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Application of digital human modeling and simulation for vision analysis of pilots in a jet aircraft: a case study[1]

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Abstract. Ergonomic evaluation of visual demands becomes crucial for the operators/users when rapid decision making is needed under extreme time constraint like navigation task of jet aircraft. Research reported here comprises ergonomic evaluation of pilot's vision in a jet aircraft in virtual environment to demonstrate how vision analysis tools of digital human modeling software can be used effectively for such study. Three (03) dynamic digital pilot models, representative of smallest, average and largest Indian pilot population were generated from anthropometric database and interfaced with digital prototype of the cockpit in Jack software for analysis of vision within and outside the cockpit. Vision analysis tools like view cones, eye view windows, blind spot area, obscuration zone, reflection zone etc. were employed during evaluation of visual fields. Vision analysis tool was also used for studying kinematic changes of pilot's body joints during simulated gazing activity. From present study, it can be concluded that vision analysis tool of digital human modeling software was found very effective in evaluation of position and alignment of different displays and controls in the workstation based upon their priorities within the visual fields and anthropometry of the targeted users, long before the development of its physical prototype.

Key words: vision analysis, digital human modeling, workstation design, aircraft cockpit

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1. Introduction

The current state-of-art in the human centric design evaluation is the application of digital modeling and simulation. With this advanced technology, human factors issues are assessed in virtual digital prototype of workstation with digital human model. Human modeling programs use computer aided design (CAD) technology to create and manipulate a 3D human model in virtual environment of computer graphics on the computer screen [9,22]. The implementation of digital human model reduces and sometimes eliminates the requirement of dummy model, card board manikin, 2D drawings and even real human trial in expensive physical mock-ups [21,37,41]. This technology is now being used to facilitate shorter design time, lower development cost, improved quality, increased productivity, enhanced safety and optimal man-machine interface [4,5]. It is being used extensively in various technology application fields including aviation industries [36, 19,15, 24].

Digital human modeling softwares, typically consider spatial accommodation, posture, reachabilities, clearance/interference of body segments, field of vision, biomechanical stresses of the operators and other standard ergonomic practices for the ergonomic evaluation of any workstation [5,36]. Among these various functionalities of digital human modeling softwares, one important feature is vision analysis.

Ergonomic evaluation of visual demands is a prerequisite for any workstation design. Visual field can be defined as "the part of one's surrounding that is taken in by the eyes when both eyes and head are held still" [14]. Human visual field can be divided into three areas : (i) distinct vision - viewing angle 1° foveal area, (ii) middle field - viewing angle from 2° to 40° and (iii) outer field – viewing angle > 40° to 70°. The foveal area is characterized by sharp vision and covers the angle of 1° to 2° around the central point. Acuity (i.e., sharpness) and colour perception are also best in the foveal area. When fixating an object, the eye moves until the image falls into this area of the retina. For reading a text, image of the text must fall on the fovea area. Peripheral vision (viewing angle > 2°) provides lower acuity and colour perception but is better at detecting movement or objects in motion.

A specific guide to the extent of the human field of view (SAE J985) is available from the Society of Automotive Engineers' Information Report (1995) [29]. The extent of the horizontal plane of the human vision is 150° for each eye (90° outside 60° inside the normal line of sight), with 120° of overlap defining the binocular view. Hence, the total horizontal field of view of human being is about 180°. The extent of the vertical plane of human vision is 110^0, 50^0 in the upper part of the visual field and 60^0 in the lower field of view. Although the visual field covers 180° horizontally and 110° vertically (with eye movement, but stationary head), attention cannot be equally allocated over the entire visual field. Designers must therefore determine which areas are the most important for providing visual information.

The location and arrangement of displays should be decided according to the operator's "normal" viewing angle, the field of view and the characteristic of eye and neck movement. To assign priorities to locations in the visual field, normal viewing angle and viewing distance need to be established first. The central visual field should be reserved for the most important displays while less important displays can be positioned peripherally. Normal viewing angle for a seated operator is about 15° below the horizontal [20]. For some tasks, less variability of viewing angles of the operators is involved as in case of pilots of the aircraft due to their fixed visual field with reference to fixed seat with restraint system. On the contrary, viewing angle often changes for a VDT operator, as the operator is free to change his/her posture.

Vision analysis tool of digital human modeling and simulation softwares are now being used by ergonomists and design engineers for analysis of vision of the operators/users in virtual workstation environment [36,42] to identify the position of the displays and controls and/or to evaluate their location as per one's visual field according to priority of task.

High density workstation like cockpit of jet aircraft where pilots need to scan all the information coming through various displays under extreme time pressure for efficient navigation, was chosen for vision evaluation of pilot in the present paper. This rapid information processing would be possible, only when there is least demand of physical workload to see the displays. To minimize physical workload, all the important displays should be placed within the primary view field of the pilot.

The research reported here comprises ergonomic evaluation of 15^0, 30^0 and 45^0 visual fields of the pilots and the placement of displays in a jet aircraft cockpit. This study demonstrates the applicability and effectiveness of vision analysis tool of digital human modeling software for these purposes.

2. Methodology

2.1 Generation of digital pilot models

Three dynamic digital pilot models: 2.5th p, 50th p and 97.5th p which were considered as the representative of smallest, average and largest Indian pilots were generated from anthropometric data [26] with the help of digital human modeling software- Jack [18]. In this software inputs for dimensions of different body segments were given through a spreadsheet type interface. With the 'advanced scaling' and 'body parts scaling' options of the 'Build Human' tool of Jack software, further adjustment were performed to achieve anthropometrically accurate pilot models.

2.2 Generation of digital prototype of the cockpit

CAD files supplied by the developers of the jet aircraft were translated in Jack software to generate the digital prototype of the cockpit in the 3D virtual environment.

The display panel of the cockpit consisted of Head Up Display (HUD), Up Front Display (UPD), right, left and lower Multifunctional Displays (MFDs) and Function Selector Panels (FSPs).

2.3 Selection of reference point

Proper positioning with appropriate posture is a very difficult task in positioning pilot model on ejection seat and it is the main source of error in evaluation with digital human model [24]. Hence in present simulation, Design Eye Point (DEP) approach [11,28] was followed to position all sized pilot models on ejection seat of the cockpit model. Matching DEP coordinate, proper adjustment of the ejection seat as per the anthropometry of 3 representative pilot models was performed based upon location of Neutral Seat Reference Point (NSRP) [8,40,25].

2.4 Interfacing cockpit model with pilot models

Three pilot models: 2.5th p, 50th p and 97.5th p were brought to the same environment of the cockpit in Jack graphics window for positioning them on the ejection seat sequentially during the analysis. For each of the pilot model, appropriate navigating posture was given first and positioned on the ejection seat with the help of two reference point (DEP and NSRP) as mentioned earlier. Ejection seat model was adjusted upward/downward from its NSRP position along the ejection rail for bringing the eyes of the pilot at the level of DEP. Positioning of the pilot was considered appropriate while the 'bottom_head_sight' (Jack software defined 'site' between two eyes) of the pilot was aligned with DEP keeping neck at 15^0 angle.

3. Ergonomic evaluation of vision

During a target detection task, Sanders (1970) distinguished three attentional areas in the view field: the stationary field, where peripheral viewing is sufficient; the eye field where supplementary use of eye movements is required; and the head field where head movements are also necessary. He noted that there were rarely eye movements for visual targets within a visual angle of < 30°. According to him, targets presented between 30° and 80° of the viewing angle, there were eye movements; and for targets beyond 80° there were complementary head movements [30].

Vancott and Kinkade (1972) stated that 15° angle between line of sight and horizontal can be considered as normal viewing area for placing the most important displays [35]. However, 30° viewing angle (visual field cone around the line of sight or below horizontal line) is frequently used for comfortable viewing where frequent changes of gaze between two equally important visual targets are equally critical. They suggested that 60° visual angle, 25° up and 35° down is the maximum eye rotation area for positioning the displays with minimal head movement.

Head and neck are not naturally held upright and level with horizontal but are at 10^0-13^0 forward tilt angles from an erect vertical upright head position during seated posture [16,39]. During vision analysis of the pilots in virtual simulation, initial neck flexion of the pilot models seated on the ejection seat were kept at 15^0 which is considered as most comfortable neck angle for sitting operation [3,31].

The vision analysis in the cockpit was carried out in following conditions:

1. Analysis with 15^0 'view cone'
2. Analysis with 30^0 'view cone'
3. Analysis with 45^0 'view cone'
4. Analysis for blind spot
5. Analysis for 'eye view window'
6. Analysis for obscuration zone

In this analysis sitting eye height of the representative pilot models (97.5th p, 50th p and 2.5th p pilots) differed from one another, but no significant variation in their vision (visual field/ visual obstruction) was observed as their eyes were positioned at the level of DEP of the cockpit. Hence, vision analysis of only 97.5th p pilot model has been presented in the current text to show the capability of vision analysis tools of digital human modeling software.

3.1 Analysis with 15^0 'view cone'

HUD is the most important display for a jet aircraft because crucial information is displayed on it and it allows external vision through it. Therefore, its position should be such that pilot can see this display with comfortable neck movement and with minimum eye strain. In the present jet aircraft under study, 97.5th p pilot model was positioned at DEP of the cockpit and his horizontal line of sight was found to be matched with the upper edge of the HUD. Previous studies indicated that viewing angle of 15^0 below horizontal has been found to be a good compromise solution between visual and musculoskeletal loads [2,31,38]. Hence, a 'view cone' of 15^0 below the horizontal line was created from both eyes of the pilot model to examine the position of the HUD. Study showed that HUD was appropriately placed within the 15^0 'view cone' (fig. 1).

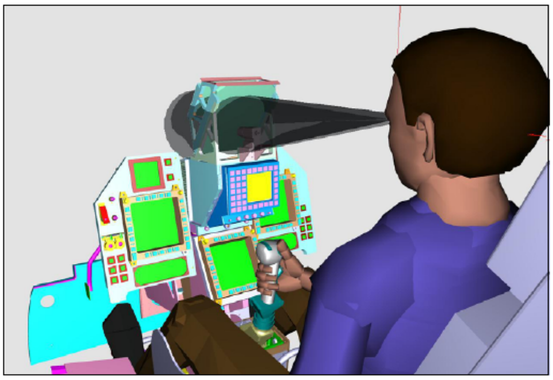

Fig. 1. HUD is placed within 15^0 'view cone' of the pilot model while eyes are at DEP level.

3.2 Analysis with 30^0 'view cone'

It is known that without any neck movement, eyes can comfortably deviate 15^0 right and left and up or down to direct the fovea to visual targets, providing a 30^0 visual cone around the line of sight [30,35]. If frequent changes in gaze occur between two equally important and critical visual targets, they should be located within this 30^0 cone [7].

The location of different displays and controls viewed by 97.5^{th} p pilot with a 'view cone' of 30^0 below the horizontal eye level was assessed (fig. 2). It was observed that the pilot could see the HUD, UFD and part of the right and left MFDs when his eyes were fixed forward and there was no neck movement (fig. 2). The neck of the pilot model was then moved to study how much neck movement may be required to see the MFDs. It was observed that to view either the left or right side MFDs completely, pilot would need to rotate and flex his neck about 7.2^0 and 11.7^0 respectively.

View of left and right side control panels with a 30^0 'view cone' are presented in fig. 3. In both cases it is evident that they could see only a part of the control panels at a time within 30^0 'view cone' with adequate neck and torso flexion and rotation.

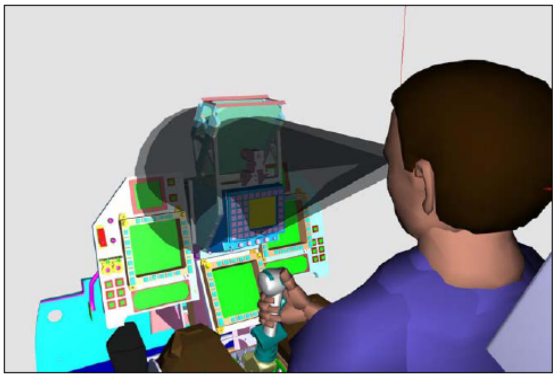

Fig. 2. Visible area of front displays with a 30^0 'view cone' below horizontal while pilot looking straight forward.

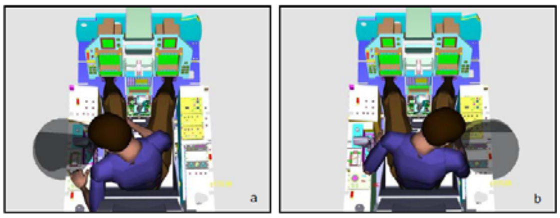

Fig. 3. Neck and torso flexion and rotation for viewing left (a) and right (b) side control panels.

3.3 Analysis with 45^0 'view cone'

It is well known that visual objects within a 'view cone' of 30^0-80^0 are easily visible with eye movement [30]. Hence, for the analysis of the visual field in the cockpit, a 'view cone' of 45^0 was created to study the area of the front displays visible normally within this view cone. Interestingly, all the front displays (HUD, UFD, MFDs and FSPs) and buttons/switches around them were found to be covered within this view cone (fig. 4).

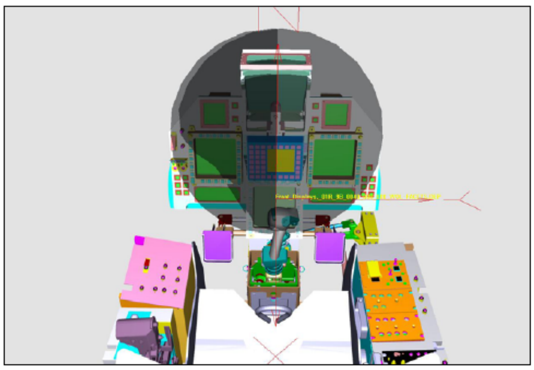

Fig. 4. Visible area on the front displays with a 45^0 'view cone' below horizontal.

A comparative analysis of the cockpit front displays seen by both the eyes with 15^0, 30^0 and 45^0 visual angle while pilot looking straight ahead, is presented in fig. 5. Coverage area increases with the increase of visual cone.

Fig. 5. Comparison of visible area on the front displays with 15^0 (a), 30^0 (b) and 45^0 (c) ‘view cones’ while pilot is looking straight forward.

3.4 Analysis for blind spot

Blind spot is an area on the retina where no image is formed. During designing a very complex workstation with high visual demand, care is always taken for placing important displays beyond this area. In the present cockpit none of the display items was found to be subtended on the blind spot when pilots fixed their eyes on the HUD (fig. 6).

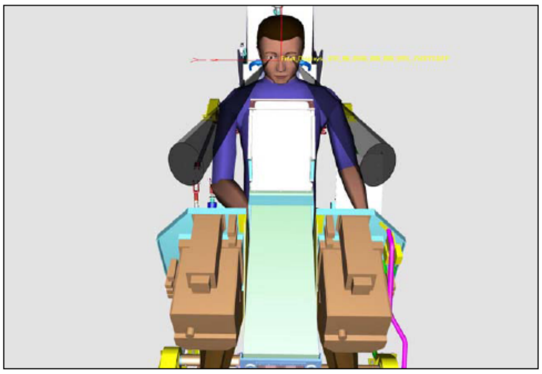

Fig. 6. Region of blind spot while pilot looking straight ahead on HUD.

3.5 Analysis with ‘eye view window’

The ‘eye view window’ tool allows the user to see through the eyes of human model and give direct impressions of which objects in the visual field are seen and which are obscured. What a pilot could be able to see when his eyes are at the DEP level and fixed on the HUD was studied by creating ‘Eye view window’. This study revealed that with the existing cockpit design, pilot would be able to see clearly the HUD, one of the rear viewing mirror and part of the external view field (fig. 7 with ‘eye view window’ (inset)).

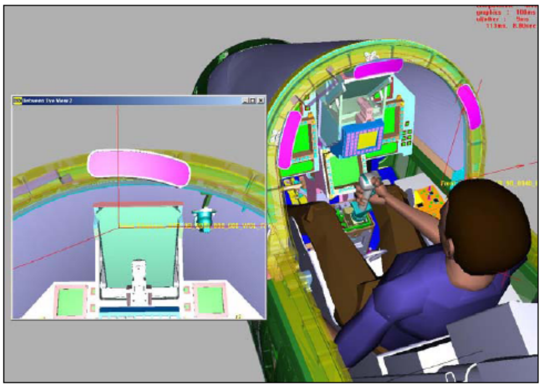

Fig. 7. Eye view window (shown inset) of 97.5^{th} p pilot for both eyes together.

3.6 Analysis for obscuration zone

Obscuration zones are the area in the visual field which is obscured by any object within the view field. The object in question can be a component of the workstation or the segments of the operator’s own body. Any obstruction in the visual field can be studied by creating ‘obscuration zone’ with the help of vision module of digital human modeling software. This tool was applied to study the obscured areas in the view field of the pilots in the cockpit as well as out side. Figure 8 describes the area on the lower MFD obscured by joystick within a 30^0 ‘view cone’ while pilot fixes his eyes on it.

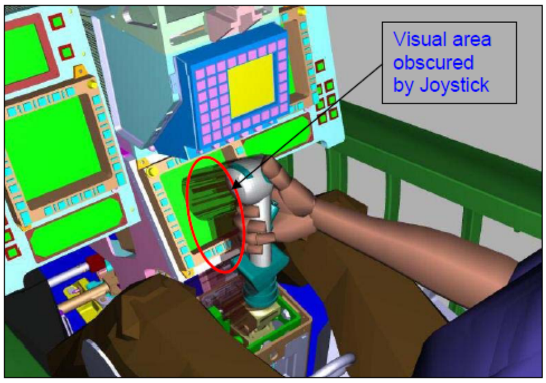

Fig. 8. Area of lower MFD obscured by forward joystick movement.

4. Discussion and Conclusion

Analysis of visual field and visual obstruction is a key requirement for ergonomic workstation design. It is of prime importance for those workstations where operators perform by continuously receiving various information though different visual displays. It becomes crucial for the users/operators when rapid decision making is needed under extreme time constraint situation like navigating task of the pilots of jet aircraft or in any other information processing task of high-density workstations.

Present paper has demonstrated how vision analysis tools of digital human modeling software can be used to study the position of various displays and objects in the view field of the pilots by creating 'view cone' of varying angles. The case study reported here showed that HUD was appropriately positioned within 15^0 'view cone' below horizontal eye level of the pilots while their eyes were at DEP. It was also observed that position of other displays and objects were also justified as those were within 30^0 and at the most 45^0 'view cone'. Study of 'obscuration zone' revealed the areas in the visual field which has been obstructed by the cockpit components. The 'eye view window' analysis showed that pilot could see out side the cockpit through the HUD and also through canopy above and below the canopy bow. Vision analysis tool also revealed that none of the displays was placed within the blind spot region of pilot's visual field. Hence, it is expected that cockpit was designed properly regarding visual requirements of the pilots and existing design would fulfill visual need of the pilots in the real physical prototype. From such virtual analysis of vision, one can easily identify any disposition or misalignment of the displays in the visual field of the operators and rectify accordingly. In other words, it is possible to determine the position and alignment of different control and displays based upon their priorities in the view field with the vision analysis tools of digital human modeling softwares.

View field of the users vary from each other due to the anthropometric variation of sitting eye height. In the present study, the effect of sitting eye height of different sized pilots was eliminated by positioning their eyes at the same DEP level.

After development of any workstation, there remains very little or no chance of making any changes in the existing design as the post-design modification incurs loss of money and wastage of time. In this regard, vision analysis in virtual environment with digital human modeling software has been proved to be very effective for positioning different displays in the workstation according to the operational requirements and anthropometry of the targeted users, long before the development of its physical prototype.

Visual fields of the DHMs are represented differently in different digital human modeling softwares. The opening angles and the level of acuity of central, middle and outer areas of visual field differ from software to software [32]. There are some limitations of the vision analysis tools of the digital human modeling softwares. Difference between visual acuity at foveal area and blurred vision in peripheral area of retina is not clearly represented by the vision analysis module of digital human modeling softwares. Moreover, neither the age of the subjects nor the mental workload are taken into account in the generation of field of view.

Advanced digital human modeling softwares have the capability to display the field of view dynamically so that the field of view changes with the movement of neck and eye balls or the position of the human model [10]. Various researchers carried out their experiments to verify whether visibility conditions inside and outside the workstations are both feasible and in accordance with all requirements of the users. Sundin et al. (2000) [33] applied vision analysis tools in industrial workplace design, Che Doi and Haselgrave (2003) [6] for sewing machine operation whereas Goutal (2000) [13] and Nelson (2001) [23] used these tools in aerospace industries for analysis of vision in virtual environment. Digital human modeling softwares including its vision module were also widely explored in automotive industries [1,12,17,27].

During describing their design and implementation of ergonomic evaluation system for 3D aircraft cockpit, Zhang et al. (2007) gave a vivid demonstration of using that system for analysis of interior and exterior visual field as well as vision evaluation according to the military standards [42]. Sun et al. (2011) studied position and arrangement of display monitor and controls in the viewing field of digital models of pilot during their evaluation of a multi-crew cockpit design of an aircraft [34]. Present research is the continuation of the previous research works with detailed information on effectiveness and applicability of individual tool of vision module of digital human modeling software.

From the present study it can be concluded that digital human modeling software is very effective for proactive analysis of the visual field/visual obstruction of the user population and for determining the optimal position of various components (particularly displays) in the aircraft cockpit as well as in any other workstations.

References

[1] D. Bowman, Using digital human modelling in a virtual heavy vehicle development environment, in: Chaffin, D. B., ed. Digital Human Modeling for Vehicle and Workplace Design, Warrendale, USA, SAE, (2001), 77-100.

[2] R. Burgess-Limerick, M. Mon-Williams and V. Coppard, Visual display height. Human Factors, 42(1) (2000), 140-150.

[3] D.B. Chaffin, Localized Muscle Fatigue- Definitionand Measurement. Journal of Occupational Medicine, 15(4) (1973), 346-354.

[4] D.B. Chaffin, Digital Human Modeling for Vehicle and Workplace Design. SAE, Warrendale, PA, 2001.

[5] D.B. Chaffin, Improving digital human modeling for proactive ergonomics in design, Ergonomics, 48(5) (2005), 478-491.

[6] M.A. Che Doi and C. Haselgrave, Evaluation of Jack for investigating postural behaviour at sewing machine workstations. Proceedings of the Digital Human Modeling Conference, SAE (Eds). 2003-01-2218: Montréal, Canada, SAE, 2003.
[7] S.N. Chengalur, S.H. Rodgers, and T.E. Bernard (Eds), Kodak's Ergonomic Design for People at Work, The Eastman Kodak Company, John Wiley & Sons, Inc., 2004.
[8] M.J. Dainoff, J. Balliet, and P. Goernert, Anthropometry and advanced ergonomic chairs, in: R. Lueder and K. Noro (Eds), Hard Facts about Soft Machines, CRC Press, London, 1994, pp. 101-115.
[9] B. Das and A.K. Sengupta, Technical note: Computer-aided human modeling programs for workstation design, Ergonomics, 38 (9) (1995), 1958-1972.
[10] T. Dukic, Visual demand in manual task performance - Towards a virtual evaluation. Licentiate Ph.D. thesis, Chalmers University of Technology, Göteborg, Sweden, 2006.
[11] S. Gerald, The Design Eye Reference Point. SAE Technical papers, document no. 871763, 1987.
[12] A.A. Godwin, T.R. Eger, A.W. Salmoni and P.G. Dunn, Virtual design modifications yield line-of-sight improvements for LHD operators, International Journal of Industrial Ergonomics, 38 (2008), 202–210.
[13] L. Goutal, Ergonomics assessment of aircraft cockpit using the virtual mockup, in: K. Landau (Ed.), Ergonomic software tools for product and workplace design - a review of recent developments in human modeling and other design aids, Stuttgart, ERGON, 2000.
[14] E. Grandjean, Fitting the task to the man. A text book of Occupational Ergonomics. Taylor and Francis, London, 1988.
[15] R.F. Green and J.A. Hudson, A method for positioning digital human models in airplane passenger seat, in:V.G. Duffy (Ed.), Advances in Applied Digital Human Modeling, CRC Press, London, 2011, pp 01-08.
[16] H. Hsiao and W.M. Keyserling, Evaluating posture behaviour during seated tasks, International Journal of Industrial Ergonomics, 8 (1991), 313-334.
[17] J. Hudelmaier, Analysing driver's view in motor vehicles, Proceedings of the Digital Human Modeling Conference, Munich, SAE, 2002.
[18] Jack: Siemens PLM software, 2011 [online]. Available from: http://www.plm.automation.siemens.com/en_us/ products/tecnomatix/assembly_planning/jack/index.shtml [Accessed 14 August 2011].
[19] T. J. Lulić, O. Muftić and A. Sušić, Ergonomical analysis of pilot seat km-1, Proceedings of 2nd International Ergonomics Conference, Ergonomics 2004, Stubičke Toplice, Zagreb, Croatia, Oct.21st-22th, 2004.
[20] MIL-STD-1472D, March 1989, Human Engineering Design Criteria For Military Systems, Equipment and Facilities, U.S. Department of Defence.
[21] M. Morrissey, Human-centric design. Mechanical Engineerig, 120 (7) (1998), 60-62.
[22] A.Naumann and M. Röetting, Digital Human Modeling for Design and Evaluation of Human-Machine Systems. MMI-Interktiv, ISSN 1439-7854, 2007.
[23] C.Nelson, Anthropometric analyses of crew interfaces and component accessibility for the international space station, in: D.B. Chaffin (Eds), Digital Human Modeling for Vehicle and Workplace Design, R-276, SAE, 2001.
[24] A.J.K. Oudenhuijzen, G.F. Zehner, J.A. Hudson and H.J. Choi, On the Creation of 3D Libraries for F-16 Pilots in their Crew Station: Method Development, Library Creation and Validation, in:V.G. Duffy (Ed.), Advances in Applied Digital Human Modeling, CRC Press, London, 2011, pp 09-18.
[25] R. Patel, A. Kumar and D. Mohan, Development of an ergonomic evaluation facility for Indian Tractor. Applied Ergonomics, 31(3) (2000), 311-316.
[26] Report No. DIPAS/06/2005, Anthropometric Survey of Airforce Personnel to Formulate Height-Weight-BMI Nomograms and Determine Sizing Parameters for Clothing and Personal Life Support Systems. Project No. RD-P1-2003/DIP 243, (Restricted Circulation), 2005.
[27] J. Rix, A. Heidger, C. Helmstädter, R. Questerand and T. Ringhof, Integration of the virtual human in CA design review, in: Landau, K. (Ed.), Ergonomic software tools for product and workplace design - a review of recent developments in human modeling and other design aids, Stuttgart, Germany, Verlag ERGON GmbH. 2000, pp 183-194.
[28] SAE –ARP 4101/2, Pilot Visibility From the Flight Deck. SAE standard, Issuing Committee: S-7 Flight Deck Handling Qualities Stds For Trans Aircraft,1989.
[29] SAE J985, Society of Automotive Engineers, Vision Factors Considerations in Rearview Mirror Design. SAE,. 1995.
[30] A.F. Sanders, Some aspects of the selective process in the visual field. Ergonomics, 13(1) (1970), 101–117.
[31] C.M. Sommerich, S.M.B. Joines, and J.P. Psihogios, Effects of computer monitor viewing angle and related factors on stain, performance and preference outcomes, Human Factors, 43(1) (2001), 39-55.
[32] A.Sundin, Participatory ergonomics in product development and workplace design. Doctoral thesis, Human Factors Engineering, Chalmers University of Technology, Gothenburg, 2001.
[33] A.Sundin and R. örtengren, Digital human modeling for CAE applications, in: G. Salvendy (Ed.), Handbook of Human Factors and Ergonomics, 2006, pp1053-1078.
[34] X. Sun, F. Gao, X. Yuan and J. Zhao, Application of HumanModeling in Multi-crew Cockpit Design, in: V.G. Duffy (Ed.): Digital Human Modeling, HCII 2011, LNCS 6777, 2011, pp. 204–209.
[35] H.P. VanCott and R.C. Kinkade (eds), Human engineering guide in equipment design, Washington, DC: U.S. Government Printing Office, 1972.
[36] P. A. Van Der Meulen and P. Diclemente, Ergonomic Evaluation of an Aircraft Cockpit with RAMSIS 3D Human Modeling Software, Proceedings of Human Modeling For Design And Engineering Conference and Exhibition, Arlington, VA, USA, 2001.
[37] J.C. Woldstad, Digital Human Models for Ergonomics, in: W. Karwowski (eds), International Encyclopedia of Ergonomics and Human Factors, Vol-II, Taylor & Francis, New York, 2001, pp 1783-1786.
[38] W. Woodson, Human Factors Design Handbook, Mc Graw-Hill, New York, 1981.
[39] W.E. Woodson, M.P. Jr. Ranc and D.W. Conver, Design of Individual Workplaces, in: H.P. Van Cott and R.G. Kinkade (Eds), Human Engineering Guide to Equipment Design, Washington, DC: American Instituits for Research, 1992, pp 381-418.
[40] M.G. Yisa, IT- Information technology and the Human Interface ergonomics of Tractors assembled in Nigeria, Biosystems Engineering, 81(2) (2002), 169-177.
[41] X. Zhang and D.B. Chaffin, A three-dimensional dynamic posture prediction model for simulating in-vehicle seated reaching movements: development and validation, Ergonomics, 43 (2000), 1314-1330.
[42] L. Zhang, X. Yuan, L. Wang and D. Dong, Design and implementation of ergonomics evaluation system of 3D airplane cockpit, in: V.G. Duffy (Ed.), Digital Human Modeling, HCII 2007, LNCS 4561, Springer-Verlag Berlin Heidelberg, 2007, pp. 1047-1055.