Ergonomical contributions to flight simulators design in virtual reality immersive environment

Profº. Dr. Alexandre Amorim dos Reis[1]

Profº. Dr. Marcelo Gitirana Gomes Ferreira[2]

Alice Mazon Miranda[3]

Fabio C. Brodbeck[4]

Felipe E. Cardoso[5]

Ramon R. Melo[6]

DESIGN

Abstract: This work approaches the developments in research to flight simulators in immersive virtual reality's design. Focused in the design field, the research has received substantial resources from agencies of research's foment, aiming the overcoming of ergonomical deficiencies verified in existing flight simulators, especially in those to military and acrobatics airplanes.

The research does not reduce itself in adapting to the simulator module the components of human interaction of the airplanes, because the human relationship with the virtual environment, virtual reality, demands its own solutions, not only to simulate a real situation, but for characterizing in an interaction that effectively happens in a proper environment, which is physical and virtual simultaneously, generating sensorial stimulations and singular perceptions which, beyond that, must simulate perceptions of distinct natures from the ones that may be experienced already.

Yet in immersion in the virtual environment, using a HMD (Helmet Mounted Display), the user (pilot) keeps physical contact with the simulator equipment, experiencing sensations that belong to a real interaction which should never conflict with the ones suggested by the imposed virtual reality, in other words, it is unacceptable the occurrence of discrepant perceptions from the sensorial stimulations experienced by the involved senses with real and virtual environments.

However, the development of the research referring the virtual reality movements simulators design shows that, in this area, a lot still must be reached, above all as for the ergonomical aspects, because if the art state is advanced to engineer focus, concentrated in mechanical, electronical and software viability aspects, in what concerns human interaction, ergonomic and design studies focus, lacks scientific and technological depth to the favoring of VR's immersion.

[1] Docente da Universidade do Estado de Santa Catarina (UDESC); email: alexandre.reis@pq.cnpq.br.

[2] Docente da Universidade do Estado de Santa Catarina (UDESC); email: marcelo.gitirana@gmail.com

[3] Acadêmica do Curso de Design da Universidade do Estado de Santa Catarina (UDESC); email: limmiranda@hotmail.com

[4] Acadêmico do Curso de Design da Universidade do Estado de Santa Catarina (UDESC); email: fabiobrodbeck@gmail.com

[5] Acadêmico do Curso de Design da Universidade do Estado de Santa Catarina (UDESC); email: cardosoefelipe@gmail.com

[6] Acadêmico do Curso de Design da Universidade do Estado de Santa Catarina (UDESC); email: ramonrmelo@yahoo.com.br

1. Antecedents

This article communicates results and unfolding of researches kept by UDESC's Design Department, focused in ergonomical aspects involved with Virtual Reality technologies, financed by CNPq (National Counsel of Technological and Scientifical Development) and by FAPESC (State of Santa Catarina's Foundation for Scientifical and Technological Research Support).

Initially, in a first project initiated in 2004, researchers of UDESC's Design Department were invites to join a cooperative action with UFSC's (Federal University of Santa Catarina) Mechanical Engineering Department and a high technology local enterprise of the metal-mechanic segment. This cooperative project did studies and works which obtained significant results, as the international patent of the innovative conception and an ante project of the simulator module. This is a project of academic-industrial cooperation in virtual reality (VR) applied to movement simulation.

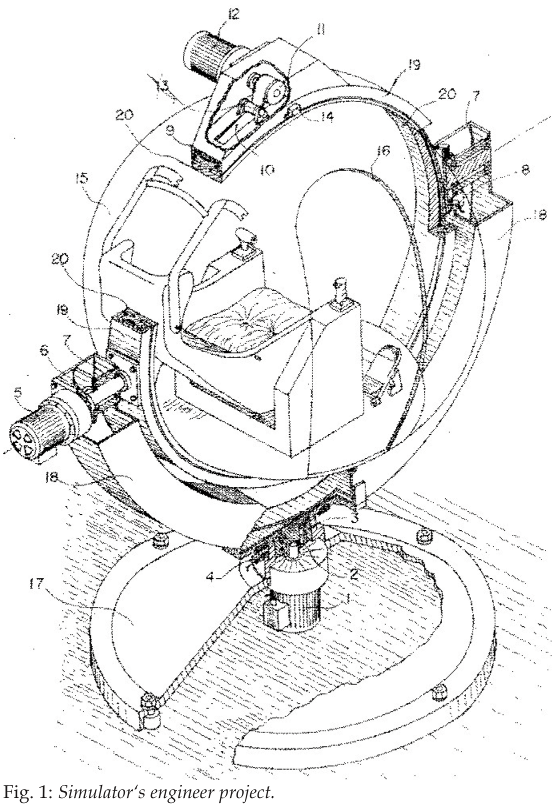

Fig. 1: *Simulator's engineer project.*

The simulator system, composed by three integrated subsystems: a) the mechanical module that includes the electromechanically activating system; b) the subsystem of movement control that commands movements in a synchronized way and; c) the virtual reality (VR) subsystem, that executes the vehicle simulation according to the environment in which is inserted. Four basic structural elements are conceived to the mechanical module, illustrated in figure 1: a) a fork with a second axis A (vertical) spin; b) a ring (external) with a spin according axis B (horizontal) articulated in the fork; c) a cabin (bubble) whose interior must contain the seat, pedals, panels, yoke and thrust levers, among others, solidary to d) an internal ring that spins according to axis C in relation to the external ring, with combined movements in accordance to the aircraft in simulation, to transmit movements of pitch, rolling and yaw[7].

Data transmission is high-speed wireless, totally synchronized to mechanical events of the interactive simulation process with the virtual pilot; a graphic processor generates the flight scenery images projected in a stereoscopical HMD (Helmet Mounted Display), equipped with microphone, auricular phones and also a movement tracing device to identify, orient and present images according to the pilot's point of view, allowing the simulation of flight procedures in diverse environmental and meteorological conditions, as already happens in specific flight simulators software.

High dynamic activating systems are applied in a way to obtain movement over the mobile parts, being configured in the inedited conception of all system. Simulation software coordinate all equipment's movement, aiming, in the actual technological limits, providing maximum pilot's immersion in the aircraft's virtual environment, which will command actions physically through the yoke, pedals, thrust lever and a data glove, which will promote the pilot's manual interaction to the command surfaces (panels). Oral, auditory and visual interactions with the virtual environment are given by the HMD's use.

To reach the research's proposed results with the contribution of the design, were traced methodological procedures, which are: a) digital modeling of all pre-existent solutions in the ante project; b) studies' elaboration to information and reflections on the project; c) methodological procedures adaptation in design to the final solutions proposal of the research object; d) efficiency evaluation through methodological tool of Value Analysis (VA) to the previously existent solutions; e) ergonomical problem investigation proved and its

[7] Pitching - aircraft's movement around its transversal axis; Rolling - movement around the longitudinal axis; yaw - movement around the normal axis.

impacts in the material and productive fields; f) ergonomical specifications preparation to a better interaction man x simulator module; g) QFD (Quality Function Deployment) tool application to the elaboration of the specifications of the project's quality requirements; h) analyses and selection of material and productive processes; i) planning, based on previous results, the project containing specifications, requirements and general restrictions to the product; j) results' application in the investigations searching for solutions of project to the ergonomical problem involving: customizing, assembly and disassembly, accessibility, reliability, maintenance, in factory and use operations; l) project using Value Engineering (VE); m) confirmation on the reached solutions according to specifications and requirements planned in the project and; n) virtual models construction.

Concluded the project's interaction step, methodological procedures adaptation started to the final solutions' development, here understood as the opportunity to practical verification of alternative methodological conceptions, originated in other knowledge areas, as engineering, transferred to design, but yet lacking scientifical corroborations in this field of industrial production, specially to inedited projects involving high technology to complex systems and subsystems. Among some of the investigated procedures, is the TRIZ, Russian sign to Teória Rechénia Izobretátelskih Zadátchi (Problems' Inventive Solutions Theory), systematic method directed to the human factor, oriented to the problems' solution investigation. Its basic principles were tested, as: heuristics, based in patents; natural consequences analysis as problematic situations and; investigation and application of knowing related to the field that involves the problem to be solved, in this case, ergonomics.

These procedures were effective to the research's evolution and reaching the results. TRIZ orientation to the human being happens by its heuristics been directed to human use, it is effective in solutions concepts, considering the problem, the investigation and the solution as elements of a system.

A great part of the ergonomical problems identified in the ante project, did not depend on a rigorous Ergonomic Analysis of Work, were easily diagnosed by the students of industrial design, scientific initiation scholarships holders participants in the project, however only the systematization of the methodological procedures allow to inventory objectively many possibilities to the project's solutions.

The functional performance analyses started then, where the use of diagnostic and viability methods (VA and VE) were crucial. The determination of the most promising solutions ahead the countless variables could not be reached only empirically, given the complexity of all project and the intimate relations between sets and components, every possible solution took, invariably, repercussions not always desirable to the whole system, in a way that an apparent solution was translated, in reality, in the creation of hard equation problems in other component or set of components. Only the systematic planning of possible solutions could certify the most promising ones.

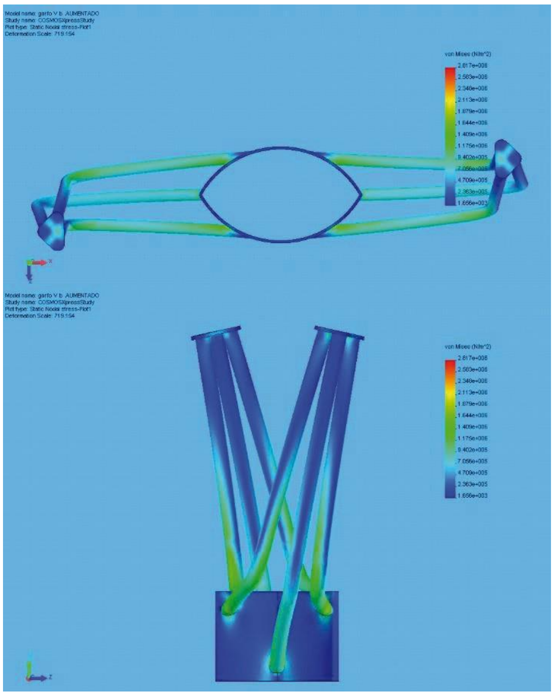

Fig. 2: *Tests of fork torsion of rotating activation.*

As immediate results of this research in the design area, based mainly in anthropometrical adaptations, determined the cabin's measuring that, amplified, needed material increment to its configuration and, undesirably, the increase of mass would need bigger power to the electromechanical activation, already carefully measured by the engineer team.

Alternatives were focused in the rationalization of material to the fork of rotating activation, by the replacement of the heavy metallic foils for tubular structures, an option that would reduce significantly this element's mass without compromising, at first, the mechanical resistance of the component and, objectifying the proposed solutions confirmation - at what touches mechanical resistance aspects, computer resources were applied to test material and structural viability. The selected solutions for the project were virtually modeled through the Solidworks software and tested with superior efforts to which would be submitted in the expected use, for this Cosmos Express software was used (figure 2).

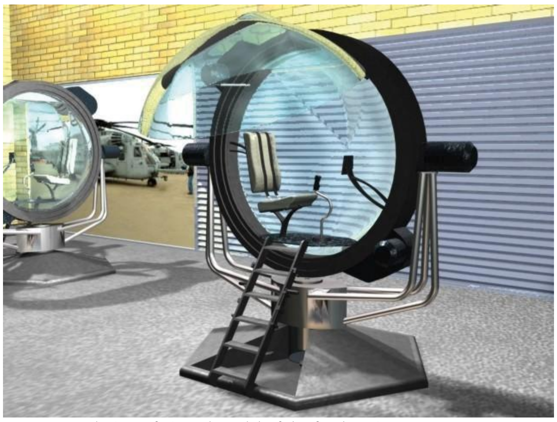

Fig. 3: *Rendering of virtual model of the final project.*

Along the viability of the selected solutions, it was reached the fulfilling of ergonomical specifications and requests planed in the project, moving forward with the virtual models construction, preparation and finalization of the descriptive documentation.

Fig. 4: *Rendering of virtual model of the final project.*

The reached result did not interfere in the engineer solutions proposed to the project in advance, as the specified electro-mechanical activations, its configuration was kept unaltered despite all necessary interference to the most appropriate ergonomical adjustment, such to the final use, the piloting, as to the production, maintenance and customizing actions, especially in the access ways and in the interior of the cabin, which is able to be personalized to the command positions of each aircraft or group of aircrafts, according the piloting appropriate solutions, especially by the use of accessories as seat, panels, yoke and pedals, to which full assembly customizing is allowed.

Figures 3 and 4 present renderings of the simulator module resulted of this project, produced with the 3DMax software, in a basic configuration of seat and yoke appropriate to Squirrel Helicopters series AS350 (figure 5), without panels and pedals that, as described previously, will be configured according customizations needed to diverse aircraft simulations (civil, military, planes or helicopters).

Fig. 5: *Photograph of Squirrel Helicopter AS350 interior.*

It was included in the project a series of inexistent items in the original project, all of them meant to the simulator's ergonomical optimization, as well as the adopted solution to the bubble's closure (access) at the cabin, configures in wing. Other project's incorporation, as ergonomical evaluations result, is the format of the bubble of cabin's closure, in an oval transversal section and not spherical anymore (figure 6), allowing more amplitude to the pilot's superior members movement, necessary to the control panels access.

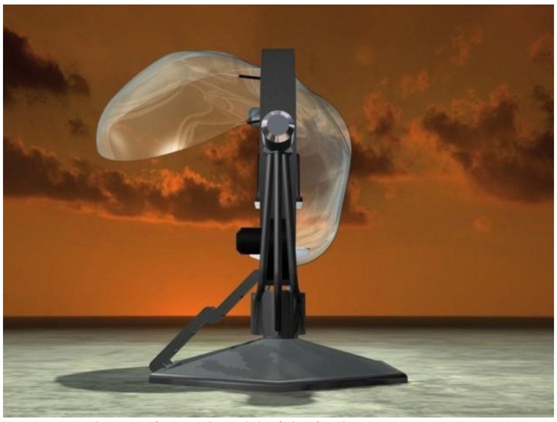

Fig. 6: *Rendering of virtual model of the final project.*

Among the material and components specified to the project, it is pointed out chrome steel molybdenum SAE 4130 and aluminum 6065, both frequently used in aeronautics, that if have a high cost, count with considerable mechanical resistance, property that allows them to weight reduction, by the possibility of being used in much inferior thickness than more usual aluminum and steel alloys. The exceeding comparative cost of these materials is justified in the project by the need of low weight, what favors the use of serve-motors of reduced power that, as high dynamics equipments, have costs proportionally higher than the applied materials, this way the materials cost increase, keeping relatively low the global cost of the simulator module for a cheaper motorization, optimizing the whole system's reliability. These are all construction's solutions necessary to be able to attend the desirable ergonomical demands.

2. Unfolding

It is considered meaningful the results, as solutions are presented to the challenges were established in the limits of technological viabilization to the ergonomical adaptation, to the involved technological humanization, leading to the corroboration of the obtained results and the used project's methodological process.

However, the research's development, in what refers to virtual reality movement simulators design, shows that in this area a lot must be reached, above all as to the ergonomical aspects, therefore it is advanced in engineer's focus, concentrated in the aspects of mechanical, electronical and software viabilization, in what concerns human interaction, design and ergonomic studies focus, it lacks scientifical and technological depth to favoring VR immersion.

It is important to point out that the mentioned research did not care only about adaptation to the simulator module human interaction of the aircrafts in project's form. All proposed interventions were beaconed in the research around the understanding that human relationship with virtual environment, the virtual reality demands its own solutions, not only to simulate a real situation, but for characterizing itself in an interaction that effectively will happen in an appropriate environment, which is physical and virtual simultaneously, generating sensorial stimulation and singular perceptions that, beyond that, must simulate distinct nature perceptions of the ones that may be being experienced.

In this sense, according to Morie [1], VR can also be characterized by the integrated coexistence of the two main concepts to this theme, these are immersion and interaction. The idea of immersion is connected to the feeling of being part of the environment. Cruz-Neira [2] affirms that, usually, an immersive system is obtained by the use of the HMD or also immersive systems can be based in rooms with projections of the views into walls, ceiling and floor. Beyond the visual factor, dispositives connected to the other senses are also important to the immersive feeling, as the sound, according related in the work of Begault [3], the person and head's movements - automatic positioning, reactive controls, etc., according to Gradecki [4]. A 3D scene visualization in a monitor is considered non immersive, this way Leston [5] considers VR immersive and non immersive.

Part of the sensorial stimulation to which the user in immersion is submitted comes from the virtual environment, but in bigger or smaller levels, other part comes from the real environment, depending on the used technological resources. Countless resources are usually applied to avoid such undesirable interferences, as acoustic isolation, aiming to reduce to its minimum the stimulation from the real environment. The visual represent the bigger part of the stimulation promoted in the virtual reality immersion, are more easily applicable and for many cases of stimulation are sufficient to promote real perceptions of complete interaction with the virtual environment, also due the priority of visual perception in most human interactions.

During the development of the related research, interviews done with pilots and flight instructors of Brazilian Aeronautics and Marine Corp, amazingly revealed the common opinion that it is close to the real to virtually fly aircrafts in their personal computers than in existent flight simulators available to them.

It must be considered that in immersion in the virtual environment, the user (pilot) also keeps physical contact with the simulator equipment, experiencing sensations characteristic of a real interaction that in any way could conflict with the ones suggested by the imposed virtual reality. It is unacceptable the occurrence of discrepant perceptions from the senses involved with the real and virtual environments.

Literature relates organical disturbs in flight simulators due conflicts of this nature, nausea are usual, where experienced pilots are more inclined than users who never did fly a real aircraft, due those to be mentally conditioned in waiting body efforts as response to some flight attitudes, efforts that do not occur in conventional simulators, for being, in reality, on the ground and "zero" speed.

For this matter, the hypothesis here raised was: flight simulators that try to promote VR are stuck to the paradigm of simulating aircrafts - movements and not simulating the movements that would generate the efforts to which pilots are really submitted, yet such efforts come to occur in smaller intensity, but still were sufficient to not generate opposite stimulation and, therefore, discrepant.

Researches in current development by this team, members of UDESC's Design Department, are focused in ergonomic solutions to these problems. It is necessary to keep in mind that in VR immersive flight simulations the pilot does not have visual or auditory contact with the real environment.

Said that, it is verified that the simulators' platforms movements, yet generated by an interface software among serve-motors and simulation software, use the outputs of these software to their activation, more specifically outputs generated by the visual environment construction (video), along, in the limit of the platform's movement, the banks generated in videos resulting from pitching, rolling and yawing, being that if an aircraft, during a simulated flight, makes a roll of 15º, this bank is appropriately represented in video and this signal commands the platform to make the same movement. This way, the feeling to which the virtual pilot is submitted in this case is the one of a 15º bank angle, what would not occur in a real flight situation. It is defended that this discrepant phenomenon is related to the nausea to which experienced pilots feel.

The simulators adopted by airlines or those used to small civil aircrafts simulations, the commercial flight simulators used for training, are not affected for this limiting, therefore such aircrafts do not impose drastic efforts to the pilots, given they do not perform sudden moves enough to generate strength that over force the inertia on their bodies.

In real flights of high performance aircrafts, as military fighter and acrobatic airplanes, pilots are submitted to high power that easily overcome in many times gravitational force, frequently represented by "n" times "G" (2G´s, 3G´s ... nG´s), demanding from them a substantial body effort to keep balanced in their command positions. What happens is, that in a general way, in the so called coordinated flights (where, for aerodynamics matters, are simultaneously used the yoke and pedals to the coordinated command of aileron, rudder and elevator), such power generated over the pilots is produced in the longitudinal and transversal axis (front - back) of their bodies, in alternate directions, depending on the flight situation in practice, but in a general way in the head to feet and chest to back directions, keeping the pilot pressed to the seat (seat and back seat). Only occasionally side forces happen, but this is not what the movement's platforms do, they always reproduce side banks, generating attraction forces to the ground in the bank over virtual pilots, what is completely discrepant.

These radical performances flight simulations platforms incoherencies are related to stimulations of a few used human senses in VR immersive systems, opposite to vision and auditory, that is the tact.

Tact is usually neglected in simulators systems, immersive or not, the "force feedback", reactive dispositive, is an example of exception that simulate vibrations in video games' joysticks, it is treated this way for promoting body perceptions in a general way automated, almost always happening in a second plan in cognitive human interactions, perception is sharpened in discomfort situations, as the feeling of heat or cold, however such sense plays fundamental role in human life's maintenance.

The great trouble in using immersive ways which favor this sense is that tact does not appear in a specific region, because all these organism's regions, according to Bear, Connors and Paradiso [6], have mechanic-receptors responsible for the touch perception, thermoreceptors responsible for the cold and heat perception and free nervous terminations responsible for pain perception what changes only in intensity, the responsible organ for the tact is the biggest in the human body, the skin, and the responsible mechanisms for the tact are in the second layer of the skin, the derme. Its importance is such that it is the first sense in developing in the human embryo.

The balance sensation is a combination of perceptions in which the senses of tact and vision are fundamental, balance is not innate and develops through human life according the experiences to which individuals are submitted.

At first, it could be suggested that balance was a sensation of little importance in flight simulators, because every pilot, in his initial phases of training, is recommended to never trust his senses, except in the aircraft's instruments. However, even they cannot use it to coordinate their actions in the flight command; pilots learn in the accumulation of their practical experiences how their senses react to the many aircrafts' behaviors, it is known this to be the reason they are more prone to nausea during VR immersive flight simulations, and not the individuals who never really piloted an airplane.

At the moment, the research's efforts are concentrated in the construction of a 6 DOF (Degrees of Freedom) platform, as the model at figure 7, aiming experiencing with military and acrobatic pilots movements propositions that stimulate them with power application in the appropriate directions, in a more coherent way with the forces observed in real flights.

Fig. 7: *6 DOF Movements platform's model.*

The expected result is that from the observations in experiments the establishment of requirements in the ergonomic field to the production of physical sensations in VR immersive simulation systems.

Finally it is concluded that flight simulator equipment will not be able to reproduce the efforts to which pilots are submitted in real flights with equal intensity, however, because of the range of possible movements, this study anticipates the reach of efforts' reproduction that can correspond more closely the reactions and perceptions experienced in reality through movements' configuration using only gravitational force. It is known that such configurations are of high complexity, therefore deign researches will focus in the requirements establishment, appropriate software to attend these necessities will depend on specialists actions in their developments.

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DESIGN