Development of a Distributed Representative Human Model (DRHM) Generation and Analysis System for Multiple-Size Product Design

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Agenda

- Introduction
  - Background
  - Objective of the Study
- Literature Review
- System Development
- Application: Flight Suit Sizing System
- Discussion
Multiple-size product: \( n \) sizes to fit \( n \) groups of people within a designated percentage (e.g., 90\%) of the population (Winks, 1997; Ashdown, 2003; Jung et al., 2010)

⇒ Sizing system of multiple-size product: Need to be properly designed to accommodate the anthropometric characteristics of a target population
DRHMs: Human models chosen over a set of grids which accommodate a designated percentage (e.g., 90%) of the population in the distribution of anthropometric dimensions (Robinette and Annis, 1986; Kwon et al., 2009; Jung et al., 2010)

DRHM generation method: Grid method
(accommodation percentage = 90%)

⇒ Body sizes of DRHMs: Applied for the design and evaluation of a sizing system
DRHM Generation Methods & Limitations

- **DRHM generation method:** Form a set of grids to accommodate a designated percentage (e.g., 90%) of the target population (Jung et al., 2010)

- **Limitations:** (1) unavailability of computerized systems, (2) time demand, (3) complexity

  ⇒ Not easy to choose an optimal sizing system out of a variety of sizing system alternatives without computerized systems
Objectives of the Study

Development of a Distributed Representative Human Model (DRHM) Generation and Analysis System for Multiple-Size Product Design

1. Analyze the DRHM generation process and methods

2. Develop a computerized system for DRHM generation and analysis

3. Examine the effectiveness of the DRHM computerized system by applying to flight suit design
Jung et al. (2010) established the DRHM generation process and methods based on a comprehensive literature review.

**S1: Determination of key dimensions/factors**

- AD = anthropometric dimension, K = key dimension/factor

\[
AD_1 = f_1(K_1, K_2)
\]
\[
AD_2 = f_2(K_1, K_2)
\]
\[
\vdots
\]
\[
AD_n = f_n(K_1, K_2)
\]

**Method**

- Regression analysis (RA)
- Factor analysis (FA)
- Principal component analysis (PCA)
- Grid method
- Clustering method
- Optimization method
- Estimated case
- Real case
## DRHM Generation: Methods

<table>
<thead>
<tr>
<th>Method</th>
<th>Grid</th>
<th>Clustering</th>
<th>Optimization</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Illustration</strong></td>
<td><img src="image1.png" alt="Grid Illustration" /></td>
<td><img src="image2.png" alt="Cluster Illustration" /></td>
<td><img src="image3.png" alt="Optimization Illustration" /></td>
</tr>
</tbody>
</table>
| **Studies** | • Robinette and Annis (1986)  
• Rosenblad-Wallin (1987)  
• Moon (2002)  
• Kwon et al. (2004)  
• Zheng et al. (2007) | • Laing et al. (1999) | • McCulloch et al. (1998) |
| **Formation method of grids/clusters** | • Generate grids which accommodate a designate percentage of the target population | • Generate clusters using $K$-means cluster analysis | • Generate grids applying the Nelder-Mead optimization algorithm |
| **Parameters** | • Design fitting tolerance  
• Accommodation percentage | • Number of clusters ($K$) referring to within- and between-cluster average distances | • Loss score  
• Accommodation percentage |
System Development
System Features

F1. Procedural interface of DRHM generation

F2. Sophisticated input and output interfaces in one panel

F3. Interoperation with anthropometric databases
Procedural Interface for DRHM Generation

S1. Selection of target population

S2. Selection of anthropometric variable

S3. Determination of key dimensions/factors

S4. Selection of DRHM generation method

S5. Determination of DRHMs’ body sizes
S1. Selection of **Target Population**

- Select an anthropometric database and form a target population.

<table>
<thead>
<tr>
<th>Database</th>
<th>US Army</th>
<th>US Army Pilot</th>
<th>Korean Pilot</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year disseminated</td>
<td>1988</td>
<td>1988</td>
<td>2007</td>
</tr>
<tr>
<td>Sample size (n)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>2,208</td>
<td>334</td>
<td>-</td>
</tr>
<tr>
<td>Male</td>
<td>1,774</td>
<td>487</td>
<td>1,237</td>
</tr>
<tr>
<td>Total</td>
<td>3,982</td>
<td>821</td>
<td>1,237</td>
</tr>
<tr>
<td>Range of age</td>
<td>10s ~ 40s</td>
<td>20s ~ 40s</td>
<td>20s ~ 40s</td>
</tr>
</tbody>
</table>

- Distribution of Key Dimensions:
  - Age groups: 10s, 20s, 30s, 40s
  - Gender: Female, Male

- Target Population:
  - Gender: Composite (F:M = 70:30)
  - Age: 2 groups (10s, 20s, 30s, 40s)
  - Ratio (%): Female 60, Male 40
  - Sample size (n): Total 3,982

- Target Anthropometric Variables:
  - Distributed RHM Generation
  - Key Dimensions: Regression Analysis, Factor Analysis, Principal Component Analysis, Determination of Distributed Method, Grid (Robinette and Annis, 1998), Clustering (Laine et al., 1998), Optimization (McCulloch et al., 1998), Determination of Body Sizes of RMHs, Estimated Case, Real Case

- Group Analysis:
  - Group 1: Female 742, Male 318, Total 1060
  - Group 2: Female 495, Male 212, Total 707
  - Group 3: Female 0, Male 0, Total 0
  - Group 4: Female 0, Male 0, Total 0
  - Total: Female 1,237, Male 530, Total 1,767

- Distribution: 70% Female, 30% Male

- Ergonomic Design Technology Lab
S2. Selection of **Anthropometric Variable**

- Provide a hierarchical interface for systematic and efficient search of anthropometric variables (You et al., 2004)

<table>
<thead>
<tr>
<th>Target Population</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender: Male/Female</td>
</tr>
<tr>
<td>Age: 10s, 20s, 30s, 40s</td>
</tr>
<tr>
<td>Flato (%)</td>
</tr>
</tbody>
</table>

**Anthropometric databases**

<table>
<thead>
<tr>
<th></th>
<th>US Army</th>
<th>US Army Pilot</th>
<th>Korean Pilot</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of AVs</td>
<td>132</td>
<td>132</td>
<td>16</td>
</tr>
</tbody>
</table>

- e.g., selection of chest circumference

![Diagram showing anthropometric variables and a hierarchical interface for systematic and efficient search of anthropometric variables](image)
S3. Selection of Key Dimension: User-Defined

- Determine key dimensions directly by a user’s preliminary knowledge

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**Target Population**

- Gender:
  - Female
  - Male
- Composite (%): F : M = 20 : 30
- Age:
  - Number of Age Groups: 2
- 10s
- 20s
- 30s
- 40s
- 50s
- Ratio (%): 60 : 40

**Target Anthropometric Variables**

**Distributed RH M Generation**

- S1. Extraction of Key Dimensions
  - Analysis
  - User-defined
- S2. Determination of Distributed Method
  - Grid (Robinetts and Annis, 1985)
  - Clustering (Lauing et al., 1993)
  - Optimization (McCulloch et al., 1993)
- S3. Determination of Body Sizes of RHMs
  - Estimated Case
  - Real Case

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**User-defined Key Dimensions (Select 2 – 5 variables)**

- Ankle Circumference: Circumference, Foot/Ankle, Leg/Foot
- Buttock Circumference: Circumference, Upper Leg/Hip, Leg/Foot

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**Note:**

- e.g., # anthropometric variables = 9
S3. Selection of **Key Dimension: Regression Analysis**

- Determine key dimensions by referring to increase in average adjusted $R^2$ by # key dimensions

<table>
<thead>
<tr>
<th>Target Population</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender: Male, Female</td>
</tr>
<tr>
<td>Composite: F:M = 30:30</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Age Groups: 2</td>
</tr>
<tr>
<td>10s</td>
</tr>
<tr>
<td>No</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Fisio (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>60%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Target Anthropometric Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1. Extraction of Key Dimensions</td>
</tr>
<tr>
<td>Analysis</td>
</tr>
<tr>
<td>Regression Analysis (RA)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Distributed HMM Generation</th>
</tr>
</thead>
<tbody>
<tr>
<td>S2. Determination of Distributed Method</td>
</tr>
<tr>
<td>Grid (Robinettes and Annis, 1996)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>S3. Determination of Body Sizes of HMMs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Estimated Case</td>
</tr>
</tbody>
</table>

Select # key dimensions referring to increase in average adj. $R^2$

Provide adj. $R^2$ between key dimension candidates and other dimensions in descending order for quick search of key dimensions with high performance

E.g., # anthropometric variables = 7

Average adj. $R^2$
S3. Selection of Key Factor: Factor Analysis

- Determine key factors by referring to eigenvalue and cumulative percent variability.
S3. Selection of Key Factor: Principal Component Analysis

- Refer to eigenvalue and cumulative percent variability
e.g., # key dimensions = 3

Eigenvalue > 1 or cumulative percent variability > 80%
(Latin, 2003)
S4. Selection of DRHM Generation Method: Grid

- Set **fitting tolerance** (size of a grid) and **accommodation percentage**

**Key dimensions**

1. **Target accommodation rate**: accommodation rate of all grids > 95%
2. **Minimum presence rate**: accommodation rate of each grid > 2%

**Descriptive statistics of key dimensions**

- # key dimensions = 2

**Fitting tolerance**
S4. Selection of DRHM Generation Method: Clustering

- Determine the number of DRHMs referring to within- & between-cluster distance plots.

Within-cluster homogeneity $\uparrow$

Between-clusters heterogeneity $\uparrow$

Target Population
- Gender: Female, Male
- Age: 10s, 20s, 30s, 40s
- Ratio (%): 60:40

Distributed RHDM Generation
- S1. Extraction of Key Dimensions
  - Analysis
  - User-defined
  - Regression Analysis (RA)
  - Factor Analysis (FA)
  - Principal Component Analysis (PCA)
- S2. Determination of Distributed Method
  - Grid (Robinetta and Annis, 1998)
  - Clustering (Laih et al., 1998)
  - Optimization (McCulloch et al., 1998)
- S3. Determination of Body Sizes of RHDMs
  - Estimated Case
  - Real Case

Clustering Method
- Number of clusters: 15

15 clusters: recommended
S4. Selection of DRHM Generation Method: Optimization

- Set the number of DRHMs with the target accommodation percentage

\[ \min \sum_{i=1}^{n} l(p_i)k_i + l(c_a)(1-k_i) \]

\[ k_i = \begin{cases} 
1 & \text{if } l(p_i) < l(c_a) \text{ where } l(p_i) \\
0 & \text{o/w} 
\end{cases} \]

\[ d(x_i, y_j) = \sum_{j=1}^{k} [d(x_{i,j}, y_{j})]^2 \]

\[ d(x_{i,j}, y_{j}) = \begin{cases} 
(y_{j} - x_{i,j}) & \text{if } x_{i,j} \leq y_{j} \\
(x_{i,j} - y_{j}) & \text{if } x_{i,j} > y_{j} 
\end{cases} \]

where:  
- \( n \) = number of the target population, 
- \( l(p_i) \) = loss score of person \( i \), 
- \( l(c_a) \) = loss cutoff to determine whether a person is accommodated or not, 
- \( d(x_{i,j}, y_{j}) \) = distance between person \( i \) and its nearest grid, 
- \( k \) = number of key dimensions, 
- \( x_{i,j} \) = body size of key dimension \( j \) of person \( i \), and 
- \( y_{j} \) = centroid of the nearest grid \( s \) in key dimension \( j \).

\[ l(p(x_k)) \leq l(c_x) \leq l(p(x_m)) \]
S5. Determination of Body Sizes of DRHMs

- Select a body sized determination method

<table>
<thead>
<tr>
<th>Target Population</th>
</tr>
</thead>
<tbody>
<tr>
<td>Database: US Army (1980)</td>
</tr>
<tr>
<td>Number of Age Groups:</td>
</tr>
<tr>
<td>Ages: 10s, 20s, 30s, 40s</td>
</tr>
<tr>
<td>Fitness (%): 60, 40</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Target Anthropometric Variables</th>
</tr>
</thead>
</table>

**Distributed RHM Generation**
- S1. Extraction of Key Dimensions
  - Analysis, User-defined
  - Regression Analysis (RA), Factor Analysis (FA), Principal Component Analysis (PCA)
- S2. Determination of Distributed Method
  - Grid (Robinet and Annis, 1995)
  - Clustering (Lains et al., 1993)
  - Optimization (McCulloch et al., 1998)
- S3. Determination of Body Sizes of RHMs
  - Estimated Case, Real Case

**Diagram**
- **Estimated case**
  - Centroid: Finding an object \( i \) located geometric center in a grid
- **Real case**
  - Medoid: Finding an object \( i \) whose average distance is the closest in a grid
Specialized DRHM Analysis

R1: DRHMs’ body sizes
R2: Multivariate accommodation percentage (MAP)
R3: DRHM Plot
R4: Additional Info.
1. **Body Sizes of DRHMs**

- Provide generated DRHMs’ body sizes by anthropometric variable

- Example: # DRHMs = 20, # anthropometric variables = 13

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1359.9</td>
<td>899.8</td>
<td>356.6</td>
<td>952.0</td>
<td>877.2</td>
<td>377.5</td>
<td>347.7</td>
<td>527.7</td>
<td>1577.9</td>
<td>359.6</td>
</tr>
<tr>
<td>2</td>
<td>1484.2</td>
<td>841.4</td>
<td>373.4</td>
<td>925.1</td>
<td>859.5</td>
<td>380.0</td>
<td>343.5</td>
<td>581.4</td>
<td>1713.4</td>
<td>389.7</td>
</tr>
<tr>
<td>3</td>
<td>1455.2</td>
<td>899.7</td>
<td>373.2</td>
<td>955.5</td>
<td>902.2</td>
<td>385.2</td>
<td>357.7</td>
<td>569.2</td>
<td>1681.5</td>
<td>384.0</td>
</tr>
<tr>
<td>4</td>
<td>1443.4</td>
<td>952.5</td>
<td>375.5</td>
<td>983.5</td>
<td>944.7</td>
<td>391.1</td>
<td>372.1</td>
<td>564.5</td>
<td>1668.4</td>
<td>382.6</td>
</tr>
<tr>
<td>5</td>
<td>1316.1</td>
<td>986.8</td>
<td>366.1</td>
<td>997.3</td>
<td>940.8</td>
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<td>368.9</td>
<td>509.3</td>
<td>1529.9</td>
<td>351.0</td>
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<tr>
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<td>1054.1</td>
<td>380.0</td>
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<td>1026.7</td>
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<td>399.9</td>
<td>555.7</td>
<td>1644.3</td>
<td>380.1</td>
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<td>7</td>
<td>1390.5</td>
<td>970.9</td>
<td>367.8</td>
<td>991.5</td>
<td>946.7</td>
<td>389.2</td>
<td>372.0</td>
<td>541.6</td>
<td>1610.8</td>
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<tr>
<td>8</td>
<td>1626.4</td>
<td>996.0</td>
<td>410.9</td>
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<td>1030.4</td>
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<td>404.2</td>
<td>644.3</td>
<td>1867.0</td>
<td>430.8</td>
</tr>
<tr>
<td>9</td>
<td>1408.1</td>
<td>903.7</td>
<td>365.3</td>
<td>955.9</td>
<td>893.2</td>
<td>381.9</td>
<td>353.9</td>
<td>548.7</td>
<td>1630.3</td>
<td>372.0</td>
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<td>1049.3</td>
<td>403.2</td>
<td>1039.9</td>
<td>1058.2</td>
<td>412.9</td>
<td>412.7</td>
<td>614.7</td>
<td>1791.6</td>
<td>414.7</td>
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<td>11</td>
<td>1413.2</td>
<td>842.3</td>
<td>361.1</td>
<td>923.0</td>
<td>841.5</td>
<td>374.4</td>
<td>336.3</td>
<td>550.5</td>
<td>1636.2</td>
<td>371.5</td>
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<tr>
<td>12</td>
<td>1619.6</td>
<td>1111.8</td>
<td>419.2</td>
<td>1075.9</td>
<td>1128.6</td>
<td>426.1</td>
<td>437.8</td>
<td>642.2</td>
<td>1859.1</td>
<td>432.6</td>
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<tr>
<td>13</td>
<td>1535.8</td>
<td>1002.8</td>
<td>395.7</td>
<td>1014.0</td>
<td>1012.4</td>
<td>405.2</td>
<td>396.7</td>
<td>605.0</td>
<td>1768.6</td>
<td>407.8</td>
</tr>
</tbody>
</table>
R2. Multivariate Accommodation Percentage

- Provide multivariate accommodation percentages (average, SD, median, minimum, and maximum) by the number of anthropometric variables

  e.g., # anthropometric variables = 13

**Analysis of Multivariate Accommodation Percentages (MAPs)**

<table>
<thead>
<tr>
<th>For key dimensions: 95.2 %</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAPs for the different number of anthropometric variables</td>
</tr>
</tbody>
</table>

Average of accommodation percentages of 78 cases \( \binom{13}{2} \)
R3. DRHM Plot

- Provide plot of DRHMs on the grid in the distribution of key dimensions/factors by the DRHM generation method.

**Grid method**

- Generated grid
- DRHM

**Clustering method**

- Automatic color coding for different clusters

**Optimization method**
Provide population information, regression equations for RA, and factor/principal component loadings and scores for FA/PCA

- Example regression equation for Overhead Reach:

  \[ \text{Overhead Reach} = 10.848 - 0.889 \times \text{Sitting Height} + 1.723 \times \text{Stature} \]

  \( \Rightarrow \) Overhead reach estimation equation by key dimensions
Design Application
Establish an optimal men’s sizing system for flight suit design

Target population & anthropometric variables

- US Army male pilots ($n = 485$; Gordon et al., 1998)
- 13 anthropometric variables for flight suit design (Jeon et al., 2009)

<table>
<thead>
<tr>
<th>Major class</th>
<th>Sub class</th>
<th>Measurement type</th>
<th>Anthropometric variable (AV)</th>
<th>Code</th>
<th>Descriptive statistics (unit: mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Mean</td>
</tr>
<tr>
<td>Trunk</td>
<td>Chest</td>
<td>Width</td>
<td>Biacromial breadth</td>
<td>AV1</td>
<td>400.6</td>
</tr>
<tr>
<td>Leg/Foot</td>
<td>Upper Leg/ Hip</td>
<td>Circumference</td>
<td>Buttock circumference</td>
<td>AV2</td>
<td>991.5</td>
</tr>
<tr>
<td>Head/Neck</td>
<td>Neck</td>
<td>Height</td>
<td>Cervical height</td>
<td>AV3</td>
<td>1531.8</td>
</tr>
<tr>
<td>Trunk</td>
<td>Chest</td>
<td>Circumference</td>
<td>Chest circumference</td>
<td>AV4</td>
<td>1009.2</td>
</tr>
<tr>
<td>Trunk</td>
<td>Chest</td>
<td>Circumference</td>
<td>Chest circumference – at scye</td>
<td>AV5</td>
<td>1035.8</td>
</tr>
<tr>
<td>Trunk</td>
<td>Combined</td>
<td>Length</td>
<td>Crotch length</td>
<td>AV6</td>
<td>772.0</td>
</tr>
<tr>
<td>Trunk</td>
<td>Back</td>
<td>Length</td>
<td>Interscyte distance</td>
<td>AV7</td>
<td>408.7</td>
</tr>
<tr>
<td>Arm/Hand</td>
<td>Combined</td>
<td>Length</td>
<td>Sleeve outseam</td>
<td>AV8</td>
<td>601.4</td>
</tr>
<tr>
<td>Overall</td>
<td>-</td>
<td>Height</td>
<td>Stature</td>
<td>AV9</td>
<td>1771.0</td>
</tr>
<tr>
<td>Trunk</td>
<td>Back</td>
<td>Length</td>
<td>Waist back length</td>
<td>AV10</td>
<td>421.6</td>
</tr>
<tr>
<td>Trunk</td>
<td>Abdomen</td>
<td>Circumference</td>
<td>Waist circumference</td>
<td>AV11</td>
<td>856.4</td>
</tr>
<tr>
<td>Trunk</td>
<td>Abdomen</td>
<td>Height</td>
<td>Waist height</td>
<td>AV12</td>
<td>1131.4</td>
</tr>
<tr>
<td>Leg/Foot</td>
<td>Upper Leg/ Hip</td>
<td>Length</td>
<td>Waist hip length</td>
<td>AV13</td>
<td>184.0</td>
</tr>
</tbody>
</table>
Decision Tree: 18 Sizing System Alternatives

S3. Determination of key dimensions/factors
S4. Application of DRHM generation method
S5. Determination of body sizes

Coded Sizing System

R-G-E
R-G-R
R-C-E
R-C-R
R-O-E
R-O-R
F-G-E
F-G-R
F-C-E
F-C-R
F-O-E
F-O-R
P-G-E
P-G-R
P-C-E
P-C-R
P-O-E
P-O-R
## Analysis Method: Measure

- **Number of generated DRHMs**
- **Key dimensions:** accommodation percentage (AP; %)
- **Non-key dimensions**
  - Cover ratio (%)
  - Number of outlier DRHMs

### Non-key dimensions

- **Cover ratio (%)**
- **Number of outlier DRHMs**

### Cover ratio

\[
\text{Cover ratio} = \left( \frac{2101.9}{2593.0} \right) \times 100 = 81.0\% 
\]

### Number of outlier DRHMs

- Number of generated DRHMs = 26
- Number of outlier DRHMs = 2

### Anthropometric variables

<table>
<thead>
<tr>
<th>No.</th>
<th>Anthropometric variable</th>
<th>Original dimensions</th>
<th>Generate DRHM’s dimensions</th>
<th>Generated DRHM’s dimensions</th>
<th>Outlier dimensions</th>
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<tr>
<td></td>
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<td>Min Max Range</td>
<td>Min Max</td>
<td>Covered Range</td>
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<td>1</td>
<td>Biacromial breadth</td>
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<td>2</td>
<td>Buttock circumference</td>
<td>849.0 1200.0 351.0</td>
<td>879.9 1132.5 252.6</td>
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<tr>
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<td>Chest circumference – at syce</td>
<td>894.0 1203.0 309.0</td>
<td>937.0 1183.0 246.0</td>
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<td>Crotch length</td>
<td>314.0 467.0 153.0</td>
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<td>Interscye distance</td>
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<td>Sleeve outseam</td>
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<td>Waist back length</td>
<td>363.0 493.0 130.0</td>
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<td>Waist circumference</td>
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<td>Waist hip length</td>
<td>122.0 240.0 118.0</td>
<td>127.1 229.4 102.3</td>
<td>155.2 157.4</td>
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</tbody>
</table>

### Total

- Cover ratio = (2101.9/2593.0) × 100 = 81.0%
- Number of outlier DRHMs = 2
Comparison of Sizing Systems

- **Total calculation time of generating 18 sizing systems** ≈ 2 hrs

<table>
<thead>
<tr>
<th>No.</th>
<th>Sizing System</th>
<th>Accommodation percentage for key dimensions (%)</th>
<th>Number of generated DRHMs</th>
<th>Non-key dimensions</th>
<th>Cover ratio (%)</th>
<th>Number of outlier DRHMs</th>
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<td>P-O-R</td>
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</table>

: controlled value
Optimal Sizing System

⇒ Candidates: P-C-E (22 sizes; 59%) vs. P-O-E (25 sizes; 69%)
⇒ Economical sizing system: P-C-E (less than # sizes of P-O-E)
Discussion (1/2)

- Developed a computerized system for DRHM generation and analysis by incorporating the DRHM generation process and methods.

⇒ Can save time and effort in establishing a desirable sizing system.
Discussion (2/2)

- Developed sophisticated interfaces incorporating complex and various algorithms for DRHM generation

⇒ Helpful for identifying an optimal sizing system out of sizing system alternatives easily and efficiently
Thank You 😊
APPENDIX
Demonstration: RA – Grid – Estimated Case
Generation Method

**S3. Extraction of key dimensions**
- RA
  - Grid
  - Clustering
  - Optimization
  - Fitting tolerance = 50 mm
  - Accommodation rate = 95%

**S4. Determination of distributed method**
- FA
  - Grid
  - Clustering
  - Optimization
  - Number of iterations = 1,000
  - Fitting tolerance = 2.35*

- PCA
  - Grid
  - Clustering
  - Optimization
  - Number of iterations = 1,000
  - Fitting tolerance = 3.32*

Random initial solution
- Clustering
- Optimization
- Number of trials = 10
- Find the minimum number of DRHMs

---

**Factor scores**

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<tr>
<th>No.</th>
<th>F1</th>
<th>F2</th>
<th>F3</th>
<th>F4</th>
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<td>1.115</td>
<td>-0.689</td>
<td>-1.155</td>
<td>-0.834</td>
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<td>1.975</td>
<td>1.278</td>
<td>0.164</td>
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<td>-0.331</td>
<td>-1.414</td>
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<td>-0.071</td>
<td>-0.827</td>
<td>-1.313</td>
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<td>8</td>
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<td>-0.520</td>
<td>-0.663</td>
<td>0.857</td>
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<tr>
<td>9</td>
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<td>0.527</td>
<td>-0.165</td>
<td>-1.025</td>
<td>2.028</td>
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</table>

**Descriptive statistics**

- **Mean**: F1: 0.0, F2: 0.0, F3: 0.0, F4: 0.0
- **S.D.**: F1: 1.0, F2: 1.0, F3: 1.0, F4: 1.1
- **Minimum**: F1: -2.7, F2: -2.6, F3: -3.5, F4: -3.7
- **Maximum**: F1: 2.5, F2: 3.2, F3: 2.9, F4: 3.7
- **Range (Max - Min)**: F1: 5.2, F2: 5.9, F3: 6.4, F4: 7.4
- **1st percentile**: F1: -2.7, F2: -2.6, F3: -3.5, F4: -3.7
- **99th percentile**: F1: 2.5, F2: 3.2, F3: 2.8, F4: 3.7
- **1-99 percentile range**: F1: 5.1, F2: 5.8, F3: 6.3, F4: 7.3

*equivalent to 50 mm of R-G’s fitting tolerance
Key Dimensions for Flight Suit Design

- Chest circumference and Stature considering both performance (average adjusted $R^2$ with other dimensions = 0.574; current key dimensions) and usability
Comparison of Sizing Systems: Average of MAPs

<table>
<thead>
<tr>
<th>No.</th>
<th>Sizing System</th>
<th>Generated number of DRHMs</th>
<th>Number of anthropometric variables</th>
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<tr>
<td>1</td>
<td>R-G-E</td>
<td>29</td>
<td>1   2   3   4   5   6   7   8   9   10  11  12  13</td>
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<tr>
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<td>98.7 90.7 76.8 61.7 48.3 37.5 29.2 23.0 18.4 15.1 12.6 10.7 9.3</td>
</tr>
<tr>
<td>2</td>
<td>R-G-R</td>
<td></td>
<td>98.9 91.3 77.6 62.3 48.5 37.2 28.6 22.1 17.4 13.9 11.4 9.5 8.0</td>
</tr>
<tr>
<td>3</td>
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<td>99.1 92.4 80.4 66.7 53.8 42.8 33.9 26.9 21.4 17.3 14.0 11.5 9.5</td>
</tr>
<tr>
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<td>93.0 78.0 59.9 43.9 31.6 22.8 16.6 12.4 9.5 7.4 5.9 4.7 3.9</td>
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<td>87.1 68.3 51.6 38.4 28.7 21.6 16.5 12.9 10.2 8.3 6.8 5.7 4.7</td>
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<td>86.7 69.5 53.5 40.4 30.3 22.8 17.3 13.1 10.0 7.5 5.7 4.2 3.1</td>
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<td>99.6 92.4 70.5 45.4 27.3 16.5 10.4 6.9 4.9 3.6 2.8 2.3 1.9</td>
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<td>98.3 91.7 78.3 61.2 45.1 32.4 23.3 17.1 12.8 9.8 7.7 6.1 4.9</td>
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<td>22</td>
<td>98.2 90.4 76.8 61.2 47.0 35.6 27.1 20.9 16.3 13.0 10.5 8.7 7.2</td>
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<td>16</td>
<td>P-C-R</td>
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<td>98.4 89.7 75.3 59.4 45.3 34.0 25.6 19.4 14.8 11.4 8.7 6.7 4.9</td>
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<td>P-O-E</td>
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<td>98.6 91.5 77.9 61.9 47.2 35.3 26.5 20.1 15.5 12.2 9.7 7.9 6.4</td>
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<td>99.1 91.6 77.1 60.3 45.3 33.5 24.8 18.7 14.3 11.0 8.6 6.7 5.2</td>
</tr>
</tbody>
</table>
**Follow-Up Studies**

- Development of (1) a boundary representative human model (BRHM) generation and analysis system for one-size product design and (2) a linkage with the custom-built interface of digital human model simulation systems.

**Distributed RHM**
- Body sizes

**Boundary RHM**
- Body sizes

**Automatic inputting**

**RAMSIS®**

**Jack®**

**Multiple-size product** (e.g., clothing, gloves)

**One-size product** (e.g., cockpit, seat)

**Reach**
- Comfort
- Visibility
- Clearance