ORIGINAL

Improvement of a spatial disorientation simulator based on the concept of Bárány

Perfeccionamiento de un simulador de desorientación espacial basado en el concepto de Bárány

Aperfeiçoamento de um simulador de desorientação espacial baseado no conceito de Bárány

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ABSTRACT

Spatial disorientation is a condition in which a pilot is unable to accurately determine the aircraft position relative to the airspace surrounding it or to the ground surface, putting at risk the flight safety. All individuals are susceptible to this experience, especially when flying at night or in adverse weather conditions. Therefore, this project aimed to make improvements to a Spatial Disorientation Simulator (SDS) based on the concept of Bárány, to facilitate pilot training and enable aerospace physiology research to take place. To this end, a survey was conducted on the limitations presented by the control software and hardware, and on the mechanical structure of the existing MicroG Centre simulator, from which were identified those features requiring improvement. The resultant SDS is equipped with magnetic braking, direction reversal and fine control of speed and acceleration, features found only in this version of the simulator, which enabled it to meet the needs established by aerospace physiology study protocols. This work results from more than a decade of experience conducting research in spatial disorientation, for which international recognition has been achieved. The data presented demonstrated the positive impact of the improvements achieved in conducting clinical-physiological research.

Keywords: Simulator. Spatial disorientation. Concept of Bárány. Air accident.

RESUMEN

La desorientación espacial es una condición en la cual un piloto no puede determinar, con precisión, la localización de la aeronave en relación al ambiente aéreo y a la superficie terrestre, colocando en riesgo la seguridad del vuelo. Todas las personas son susceptibles a ella, especialmente cuando vuelan de noche o en condiciones meteorológicas adversas. De esa forma, este trabajo tuvo como objetivo el perfeccionamiento de un Simulador de Desorientación Espacial (SDE), con base en el concepto de Bárány, para el entrenamiento de pilotos y realización de investigaciones en fisiología aeroespacial. Para eso, se realizó un relevamiento de las limitaciones presentadas por el hardware y software de control y por la estructura mecánica del SDE existente en el Centro de Microgravedad de la PUCRS. Después de esa etapa, fueron definidas cuales mejoras serian contempladas. El SDE resultante de este estudio permitió el frenado magnético, inversión de dirección de movimiento y control fino de velocidad y aceleración, características presentes solamente en esta versión del simulador, lo que posibilitó al mismo atender las necesidades establecidas por protocolos de estudios en fisiología aeroespacial. Este trabajo representa más de una década de experiencia en la realización de investigaciones en desorientación espacial, obteniendo resultados con reconocimiento internacional. Los datos presentados demostraron el impacto positivo de los perfeccionamientos alcanzados en la realización de investigaciones clínico-fisiológicas.

Palabras-clave: *Simulator. Desorientación espacial. Concepto de Bárány. Accidente Aéreo.*

RESUMO

A desorientação espacial é uma condição na qual um piloto não pode determinar, acuradamente, a localização da aeronave em relação ao ambiente aéreo e à superfície terrestre, colocando em risco a segurança do voo. Todas as pessoas são suscetíveis a ela, especialmente quando voam à noite ou em condições meteorológicas adversas. Dessa forma, este trabalho teve como objetivo o aperfeiçoamento de um Simulador de Desorientação Espacial (SDE), com base no conceito de Bárány, para o treinamento de pilotos e realização de pesquisas em fisiologia aeroespacial. Para tanto, foi realizado um levantamento das limitações apresentadas pelo hardware e software de controle e pela estrutura mecânica do SDE existente no Centro de Microgravidade da PUCRS. Após essa etapa, foram definidas quais melhorias seriam contempladas. O SDE resultante deste estudo permitiu a frenagem magnética, inversão de direção de movimento e controle fino de velocidade e aceleração, características presentes apenas nessa versão do simulador, o que possibilitou ao mesmo atender às necessidades estabelecidas por protocolos de estudos em fisiologia aeroespacial. Este trabalho representa mais de uma década de experiência na realização de pesquisas em desorientação espacial, tendo seus resultados obtido reconhecimento internacional. Os dados apresentados demonstraram o impacto positivo dos aperfeiçoamentos alcançados na realização de pesquisas clínico-fisiológicas.

Palabras-clave: *Simulador. Desorientação espacial. Concelto de Bárány. Acidente aéreo.*

1 INTRODUCTION

The human physiology adaptation capacity to different environments, other than land, is not limited. In a flight, for instance, references for balance and orientations are different from those used in land, which causes a conflict of information and reduction or loss of spatial orientation capacity (BENSON, 1998).

In the English publication Medical Problems of Flying (FLACK, 1920), there was already a concern with the study on corporal balance and orientation in aeronautical environments. Global aviation reports that around 10% of aerial accidents are caused by spatial disorientation, and approximately 90% of them are fatal (CLARK, 1971, 1955, 1953; KIRKHAM, 1978; TREDICI, 1980). In face of the impossibility of a physiological adaptation to disorientation in flights, this phenomenon prevention is optimized, in order to minimize spatial disorientation participation in the genesis of air accidents (PARKER, 1980; RUSSOMANO, 2012).

Spatial disorientation or "pilot vertigo" is a condition where the pilot cannot determine, with precision, the aircraft location against the aerial environment and earth surface. All pilots are susceptible to it, particularly when they fly at night or under adverse meteorological conditions.

According to Benson (1974, 1975), spatial disorientation has been a constant phenomenon in pilots routine. Practical classes administered in aviation courses attempt to demonstrate the effects of different types of spatial disorientation that may occur in flights. For that, simulators are used, based on concept of Bárány, where spatial disorientation occurs by means of the use of a set of angle stimulation of the vestibular system in its three levels.

In general, this device consists of a chair assembled on a platform with a rotary axis that makes it rotate in a controlled way. However, one important limitation is the fact that chairs are usually driven manually, thus resulting in an undesired oscillation of angle acceleration, which may assist in the pilot spatial orientation and therefore invalidating the test.

2 OBJECTIVE

The objective of this work was the improvement of a Spatial Disorientation Simulator (SDS) control and mechanic systems, based on concept of Bárány, developed by PUCRS Microgravity Center Aerospace Engineering Laboratory, for training of pilots and use in aerospace physiology researches.

3 LITERATURE REVIEW

The literature review approaches the most relevant aspects of the different types of spatial disorientation and illusion connected to the vestibular system, as well as the technique developed by Robert Bárány for demonstration and study.

3.1 Spatial disorientation during a flight

Aeronautical accidents are many times caused by spatial disorientation during the flight. There are three basic types of spatial disorientation that pilots may experience:

Type I (not acknowledged): the pilot doesn't know that he is disoriented or that he lost the situation awareness and this is very dangerous, for the pilots keeps on piloting the airplane normally and will do nothing to correct the problem. In sum, it means that the pilot commands the airplane according to a wrong perception of the orientation. It is said that the pilot "dies with a smile".

Type II (acknowledged) is more common than Type I. In it, the pilot is aware that there is a problem and that his sensorial system is providing information that are not in accordance with those provided by the flight instruments. Thus, pilots capacitation to these situations has shown to be an important tool, for, by acknowledging the spatial disorientation, the pilot can take correct measures, based on the reading of the aircraft instruments.

Type III (incapacitant), the pilot is exposed to a more stressing form of disorientation, because, though he is aware of the disorientation, it is very intense, making impossible any reaction.

Table 1 shows the number of experiences reported in one study performed by Clark (1971) on spatial disorientations experienced by pilots.

Table 1: Experiences in flights related to spatial disorientation, based on questionnaires carried out with 137 pilots (1956) and 321 pilots (1970).

Pilots who reported incidents in (%)	1956	1970
Feeling that one of the wings is lower while they are both leveled.	60	67
In leveling after banked curve tends to bank to the opposite direction.	45	67
Feels that it is leveled while performing the curve.	39	66
Confusion of information from instruments and visual information.	34	31
While recovering from a sharp curve, feels rotation in opposite direction.	29	55
Feeling of isolation and separation from land when in high altitude (break-off).	23	33
In a dark night, illuminated point below seems to be moving deviously.	21	23
Failure in checking of altimeter and gets too close to land.	12	12

Source: adapted from Clark (1971).

Table 2 summarizes, by means of questionnaires analysis, the experience of spatial disorientation of 104 pilots from North American Navy (USN) (TORMES, 1974), 182 pilots from British Royal Air Force (RN1) (STEELE-PERKINS, 1978) and 300 pilots from British Royal Navy (RN2) (TORMES, 1974).

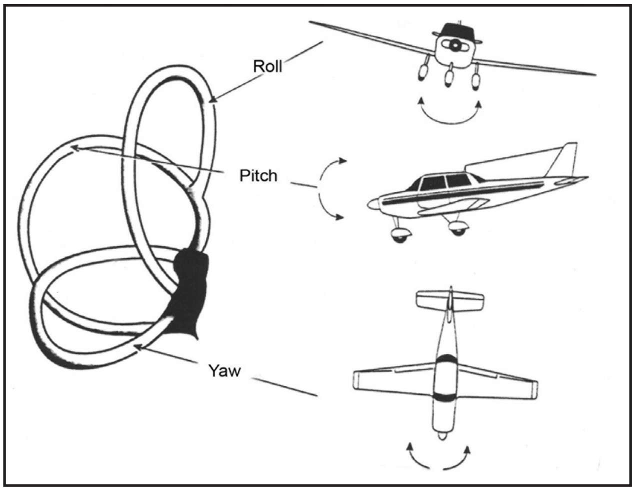
Table 2: Percent of pilots who experienced disorientation, based on questionnaires analysis.

Classification	SN	RN1	RN2
Feeling of not being leveled after performing a curve.	91	96	94
Error in relative position or airship movement in night approximation.	58	73	74
Error in real horizon interpretation in maneuver within a cloud.	47	46	45
Error in altitude interpretation soon after airship take-off.	21	34	38
Error in real horizon interpretationfor observing lights on land.	33	28	15
Feeling of being suspended in space.	*	19	16
Feeling of instability (balancing on a knife edge).	*	*	18

Source: adapted from Tormes (1974) and Steele-Perkins (1978).

Spatial disorientations may occur due to the illusion by linear acceleration or illusion by rotational acceleration, focus of this study. The portion of the vestibular system responsible for rotational balance perception is the semicircular canals, of internal ear, located next to utricle and saccule. Semicircular canals are divided into: anterior, posterior and horizontal, and are disposed in right angles among each other, representing the three Cartesian space planes. Each semicircular canal presents dilation in each of its ends, called ampulla, where its mechanic/electric transducer is located - the crista ampullaris. Each crista ampullaris contains hair cells, and on its superior portion, there is a gelatinous mass called cupula, covered with hair cells. Bathing the crista ampullaris, there is endolymph (liquid that fills semicircular canals, in its membranous portion). The endolymph flow in the ampulla, generated by head inclination, stimulates the hair cells, indicating the movement direction. The illusion by rotational acceleration, as can be observed in Figure 1, displays the relation of the human vestibular system semicircular canals with the three Cartesian space planes and the airship movements.

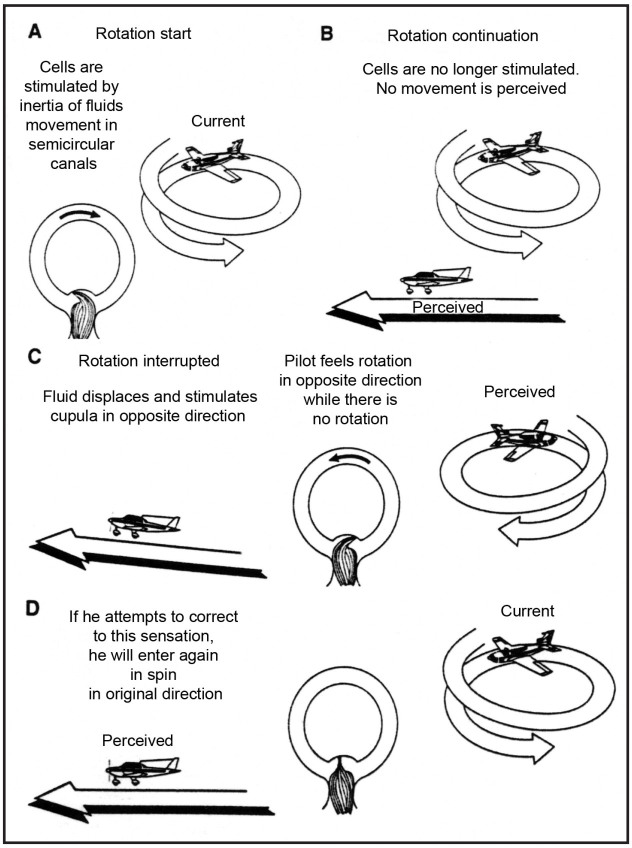
Figure 1: Space planes.



Source: Piedade (2001).

A common illusion of vestibular system (Graveyard Spin), associated to rotational acceleration, occurs when the pilot makes a spin in one rotation direction and semicircular canals identify the spin direction, making the pilot perceive the rotation. After some seconds, in case there is no variation in acceleration magnitude, the rotation feeling decreases gradually and disappears, giving the impression that the airship is no longer in a curve. When the pilots leaves the maneuver, by inertia, endolymph, which keeps on rotating, bending the crista ampullaris (transducer), creates the false impression that the individual is rotating in opposite direction (feeling that the pilot has over-corrected the rotation). At this moment, the pilot rotates again in the original direction, without leaving the spin, and thus causing the accident. In Figure 2A, the cupula, semicircular canals structure responsible for identifying the rotational movement, is stimulated by endolymph inertia and, in Figure 2B, angle acceleration is null and movement is not perceived. While leveling the airplane, the pilot perceives, by endolymph inertia, a rotation direction opposite to that of the maneuver, and the feeling is that the rotation was wrongly made (Figure 2C). The pilot then corrects the false perception, once again making a spin, in the original direction (Figure 2D).

Figure 2: (A) Maneuver start, (B) continuation, (C) airplane leveling, (D) spatial disorientation.



Source: Piedade (2001).

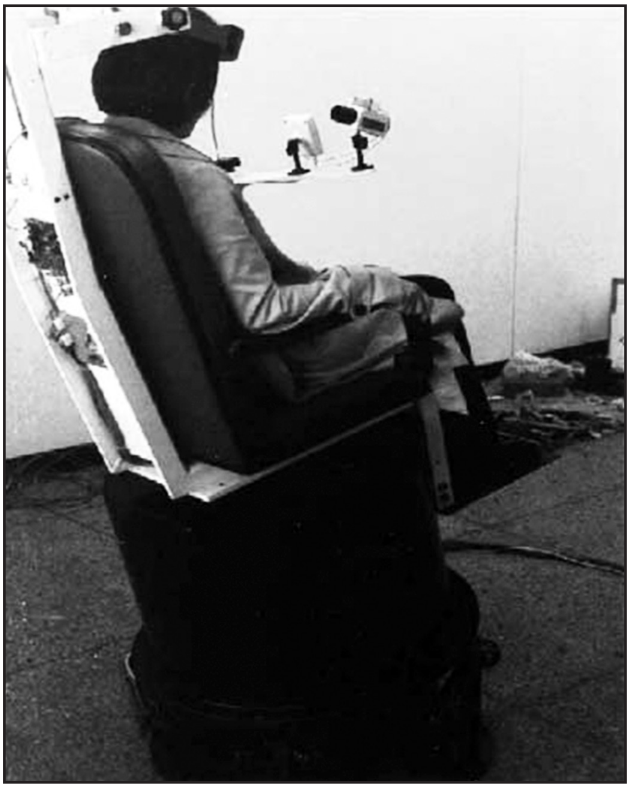
Spatial disorientation, however, is not restrict to the interaction among environment, man and airplane. Helicopters are also object of studies, because the same types of spatial disorientation may occur in helicopters as well (STEELE-PERKINS, 1978; TORMES, 1974).

3.2 Spatial disorientation Simulator – concept of Bárány

SDS is a device employed to carry out spatial disorientation testing, particularly for pilots and aeronautical sciences colleges' students.

Ko (2003) shows the development of the model and control system for de-centralized SDSs, where vestibule-ocular reflex is measured by cameras (Figure 3).

Figure 3: Rotational chair with inclined plane.



Source: Ko (2003).

Different SDSs are already available in the market by dedicated companies. Enticott (2005) and Byun (2010) demonstrate the use of the Micromedical Technologies System 2000 Rotational Chair device, where different rotation protocols for stimulation of disorientation are explored (Figure 4).

Figure 4: Micromedical Technologies System 2000 device.

Source: Byun (2010).

Epley Omniax, developed by Vesticon, makes possible, in addition to rotation, the patient inclination from 0° to 360° (Figure 5).

Figure 5: Vesticon Epley Omniax® System .

Source: Vesticon (2014).

Complementary to stimulation and measurement of disorientation by ocular movement, some equipment already make possible the assessment of the individual in simulated situations, like flight. GAT-II by Environmental Tectoniks employs a flight Simulator and a stylized version of an airplane cabin in order to create an environment similar to actual flight (Figure 6).

Figure 6: GAT-II - training system developed by Environmental Tectonics Corporation.

Source: Embry-Riddle (2014).

In PUCRS, based on the need of practical training of students in aero spatial physiology and of performing simulation of conditions faced by astronauts, the Engineering College Microgravity Center (FENG) of Pontifícia Universidade Católica do Rio Grande do Sul (PUCRS), through its Aerospatial Engineering Laboratory, has developed, in 2001, its own SDS prototype (PIEDADE, 2001), which was later improved by Gessinger (2005), Alves (2008) and the present study.

4 MATERIALS AND METHODS

In order to define the improvement required to the disorientation system, a survey of limitations presented by the control hardware and software and by the SDS mechanic structure was carried out. At the end of this stage, the improvements to be contemplated were defined.

So, through review of studies performed in the Microgravity Center by Piedade (2001), Gessinger (2005), Russomano (2005) and Alves (2008) the main limitations appointed in protocols developed and results obtained with regard to volunteers' disorientation were compared. In order to enrich the data found, multidisciplinary discussions were arranged with members of the Aerospatial Physiology Laboratory, the biomedical engineering group form the Aerospatial Physiology Laboratory and the Microgravity Center Research, Development and Innovation Coordination.

4.1 Materials

Materials used in this study to improve the Spatial Disorientation Simulator are presented and described below.

4.1.1 Spatial disorientation System

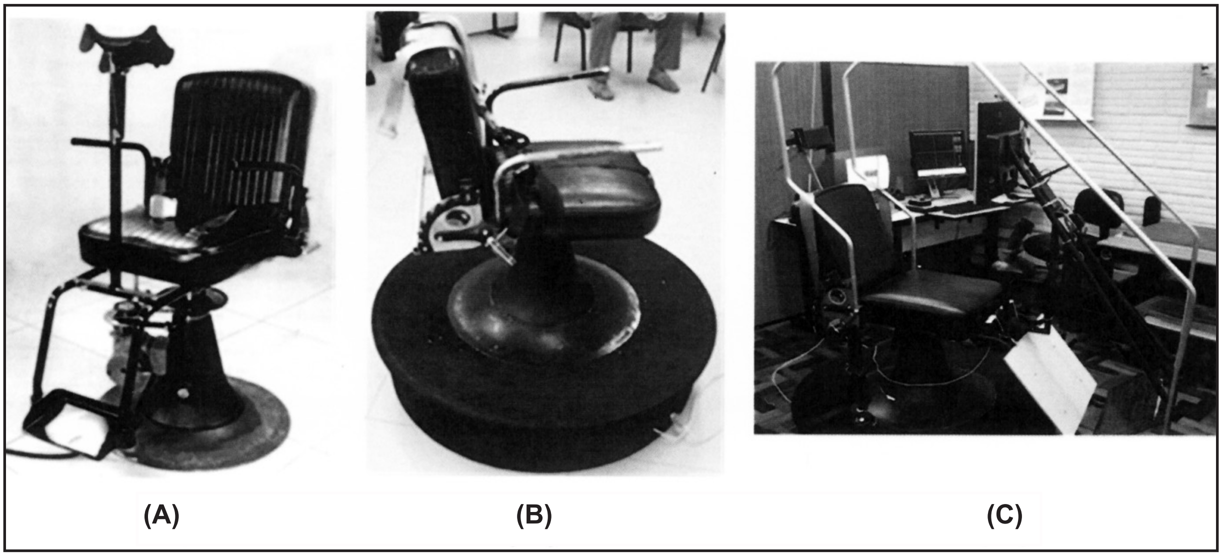
The first SDS version (Figure 7A) of PUCRS Microgravity Center was conceived by Piedade (2001) and presented an external motor set, adapted to the chair axis, composed of crown, pinion and chain. Internally, on the structure central axis, a pair of chock bearings was adapted in order to reduce engine axis attrition. In order to fix the seat, a plate was welded on the top of the central axis, where it was bolted. So as to minimize the chair unbalance and allow for more safety of the volunteer during the rotation, head and feet supports were introduced and a two-point belt. The power line system consisted of one 24V direct current electric engine, with nominal rotation of 3000 rpm and reduction factor 15:1. The transmission of movement between engine and axis was made possible by two pulleys of trapezoidal channel, with a trapezoidal profile belt "A29", generating a 5:1 relation between the motor pulley and driven pulley, and a maximum final rotation of the system of 40 rpm. The engine control was performed with a PWM (Pulse-Width Modulation) circuit, 10 kHz frequency and capacity to deliver up to 10A current. It was fed by a voltage source with 220 V_{CA} entry and 24 V_{CC} adjustable exit.

The system was equipped with a tachometer, composed of a voltage generator micro processed by a 89C2051 controller, which provided the number of turns through the variation of a certain level of electric voltage.

The second version (Figure 7B), improved by Gessinger (2005), introduced a wooden round platform, with internal acoustic coating, used as support to the chair. The motor set was moved to the platform interior, reducing considerably transmission noises and providing more stability to the chair. This reduction has made possible avoid the volunteer to obtain a sound point for spatial orientation. On the seat laterals, a dented safety lock was adapted, in steel 1020, scaled in 15º intervals, which made possible the chair backrest angulation between 0 and 90 degrees. Another resource added was a support to legs and feet, which, along with backrest inclination, made possible the use of supine position during experiments. A five-point belt was included in the structure, replacing the previous one, and ensuring more stability to the volunteer, regardless of the inclination angle used in the chair.

The third version (Figure 7C), developed by Alves (2008), promoted a modernization of the chair instrumentation, allowing for a more comprehensive assessment of the volunteer physiologic responses, as well as his performance, in the different situations expected in a flight.

Figure 7: (A) SDS by Piedade (2001), (B) SDS by Gessinger (2005), (C) SDS by Alves (2008).



Source: Alves (2008).

In order to create a cockpit situation on the chair, a structure was developed using aluminum tubes to support a rubber imitation leather (blackout), in beige, minimizing external environment influence factors (sound, air and chiefly luminosity). One 19 incher LCD monitor and one joystick with USB interface were fixed to that structure, letting the volunteer, by means of Microsoft® software Flight Simulator X, control the wheel of a virtual airship in different simulated flight. A camera with infrared light was installed to capture volunteer images during the experiments, in order to assess his reactions. For USB data transmission, a WUSB (Wireless USB) device was used, which is a wireless version of a HUB with USB ports, for power transmission to equipment used like monitor, wireless HUB USB, and the two contact unit for up to 4A was used.

To carry out the improvements identified as required for a better functioning of SDS from PUCRS Microgravity Center, two materials were acquired: a gear motor and a frequency inverter.

The Spiroplan®(SEW Eurodrive - WF10 DT56M4) angular gear motor was chosen, with 380V (three phase) feed and power of 0.1 kW, which produces a rotation of up to 1640 rpm at 60 Hz, a 8:1 reduction.

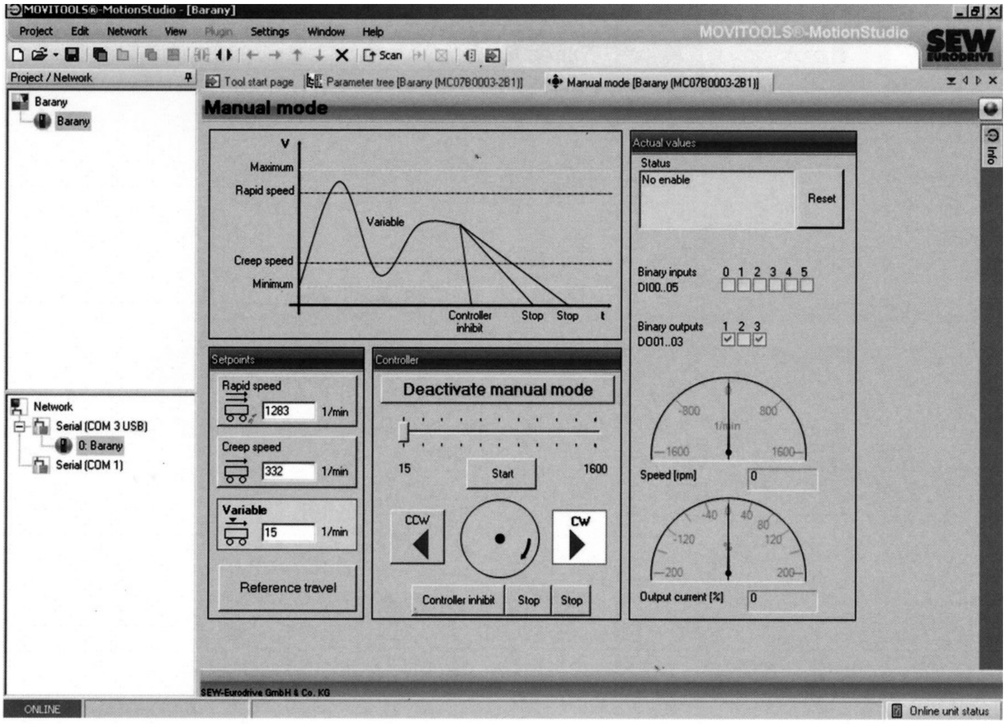
For the motor driving, acceleration and rotation speed control, the frequency inverter MOVITRAC® (SEW Eurodrive MC07B0003-2B1-4-00) was used, with 250 W power, and three-phase line of 380 V_{CA}.

The systems counts on a manual control (SEW Eurodrive FBG11B) that makes possible the gear motor rotation conditions programming (maximum desired rotation, type of engine and acceleration and deceleration ramps). In addition to the manual control, the inverter has also a RS485/ Sbus - FSC11B interface for computer, which allows for its control via Sew-Eurodrive Movitools MotionStudio v. 5.70 application, as shown in Figure 8. All parameters available in the inverter may be remotely configured with it.

4.2 Methods

Three main changes were made in the SDS project developed by Alves (2008): updating of control system, confection of a new support to the engine and reform of chair support and rotation mechanic system. The limit for volunteers mass was 90 kg.

Figure 8: Sew-Eurodrive Movitools MotionStudio v. 5.70 software interface.



Status: No enable

Binary inputs DI00..05: ☐ ☐ ☐ ☐ ☐ ☐

Binary outputs DO01..03: ☑ ☐ ☑

Rapid speed: 1283 1/min

Creep speed: 332 1/min

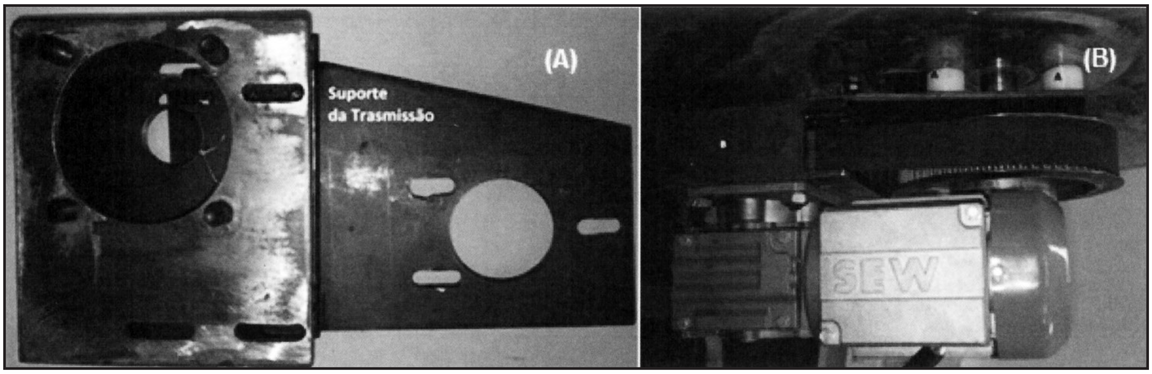
Variable: 15 1/min

Speed [rpm]: 0

Output current [%]: 0

Source: The author.

Figure 9: Fixation support to electric motor. (A) fixation support, (B) drive set.



Source: The author.

4.2.1 Updating of control system

The direct current motor and the control system by pulse width modulation (PWM) were removed from the existing system, and were replaced by the instrumented gear motor and by the digital frequency inverter acquired. Thus, parameters control, like rotation speed, acceleration and deceleration ramps and power limits delivered to the motor started to be configured by the Windows MotionStudio v. 5.70 application.

4.2.2 Confection of support to motor

In order to fix the new motor, the confection of a support was necessary. The part was designed with assistance of Solidworks® software and, then a mock-up in MDF wood to carry out the required adjustments. The support, in its final version, was confectioned in carbon steel 1020, with 6.35 mm thickness, and welded with shielded metal 6013. After this stage conclusion, the support was fixed along with the gear motor and the drive between motor and chair axis. Two trapezoidal channel pulleys with trapezoidal profile belt model “A29”, present in the previous project, were used, producing a 5:1 relation between the motor and the axis. In Figure 9A the fixation support can be viewed and in Figure 9B the assembled drive set.

4.2.3 Mechanic system reform

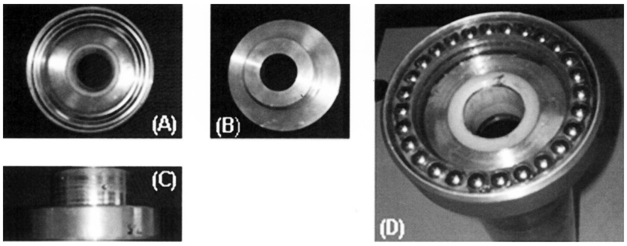
Reformation of the mechanic structure was necessary to solve back-lash problems, chiefly axial and radial, in sliding and rolling bearings. This back-lash generated vibrations during rotation, allowing movement perception by the volunteer during the experiments. So, the following changes were made: 1) chair axis fixation; 2) a remanufacture of axis and; 3) reform of rolling and sliding bearings.

At the chair seat sustaining base, a disk in steel SAE 1020 was bolted. On this disk, a round block in steel was fixed and this, in its turn, was electrically welded to the chair axis, thus providing more stability during the movement.

The new axis was confectioned in steel SAE 1020 on a bench lathe, with 900 mm in length and 30 mm external diameter, with passing internal holes. These holes, in addition to reduce the weight, increase resistance to flexion demand.

The structure presented bearings of mixed type (rolling and sliding), with axial ball bearing with simple stay. At the part center, there was a nylon bush that worked as sliding bearing, and, at the same time, as guide to the axis. Changes performed were concentrated on the bearing (Figure 10), which had its position inverted, reducing the mechanic interference and, so, improving the axis rotation performance. The nylon bush had its diameter increased, with the use of an extension lead, so as to adjust it to the new axis diameter.

Figure 10: View of bearing. (A) superior; (B) inferior; (C) lateral; (D) assembled set.



Source: The author.

5 RESULTS AND DISCUSSION

Comparing to the SDS developed by this project, solutions presented by Ko (2003) and Byun (2010) do not allow the individual movement to perform head oscillations, used by different research protocols. Solutions demonstrated by Vesticon (2014) and Embry-Riddle (2014), though having a higher number of resources, require a larger physical space and larger infrastructure and more training for their operation.

The Microgravity Center SDS, since its first conception in 2001, has suffered evolutions aligned to the research needs proposed in spatial disorientation field, and training of students and pilots in the understanding of its effects on the human being.

Among the researches performed, the assessment of medications in the fight against kinetosis symptoms by Russomano (2005) and the respective cognitive performance analysis resulting from this association, investigated by Subasinghe (2013), have yielded a better understanding of these effects. The application of technologic and electronic increments have also promoted the search for spatial disorientation quantification.

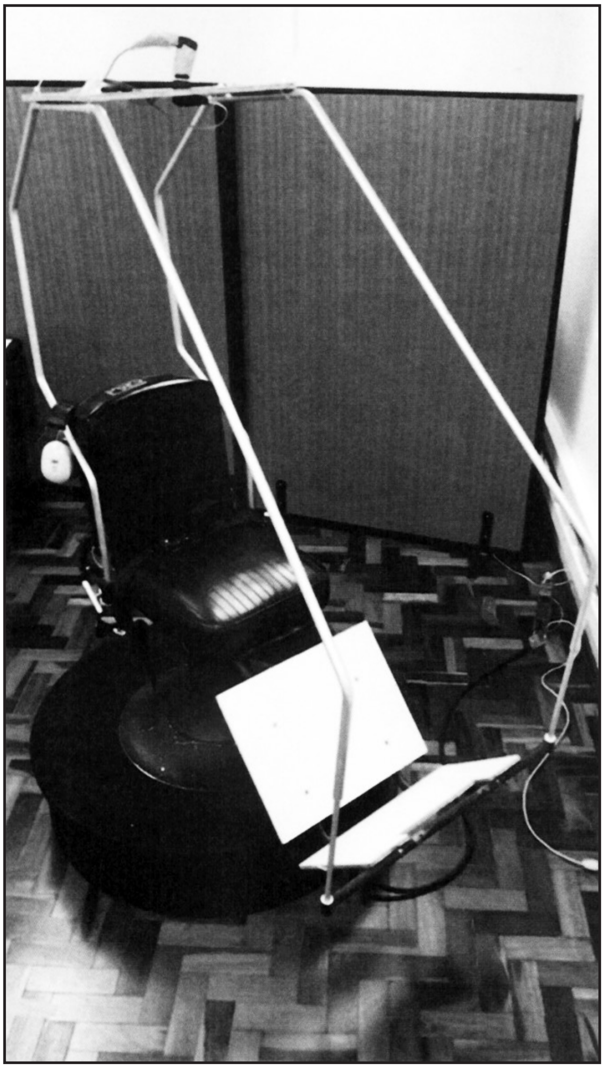
The SDS presented in the present article (Figure 11) enables the establishment of a more precise physiological testing protocol, for it makes possible the control of acceleration and deceleration ramps (proportional and integral control) of the rotation movement. Compared to the system based on PWM and direct current motor used by Alves (2008), the frequency inverter and alternating current motor of the present system have made possible the change of rotation direction and a more constant torque on axis.

The Movitools MotionStudio v. 5.70 software, by Sew-Eurodrive, manufacturer of this motor and inverter, has made possible the access to a more complete control interface, more accessible, where the user may change, quicker and more friendly, configuration variables. In the previous version, an interface composed of one potentiometer and two displays with seven segments allowed only the definition of the desired rotation per minute and checking of current rotation.

The re-fabrication of the chair axis and its bearings has conferred more stability to the movement, making the SDS more fluid and silent, and so facilitating the disorientation of the volunteer, who then had less external references as compared to previous versions.

The SDS developed was used, with success, to carry out a study with human beings, which has validated the cognitive performance variation of volunteers, when exposed to disorientation by rotation, in a research performed with cooperation from the Centre of Human Aerospace and Physiological Sciences (CHAPS), King's College London, United Kingdom.

Figure 11: Current spatial disorientation simulator.



Source: The author.

6 CONCLUSION

Spatial disorientation simulators are a valuable tool in study of human physiological response to the conflict of information received by vestibular, visual, auditory and tactile systems during flights, particularly at night or in low luminosity situations.

The SDS developed by the Microgravity Center and presented in this work is the result from over a decade of spatial disorientation researches, internationally acknowledged.

The magnetic braking, movement direction inversion and speed and acceleration fine control, characteristics exclusive to this Simulator version, have made this SDS meet the needs established by clinical-physiological protocols.

For future projects, we suggest the inclusion of a virtual reality system to extend the SDS applications and the closing of control mesh by means of inclusion of absolute position encoders.

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