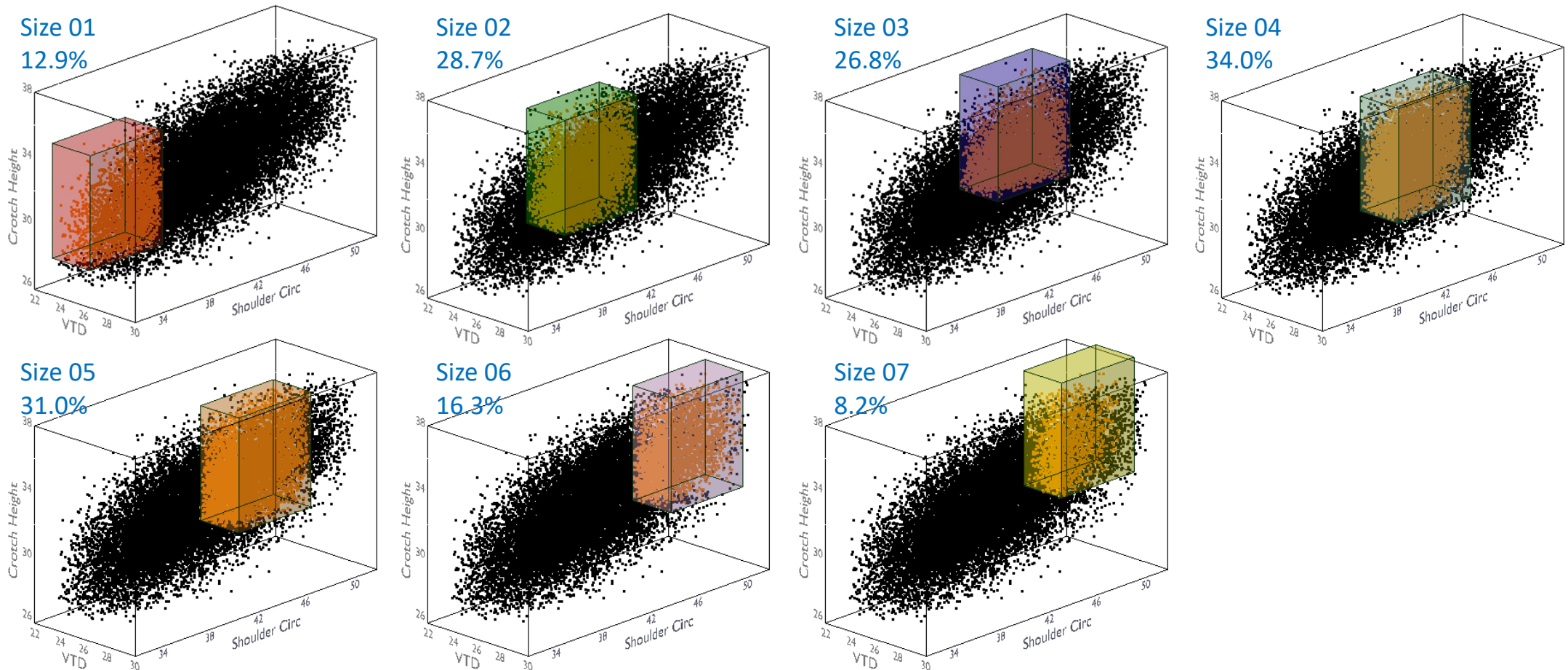
# Size Box Representation

- Dots represent persons of the crew population database
- Each dot's x-, y- and z-coordinates denote the person's VTD, ShC and CrH measurement
- Each LCVG size bucket (small, medium, etc.) was represented by a box.
  - The box origin (point **A**) represents the nominal measurements of the LCVG.
  - The nominal measurements were from the LCVG sizing chart. For example, size 04 (medium) corresponds to VTD 26.9", ShC 45.5" ShC and CrH 32.0" CrH.
  - If a dot (person) is located within the box, the corresponding fit score is  $\geq 0$ , meaning the person fits for the LCVG size
  - If a person coincides with the origin of the box (**A**), the person's fit score is 30 ("best fit")
  - As a person is located further away from the origin, the corresponding fit score decreases (**B**)
  - If a dot is located outside of the box (**C**), the fit score = 0, and the person does not fit
- Thus, each box needs to capture maximum number of dots (i.e., persons) are inside of it
- Further, more dots should be concentrated around the box origin ("best fit"), to maximize the overall fit scores



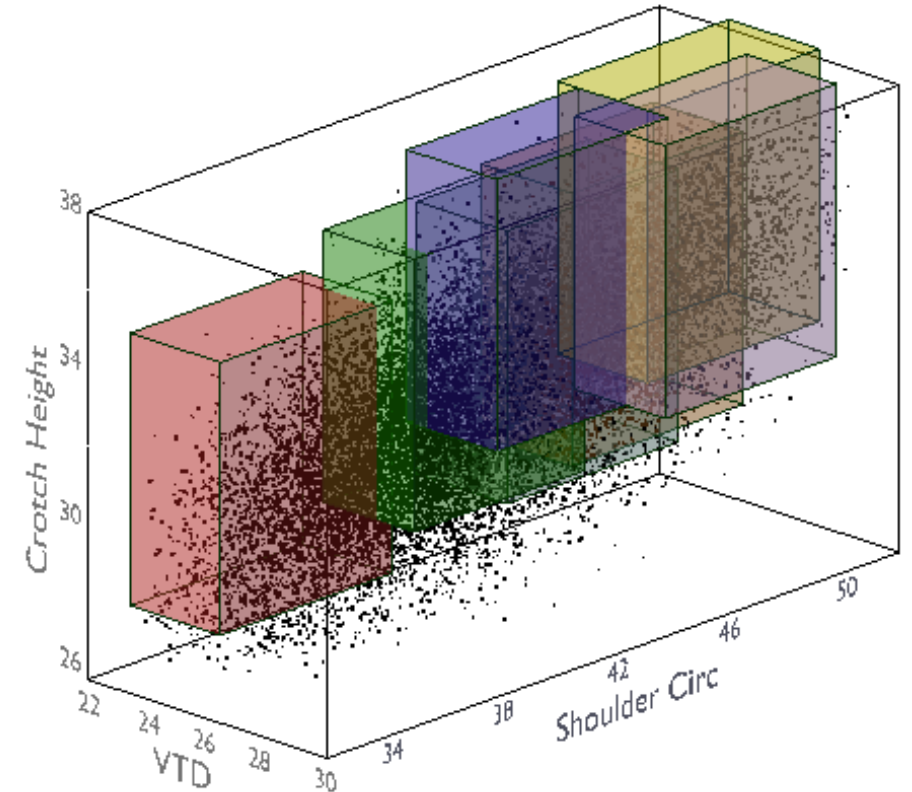
# Baseline Assessment

- The existing NASA LCVG for Shuttle EMU has 7 LCVG sizes, from X-Small Long (01) to XX-large long (07)
- Accommodation rate (proportion of the dots contained in boxes) is 81.3% (each box ranges between 8.2-34.0%)
- Average Fit score across all boxes: 20.0 (each box ranges between 21.2-23.9%)
- Proportion of “good fit” cases (proportion of cases with fit score  $\geq 22$ ): 68.5%



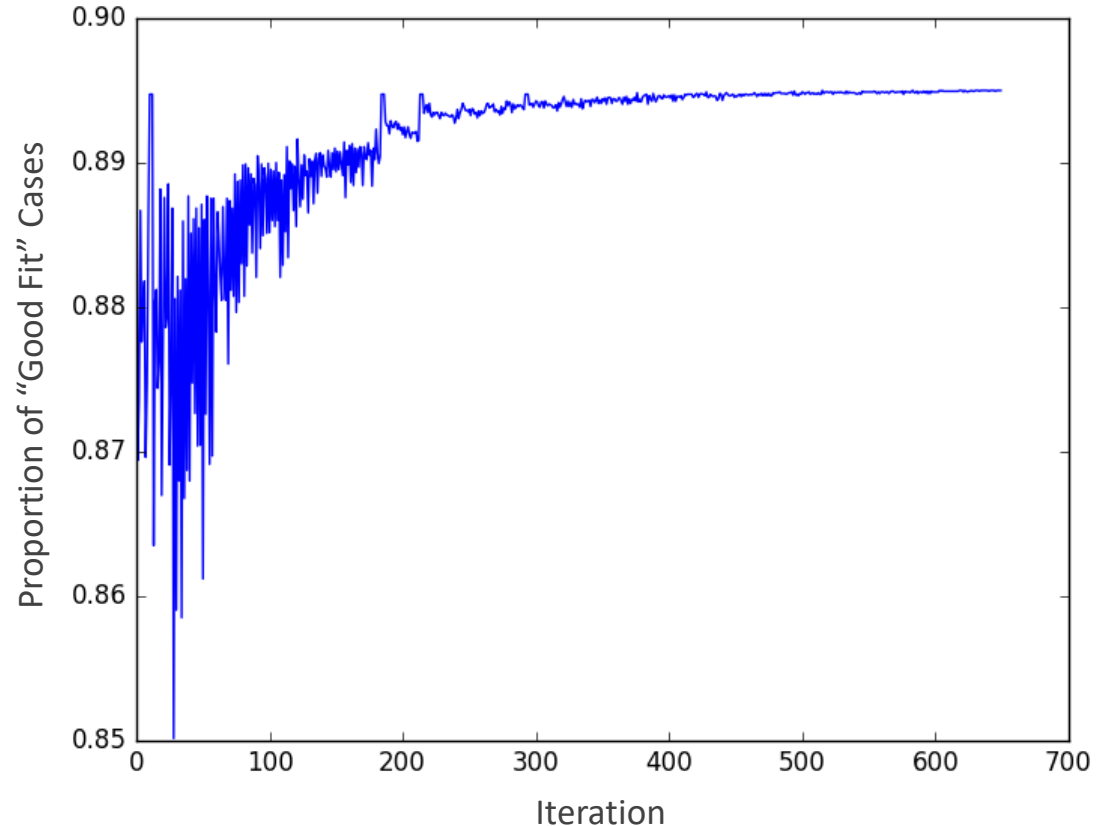
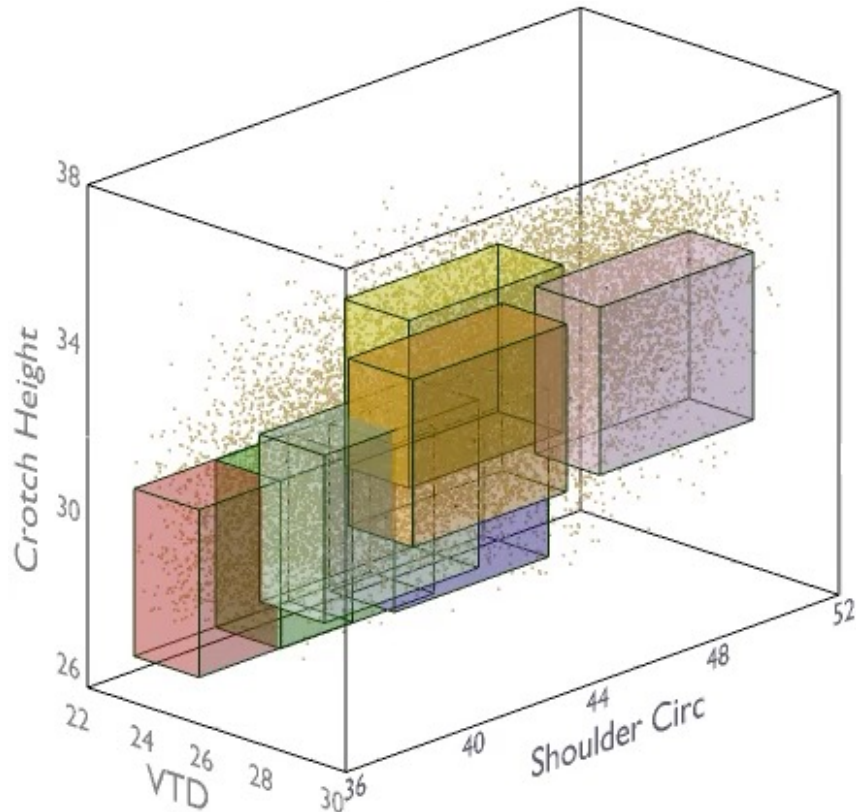
# Limitations of the Baseline Assessment

- Coverage rates (min-to-max) was 0.7 to 98.9<sup>th</sup> percentile for VTD and 1.3 to 99.4<sup>th</sup> percentile for ShC, thus meet the new NASA requirements for 1st to 99<sup>th</sup> percentile measurement accommodation
- However, CrH coverage range was 3.5 to 99.7<sup>th</sup> percentile, thus did not meet the new NASA requirements
- Some sizes accommodate substantially more people than others (e.g., Size 07: 8.2%, Size 04: 34%), and many sizing boxes overlap with each other
- Good fit cases (score  $\geq 22$ ) are 68.5%, thus needing improvement to raise the overall fit scores



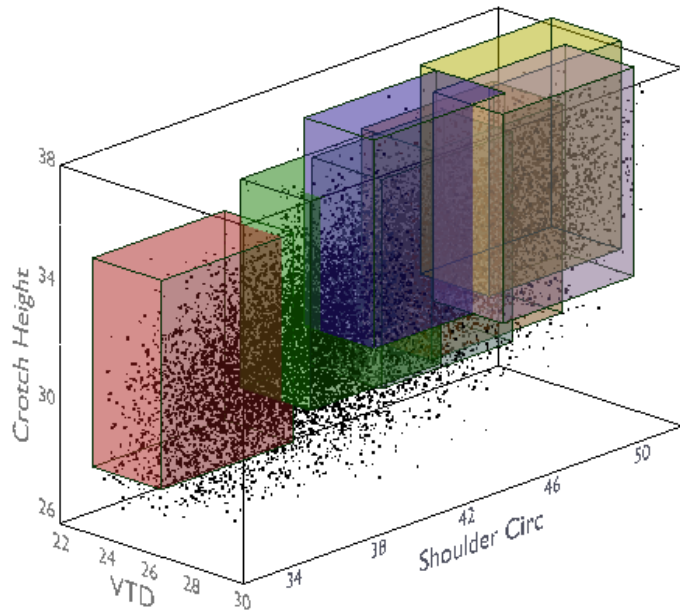
# Sizing Scheme Adjustment and Optimization

- In the new sizing scheme, the box positions of the existing sizes were iteratively adjusted using an optimization algorithm
- The objective function was to maximize the proportion of “good fit” cases (fit score  $\geq 22$ )
- The optimization algorithm converged to a solution and the proportion of good fit cases asymptotically increased with iterations
- After optimization, the accommodation rate increased from 81.3 to 92.2%
- The good fit case proportion also increased from 68.5 to 82.7%

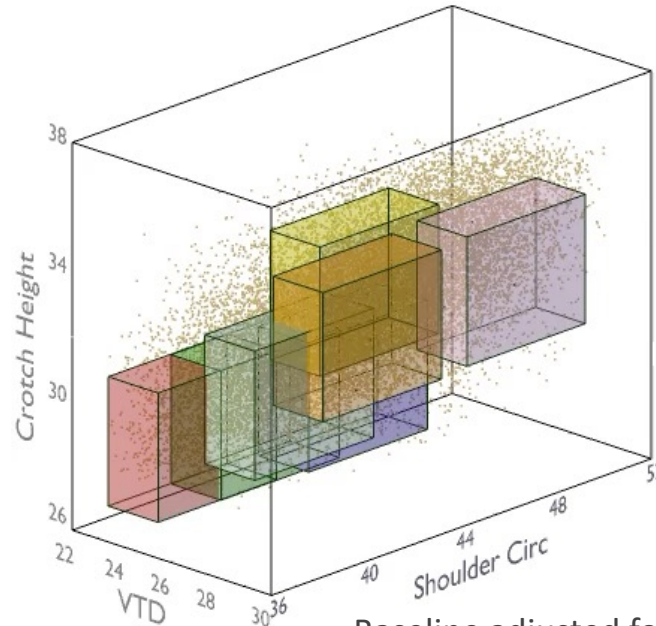


# Other Permutated Sizing Schemes

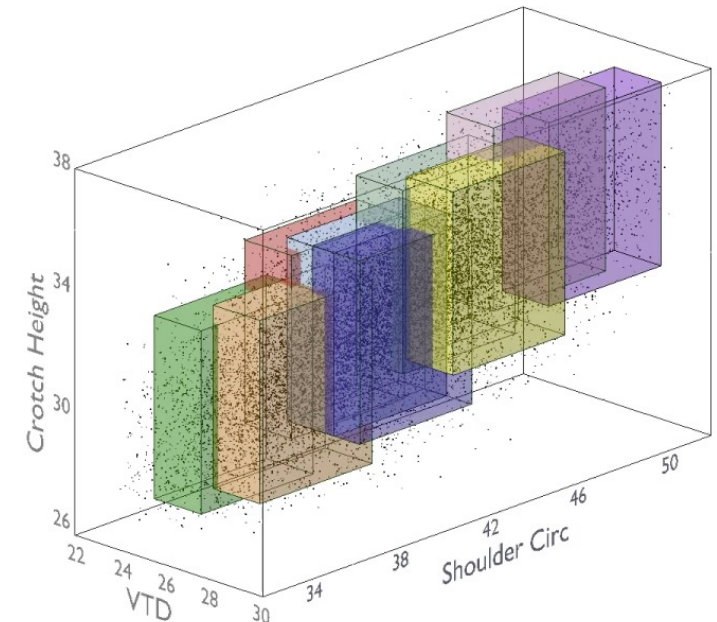
- More sizing schemes were built and tested; Accommodation performances were compared
- Across different sizing schemes, coverage range did not vary substantially, except for CrH in the baseline scheme
- However, accommodation rate and good fit proportion showed substantial improvements with new sizing schemes



Baseline Sizing Scheme



Baseline adjusted for maximum fit score



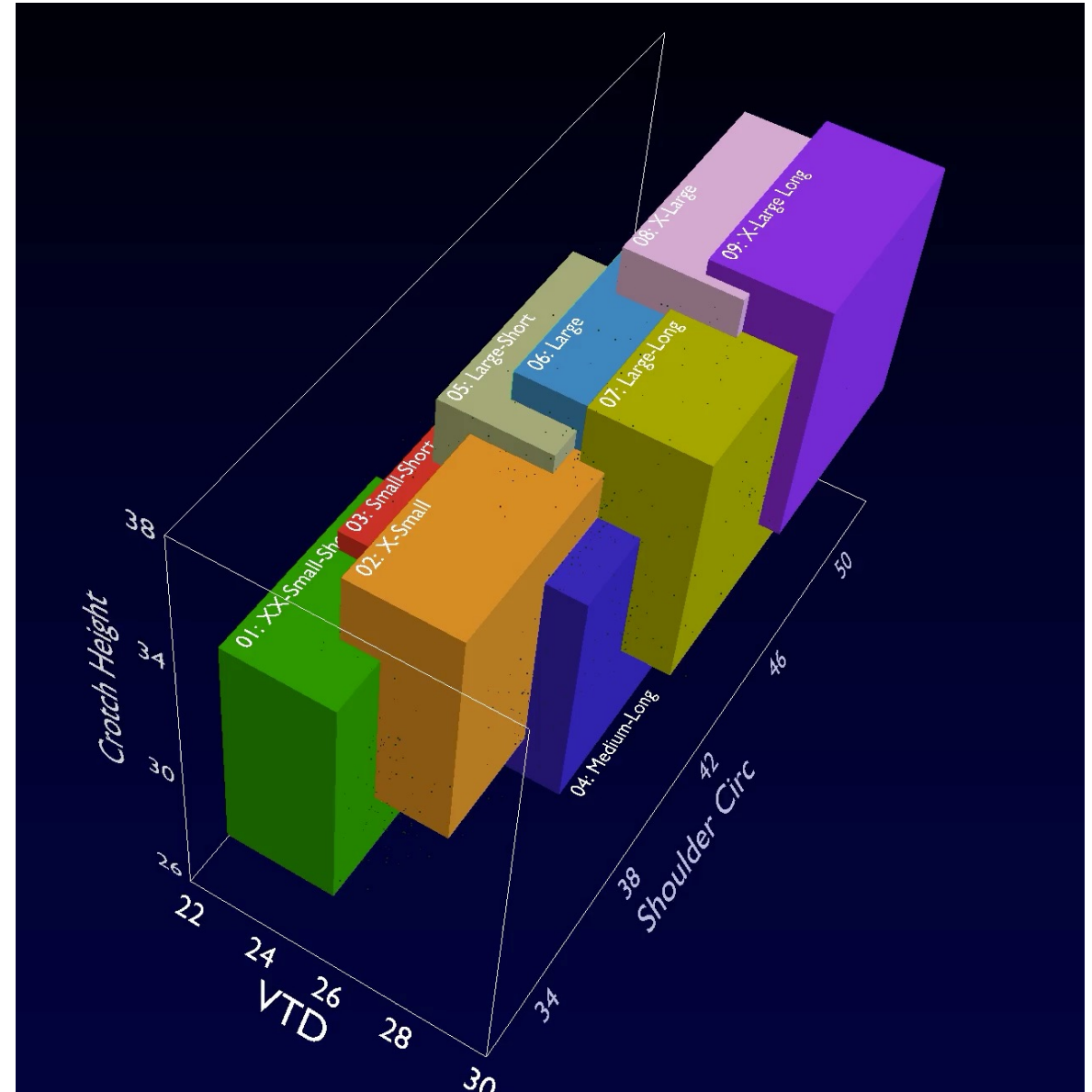
+2 Size Buckets

Accommodation Rate		81.3%	92.2%	<b>96.9%</b>
Good Fit Proportion		68.5%	82.7%	<b>89.6%</b>
Coverage	VTD	0.7 - 98.9	1.3 - 99.1	0.7 - 99.1
Range	Shoulder Circ	1.3 - 99.4	1.6 - 98.6	1.3 - 99.0
Percentiles	Crotch Height	3.5 - 99.7	0.9 - 99.4	0.9 - 99.6

# Selected Sizing Scheme

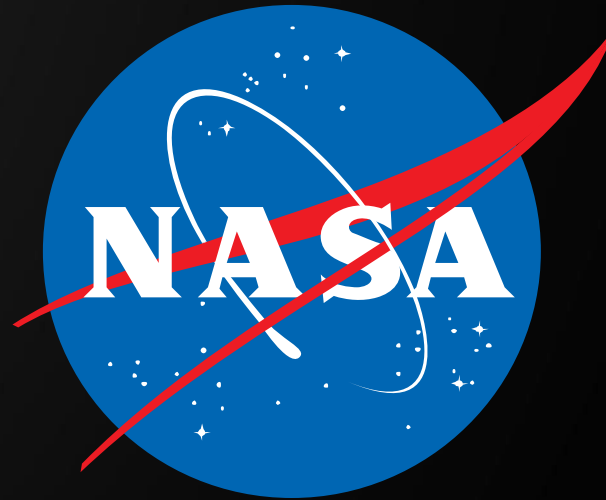
- Composed of 9 size groups
- 96.9% of crew population is expected to be accommodated
- 89.6% of crew population is expected to show “good fit” (fit score  $\geq 22$ )
- Given these metric values equal to or exceeded the 90% crew accommodation target, this 9-size system was ultimately selected by NASA for the next generation government reference design spacesuit.

	Accommodation Rate	Average Fit Score
01 XX-Small-Short	13.5%	23.5
02 X-Small	26.8%	21.7
03 Small-Short	23.9%	24.0
04 Medium-Long	34.7%	21.3
05 Large-Short	22.8%	24.2
06 Large	34.0%	23.4
07 Large-Long	26.8%	21.3
08 X-Large	14.7%	23.4
09 X-Large-Long	13.8%	21.8



# Conclusion

- LCVG sizing schemes were evaluated and improved using optimization algorithms on crew-like population distribution
- The accommodation rate and good fit case proportions improved substantially with new sizing scheme, compared to the baseline
  - In other words, although the number of size buckets was the same, adjusting the sizing box position alone (i.e., targeted body dimensions) can improve fit performance.
  - With two size buckets additionally included, the fit performance further improved, with the accommodation rate 96.9% and good fit proportion 89.6%.
- However, the coverage ranges did not change significantly across the difference scenarios, all dimensions remaining approximately at 1st to 99th percentile ranges, except for the CrH lower bound.
  - Thus, coverage ranges alone may not provide accurate information for fit performance, can be even misleading, as it is only related to the extreme ends of the sizing buckets.
- The fit scoring scheme was built based on the historical data from decades-long operation experience of NASA, which is expected to reasonably match with the actual fit experience of crewmembers.
  - However, the current technique may not work well if sufficient historical fit data are lacking. In this case, human subject testing is critical for fit assessments.



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