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The Anthropometric Model Generator (AMG) Tool: Accurate 3D Body Shapes for Custom Digital Human Modeling Applications

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Introduction

Creation of realistic digital 3D human body models has many potential applications in anthropometrics, aircrew accommodation, and ergonomics. The Anthropometric Survey of US Army Personnel (ANSUR II) dataset is a widely utilized resource comprising 76 detailed anthropometric measurements and 3D body scans of each individual [1]. CFD Research has developed the Anthropometric Model Generator (AMG) tool to generate digital 3D human shapes for use in various digital human modeling applications [2].

Methods

The 3D human body shapes are generated by summing principal component (PC) vectors computed from the ANSUR II database of scans. Each PC corresponds to a deviation of the 3D shape from the mean. Thus, an individual body shape can be created by taking the mean male or female body shape and adding a weighted sum of the PCs. After constructing a 3D body shape and updating the landmark locations for the new surface, anthropometric features can be computed based on the landmarks.

Results and Discussion

Accuracy of the 3D body shape predictions from the AMG tool was tested on 150 females. Gold standard measurements were taken by a professional tailor. Accuracy of anthropometric measurements were compared between the AMG tool and commercial 3D body scanners. The AMG measurements had the highest accuracy, with 77% of measurements having less than one inch error relative to the tailor measurements. The next closest system had only 21% of measurements with less than one inch error. The AMG tool is a reusable software library that can be incorporated into custom applications. Existing integrations include scaling of musculoskeletal models in OpenSim [3], proportional scaling of internal anatomy [4], and re-posturing of the 3D body shape using computer animation techniques [5].

Acknowledgments

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Integrating 3D Anthropometric Variability into Parametric Personalization Pipelines for Facial Interface Accommodation

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Introduction

Effective accommodation of facial interface devices, such as respirators, oxygen masks, and other facial sealing systems, remains a critical fit challenge to ensure user safety, performance, and comfort. Traditional approaches based on linear percentiles and isolated craniofacial dimensions are insufficient to capture the complexity of facial morphology, limiting the ability to anticipate contact patterns, pressure concentrations, and potential leakage risk.

Methods

This work presents a three-dimensional anthropometry-based personalization framework that integrates 3D scanning, parametric modeling, and digital contact evaluation to optimize the fit of tight-fitting facial interface devices. Using craniofacial scans from participants, a parametric environment was developed to translate key geometric features and anatomical landmarks into adjustable design parameters. The framework enables the generation of multiple individualized interface configurations and the systematic evaluation of fit performance through digital contact simulations, which are subsequently contrasted with controlled physical measurements under compression conditions. The method is grounded in 3D craniofacial scans from 3 participants, from which multiple personalized interface geometries were generated for each participant. Digital fit was quantified using surface correspondence analyses between the interface and facial geometry, and proximity and contact distribution metrics were applied to estimate regions of compression, separation, and potential leakage risk. Physical silicone prototypes were then fabricated and evaluated using a standardized hydraulic compression system against replicated facial molds, enabling measurement of pressure distribution, deformation behavior, and sealing characteristics under controlled loading.

Results

A systematic comparison between digital and physical outcomes enabled assessment of the predictive capacity of the computational model and the establishment of relationships among parametric logic, contact patterns, and personalization system performance. This approach enables exploration of accommodation limits, identification of critical mismatch regions, and mapping of morphological variability patterns, positioning personalization as a structured strategy to address shape variability in tight-fitting facial devices.

Discussion

Although the case study was developed in the context of pediatric medical interfaces, the methodological framework is directly transferable to broader applications, including respirators, personal protective equipment, and other facial sealing systems in operational environments. The work proposes a replicable model for integrating 3D anthropometric variability into parametric design processes, supporting the transition from percentile-based approaches toward shape- and contact-performance-based accommodation systems.

Enhancing PassFit Anthropometric Outputs with User-Defined Dimensions

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Introduction

PassFit™ is a portable 3D anthropometry system developed at the University of Michigan and refined in close collaboration with U.S. Army, Air Force, Navy, and others. PassFit estimates body dimensions from depth images of clothed subjects by fitting a statistical body shape model. The current DoD version of PassFit predicts 136 body dimensions using machine-learning models trained on MCANSUR, so system outputs follow ANSUR definitions and protocols. However, some users need dimensions measured using different procedures. For example, waist and chest circumference measurement methods often differ between measurers and sites.

Methods

To address this need, we have developed a calibration workflow that learns a secondary model using paired data: (1) PassFit-estimated variables (including avatar shape scores and predicted dimensions) and (2) user-collected target data such as manual measurements. We compared various learning models, including linear regression with automatic feature selection (sequential forward selection, SFS), generalized additive models (GAM), XGBoost, and random forest. We also implemented an automated module that selects the best model based on user-entered data and deploys it in the PassFit pipeline. Data from 240 participants collected in previous UMTRI studies of anthropometry and clothing fit were used to evaluate the method. Prediction accuracy improvements with user-specific calibration were evaluated for sitting height, acromial height, chest circumference, eye height, knee height, waist circumference, and buttock-knee length.

Results

Across target measures, SFS-based linear models and XGBoost most often achieved the best performance. Compared with the baseline outputs from the latest PassFit version, the mean absolute discrepancies between the target manual measurements were reduced by up to 69% for chest circumference, 46% for waist circumference, and 43% for knee height for male subjects. For female subjects, improvements were also observed, including 43% for waist circumference and 21% for sitting height.

Discussion

This automated algorithm enhancement method is not only an accuracy improvement step, but also a practical way to customize PassFit to a user's measurement protocol. Through pilot data collection, the system automatically learns a calibration model that maps PassFit outputs to these user-defined targets. This enables user customization, site-specific deployment, even adding entirely new dimensions, without the need for software development. Preliminary investigations show good results for extensions to body composition and clothing ease estimation, among other applications.

This presentation covers two abstracts, which are both presented here:

3D Hand Shape Characterization for Improved Glove Design: A Shape Descriptor Approach Using Anatomical Landmarks

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Introduction

Traditional hand anthropometry relies on isolated linear measurements that fail to capture the complex three-dimensional geometry of the human hand. This limitation has significant consequences for the design of hand-worn products, particularly protective work gloves used in high-performance environments such as firefighting and spaceflight. We present a novel shape analysis framework applied to a large 3D hand scan database (n > 800) that characterizes hand morphology through computationally derived shape descriptors.

Methods

Rather than treating measurements as isolated values, our approach extracts continuous geometric features, including curvature, arc length, angular spread, and webspace depth, from highly accurate 3D anatomical landmarks along the fingertip arc, web arc, and wrist anchor point. Cubic B-splines are fit through landmark sets to generate smooth curve representations, which are then uniformly resampled to enable consistent cross-participant comparison. The resulting shape descriptors parallel those used in computer vision, where curves, slopes, and curvature are inferred from pixel data, but our method leverages the superior accuracy of anatomical landmarking in three dimensions.

Results & Discussion

As a case study demonstrating the practical value of this framework, we conducted a comparative shape analysis between human hands in the database and the interior and exterior geometries of five firefighter glove models. Skeletal overlay visualizations revealed substantial discrepancies in webspace shape, palm length, and finger length between gloves and hands, with gloves consistently exhibiting shorter palm regions and misaligned finger proportions. These findings highlight how current glove designs inadequately accommodate actual hand shape variation, contributing to reduced dexterity, discomfort, and compromised protection. This shape descriptor framework offers a scalable, data-driven tool for evaluating and improving the fit of gloves and other hand-worn products, with direct applications to occupational safety and equipment design.

Data-Driven Development of a Female Glove Sizing System: A Multi-Database Anthropometric Analysis

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Introduction

For women, properly fitting gloves are essential for hand protection, dexterity, and comfort, yet most glove sizing systems have been historically developed using male hand anthropometric data. The objective of this study was to develop and evaluate an evidence-based glove sizing system for women using validated anthropometric datasets.

Methods

The datasets examined included the University of Minnesota (UMN) Human Dimensioning Laboratory (HDL) 3D hand scan database, the U.S. Army ANSUR II anthropometric survey (2012), the National Institute for Occupational Safety and Health (NIOSH) firefighter hand anthropometric study (2015), and the UK Chief and Assistant Chief Fire Officers Association (CACFOA) firefighter survey (2002). Female participants aged 18–45 were isolated across datasets to ensure comparable demographic profiles. Hand length and hand breadth were used as primary variables, from which summary statistics and percentiles were calculated.

Results

Statistical comparison of hand length and hand breadth revealed strong alignment among three of the four databases. The UMN HDL, U.S. Army ANSUR II, and UK CACFOA datasets demonstrated similar distributions, with mean hand lengths converging near 181 mm and consistent breadth-to-length relationships. The NIOSH hand dataset, however, showed significantly shorter mean hand length measurements (166.2 mm) with disproportionately wider breadths (85.8 mm). This discrepancy is likely attributed to methodological limitations associate with photocopier-based measurement approach used in the NIOSH Study, which may have introduced systematic dimensional distortion. Consequently, NIOSH data was excluded from the final sizing analysis.

Discussion

Using the combined HDL and ANSUR II datasets (n=2,067+), two sizing systems were developed and evaluated. A four-size system (XS through L) achieved 90.95% population accommodation, while a five-size system (XS through XL) reached 95.5% accommodation. Both systems were centered on the population mean, with the medium size aligned to the 50th percentile. These findings provide a data-driven foundation for improving female glove fit through updated pattern measurements grounded in validated anthropometric data.

Mobile 4D Body Scanning & Dynamic Anthropometry for Large-Scale Campaigns

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Introduction

Large-scale anthropometric campaigns increasingly require deployable acquisition systems and reproducible processing workflows across geographically distributed sites. While 3D and 4D body scanning technologies have matured, most available solutions remain limited to extracting predefined static measurements. This constrains the definition of application-specific metrics and limits the integration of dynamic behaviour into anthropometric analysis.

This paper presents an integrated mobile 4D acquisition and processing workflow structured around three pillars: 1) Deployability, enabled by a portable 4D body scanning configuration; 2) Configurability, achieved through template based dynamic metric definition that can be stored, reused, and applied in batch on homologous meshes—supporting not only anthropometric measures but also configurable descriptors relevant to biomechanics (e.g., contours, sections, projections, and composed metrics); and 3) Functional anthropometry, enabled by behaviour-informed measurements that quantify the body under movement conditions. Together, these capabilities support scalable data collection and consistent metric extraction across both reference postures and motion sequences.

Methods

The Mobile 4D configuration is a reduced-footprint body scanning setup designed for deployment in geographically distributed campaigns. It captures full-body surface geometry in motion, and the processing pipeline automatically generates textured, watertight, rigged meshes with consistent vertex correspondence across frames and subjects. All processing steps—from raw capture to mesh generation and measurement extraction—are fully automated and do not require manual landmarking or user-dependent intervention.

The meshes share a homologous topology and rig structure, ensuring anatomical point-to-point correspondence intrasubject (throughout motion sequences) and inter-subject (across individuals). This enables longitudinal tracking of anthropometric and biomechanical features during movement and ensures measurements remain anatomically comparable across time and population samples.

To support configurability, a template-based measurement framework is implemented directly on the homologous mesh representation[1]. Users can define custom digital anatomical landmarks and construct geometric descriptors including point-to-point distances, axis projections, sectional perimeters derived from cutting planes, surface-based contours, and composed metrics. Definitions can be stored as reusable templates and applied in batch mode to static reference postures or complete motion sequences.

Results

Mobile 4D body capture system was deployed and integrated into the acquisition and processing pipeline, producing 3D meshes with consistent vertex correspondence across dynamic conditions. The configurable module enabled the definition and automated extraction of both standard and application-specific anthropometric metrics in batch mode.

[1] Parrilla, E., Ballester, A., Uriel, J., Ruescas-Nicolau, A. V., & Alemany, S. (2024). Capture and automatic production of digital humans in real motion with a temporal 3D scanner. In Eurographics Conference.

The workflow enables dynamic anthropometry in two contexts where fit and ergonomics are crucial: 1) wearable fit and sizing through user-defined, body-conforming measures and contours temporally tracked across anatomically corresponding frames, overcoming the static-only scope of conventional anthropometric extraction; and 2) ergonomics-driven reach design and assessment from motion sequences, quantifying reachable space under natural movement strategies with coordinated multi-segment contributions (e.g., trunk and upper-limb) rather than fixed, posture-constrained reach assumptions.

The mobile 4D scanning system and new anthropometric and biomechanical workflow has been developed and is currently supporting the first dynamic large-scale anthropometric campaign in Canada[2].

Discussion

The integration of mobile 4D capture with a configurable anthropometric framework extends data collection beyond traditional laboratory settings while preserving anatomical consistency and reproducibility. By enabling the design, storage, and reuse of measurement templates directly on homologous meshes, the workflow supports standardized yet application-driven metric generation across distributed campaigns.

In dynamic contexts such as wearable fit and reach design, this approach complements conventional static anthropometry by incorporating behaviour-informed measurements derived from observed motion. This shift toward functional anthropometry broadens the analytical scope of anthropometric datasets and supports more realistic design and ergonomic decision-making.

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Beyond Pass/Fail: Quantifying Risk in Space Hardware Design and Verification

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Space hardware design and verification have traditionally relied on pass/fail (i.e., "binary") threshold requirements, such as anthropometric ranges (e.g., 1st–99th percentile) and strength limits (e.g., a handle operable by a person with arm flexion strength ≥ 9 *N*). These thresholds define compliance but do not quantify risk when requirements are unmet. Because most requirements specify only upper or lower bounds, verification often results in pass/fail decisions that may suffice to declare non-compliance but provide little insight for design improvements.

This work introduces an alternative approach: quantifying the specific risk associated with non-compliance. The case study examines vehicle volume constraints for exercise equipment and crew operation. When space is insufficient, designers need to know the percentage of crew that are unable to exercise safely, as well as the direction and magnitude of design changes required. We present a numerical method to estimate such risks, enabling informed decisions about design modifications or risk acceptance.

The analysis uses statistical permutations of individuals with varying anthropometry and movement patterns to generate probability distributions. These distributions allow for estimation of risks such as the likelihood of excluding crew members beyond certain anthropometric values or the probability of limb-obstacle contacts during exercise.

Overall, this approach moves beyond binary compliance by incorporating quantitative assessment of risk metrics. It provides actionable insights for design optimization and decision-making, offering a more nuanced understanding of crew accommodation and operational safety.

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Optimizing Earcup Fit and Sizing for U.S. Army Hearing Protection

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Hearing protection is critical for U.S. Army Soldiers, who are routinely exposed to hazardous noise levels that risk hearing damage and mission effectiveness. Earcup-style protectors must balance noise attenuation with the need for comfort, communication, and situational awareness across a population with diverse physical traits. This study focuses on developing fit and sizing recommendations for a unisex earcup design to address these challenges.

Researchers utilized the ANSUR II 3D head database, analyzing 2,910 cases (1,720 males and 1,190 females). Each ear scan was fitted by a template of 1,365 vertices and 2,670 triangulated polygons using an iterative closest point algorithm. Twenty-five linear ear measurements were digitally extracted from the fitted templates and validated against manual measurements, confirming their accuracy for design purposes. The extracted measurements indicated that asymmetry between left and right ears was negligible, allowing for unilateral analysis of right-side dimensions.

Statistical factor analysis was performed on the extracted linear measurements, across the male, female, and combined datasets. For both males and females, seven factors accounted for over 85% of the dimensional variance. The analysis revealed that while ear size differs between sexes, the morphological shape is similar. K-mean cluster analysis was then used to categorize ear shapes into two distinct groups, based on these factors.

The results of this comprehensive analysis provided the foundation for developing new fit and size guidelines intended for a universal, non-gendered earcup design scheme. These guidelines aim to improve the safety, comfort, and performance of hearing protection for all Soldiers.

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USN Aircrew Survival Vest Sizing and Fit Initiatives

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Introduction

The DoD has struggled with rotary aircrew survival vest design for many years. It is an enormous challenge to develop a vest system solution that provides the required ballistic protection, buoyancy, survival equipment compatibility, meets platform/mission specific needs, minimizes weight/bulk, optimizes load distribution, minimizes thermal burden, provides fall protection/hoisting capability, fits well, reduces musculoskeletal pain and injury risk, and optimizes mobility, endurance, and mission performance. Some vest system requirements are heavily impacted by factors entirely outside the vest designers' control (e.g., survival equipment/armor weight and volume), making it imperative that vest design be optimized for the factors that are within the designers' purview, including vest system size design and fit optimization.

Methods

A literature search for vest and fall-protection harness sizing/fit, requirements specifications, standards, and historical documents from previous development efforts yielded significant material for consideration. DoD subject matter experts from other services were consulted and provided valuable feedback. A multivariate accommodation approach in compliance with MIL-STD-1472H was used and use cases were developed to represent the central 90% of male and female aircrew separately for the measurements of primary importance to vest/harness design. The cases were generated using principal component analysis in Multivariate Accommodation Method (MAM) software (V3.2) developed by USAF collaborators. These boundary cases were used to establish appropriate requirements specification and nearest neighbor analysis in MAM was used to identify the participants in the anthropometric database that were the closest matches to these boundary cases. The deidentified 3D scans for these participants have been useful for visualization, modeling in Gerber AccuMark (V2024.1.17), and for 3D printing of torso dress forms for lab fit testing of various design iterations.

Results & Discussion

Rather than relying on a "three sizes fit all" approach for the entire vest system, which historically has not worked well, the approach here is to develop three sizes for each of four vest components to be mixed and matched with easy assembly. This novel approach offers an opportunity to address anthropometric shape variation in a way that simply is not possible when the only option is to select one of three sizes for an entire vest/harness system. The modular sizing approach and proposed sizing tables were evaluated and optimized at two aircrew fit testing events in September 2025 and a long duration wear evaluation in October/November 2025 and is expected to result in a significant improvement to system fit and accommodation.

Challenges and Advances in Body Armor Fit, Sizing, and Digital Design

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Introduction

Proper body armor fit is critical to ensuring adequate protection, mobility, and operational effectiveness for military personnel. However, traditional armor design and sizing approaches often rely on univariate percentile-based anthropometric methods that fail to represent real human body variability. There is no standard definition of good body armor fit or consensus on the best anthropometric measurements to be used for sizing. This work examines challenges associated with body armor fit and sizing for U.S. Naval aircrew, and explores emerging digital design approaches to improve accommodation, evaluation, and acquisition of protective equipment.

Methods

A mixed-methods assessment was conducted using operational observations, anthropometric analysis, and review of current body armor design and sizing practices. Fleet visits were performed across multiple naval aviation squadrons to collect feedback from aircrew, aviators, Aeromedical Safety Officers (AMSOs), and equipment specialists regarding fit and availability of survival vest and armor components. Anthropometric accommodation was evaluated. Existing sizing tables and procurement practices were also reviewed to identify factors affecting fit and equipment distribution.

Results

Findings indicate that traditional percentile-based sizing approaches inadequately represent population variability and can result in significant accommodation gaps. Multiple systemic factors were identified that contribute to poor armor fit, including inadequate sizing schemes, outdated tariffing assumptions, supply chain limitations, and fitting practices following fielding. These issues collectively degrade warfighter protection, mobility, and mission performance. Additionally, accommodation analysis indicated that currently available plate sizes are forcing warfighters to sacrifice either protection or mobility because there are not enough sizing options to provide both.

Discussion

Advances in multivariate anthropometric modeling, 3D body scanning, and digital human modeling offer opportunities to modernize body armor design and evaluation. Integrating digital human modeling, virtual fit assessment, and simulation-based design tools can support predictive evaluation of armor fit, mobility, and coverage before fabrication. Adoption of these digital engineering approaches may improve protection, reduce health risks associated with misfit, and enhance acquisition decision-making for future protective equipment systems.

Simulating Effects of High-Acceleration Exposure for Mitigation of Cervical Spine Injury in Military Pilots

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Introduction

Injury to the cervical spine is a threat to the health of military pilots. Factors that contribute to risk of injury include head-worn equipment, posture and motion, and exposure to large accelerations. In-flight biomechanical data are expensive and difficult to collect. Computational simulations provide detailed joint reaction forces, muscle forces, and ligament forces that can aid identification of potential mechanisms of neck injury. The objective of this study was to simulate cervical spine biomechanics during exposure to high acceleration-induced forces representative of flight maneuvers.

Methods

The cervical spine was modeled with 24 degrees of freedom across 8 joints and 84 musculotendon elements [1] and scaled to represent 5th, 50th, and 95th percentile height and weight values of military pilots. Simulations were performed using OpenSim 4.3[2], and a custom plugin was created to dynamically modulate the global acceleration vector to represent G-forces applied to the body during flight maneuvers. Dynamic flight acceleration profiles were applied to the models placed in an upright seated posture. Neck muscle forces were estimated using static optimization and joint reaction forces were calculated.

Results and Discussion

The cervicothoracic junction (C7-T1) was exposed to the highest average compressive joint loads. Average C7-T1 joint loads elicited during accelerations up to 5Gz was 598.5 N (± 118.1 N) and 628.6 N (± 47.5 N) for the representative male and female models, respectively. Musculoskeletal simulations indicated sex specific differences in neck loading during flight maneuvers. The location of highest joint loads were identified, providing insight into potential interventions. Future work will investigate effects of external head gear and modified postures. In addition, centrifuge data will be used to further validation of the simulations. Overall, this work highlights the benefit of musculoskeletal simulations for studying the effects of extreme acceleration exposures on neck pain development in military pilots.

Acknowledgments

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Sex Differences in Amplification of Head-Coupled Vibration

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Introduction

Repetitive long-duration exposure to whole-body vibration has been documented to cause adverse biomechanical effects [1,2]. Human vibration exposure standards (ISO 2631) were developed using almost entirely young, healthy, male participants and on the basis of vibration at the seat cushion interface [1]. It is unknown if these standards generalize well to female anatomy, yet female aircrew have reported more musculoskeletal issues than their male counterparts [2].

Methods

The Human Vibration Laboratory within the National Research Council of Canada's Flight Research Laboratory features a human-rated shaker equipped to simulate aircraft vibration. Ten participants (6 male, 4 female) were instrumented with triaxial accelerometers on the helmet, seat pad, seat pan, and shaker platform. Participants were cued to hold two postures (cruise, hover), corresponding to vibration profiles for that phase of flight.

Results

No relationship was observed between sex and vibration level at the seat pad, seat pan, or platform of the shaker when considered for each of the harmonics of the main rotor of the aircraft. The head vibration, however, shows women experience lower vibration in the first harmonic (R^2=0.55 cruise, R^2=0.48 hover), but increased vibration in the second, third, and fourth harmonics during cruise (R^2=0.43, R^2=0.41, R^2=0.31, respectively) and the second harmonic during hover (R^2=0.46).

Discussion and Conclusion

The principal resonance of the human body has been found to lie between 4 and 6 Hz, with a second principal resonance at 8 to 12 Hz [3-5]. Vibrations of 5.6 Hz have been associated with the lumbar and lower thoracic spine and vertical motion of the head, whereas frequencies nearing 10 Hz correspond to head, spinal column and pelvic vertical movement [3]. A larger sample size would be required to evaluate whether females experience more head vibration at the higher harmonics. Standards may need to define limits for vibration at the head and might best consider the entirety of the population that they are developed to protect.

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Comparative Mass Properties of Legacy and New Anthropomorphic Test Devices (ATDs)

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Introduction

A characterization study compared legacy Lightest Occupant in Service (LOIS) and Large Anthropomorphic Research Device (LARD) Anthropomorphic Test Devices (ATDs) with newly developed models at the Air Force Research Laboratory's Biodynamics Laboratory. With new ATD production occurring for the first time in over 25 years, this comparison is critical to reestablish production capability and integrate modern data acquisition technologies.

Methods

The study focused on differences in mass properties—weight, center of gravity (CG), and moments of inertia (MOI)—between legacy and new ATDs. Measurements were taken on 36 individual ATD segments (9 per ATD: head, torso, upper/lower arm/leg, thorax, foot, hand) and four full-body, seated ATDs. Each segment and full body were secured in a reference box to establish a consistent coordinate system. Mass properties were measured using a balance/scale, moment table, a MOI instrument, and a Faro Arm for digitization. Each composite (combination of segment and box) was initially weighed, then placed on the moment table, rotated in the x, y, and z directions, to calculate the CG for each segment. Moments of inertia were then determined using the Space Electronics MOI instrument. Digitized landmarks converted box-axis coordinates into mechanical (joint-based) and anatomical coordinates for more relevant CG measurements.

Results

Seated whole-body CGs were within 0.15 inches in the forward (CGx) and upward (CGz) axes when comparing the two LOIS and two LARD ATDs, respectively. The respective ATDs were within 1 lb. of each other (New LOIS = 102 lb., Legacy LOIS = 101 lb., New LARD = 240 lb., Legacy LARD 241 lb.).

Discussion

Therefore, this study concluded that the new ATDs are very similar to the legacy LOIS and LARD ATDs in terms of mass properties and geometry, supporting their continued use in test environments without introducing variability due to structural differences.

Quantifying Equivalent Muscle Reactions of a CG Adjusted Helmet

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Introduction

Helmet-mounted technologies can significantly enhance pilot capability but often shift the helmet center of gravity (CG), producing offset moments that increase neck muscle fatigue and the risk of injury during high-G maneuvers and ejection. This research was focused on quantifying and comparing the effective load on the neck muscles that can be removed by attaching a load to the back of the helmet which has been calibrated to negate the effect of the forward CG shift. We used numerical models as well as published anatomical data to define the forces in the neck and compare to the loaded helmet case.

Methods

The required rear helmet loading to negate the forward CG shift due to common front attachment configurations (Night Vision Goggles stowed & away) was determined using least square curve fits of physical model testing performed with a fulcrum-scale device. Performing a simple statics analysis of the head-helmet system by using a free body diagram to sum moments about the OC joint allowed us to calculate the muscle forces required to generate the same CG correction as the back attachment of interest. The location of the muscle force applications and the relative cross-sectional area of the muscles (rCSA) was determined through thorough research and use of an accurate 3D head model used for previous research.

Results

We found that due to the large moment arm of the rear weight, the equivalent muscles forces were nearly four times higher than the required rear attachment weight. This trend was shown in the case of both the NVG stowed and NVG engaged position, demonstrating a reliability in our experimental method.

Discussion

The large difference in equivalent force between the models indicates the importance of CG balancing devices for the health of aircraft pilots. The mechanical advantage offered by a rear weight attachment has the potential to largely reduce the stress and fatigue experienced in the neck. Further research efforts will focus on accounting for the frontal plan CG shift introduced by tilting the head which crosses a centrally aligned rear attachment over the spine of the pilot.

Segmentation Analysis of the Human Head: Implications for Helmet Mass Property Specifications and Biodynamic Modeling

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Accurate characterization of human head mass properties—including mass, center of gravity (CG), and moments of inertia—is fundamental to evaluating helmet systems, head-mounted equipment, and pilot safety in high-performance aviation environments. Current helmet specifications and biodynamic models often rely on legacy assumptions regarding head geometry, tissue composition, and coordinate system definitions that were established decades ago using simplified manikin representations and cadaver studies. These assumptions may introduce significant uncertainty into modern helmet mass-property limits and injury risk assessments.

This study evaluates how segmentation methodology, tissue property assumptions, and anatomical coordinate systems influence predicted head mass properties derived from computed tomography (CT) imaging. High-resolution CT data were segmented using 3D Slicer and SolidWorks to construct anatomical models of the human head. Multiple segmentation approaches were investigated, including homogeneous head models and multi-tissue models distinguishing soft tissue, cortical bone, and trabecular bone. Predicted mass properties were compared to experimentally measured values from physical headform measurements used in helmet system evaluations.

Results demonstrate that segmentation approaches that neglect internal bone structure can produce significant errors in predicted CG location and inertial properties. In contrast, models that explicitly represent cortical and trabecular bone distributions produce mass-property predictions that closely match experimentally measured values. The most accurate predictions were obtained using a three-tissue segmentation model, which minimized error in CG location and moments of inertia relative to measured data.

In parallel, this study examined the anatomical location of the occipital condyle centroid and upper cervical spine center of rotation, demonstrating that these critical biodynamic reference points can be reliably approximated using external anatomical landmarks defined by the Frankfurt coordinate system.

These findings challenge long-standing assumptions embedded in helmet specification standards and highlight the need for updated biomechanical models that incorporate anatomically accurate head segmentation. Improved mass-property characterization will support more reliable helmet CG limits, enhanced biodynamic simulations, and more accurate assessment of pilot safety in high-acceleration environments.

USAF Fighter, Bomber, and Trainer Anthropometric Accommodation Evaluations

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Introduction

The Airmen Accommodation Lab (AAL) is responsible for defining the anthropometric accommodation standards for aircraft crew positions. Aircraft specific pilot body size minimums and maximums were originally defined and published in the early 2000's, however many things have changed since then. Upgrades have been made to cockpits/crew stations, seats have been changed, and functional requirements for crew positions are being re-evaluated. Current data collection methods are more accurate than traditional. All of these could potentially affect and change the accommodation envelopes. Additionally, non-pilot positions have never been evaluated for body size accommodation.

Methods

The AAL recently conducted anthropometric accommodation evaluations on most of the crew stations for the fighter, bomber, and trainer aircraft in the USAF inventory. For each evaluation, anthropometry for 20-25 Test Participants (TPs) of varying body sizes were measured. Posture, clearance, and reach data were collected for each of the TPs. Analysis relates the performance data collected to body size to produce accommodation envelopes for each crew position given their functional requirements.

Results

The project is on-going, with data collection completed for 10 of 12 aircraft. The goal is to complete all 12 by the end of 2025. Initial results from the completed aircraft show some differences from the original body size accommodation study. Subject matter expert discussions of functional requirements show a shift from original definitions. Additionally, the first CSO body size standards have been established.

Discussion

At the end of this project, along with results from previous studies, there will be updated anthropometric standards for all crew positions across all platforms. New software is in development to streamline the candidate screening processes. Additionally, maintaining up-to-date anthropometric standards is critical to ensuring safety onboard all platforms. A standardized process should be defined to ensure the impact to anthropometric accommodation will be assessed given any aircraft or equipment updates.

Developing Expertise in Cockpit Fit and Anthropometric Accommodation Modelling

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Introduction

Director Technical Airworthiness and Engineering Support (DTAES) is beginning a strategic effort to build internal expertise in cockpit fit and anthropometric accommodation modelling. This initiative responds to the Royal Canadian Air Force's (RCAF) evolving operational needs and the introduction of new airframes, where inclusive crew station design is essential for safety and readiness. Historically, accommodation relied on univariate limits or entry standards; however, modern airworthiness requirements and diverse aircrew populations demand multivariate approaches that account for complex body proportion variability.

Methods

To establish foundational knowledge, DTAES conducted a two-day training exercise with the National Research Council Flight Research Laboratory. The exercise applied the U.S. Air Force multivariate anthropometric methodology to the Bell 206 Jet Ranger and Boeing 737 cockpits using the 2012 Canadian Forces Anthropometric Survey as the reference population. Activities included anthropometric measurement, cockpit fit assessments, and development of predictive models using stepwise linear regression and principal component analysis. The team also evaluated measurement tools, identified sources of error, and explored real-time data validation techniques.

Results

The exercise confirmed that multivariate methods can be replicated effectively and highlighted key predictors for accommodation tasks such as head clearance, vision angles, and reach envelopes. Preliminary models demonstrated strong predictive capability, validating the approach.

Discussion

This work represents an initial capability-building effort for DTAES. Future priorities include digitized measurement tools, head-up displays, alternative modelling techniques, and refining operational requirements. By establishing repeatable methodologies and predictive models, DTAES is laying the groundwork for comprehensive cockpit fit assessments that support airworthiness compliance and operational safety.

Comfort and Fit Copilot

Jatin Kashyap, Wenye He, Charles Cheng, and Zhiqing Cheng
Innovision, LLC.

Introduction

Human–system integration, wearable performance, and ergonomic optimization require synthesis of anthropometric data, biomechanical principles, textile engineering knowledge, and evolving standards. However, relevant information is distributed across heterogeneous sources, including technical reports, PDF documents, and online standards, making timely, evidence-based decision support challenging. Therefore, we have developed a domain-specific AI system dedicated to fit, comfort, and ergonomics—Comfort and Fit Copilot (ComFit).

Methods

ComFit integrates small language models (SLMs), retrieval-augmented generation (RAG), and agent-based workflows within a hybrid knowledge framework. The system combines curated anthropometric and ergonomics PDF repositories with live web search to support local-only, web-only, or hybrid retrieval modes. Its modular backend (FastAPI, LlamaIndex, Ollama) supports domain-specific vector stores, document appending, and configurable deep research strategies, including planning workflows and multi-strategy parallel retrieval. A RAC layer enhances factual reliability through post-generation claim verification. The graphical user interface enables multi-threaded conversational interaction, knowledge-domain selection, source traceability, and image extraction from indexed documents.

Results

ComFit delivers traceable, citation-supported responses tailored to engineers, human factors specialists, and program managers. The system supports evidence-grounded ergonomic assessment, anthropometric analysis, sizing evaluation, and wearable design optimization. Hybrid retrieval and domain-based vectorization improve contextual precision, while transparent source display and optional reasoning views enhance interpretability and user trust.

Discussion

By bridging structured anthropometric databases, unstructured scientific literature, and real-time standards, ComFit advances AI-assisted decision support in comfort and fit engineering. The platform demonstrates how domain-tuned SLM systems can extend beyond static knowledge retrieval toward adaptive, explainable, and multimodal ergonomic intelligence, supporting defense, aerospace, industrial, and wearable system applications.

Re-evaluation of Minimum Sitting Height Requirements for USAF Ejection Seat

Jennifer Whitestone, Jeffrey Hudson
SENTIR Accommodation Research Center

Current United States Air Force policy establishes a minimum sitting height of 33 inches for assignment to ejection seat aircraft, as reflected in the Aerospace Medicine Waiver Guide and the Medical Standards Directory. The historical basis for this restriction is not clearly documented in relation to specific mishap data or system safety analyses. Multiple sources of anthropometric, operational, and engineering evidence suggest that the requirement may warrant re-evaluation within a modern system safety framework. This study examines whether available anthropometric and accommodation data are consistent with the possibility that a lower sitting height threshold—potentially near 31 inches—could remain compatible with established ejection seat design constraints.

The analysis integrates JPATS boundary case development, accommodation records from the WebPASS database, anthropometric design criteria specified in MIL-S-9479, and whole-body seated center-of-gravity (CG) measurements derived from the Albery anthropometric datasets. Operational accommodation data indicate that pilots with sitting heights below 33 inches have successfully trained and flown certain ejection seat aircraft platforms. Additionally, small-occupant qualification testing has utilized the LOIS anthropomorphic test device, representing sitting heights between approximately 32.4 and 32.8 inches. Regression modeling of USAF and JPATS anthropometric databases indicates that a 31-inch sitting height falls within expected population variability.

Principal component regression modeling of seated whole-body mass properties indicates that predicted CGx and CGz values for individuals with a 31-inch sitting height fall within the ±2-inch CG tolerance envelope specified in MIL-S-9479 design guidance. When accounting for CG shifts associated with aircrew flight equipment, modeled values remain generally consistent with stabilization subsystem design limits.

These findings suggest that a minimum sitting height closer to 31 inches may be compatible with existing anthropometric and CG design envelopes. However, additional biomechanical analysis, cockpit clearance evaluation, and system-level validation would be required to fully assess operational safety implications.

Ejection Modeling and Simulation System (EMASS)

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Introduction

Ejection seats serve as critical safety mechanisms for aircrew survival during emergency escape scenarios. However, current modeling tools often lack the fidelity and scope required to accurately assess injury risk—especially to the neck and spine—throughout the full ejection sequence. This work presents a next-generation Ejection Modeling and Simulation System (EMASS), integrating Human Digital Twin (HDT) and Generative AI technologies to address this gap.

Methods

EMASS models the ejection sequence in four phases: (1) seat-canopy separation, (2) windblast effects, (3) parachute deployment, and (4) landing impact. It utilizes validated THUMS models (AF05, AM50, AM95), morphed through ANSA to match pilot anthropometries, and incorporates muscle activation states for realistic biofidelic response. LS-DYNA's FEA and Fluid-Structure Interaction (FSI) capabilities are used alongside CFD to simulate windblast and parachute dynamics. GenAI modules adapt restraint settings, ejection timing, and posture based on scenario conditions and predictive analytics.

Results

Simulation results demonstrate that the adaptive HDT models accurately reproduce injury mechanisms across diverse pilot profiles. The use of real-time parameter optimization enables more accurate predictions of head, neck, and lumbar injuries using criteria such as Nij, HIC, and intradiscal pressure. The modular platform supports integration with legacy and emerging USAF ejection systems.

Discussion

By bridging validated biomechanics models, AI optimization, and high-fidelity simulation tools, EMASS offers a unified environment for comprehensive injury risk evaluation. This system enhances pilot safety analysis and can support training, test planning, and design of next-generation ejection systems. Its scalability and compatibility with DoD digital engineering ecosystems position it for widespread adoption.

A Parametric Human Body Modeling Framework: Bridging Population Variability and Injury Prediction

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Introduction

Human size-and-shape variability is critical in digital human modeling for safety. UMTRI's HERMES model enables efficient parametric, posable finite-element modeling but lacks active muscles, limiting realism in bracing. In contrast, high-fidelity THUMS model supports tissue-level injury prediction but is harder to scale and reposition. This study develops a unified parametric framework that adds active musculature to HERMES and integrates THUMS for injury assessment across diverse anthropometries and seated postures.

Methods

A unified framework was developed for HERMES and THUMSv7.0 by adding active muscles to HERMES using THUMS-based origin/insertion points mapping and muscle definitions; aligning THUMS to the same statistical skeletal geometry as HERMES; and re-positioning via landmark-driven radial basis function morphing with joint- center rotations. Morphed and re-positioned midsize male HERMES and THUMS models were simulated under a 10G vertical drop tests (VDT)-style pulse in passive and active conditions, and head-neck kinematics were compared with volunteer data. Active HERMES sensitivity to initial muscle activation was evaluated and a Python-based GUI was implemented for model generation, re-positioning, and multi-model comparisons.

Results

The framework and Python-based GUI were successfully implemented. In passive simulations, the models showed closely matching head center-of-gravity trajectories and head-neck kinematics, indicating consistent baseline behavior after morphing and re-positioning. With muscles enabled, both models better maintained initial seated and neck posture. Active HERMES showed strong sensitivity to initial muscle activation inputs.

Discussion

The unified framework provides consistent baseline behavior across model fidelities and demonstrates the value of active musculature for bracing-dominated response, motivating further tuning of neck and trunk muscle initial activation for braced VDT conditions. Although demonstrated with midsize male models, the framework is designed to scale across diverse anthropometries and seated postures where anatomy, posture, and bracing affect kinematics and injury mechanisms. Overall, it streamlines population-level parametric modeling while improving bio fidelity and tissue-level injury prediction.

Bridging Virtual and Real Fit – the Importance of Real Fit Testing

Panel Presentation:

Why, after all these years and mountains of anthropometric data, do we still face fit and sizing problems? What is it that enables us to adopt new technologies successfully? What are the barriers to bridging virtual and real fit? This panel discusses these topics and introduces a systems engineering framework that breaks down the problems, the solutions and demonstrates why real people and fit testing are essential today. Daisy Veitch will introduce the topics, the terminology, and the Sustainable Product Evaluation, Engineering and Design (SPEED) framework. Dr Kathleen Robinette will talk about today's best practices for learning how to optimize design and sizing and introduce what is needed to improve our technologies in the future. Karen Bredenkamp will speak about virtual fit testing, its advantages, limitations, and needs. Dr Sandra Alemany will talk about developing fit intelligence through standards, fit databases and AI. The goal is to discuss, (with the BEAM community), opportunities and roadblocks for building better products in less time with less waste. This includes discussion of the needs for fit testing with real people, fit standards, testing standards and fit databases. It also includes a discussion of the potential for AI to improve virtual models for better fit prediction.

Introduction

Daisy E Veitch, PhD

Anthrotech Inc., Yellow Springs, OH

Virtual technology promises better results in less time, however right now this promise is not fully realized. Two things are needed that don't exist today to realize this promise: 1) fit data on all types of products and materials, and 2) virtual models that can reveal fit problems. We can't train our virtual models to reveal fit problems unless we have data for all kinds of products on things such as location on the real body, comfort, performance, functionality, personal preference, integration of components, and safety. Today these things are only obtainable by fit assessment with real people. In this presentation the overarching systems engineering process for obtaining this data will be presented. It is called the Sustainable Product Evaluation, Engineering and Design (SPEED) process. Terminology for things that can help in the standardization of fit data collection will also be introduced including the concept-of-fit (COF), the range-of-fit (ROF), fit audit, and sustainable fit standard. The goal is to begin the conversation with a common language so we can discuss how we might standardize the fit collection process and create a fit database that provides the data we are missing for future virtual model development.

Understanding Who We Fit and Who We Don’t

Kathleen M. Robinette, Ph.D.

Fitmetrix LLC, Waynesville, OH

It is estimated, based on fit audits of uniform and fashion apparel sizing, that today’s fashion apparel industry is accommodating just 25-45% percent of their target market, when they could be accommodating up to 99% with the same number of sizes. They also produce sizes that are not needed that end up on the sales rack or in the bin. Why? Because they do not know who they fit. They know they fit enough people to make money, and they judge their fit solely on how well the product sells. They often know there are many people who have fit issues with their products, but they don’t know why and they add or change sizes or patterns without sufficient evidence. This is also a problem for all other wearables. For example, an audit of a flight helmet revealed that two of the three sizes were too long for everyone, and the one size remaining only fit about half of the target population. The remaining 50% needed either a wider helmet or a narrower one, neither of which existed. An audit of a head worn optical system revealed that the systems shape would accommodate very few in the Asian population and one of the three sizes was completely unnecessary. With the advent of worn optical devices and worn monitors, the fit precision needed has increased, making it both more difficult and more important to know who we fit. These problems can be alleviated by using the SPEED process with real people throughout development to understand who we fit and who we don’t. In this presentation we review today’s best practices for selecting cases, determining the range-of-fit for the design and optimization of size assortment and population coverage. The purpose is to initiate discussions about the opportunities and roadblocks for future standardization.

Virtual fit testing is transforming how products are designed, validated, and sold online

Karen Bredenkamp

Magic Leap Inc., Plantation, FL

In a fast-paced world, the benefits of virtual fit testing are easy to imagine. However, poor understanding and over optimistic expectations, maybe even the desperate need to progress faster through wearable product design and development processes, is creating a false expectation that virtual fit testing enables by default “accurate evaluation of fit, comfort, and performance” and even accomplishes this before physical prototypes exist. The reality is however that virtual fit testing requires significant development investment, which must include several validation and improvement cycles to the virtual fit testing tool. Even then, certain aspects, such as individual comfort, personal preference and even some performance aspects, will still at best be simulated estimates. In addition, understanding the level of accuracy required by different products and fit testing applications, will furthermore drive virtual fit testing validation goals. Understanding the shortcomings and need for validation, put us in a position to strategize and develop better input data and protocols to accelerate improvement of virtual fit testing models/tools. This talk aims to initiate discussions to level-set our expectations and experiences with virtual fit tools, but also to entice strategies and discussion about methods to speed up virtual fit tool validation, and subsequently virtual fit testing accuracy. An example of a virtual fit testing validation protocol will serve as a basis for discussion about approaches and challenges.

Towards Fit Intelligence: Standards, Fit Databases, and AI for product design

Sandra Alemany, PhD,

Instituto de Biomechanica (IBV) de Valencia, Valencia, Spain

Over many years, research has focused on the definition of anthropometric measures, measurement protocols, and population datasets to enhance fit and sizing. However, fit data remain limited in volume, heterogeneous in definition, and insufficiently structured for reuse. This deficit constrains systematic fit improvement, reduces the evidential basis for validating virtual fitting approaches, and restricts the potential provided by the application of AI models intended to support design decisions. A principal limitation is the absence of broadly applicable fit standards and fit databases derived from real-person testing.

We propose an open discussion to work towards an intelligent fit framework centered on standardization: a shared fit ontology (anatomical zones + fit criteria + use conditions) and associated protocols enabling consistent zone-based fit annotations and fit ratings. Fit is treated as a multi-zone construct capturing localized outcomes such as pressure/tightness, excess ease, slippage, restriction, and contact/stress hotspots, recorded under static, dynamic, and extreme postures appropriate to product and activity. Each labelled fit outcome is paired with (i) body descriptors (shape/proportion features), (ii) product specifications (concept of fit, materials, construction), and (iii) design descriptors (patterns/lasts/geometry and grading parameters), forming a "body–product–design → fit outcome" dataset that can be incrementally populated through routine fit trials.

On this basis, AI models can: (1) predict where and for whom a design fits best/worst (body-specific fit guidance), (2) identify recurrent causes of misfit and recommend targeted design changes, (3) learn data-driven ease/grading rules across sizes and styles, (4) benchmark fit performance objectively across blocks/materials, (5) provide insights for generative design exploration, and (6) inform size-range design by estimating population coverage and trade-offs between fewer sizes, better fit outcomes, and manufacturing complexity. Real-person fit testing remains essential while databases mature, but standardized labelling ensures each test compounds into transferable knowledge for improving fit standards and training AI.

Methods for Synthesizing Anthropometric Data

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Introduction

Anthropometric datasets are widely used to evaluate accommodation in design, yet no single dataset is both comprehensive and representative for most populations. Designers therefore rely on data synthesis to fill gaps or adapt existing data to new populations. However, practical guidance on how synthesis approaches affect design outcomes—and when each method should be used—remains limited. This work reframes anthropometric data synthesis as a decision-making process and presents a structured,

practice-oriented framework for selecting and applying synthesis methods in inclusive design contexts where available data are incomplete or mismatched with the target population.

Methods

Synthesis approaches are organized into three categories: (1) regression-based methods that estimate missing measures from relationships in existing data, (2) population reweighting which adjusts datasets to match a target population, and (3) distribution-based methods that model and generate representative populations. Multiple approaches within each category were examined through two case studies. First, ANSUR II data were synthesized to replicate ANSUR II under controlled conditions. Second, ANSUR II data were used to synthesize anthropometric measures for a Japanese population, representing a realistic design challenge. Methods were evaluated to clarify assumptions, implementation requirements, strengths, limitations, and appropriate use conditions.

Results

Each synthesis category produced distinct population characteristics with design-relevant implications. Regression-based methods effectively estimated missing variables but required careful modeling to preserve variability. Population reweighting approaches aligned data with target populations when sufficient overlap existed, though performance declined as populations diverged. Distribution-based methods enabled population reconstruction or expansion but relied on complex modeling decisions. These findings were consolidated into practical guidance outlining method suitability and tradeoffs.

Discussion

Rather than advancing a single preferred technique, this work provides structured guidelines for selecting synthesis methods based on data availability, population similarity, and design objectives, supporting more transparent and context-sensitive use of anthropometric data in inclusive design.

Integrating Three-Dimensional Anthropometry into Real-Time Design: A Data-Driven Module for Optimizing Accommodation

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Introduction

Detailed anthropometric data of the hand remains limited, making it difficult to design products that require precise fit of the fingers. Even when large databases with specific measurements are available, such as the Greiner's hand anthropometric database, traditional linear measurements alone are often insufficient because they do not capture the three-dimensional contours and shape variability of the fingers. Furthermore, accommodation analyses are typically performed after a device has already been designed, meaning that poor fit is often identified too late in the development process, requiring costly redesign iterations.

Methods

This work presents the development of a design module created for the development of a high-precision finger-based medical device. This module integrates anthropometric and three-dimensional finger geometry directly into the engineering design software, enabling accommodation to be calculated simultaneously as the device geometry is created and modified. An initial target population analysis conducted by the HDL revealed that the original device dimensions yielded an overall accommodation rate of only 15%, indicating that significant dimensional and shape modifications were required. By comparing key finger geometry to device geometry and leveraging the integrated design module, engineers were able to iteratively adjust the device form to better fit the target population.

Results

With the HDL's design recommendations and the data-driven module in place, overall accommodation increased to 97%. Critically, this approach also incorporated an estimated comfort ratio for reach, meaning that beyond sizing and shape considerations, the biomechanical capacity for comfortable index finger reach was also evaluated.

Discussion

This integration of population-level anthropometric data into the design workflow represents a substantial improvement over conventional methods, shifting accommodation assessment from a post-design evaluation to a real-time, concurrent design activity that optimizes both fit and functional comfort across diverse user populations.

Escaping the 1D Bottleneck: An Online Framework for Applying Population-Level 3D Anthropometry to Design

Matthew P. Reed and Byoung-Keon Daniel Park
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Introduction

Rapid advances in sensors and software are continually reducing the cost of gathering human 3D surface data. Yet, more than 30 years after the first 3D military anthropometry surveys, very little 3D data is actually used by the designers of helmets, body armor, and other close-worn clothing and equipment. Scan data remains hard to use, and statistical methods and software have lagged behind data acquisition technology. Instead, the data from most 3D surveys is reduced to traditional 1D measures before the practitioners have access to the information. Only a small number of 3D cases are ever directly used for product design and evaluation. In most studies, the 3D scanner is just a faster tape measure. Actual population-level 3D datasets are only available to a small cadre of experts, while most product designers are working with minimal 1D guidance.

Methods

Through decades of experience in 3D anthropometry, our team has seen first-hand the challenges in gathering and applying 3D anthropometric data. We're now working to break down the barriers that have prevented population-level 3D data from being used in product design. The foundational elements of this approach include (1) measurement protocols that produce high-quality data, (2) standardizing data by fitting consistent, homologous templates to scans, using manual and automatic landmarking as needed, (3) statistical analyses to generalize from samples to populations, (4) designer-facing data analysis tools that enable interaction with an entire population of 3D avatars, and (5) new design processes to take advantage of this unprecedented access.

Results

We have recently launched HumanShape.app, a new online design framework based on population-scale 3D anthropometric data. Users are able to define their own point-to-point and surface-contour measurements and immediately compute them across the desired population. Many tools previously only available to anthropometry experts are now available to product designers, including custom 3D shape regressions, PCA-based boundary cases, and multivariate accommodation assessments.

Discussion

The long-term vision is user-guided automated design, where the software handles the extraction and processing of the body size and shape data while the designer focuses on the product characteristics. Critically, designers will no longer be limited to a small number of pre-defined anthropometric measures, resulting in products that fit and perform better, with quicker, more efficient design processes.

For more info: http://humanshape.app/

From Designer Intent to Quantitative Specification: A Human–AI Collaborative Approach

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Introduction

Designers frequently describe product requirements in natural language (e.g., "accommodate 95% of users"), yet translating these requirements into technically valid, multivariate design specifications remains complex. Large language models (LLMs) can interpret user intent, but they are unreliable in extracting domain-specific data and performing multivariate calculations. This work proposes a structured strategy for integrating AI with a verified computational backend to support inclusive, data-driven design across a wide range of product domains.

Methods

The proposed framework combines (1) natural-language interpretation by an LLM, (2) structured function-calling to a custom analysis engine, and (3) validation of the AI-generated problem translation prior to execution. When a designer submits a prompt, the LLM maps design variables to relevant quantitative measures and constructs structured inputs (target performance level, variable relationships, and evaluation ranges). Then, the translated problem is intercepted prior to analysis to ensure appropriate variable selection, logical operators, and realistic parameter ranges. This collaboration allows designers to evaluate the variable mapping, logical interpretation, and parameter bounds prior to computation. The verified inputs are then passed to a multivariate calculation function that evaluates performance across combinations of design variables.

Results

This framework was implemented in a web-based tool that uses ChatGPT and multiple databases, including ANSUR II, to provide recommendations on natural language multivariate design problems. Using prompt engineering, we were able to mitigate errors produced in the test cases, creating a tool that could consistently solve simple design problems that only involved comparison of design variables against anthropometric data.

Discussion

By separating language understanding from quantitative analysis, this strategy mitigates hallucinated data, univariate oversimplification, and logical inconsistencies. The framework generalizes beyond a single product example and offers a scalable approach for translating qualitative design intent into verified multivariate specifications for complex design problems.

iSize: A Data-Driven Solution for Optimizing Clothing and Textile Sizing in the U.S. Military

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Introduction

The U.S. Military currently lacks a standardized sizing system for clothing and textiles (C&T). To address this challenge, the Air Force Uniform Office (AFUO) is utilizing the size optimization tool, iSize by Humanetics, which introduces a data-driven digital tool that integrates real-time anthropometric data to optimize sizing for the Warfighter population. This tool provides transparency, visibility, and actionable insights to improve the efficiency and effectiveness of military clothing design and distribution processes.

Purpose

The AFUOs primary objective with iSize is to leverage digital inputs derived from anthropometric studies to offer real-time recommendations on size distribution, fit optimization, and sizing tariffs for the military population. By applying these insights to the C&T sector, iSize enables more informed decision-making and enhances the ability to meet mission-specific requirements.

Methodology

iSize integrates digital body measurements against both legacy and new sizing systems, delivering real-time analytics on size optimization. The tool supports various sizing models and is fully interoperable with the Department of War's design/development process, as well as industry tools such as 3D avatars and dress forms. It provides visibility into standardized body landmarks for consistent measurement and scanning.

Results

iSize delivers multiple outcomes, including:

- Real-time analytics for applying anthropometric data to clothing and textiles.
- Size optimization insights (2/98, 5/95) for improved fit.
- Seamless integration with Department of War design/development processes and industry tools.
- Enhanced transparency in body measurement landmarks.

Impact

The AFUO addresses a critical gap in the ongoing collection and application of anthropometric data for military C&T. By incorporating real-time data, size optimization software enhances agility, reduces inventory waste, and improves forecasting accuracy. It fosters sustainable workflows, better readiness, and promotes more responsive and efficient decision-making. Additionally, iSize supports the continuous collection and integration of anthropometric data into the military's population dataset, aiding in size distribution forecasting and demand risk management.

Limitations

The size optimization tool, iSize, does not interfere with existing government methodologies for anthropometric data collection, nor does it restrict the use of global apparel tools or specific approaches to uniform design that meet mission requirements. There are some limitations utilizing anthropometric data online due to proprietary information, as the tool is unable to incorporate specific, confidential anthropometric datasets that are restricted by privacy or intellectual property agreements. Additionally, personally identifiable information (PII) is not included in this tool, ensuring user privacy and confidentiality. However, without access to specific PII, such as exact body measurements paired with unique characteristics, the tool may not be able to offer the most precise or contextually relevant sizing suggestions.

Conclusion

Size optimization tools represent a significant advancement in the military's ability to integrate real-time, data-driven insights into C&T decision-making processes, improving sizing accuracy and operational efficiency while fostering innovation in the design and development of military uniforms.

Creation of a New Unweighted Matched United States Air Force Anthropometry Database Using Bin Signature Matching

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Introduction

Matching leverages information in previous large-scale US Army and US Marine Corps data to generate a new dataset at a much lower cost than a full-scale survey. We report the development of a new US Air Force matched dataset USAF2025.

Methods

The match uses a bin signal method where individuals are binned by category. Each bin is given a number. Bin numbers are concatenated into a bin signal value. Thus, a Hispanic (5) woman (1) whose age is 31-35 (3) and BMI < 27 (1) has a bin signal of 5131.

The Reference data set is demographics and height, weight, and BMI from USAF Life Cycle Management Center (AFLCMC) personnel (male = 4797 and female = 1505). The Source data is the 2010 US Marine Corps Anthropometric Survey (MCA) and the 2012 US Army Anthropometric Survey II (A2) (male = 9342 and female = 4396).

Initial per bin estimates found the Source dataset did not populate the men's "Multi" race/ethnicity Target bins fully. Rather than reduce the overall sample, Source bins were up sampled by applying the Synthetic Minority Oversampling Technique (SMOTE).

To populate the Target dataset bins, random individuals were selected by bin signature from the Source dataset. The Target dataset (male = 3001, female = 1219) was evaluated with univariate statistics versus the Reference dataset.

Results And Discussion

Statistical tests comparing Source and SMOTE data found no significant differences. Men's and women's Target and Reference data sets have statistically significant differences for stature and body weight. BMI was not statistically different. Differences in Reference and Source distributions influence the final match. Another source for Reference data is being investigated. As it stands, the bin signature method is a straightforward approach to matching. Up sampling low count bins with SMOTE data improves overall match sample size.

The Shape of the Future Warfighter: National Estimates from YouthShape.US

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Introduction

Fewer than 30% of U.S. young adults currently meet eligibility standards for military service, with excess body weight and inadequate physical fitness representing the most common disqualifiers. These challenges reflect long-term changes in growth, body composition, and physical activity, yet contemporary population-based data linking anthropometry with physical capability in youth remain limited. YouthShape.US was developed to address this gap by providing an integrated, publicly accessible resource characterizing body size, shape, strength, power, and activity patterns in U.S. children and adolescents. Because physical capability at accession age reflects cumulative developmental influences, such data are critical for anticipating the characteristics of near-term recruiting cohorts and informing training, equipment design, and injury-prevention strategies.

Methods

YouthShape.US is a multi-phase study of U.S. children and adolescents using standardized protocols to quantify anthropometry, body shape, and physical capability. The present analyses focus on participants aged 15–17 years, corresponding to near-term recruiting populations. Phase 1 involved comprehensive laboratory-based measurements, including manual anthropometry, whole-body 3D surface scans, grip strength, lower-extremity power, body composition, physical activity monitoring, and questionnaires. Phases 2 and 3 employ progressively streamlined protocols emphasizing a common core of manual anthropometry, whole-body 3D scanning, grip strength, body composition, and questionnaires to support demographic expansion and scalable data collection. Analyses focus on measures common across phases to enable aggregation and population-level interpretation, with selected Phase 1–only measures that are closely linked to physical fitness in prior work (e.g., vertical jump–derived lower-extremity power).

Results and Discussion

Results show substantial departures from legacy anthropometric references, particularly in upper quantile dimensions related to body mass and adiposity, consistent with national trends. YouthShape.US tracks contemporary population patterns in stature and body weight while providing substantially greater resolution in body shape, strength, and physical activity attributes directly relevant to military training demands, load carriage, and injury risk. By integrating anthropometry with functional measures, YouthShape.US offers an empirically grounded basis for estimating baseline physical fitness profiles of future recruiting-age populations. As later phases expand sample size and demographic coverage, the dataset will support forward-looking assessments of physical readiness, training margins, and equipment accommodation across military and other physically demanding occupations.

National Anthropometric Characterization of U.S. Firefighters: Implications for PPE Fit, Apparatus Design, and Safety Standards

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This study presents the first large-scale national anthropometric survey of U.S. firefighters conducted to modernize fire apparatus design and update national safety standards. A total of 951 firefighters were enrolled across four geographic regions (Rockville, MD; Phoenix, AZ; Philadelphia, PA; and Ft. Worth, TX), with findings from the first two sites (n = 474) reported herein. Participants were measured using a combination of traditional anthropometry and advanced digital methods to comprehensively characterize firefighter body dimensions, protective equipment fit, and seated spatial requirements relevant to apparatus cab and seat design.

Linear and vertical dimensions were collected using a FARO digitizing arm, while circumferences and breadths were obtained using tape measures and calipers. Three-dimensional (3D) surface scans of the head and right foot were acquired using surface scanning systems. Head scans were collected in three conditions—unencumbered, with helmet, and with face piece—allowing quantification of equipment–head spatial relationships. The right foot was scanned with and without the boot. Measurements were obtained in standing and seated postures, with and without full personal protective equipment (PPE), to directly inform equipment compatibility and apparatus configuration standards. Participants were also surveyed to document demographics and identify fit and usability concerns.

Summary statistics and multivariate analyses of seated dimensions revealed critical mismatches between legacy design assumptions and the dimensional requirements of modern firefighters in full PPE. The findings directly informed the revision of NFPA structural firefighting glove sizing standards, replacing outdated sizing models with updated population-based anthropometric data. Additionally, evidence from this study demonstrated that traditional four-across cab seating configurations did not adequately accommodate firefighters in PPE, contributing to an industry-wide shift toward safer three-across seating designs. Collectively, this work establishes an evidence-based foundation for firefighter safety standards, apparatus engineering, and protective equipment design nationwide.