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Dutch anthropometry for vehicle design and evaluation

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Nederlandse antropometrie voor voertuigontwerp en -evaluaties

Probleemstelling

Thans staan we aan de vooravond van een omvangrijk project genaamd 'Project defensiebrede vervanging operationele wielvoertuigen'. De DMO heeft TNO Defensie en Veiligheid gevraagd om een document op te stellen met ergonomische eisen voor de operationele wielvoertuigen. Het project werd gefinancierd vanuit additionele middelen.

Beschrijving van de werkzaamheden

Uitgaande van afmetingen van Nederlanders zijn grenswaarden voor negen paspoppen, met variërende lichaamsafmetingen en lichaamsverhoudingen, berekend. Daarnaast zijn comforthoeken, toeslagen voor kleding en benodigde vrije lichaamsruimte vastgesteld voor het jaar 2015. Hierbij is uitgegaan van een Nederlands antropometrisch bestand (NedScan).

Resultaten en conclusies

Het resultaat is een kort rapport met ergonomische eisen voor het ontwerp en evaluatie van voertuigen.

Toepasbaarheid

Het resultaat zal worden toegepast, door de KL, TNO en de industrie om de ergonomische kwaliteit van kandidaat-voertuigen te toetsen.

PROGRAMMA	PROJECT
Programmabegeleider -	Projectbegeleider maj ir. M.J.W. van Opstal, KL, DMO
Programmaleider -	Projectleider ir. S.A. van Merrienboer, Operationele Analyse
Programmatitel -	Projecttitel Ondersteuning Project defensiebrede vervanging operationele wielvoertuigen
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Samenvatting

Dit document omschrijft de Nederlandse antropometrie voor ontwerp en evaluatie van voertuigen. Hiervoor zijn grenswaarden voor negen paspoppen, met variërende lichaamsafmetingen en lichaamsverhoudingen, vastgesteld voor het jaar 2015.
Hierbij is uitgegaan van een Nederlands antropometrisch bestand (NedScan) en van lichaamsafmetingen van goedgekeurde KL rekruten.
De grenswaarden omvatten 95% van dat Nederlandse bestand, uitgaande van een leeftijdsgroep van 20 tot en met 40 jaar gecorrigeerd voor KL rekruten. Bovendien zijn toeslagen op lichaamsafmetingen beschreven, om rekening te houden met kleding en uitrusting. Naast de bovengenoemde afmetingen zijn ook comforthoeken beschreven om houdingscomfort van voertuigen te kunnen toetsen. Het rapport sluit af met een korte omschrijving van methodes om voertuigen te toetsen op hun geschiktheid voor de negen paspoppen.

Summary

This document describes Dutch anthropometry for application in design and evaluation of vehicles. As such, nine boundary cases, ranging in body dimensions (size and proportion), were defined based on Dutch anthropometry (NedScan) and bodydimensions for Dutch Army recruits. A level of 95% accommodation was used to define the targeted Dutch vehicle population. Furthermore, the secular trend of body size (stature) acceleration was used to define a set of future test cases which represents a Dutch vehicle population for the year 2015, valid for ages between 20 to 40 years corrected for Dutch Army recruits. For various design applications the nine Dutch Anthropometric cases were seated in digital vehicles and manipulated into various postures. In order to assure an acceptable level of comfort, minimum postural angles of comfort are defined and related to various vehicle types (e.g. trucks, vans and cars). In addition, increases to body dimensions are offered to account for various types of protective gear and clothing. Finally, the last section of this report is a general discussion of methods used to verify that the vehicles accommodate the target working population.

Contents

1 Introduction

This document describes Dutch anthropometry with application to design and evaluation of vehicles. Topics for this document are:

- The Dutch anthropometry and definition of test cases for the 'nude' human body. The baseline chosen for this document is a target accommodation of 95% of the young Dutch population.
- The anthropometry of Dutch Army recruits.
- The angles of minimum comfort to be addressed for the accommodation of personnel (driver and passengers) in various vehicle types (e.g. trucks, vans and cars).
- Increased dimensions to the 'nude' human body to account for apparel, protective gear, etcetera.
- Testing procedures/techniques used to show that the vehicles accommodate the target working population.

2 Dutch anthropometry

Today, several standards define anthropometry for design and evaluation: SAE (SAE J833) defines human basic dimensions for a world population and the Dutch recommended practice NEN 5518 (2000) for the Dutch population of 2000. Still, there is a need to focus on Dutch anthropometry for the design an evaluation of vehicles, when purchasing for the years to come. The reason for this is that the current and expected population for 2015 will differ in size and clothing from those defined in the previous mentioned standards. Therefore, nine representative cases were defined, for the Dutch population in 2015, for the design and evaluation of vehicles (see Table 1).
The application of these nine multivariate boundary cases are key to ensuring overall vehicle accommodation (both driver and passenger) for the median 95% of eligible Dutch military candidates (see section below). The anthropometric dimensions for the vehicle population were selected in a manner consistent with the analytical approach defined by Zehner (1996) and Meindl (1993). The methods of Meindl and Zehner were originally used to define the pilot cases for the JPATS (the USAF pilot trainer, Joint Primary Aircraft Training System) and the F35 (or the Joint Strike Fighter, JSF). This method constructs cases using principal component analysis (PCA: used as a data reduction procedure for the purpose of constructing accommodation limits for populations. This method was also used to define the Dutch vehicle population. Only, here the Dutch dataset (called NedScan) coming from the CEASAR project, as described by Daanen and Robinette (2001), was used. Another difference was that the NedScan database had to be filtered, using the criterion age, in order to create a dataset based on eligible Dutch military candidates. Only subjects between 20-40 years of age were used for the vehicle dataset. As such, a baseline Dutch vehicle population, for the year 2000 was defined for ages ranging from 20 to 40.

The aim of this document is to define anthropometric criteria for the near future, the year 2015. A two step extrapolation was carried out in order to get the desired data for this target year. The 2000 baseline Dutch population for vehicles was extrapolated following the methods used earlier by Werkhoven (1996) and Oudenhuijzen (1997) for the year 2006 for the first step. For the second step, the most recent data on the secular trend of acceleration were plotted (see Figure 1). It is apparent that the secular trend decreased for males and females in the year 2006: the yearly secular trend decreased to 0.4 mm. This newly found secular trend was used to extrapolate the extrapolated data for 2006 to the targeted year 2015 in the second step. This resulted in a set of anthropometric criteria ensuring optimal future accommodation of personnel.
The resulting 2015 Dutch vehicle population is shown in Table 1.

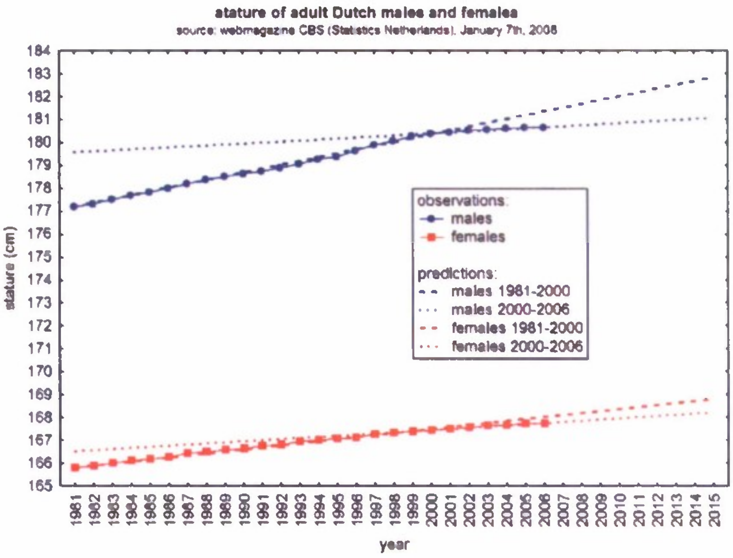

Figure 1 The secular trend of acceleration for Dutch males and females for 1981 until 2015 (dimensions are given in cm).

Table 1 The 2015 Dutch population, in nine cases, for various body sizes (dimensions in mm).

Females 2015		CASE 1 Case B Small Long limbs	CASE 2 Case D Small Long Torso	CASE 3 Case X Medium long limbs	CASE 4 Case Z Medium Long torso
Thumb Tip Reach		729	672	796	715
Buttock-knee Length		591	542	647	578
Knee-height Sitting		495	458	546	492
Sitting Height		821	868	868	934
Bust Chest Circumference		977	854	1051	877
Eye Height Sitting		710	760	752	823
Shoulder Height Sitting (acromial height)		532	574	569	627
Calculated Stature		*1593*	*1556*	*1724*	*1688*
Males 2015	CASE 1 Case X Medium Long limbs	CASE 2 Case Z Medium Long Torso	CASE 3 Case A Large Long limbs	CASE 4 Case C Large Long torso	CASE 5 Case W Overall large
Thumb Tip Reach	877	786	932	868	928
Buttock-knee Length	690	598	726	661	714
Knee-height Sitting	596	537	637	596	637
Sitting Height	917	1000	994	1053	1050
Bust Chest Circumference	982	971	1037	1029	1057
Eye Height Sitting	795	883	870	932	927
Shoulder Height Sitting (acromial height)	603	667	667	712	712
Calculated Stature	*1871*	*1815*	*2006*	*1967*	*2046*

3 Differences in anthropometry between the Dutch population and Dutch Army recruits

The NedScan population (see Section 1) was compared with an anthropometric dataset for Dutch Army recruits, in order to investigate potential differences between these two populations. This was done for stature since data available on Dutch Army recruits only involve stature (see Table 2).

Table 2 A comparison between the NedScan and Dutch army recruits for stature.

		males		females	
	All dimensions in cm	NedScan 1999	Dutch Army recruits 2006	NedScan 1999	Dutch Army recruits 2006
Age 20 – 40	N	267	3126	365	592
	Mean	183.2	181.2	169.7	169.2
	Std. Dev.	8.1	7.1	7.6	6.7
	P01	167.3	164.5	151.1	153.0
	P05	171.0	170.0	157.2	159.0
	P10	172.6	172.0	159.7	161.0
	P50 (median)	182.7	181.0	169.9	169.0
	P90	194.0	190.0	178.7	178.0
	P95	197.1	193.0	182.0	181.0
	P99	204.6	198.0	187.4	188.0

The following can be concluded from Table 2[1].

1 The differences between NedScan and Dutch Army recruits are very small for females and can be neglected.
2 The mean (and std. dev.) stature of the NedScan population is significantly taller compared to Dutch Army recruits.

These differences may be the result of:

1 a self filtering mechanism for recruits: tall people are aware of possible fit problems;
2 lower education for recruits: it is well known that lower educated people are smaller than higher educated people.

It is necessary to correct the NedScan cases in order to derive the Dutch Army cases, because of the difference for stature found between both populations for males.
This correction poses a small challenge: data available on Dutch Army recruits only involve stature. In order to correct the NedScan cases, we made the assumption that the body proportions are similar for both NedScan and Dutch Army recruits. As a result, it is possible to reduce all anthropometric dimensions with one factor: mean average stature for Dutch Army male recruits divided by mean average male stature for NedScan. The resulting corrected cases can be found in Table 3.

[1] The NedScan data are not corrected for the secular trend in Table 2.

Table 3 The 2015 Dutch Army population in 9 cases for various body dimensions (dimensions in mm).

Females 2015		CASE 1 Case B Small Long limbs	CASE 2 Case D Small Long Torso	CASE 3 Case X Medium long limbs	CASE 4 Case Z Medium Long torso
Thumb Tip Reach		729	672	796	715
Buttock-knee Length		591	542	647	578
Knee-height Sitting		495	458	546	492
Sitting Height		821	868	868	934
Bust Chest Circumference		977	854	1051	877
Eye Height Sitting		710	760	752	823
Shoulder Height Sitting (acromial height)		532	574	569	627
Calculated Stature		*1593*	*1556*	*1724*	*1688*
Males 2015	CASE 1 Case X Medium Long limbs	CASE 2 Case Z Medium Long Torso	CASE 3 Case A Large Long limbs	CASE 4 Case C Large Long torso	CASE 5 Case W Overall large
Thumb Tip Reach	867	777	922	859	918
Buttock-knee Length	682	591	718	654	706
Knee-height Sitting	589	531	630	589	630
Sitting Height	907	989	983	1042	1039
Bust Chest Circumference	971	960	1026	1018	1045
Eye Height Sitting	786	873	861	922	917
Shoulder Height Sitting (acromial height)	596	660	660	704	704
Calculated Stature	1851	1795	1984	1946	2024

4 Angles for a minimum degree of comfort and outside view

It is, obviously, possible to shoehorn even the tallest amongst us into the most cramped workplaces, it is just a matter of folding up. However, this comes at a certain cost: more folding means more discomfort. As such, it is important to define angles to ensure a minimum degree of comfort for drivers and passengers. These angles differ between vehicle types, drivers sit more straight up in large trucks and sit more reclined in cars. Therefore, in the tables below (see Figure 1 and Table 4) angles of minimum comfort are shown for trucks, vans and cars. These angles of minimum comfort are based on the Dutch recommended practice NEN 5518.

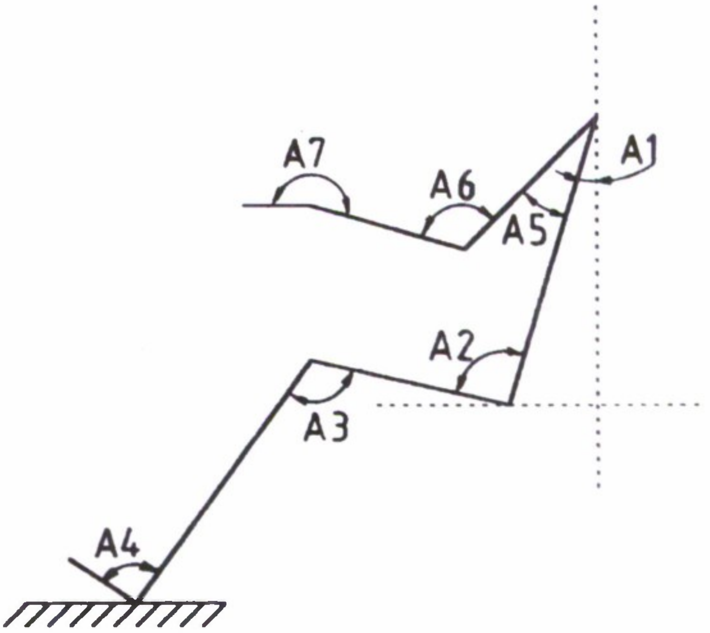

Figure 2 The angles (in degrees) for various parts of the human body.

The outside view shall be in accordance with the Council Directive of the EU (1977).

Table 4 The body angle definitions and the required angles (in degrees) and corresponding tolerances for trucks, vans and cars.

Angle	Definition	Trucks		Vans		Cars	
		Angle	Tolerance	Angle	Tolerance	Angle	Tolerance
A1	Vertical – trunk	15	+/- 10	17.5	+/- 10	20	+/- 10
A2	Trunk – thigh	100	+/- 10	100	+/- 10	100	+/- 10
A3L	Thigh - lower leg (left hand side)	115	+/- 10	130	+/- 10	145	+/- 10
A3R	Thigh - lower leg (right hand side)	115	+/- 10	130	+/- 10	145	+/- 10
A4L	Lower leg – foot (left hand side)	95	+/- 5	95	+/- 5	95	+/- 5
A4R	Lower leg – foot (right hand side)	95	+/- 5	95	+/- 5	95	+/- 5
A5L	Trunk - upper arm (left hand side)	30	+/- 15	30	+/- 15	30	+/- 15
A5R	Trunk - upper arm (right hand side)	30	+/- 15	30	+/- 15	30	+/- 15
A6L	Upper arm - lower arm (left hand side)	120	+/- 40	120	+/- 40	120	+/- 40
A6R	Upper arm - lower arm (right hand side)	120	+/- 40	120	+/- 40	120	+/- 40
A7L	Lower arm – hand (left hand side)	180	+/- 10	180	+/- 10	180	+/- 10
A7R	Lower arm – hand (right hand side)	180	+/- 10	180	+/- 10	180	+/- 10

5 Additions/sizes of apparel and protective gear

It is assumed that the vehicle crew will be wearing the clothing and equipment listed below, and are to be able to fully operate the vehicle while doing so. Therefore, the vehicle crew, consisting of the ten above mentioned cases, need to be accommodated taking into account:

- their nude anthropometry;
- their seated posture;
- additions to body dimensions due to the size and shape of clothing, apparel and protective gear.

Table 5 lists the clothing and equipment as well as the increases to various body dimensions. These dimensions were measured on 5 soldiers in 2001 following the method described by Daanen et al. (1995).

Table 5 The additions to body sizes for clothing/protective gear/apparel (dimensions in mm).

	Thumb Tip Reach	Bust chest Circumference	Buttock-knee Length	Knee-height Sitting	Sitting Height	Eye Height Sitting	Shoulder Height Sitting (acromial height)	Stature
Flameproof or tank overall basic combat gear	4	10	6	4	4	4	4	0
Boots combat	0	0	0	35	0	0	0	35
Cold weather clothing	4	10	4	4	4	4	4	0
Harness / opsvest	4	25	0	0	8	0	8	0
NBC suit	0	8	4	4	4	4	4	0
Combat body armour	20	80	20	0	0	0	8	0
Helmet	0	0	0	0	50	0	0	50
Standard headset / tank cap	0	0	0	0	25	0	0	25

Additionally, there is a minimum required distance of 40 mm of free space between structural parts of the vehicle cabin and body parts (e.g. the head, shoulders, knees) for safety and comfort in accordance with Military Standard 1333B.

6 Testing methods, techniques and procedures

There are several ways to verify that vehicles will accommodate the 2015 Dutch vehicle population. One method uses a pool of subjects, varying in body size and proportion, specially selected for their close match to the defined cases, while others use digital human manikins in a computer system. For the first method, once a subject is positioned in the workspace of the vehicle cabin they are evaluated while performing critical reach and vision tasks. Here, the body sizes of the subjects, their body angles (as well as the adjustments used) and free space between structural vehicle parts must be measured. The second method documents the same aspects, but, creates the subjects using digital human modelling systems. Applicable human modelling systems, capable of an adequate accuracy are Safework, Jack and RAMSIS. Two aspects are important when using the digital human modelling system approach:

1. The results documents should clarify the accuracy of the human modelling system used.
2. The results documents should clearly describe what methods were used to position the digital subjects (manikins) accurately in the computer workplaces.
   This document should clarify clearly how positioning of manikins was verified for accuracy.

In the past, digital human modelling systems were used without knowledge of the accuracy of the systems. Inherently, large differences were observed between results from field tests (using real subjects) and corresponding tests supported by digital human modelling systems [Oudenhuijzen, Zehner, Hudson, 2002]. If possible, it is best to use both approaches: first, the digital human modelling system is excellent in identifying potential problem areas in workstation design; and second, life subject accommodation evaluations can be conducted, not only to verify the results from the digital phase, but also to statistically quantify the level of accommodation.

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Soesterberg, October 2008

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15. ABSTRACT (MAXIMUM 200 WORDS (1044 BYTE))

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