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ERGONOMICS AND AIRPLANE SEATS: A STUDY OF COMFORT AND WELL-BEING FOR THE USER

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Abstract

In the 21st century, passengers in the economy class of commercial flights have still shown displeasure with the seats offered by airlines. For this reason, this work aimed to perform an ergonomic analysis in a standard airplane seat model, in order to verify its potential points of improvement, and thus propose a new model that is within the standards recommended by ergonomics. Simulations were performed in the CATIA Ergonomics For Car Design software, which uses the RULA method to generate an ergonomic evaluation. The simulations were applied to six digital mannequins of five different nationalities, including German, American, French, Indian and Japanese, of both sexes, with the average dimensions of each of the populations studied. In this way, it was possible to cover a majority of the world's population with the resources available through the software. The results of the simulations indicated that the main triggering factor of discomfort in the passengers was the width of the armchair, which had smaller dimensions than the appropriate ones, causing users to have to shrink to accommodate the seats. This factor served as the basis for the creation and construction of the new armchair model that was later designed using the CATIA V6 and 3D Experience software. In order not to reduce the number of seats inside the aircraft, the arrangement of the seats inside the aircraft was changed using geometric calculations by applying the Pythagorean theorem and the Triangle Similarity, to determine how much the dimensions could be changed. The modifications made to the chair analyzed resulted in ergonomic improvements for all mannequins submitted to the tests providing the same greater comfort and safety during short and long trips.

Keywords: Ergonomy in aircraft. Airplane seat. Ergonomic simulation. RULA method. Seat design.

1. INTRODUCTION

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According to research published in The New York Times in 2016 (Rosenbloom, 2016), one in twenty people is right to complain about the extreme discomfort caused by economy class airplane seats. The study points out the fact that aircraft seats do not fit the human anatomy, which can bring a series of harms to the user, such as back, spine, neck pain and poor posture problems. Seats have been a persistent challenge for our customers," said Shemm, vice president of finance and operations, Boeing Commercial Airplanes (Vinholes, 2018).

In conjunction with the desire to provide comfortable seats for their passengers, airlines are constantly battling the issue of excess weight inside aircraft. According to a report carried out in 2018 by the Blog Todos a Bordo (Casagrande, 2018), the airline United Airlines claimed savings of 3.2 million dollars in fuel per year, just by reducing the weight of some products it used to take on board, such as thinner sheets in magazines and reduction of some drinks. Therefore, reducing the weight of the airplane seats would lead to a large reduction in the total weight of the aircraft, resulting in a great economic advantage for the airline.

Another factor to be analyzed is the limited available space inside the planes, which makes one of the major concerns of airlines is to allocate the largest number of people on the same flight. Thus, in order to transport the maximum number of passengers per trip, airlines have been reducing the spaces between seats significantly, leaving aside the comfort and well-being of those who use the seats.

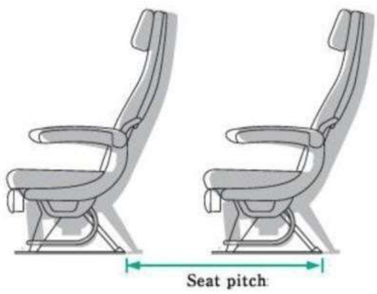
As a consequence of airlines leaving the comfort of their passengers in the background, there has been a huge increase in the number of complaints related to seats. This increase led the National Civil Aviation Agency (ANAC) to create the ANAC Label in 2010, which aims to inform passengers at the time of ticket purchase of the characteristics of the seat that will be provided in economy class, both for domestic and international flights (National Civil Aviation Agency, 2009). Compliance with the label is mandatory for airlines governed by the Brazilian Aeronautical Homologation Regulation 121 (RBHA 121) that have aircraft with a maximum takeoff weight of more than 5,700 kg and a number of seats greater than 20 (DAC, 2005).

The label informs the minimum distance between one seat and another, as shown in Figure 1, measured from a point of 75 mm above the seat *pitch and* classifies it into five categories (with "A" being the best and "E" the worst):

- "A": minimum usable space between seats greater than 73 cm.
- "B": minimum usable space between seats less than or equal to 73 cm and greater than 71 cm.

- "C": minimum usable space between seats less than or equal to 71 cm and greater than 69 cm.
- "D": minimum usable space between seats less than or equal to 69 cm and greater than 67 cm.
- "E": minimum usable space between seats less than or equal to 67 cm.

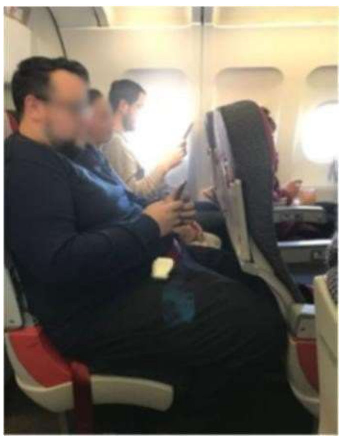
Figure 1 - Representation of seat pitch



Source: (SKYTRAX, n.d.)

Figure 2 below, photographed in July 2018, shows a seat pitch of the seats on a commercial LATAM Airlines flight rated "D" (minimum usable space between seats less than or equal to 69 cm and greater than 67 cm). As can be seen in the image, the passenger's legs, in this situation, touch the seat in front, ratifying the importance of an ergonomic study in the aircraft seats in order to adapt them to the needs of all passengers and provide them with a safe and comfortable flight.

Figure 2 - Seat of the LATAM commercial flight



Source: (AUTHORS, 2018).

In this way, with the objective of improving the quality of flights in economy class, without increasing the weight carried by the plane, reducing the number of seats in it and still respecting the pre-established safety standards; An ergonomic study was carried out, using the RULA (RAPID UPPER LIMB ASSESSMENT) method, in search of an armchair suitable for the human anatomy and that, if possible, can bring economic and competitive gains to the airline.

Mcatamney and Corlett (1993) were responsible for the development of the RULA method, whose main objective was to propose an assessment of workers' exposure to risk factors related to musculoskeletal disorders in the activity performed (Dombidau Junnior et al., 2017; Mateus Junior, 2009; Shida & Bento, 2012).

According to Shida and Bento (2012), the application of the method begins with the observation of the activity, during some work cycles, in order to identify the most relevant postures to carry out the analysis. Using body posture diagrams and scoring tables (Iida & Buarque, 2016), it is possible to assess the worker's exposure to risk factors. These risks are named external load factors, namely (Dombidau Junnior et al., 2017): Number of movements; Static muscle work; Strength; Work postures; Working time without break.

The RULA method, therefore, proposes the determination of the need for intervention or subsequent investigations carried out by experts, related to the postures involving the neck and upper limbs of workers during their activity and their observed risks.

2. METHODOLOGY

2.1. Market Research

In order to better understand the intensity of the problem addressed in this study, it was necessary to determine the main factors that interfere with the discomfort experienced by passengers during air travel. Thus, a market research was carried out.

The market research was created using the Google Docs1e Forms tool distributed to the target audience through social media, including Facebook and WhatsApp, over a period of 4 months in which 442 responses were obtained.

When it comes to constructing a questionnaire, it is necessary to follow the following steps (Iida & Buarque, 2016): Establish the objectives of the research, in order to define what is expected to be obtained from it; Define the most appropriate method to collect each type of information, whether they are multiple choice, evaluation scales or essay questions; Define who the target population is; Define the desired degree of accuracy in the job in order to determine the chosen sample size

Thus, for this work, the research questionnaire had the following objectives:

a) prove interest in the solution of the work;

b) define the main discomforts experienced during air travel;

c) establish a relationship between the physiological characteristics of passengers and the discomforts experienced by them;

After defining the objectives, the market research was divided into 3 parts. The first part intended to restrict responses to the target audience, so that only responses from people who have already traveled by plane were considered. This stage consisted of a multiple-choice question, in which the user could choose between only two answers, "yes" (I have traveled by plane) or "no" (I have never traveled by plane).

In a second part of the research, the physiological characteristics of airplane seat users were evaluated. Among these characteristics: the age, gender, weight and height of the passenger.

The definition of the genre was established through a multiple-choice question, in order to avoid inconsistency in the data. The answer options to these questions were: "feminine", "masculine" and "other". The "other" field was added to fit the new standards of society, allowing freedom of expression.

To define the age ranges of the users, it was studied how the human physiognomy changes according to the years lived, and age groups were established in which the human body does not undergo major changes, in the form of multiple choice. Thus, the answers could be: "up to 13 years old", "from 14 to 30 years old", "from 31 to 50 years old" and "Over 50 years old".

To determine the users' weight, weight ranges were established in order to avoid embarrassment and false answers. The question, also in multiple choice format, allowed the user to choose between 5 alternatives, namely: "Less than 50 kgs", "From 51 to 65 kgs", "From 65 to 75 kgs", "From 75 to 85 kgs" and "More than 85 kgs". These weight ranges were chosen in order to check whether flights are more uncomfortable for those of higher weight.

Then, to determine the height of the users, the same method of question mentioned above was used. Among the answers, the survey participants could choose between 6 options: "Less than 1.50m", "Between 1.50 and 1.60m", "Between 1.61 and 1.70m", "Between 1.71 and 1.80m", "Between 1.81 and 1.90m" and "More than 1.90m". The purpose of this question was to determine whether, in addition to their weight, the user's height also influences the level of discomfort they feel during air travel.

After determining the physiology of the market research participants, questions are asked directly related to the main issue of the work, which is the discomforts felt by the passengers.

In this third part of the survey, users were first asked what were the main discomforts encountered by them during their trips. In order not to induce them to a desired response, this question also included responses that were not related to physical discomfort, but to other types of discomfort. The target audience could mark 2 alternatives, among the 6 proposals, namely: "Price of air tickets", "Long waiting lines for *check-in* and boarding", "Uncomfortable and not very spacious seat", "Weight limit for luggage", "On-board service" and "Little space for hand luggage". This question was intended to prove the interest in the solution of the work.

The next questions became more and more specific. The following two questions aimed to identify whether the time spent traveling was a factor that influenced the maximization of the pain and discomfort in question. The first question was about short trips of up to 3 hours and the second about long trips (over 3 hours), and, for each question, it was asked if passengers usually feel pain after flights. 3 answers were allowed: "yes", "no" and "sometimes".

If any of the two previous questions had been answered with "yes" or "sometimes", the user received yet another question, in which he could mark the parts of the body in which the pain was felt, namely: "Neck", "Legs", "Back", "Spine", "Arms" and "Others". The respondent could mark as many options as he wanted and, if he checked the "others" field, he was allowed to write the other part of the body with pain. In this way, the field of answers became wider and the ability of users to express themselves increased.

The last two questions of the field research were specific to the problem presented in this work and aimed to prove the interest in the solution of the work, in addition to defining the main discomforts experienced during air travel. One of these questions allowed the user to evaluate from 1 to 5 how satisfied he was with the seats offered by the airlines, with 1 being "very dissatisfied" and 5 "very satisfied".

The last question of the market research allowed the user to evaluate from 1 to 5 the level of discomfort due to each situation presented, namely: "Small space between your seat and the one in front of you", "Little recline of the chair", "Hardness of the seats" and "Small space in the armrests of the chairs". For this question, users considered 1 as "It doesn't bother me" and 5 as "Extremely bothered".

Before the research was released to the target audience, it was tested with a smaller group of people, including teachers, close friends and family members. After the test, it was possible to improve and correct some aspects of the survey, in order to make it clearer to those who answered it.

In order for the answers to a questionnaire to be valuable and reliable, it is first necessary to calculate the sample size. For this, the population size, margin of error, confidence level and percentage value are used, according to Equation 1:

$$\frac{\frac{z^2 \times p(1-p)}{e^2}}{1 + \left(\frac{z^2 \times p(1-p)}{e^2 N}\right)}$$

Equation 1

Where:

N: Population size

e: Margin of error (decimal value) z: Confidence level (z-value)

p: Percentage Value (decimal value)

To determine the size of the sample needed in this survey, it was calculated, according to the desired level of uncertainty, what would be the number of people who would have to answer the survey for it to become valid.

After determining the sample size, the questionnaire was shared in groups on social networks, such as Facebook and WhatsApp.

2.2. RULA Simulation

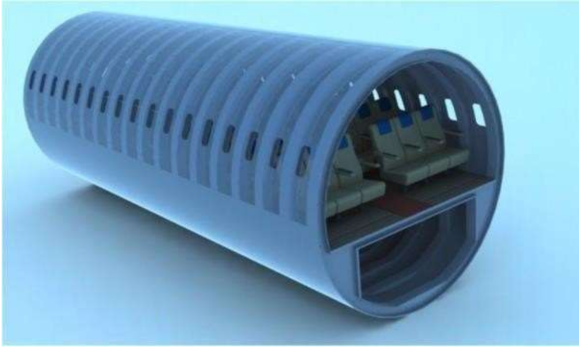
The RULA (Rapid Upper-Limb Assessment) method evaluates static muscle work and the forces exerted by the body segments and, as a result, indicates the level of action in which the movement fits. Level 1 indicates that the posture is acceptable, and no investigations are necessary. At level 2, medium-term investigations are needed. At level 3, it is necessary to investigate and take action in the short term. At the last level, level 4, it is necessary to investigate and take immediate action (Iida & Buarque, 2016; McAtamney & Corlett, 2016).

In order to verify the possibility of inadequacy of the airplane seats currently supplied in economy classes, simulations were carried out using the Dassault *Systemes software*, called 3D *Experience*. In this software, the following applications were used: CATIA Bent Part Design, CATIA Ergonomics for Car Design, CATIA Human Design and CATIA 3D Printing Preparation (Dassault Systèmes, n.d.).

In order to keep the simulation conditions closer to real conditions, an armchair model similar to the one currently used in economy classes on commercial flights was sought.

Using GrabCAD Community, a 3D model sharing site, the 3D seat design most similar to the real one, the AirBus A320 seat, was selected. In Brazil, this seat is used in 168 aircraft, which belong to the companies LATAM, Avianca, Brasil and Azul. The file of the 3D model representing the A320 aircraft, was made available by an engineer named Ali Hechi, and had the following measurements shown in Figure 3.

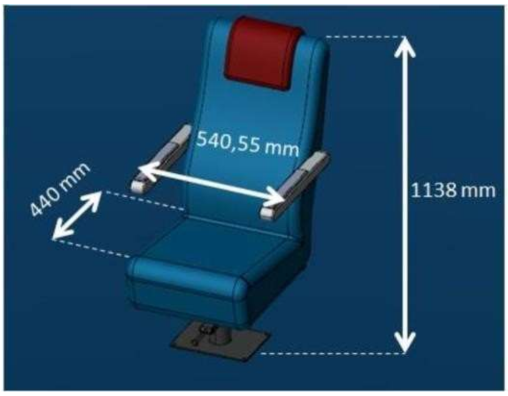
Figure 3 - 3D model selected for analysis



Source: (ELHECHI, 2013)

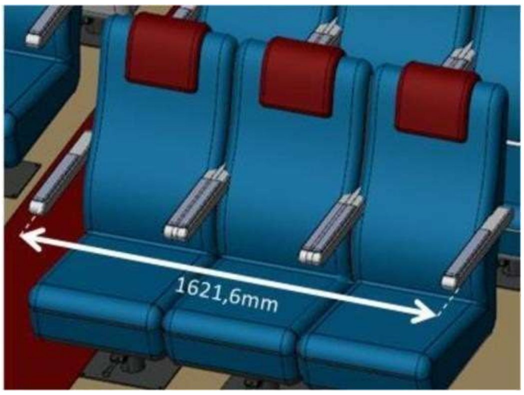
As can be seen in Figure 4 and Figure 5, the colors of the seat were changed, in order to allow a better visualization of its parts and obtain greater contrast when with an avatar positioned on it.

Figure 4 - Measurements of the armchair model studied



Source: (ELHECHI, 2013 modified)

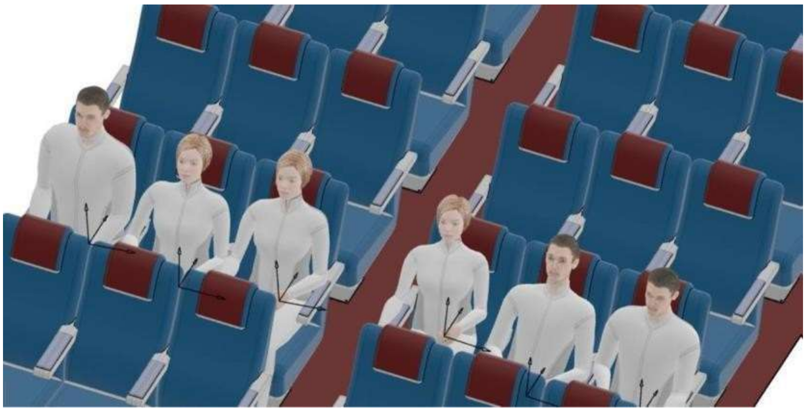
Figure 5 - Measurement of a row composed of 3 seats



Source: (ELHECHI, 2013 modified)

After selecting the seat model, the study avatars were created. With the use of the CATIA Ergonomics for Car Design tool, six avatars with distinct physical characteristics were created, as illustrated in Figure 6.

Figure 6 - Avatars selected for study



Source: (AUTHORS, 2018)

In order to reach the majority of the population with this study, each avatar created represented a distinct part of the population. The application of the 3D Experience, CATIA Ergonomics for Car Design, allows users to choose the nationality of the human representation created, as indicated in Figure 7. For this study, the 95% percentage of trust in all avatars created was used, aiming to represent the majority of the population.

The first avatar created (first on the left in Figure 6) was designed to represent the American male population. Her height, specified by the CATIA Ergonomics for Car Design software, was 1.88 m and her weight was 119.36 kg. Next to him, the second avatar, represents the American female population, measuring 1.73 m and weighing 75.74 kg. Next, a third avatar representative of the female population of France was created, with an average weight of 72.21 kg and a height of 1.72 m

On the other side, to the right, of the corridor in Figure 6, 3 more avatars were created. The first of them was created to represent the German male population, with an average weight of 97.24 kg and an average height of 1.85 m. Next to him, a representative of the population, also male, Japanese, weighing 79.35 kg and measuring 1.77 m, is seated. Finally, alongside the Japanese representative, an avatar was created to represent the female population of India. This last avatar was created with 63.75 kg and 1.61 m.

Figure 7 - Avatars in creation

Source: (AUTHORS, 2018)

After creating the avatars and importing the model of airplane seats to CATIA, the CATIA Ergonomics for Car Design application was used in order to analyze and measure the ergonomic issues involved.

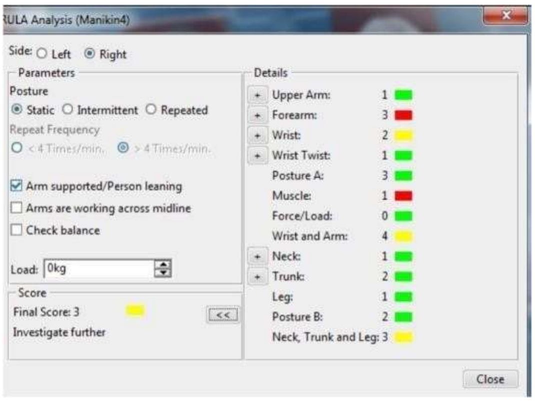
First, the mannequins created were properly positioned in the seats, as shown in Figure 6.

The report generated by the simulation, using RULA analysis, allows you to analyze how each member of the mannequin's body is affected by the position in which it is, generating at the end a score from 1 to 9 that represents the level of action to be taken, with options ranging from acceptance, investigation, future change or immediate change of posture.

In this work, we opted for the static RULA analysis, that is, considering that passengers remain seated in the same position during flights. In addition, it was considered that the passengers would not be holding any type of cargo while seated and that their arms would be supported on the side rests.

In the application used to generate the RULA analysis in question, it was possible to indicate whether or not the passenger was supporting his arms, in order to generate more reliable results, as indicated in Figure 8.

Figure 8 - Report generated by RULA analysis



Source: (AUTHORS, 2018)

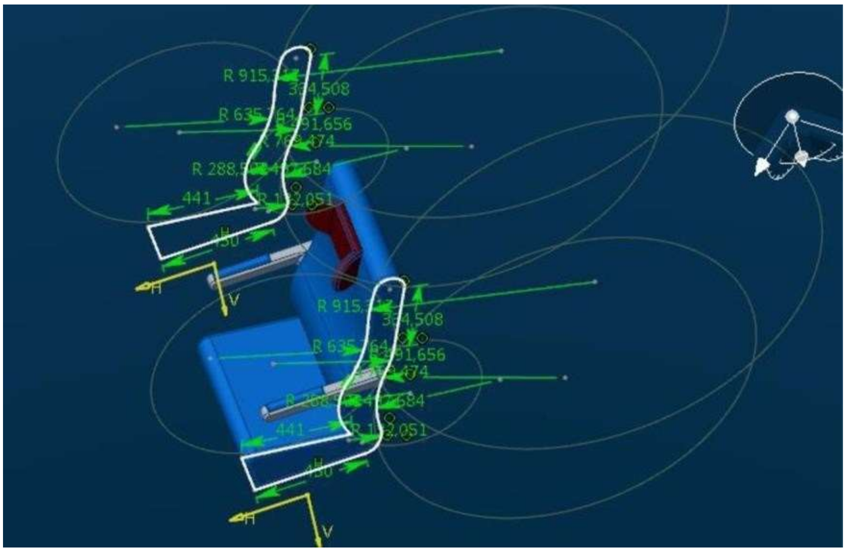
2.3. Creation of the new airplane seat model and analysis of possible changes in the interior layout of the aircraft

After performing the RULA analysis for all the mannequins created, it was possible to perceive which limbs of their bodies were subject to greater discomfort when in the position determined by the seat of the A320 aircraft.

Based on the results of the ergonomic analysis (which will be presented in the next chapter), an investigation was initiated on the possible changes in the existing seat model, in order to improve it and reduce the score generated in the RULA analyses, making the position of passengers acceptable during trips.

For this purpose, the application of the 3D Experience called CATIA Part Design was used (Figure 9). With the use of this tool, it was possible to make changes to those parts of the seat that were believed to cause greater discomfort to passengers. A new RULA analysis report was applied to each change to verify whether the altered parts really influenced the score found.

Figure 9 - Use of the Part Design application for the elaboration of the new model of armchair

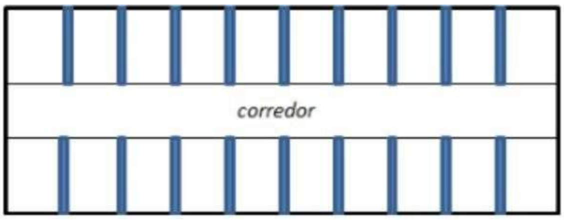


Source: (AUTHORS, 2018)

After locating the dimensions (width, height and length) of the seat that had the greatest impact on the passengers' discomfort, and which, therefore, needed to be changed, we thought about how to make such changes without also changing the number of seats inside the aircraft.

In this sense, it was necessary to modify the arrangement of the seats generating a new layout inside the plane. First, the dimensions of the existing airplane seat and the *seat-pitch* used in the A320 aircraft arrangement were measured. Then, with the use of geometry techniques, such as the Pythagorean theorem and the triangle similarity theorem, it was possible to determine the space available for change in the seat measurements and thus obtain its new dimensions and the new internal arrangement of the aircraft. Figure 10 represents the seating arrangement on the current model of the Airbus A320 aircraft.

Figure 10 – Current layout of the AIRBUS A320 aircraft



Source: (AUTHORS, 2018)

In addition, as a basis for study aid and ergonomic analysis, the Kroemer survey of anthropometric measurements and dimensions performed for 15,700 men and 17,700 women in Germany was also used. Comparisons with other studies reveal that the data obtained are quite similar for both sexes in Switzerland, England, the USA and France. The project-relevant frames that were used in the creation of the ideal seat are shown in Figure 11 and Figure 12.

Figure 11 - Anthropometric dimensions of the Kroemer survey

Measurements (cm)	Women				Men			
	5%	50%	95%	D.P.	5%	50%	95%	D.P.
1 STANDING BODY								
1.1 Stature, erect body	152.78	162.94	173.73	6.36	164.69	175.58	186.65	6.68
1.2 Eye height, standing	141.52	151.61	162.13	6.25	152.82	163.39	174.29	6.57
1.3 Shoulder height, standing	124.09	133.36	143.20	5.79	134.16	144.25	154.56	6.20
1.4 Altuia of the elbow, standing	92.63	99.79	107.40	4.48	99.52	107.25	115.28	4.81
1.5 Height of center of hand, standing	72.79	79.03	85.51	3.86	77.79	84.65	91.52	4.15
1.8 Chest depth	20.86	23.94	27.78	2.11	20.96	24.32	28.04	2.15
2 SEATED BODY								
2.1 Head height, seated, from seat	79.53	85.20	91.02	3.49	85.45	91.39	97.19	3.56
2.2 Seated eye height from seat	68.46	73.87	79.43	3.32	73.50	79.20	84.80	3.42
2.3 Shoulder height, seated, above seat	50.91	55.55	60.36	2.86	54.85	59.78	64.63	2.96
2.4 Elbow height above seat	17.57	22.05	26.44	2.68	18.41	23.06	27.37	2.72
2.6 Buttock-to-knee length, sitting	54.21	58.89	63.98	2.96	56.90	61.64	66.74	2.99
2.9 Buttock-popliteal length, sitting	44.00	48.17	52.77	2.66	45.81	50.04	54.55	2.66
2.11 Thigh height above seat	14.04	15.89	18.02	1.21	14.86	16.82	18.99	1.26
2.13 Hip width, seated	34.25	38.45	43.22	2.72	32.87	36.68	41.16	2.52
3 HEAD								
3.2 Head width	13.66	14.44	15.27	0.49	14.31	15.17	16.08	0.54
3.4 Distance between eyes	5.66	6.23	6.85	0.36	5.88	6.47	7.10	0.37
3.5 Head circumference	52.25	54.62	57.05	1.46	54.27	56.77	59.35	1.54
4 HANDS								
4.1 Hand length	16.50	18.05	19.69	0.97	17.87	19.38	21.06	0.98
4.4 Palm width	7.34	7.94	8.56	0.38	8.36	9.04	9.76	0.42
4.5 Palm circumference	17.25	18.62	20.03	0.85	19.85	21.38	23.03	0.97
5 FEET								
5.1 Foot length	22.44	24.44	26.46	1.22	24.88	26.97	29.20	1.31
5.2 Foot width	8.16	8.97	9.78	0.49	9.23	10.06	10.95	0.53
7 WEIGHT (kg)	39.2	62.01	84.8 '	13.8*	57.7"	78.49	99.3 *	12.6"

Source: (Kroemer et al., 2000)

Figure 12 - Data on anthropometric dimensions

Greatness	Men (mm) average -	90%	Women (mm) 90% average-	
Leg length	450	420-480	430	400-460
Thigh Length	500	460-540	460	430-500
Distance between elbow and seat base	240	200-280	240	200-280
Forearm Length	470	430-510	420	380-460
Distance between shoulder and seat base	590	540-640	540	490-590
Distance between top of head and base of seat	900	840-960	850	790-910
Leg length to above the knee	550	510-590	500	460-540
Shoulder width	435	--	412	--
Pelvis Width	340	--	343	--

Source: (Kroemer et al., 2000)

In view of the dimensions presented in the tables above, it was possible to validate whether the measurements of the new airplane seat model were adequate to the anatomy of the human body.

3. Results and discussions

3.1. Market research result

According to data from the Air Transport Yearbook carried out by the National Civil Aviation Agency (ANAC) in 2016, the number of passengers transported in 2016 on domestic flights in Brazil was 109.6 million. Thus, this was the value used as the population size to calculate the sample size.

The margin of error or sampling error represents the maximum estimate of errors in a survey. In this sense, the greater the precision required by the survey, the lower the error rate chosen for the calculation of the sample size. The generally established margin of error is 5%, with a confidence interval (CI) of 95%, which establishes the z-value as 1.96. The commonly used percentage value is 0.5 (50%).

Using the formula indicated in Equation 1, presented in the previous chapter, it was possible to calculate that 385 responses would be needed for the market research to be used as a reliable source, and in this way, the number was established by the group as the goal that should be achieved.

The goal was successfully achieved since the market research disseminated on all social media obtained 442 responses.

The first question "Do you usually travel/or have you ever traveled by plane?", was answered by 442 people, of which 437 (98.9%) answered that they had already traveled this way, that is, only 5 of the voters (1.1%) had never had this experience. The next question sought to know the gender of the respondents, the vast majority of whom 77.4% revealed that they were female, while only 22.6% were male.

Of the survey participants, 275 (62%) stated that they were between 14 and 30 years old, 72 (16.3%) assumed to be between 31 and 50 years old, and 95 (21.5%) reported being over 50 years old. There was also the option "up to 13 years old", which was not chosen by any of the respondents.

Regarding the weight of the users, the answers were well distributed in the various pre-established weight ranges. Of the respondents, 34 (7.7%) reported weighing less than 50 kg, while a large number of 164 (37.1%) said they weighed in the range of 51 kg to 65 kg. On the other hand, 118 people (26.7%) reported weighing between 75 kg and 85 kg, and, finally, 57 (12.9%) of the respondents answered that they weighed more than 85 kg.

The last physiological question about users asked for information about their height. Of the respondents, 108 people (24.4%) selected the option between 1.50 m and 1.60 m and almost half of the participants, 199 (45%) declared to be between 1.61 and 1.70 tall. The option with the range of 1.71 m to 1.80 m was chosen by 98 people (22.2%). Also, 29 users (6.6%) declared to be between 1.81 m and 1.90 m and, finally, only 7 respondents (1.6%) would have their height exceeding 1.90 m.

Regarding the question about the main discomforts encountered in airplane travel, the most voted, as predicted, was the "uncomfortable and not very spacious seat", with 82% of the votes; followed by the factor of "price of air tickets", chosen by 70% of the total voters.

Still in relation to the same question, the option "weight limit for luggage" was voted by 24.1% of travelers, coming in third. The other questions, less voted, were: "on-board service (attendance, food)", chosen by 10% of voters; "long waiting lines for check-in and boarding", voted by 9.8% of respondents and "little space for hand luggage" chosen by only 7.3% of users.

Thus, with the answers obtained through this question, it was possible to confirm that the seats currently used by airlines are not completely satisfying their customers, who consider it uncomfortable and not very spacious.

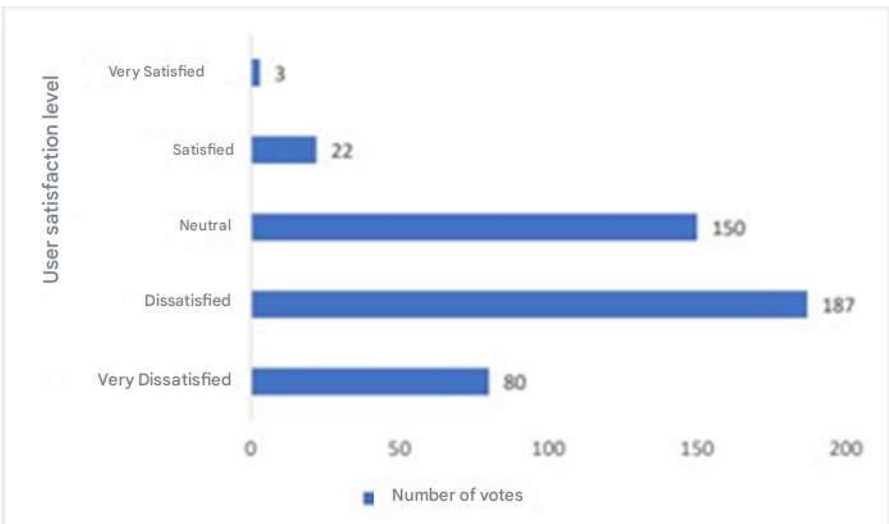
Faced with the question "Do you usually feel pain after short trips (up to 3 hours)", 54.1% of travelers answered no, while 29.6% said they sometimes feel pain and 16.3% said they feel pain on short trips.

However, on long trips (over 3 hours) the values change a lot: 64.3% of the respondents declared feeling pain; 25.6% understand that this suffering occurs sometimes and only 10.2% said they do not feel pain after long plane trips. These numbers reflect the number of users who feel pain when using the current seats and the importance of looking for new ergonomically correct solutions.

Subsequently, those who answered yes in the previous questions were asked in which parts of the body they usually feel such pain, and were allowed to select more than one option. The vast majority of users reported pain in the "back" (50.5%), "neck" (48.4%), "legs" (44.1%) and "spine" (41.9%). Some travelers also opted for the options pain in the "arms" (1.6%), knee (1.1%) and "lumbar" (0.7%). Finally, there were users who included new options such as "tailbone", "shoulder", "gluteus", "ear" and "ankle".

The following questions allowed the user to select a number from 1 (very dissatisfied) to 5 (very satisfied). The first of them asked the user directly how satisfied he is with the seats currently offered by airlines in economy class. The answers are described in Figure 13:

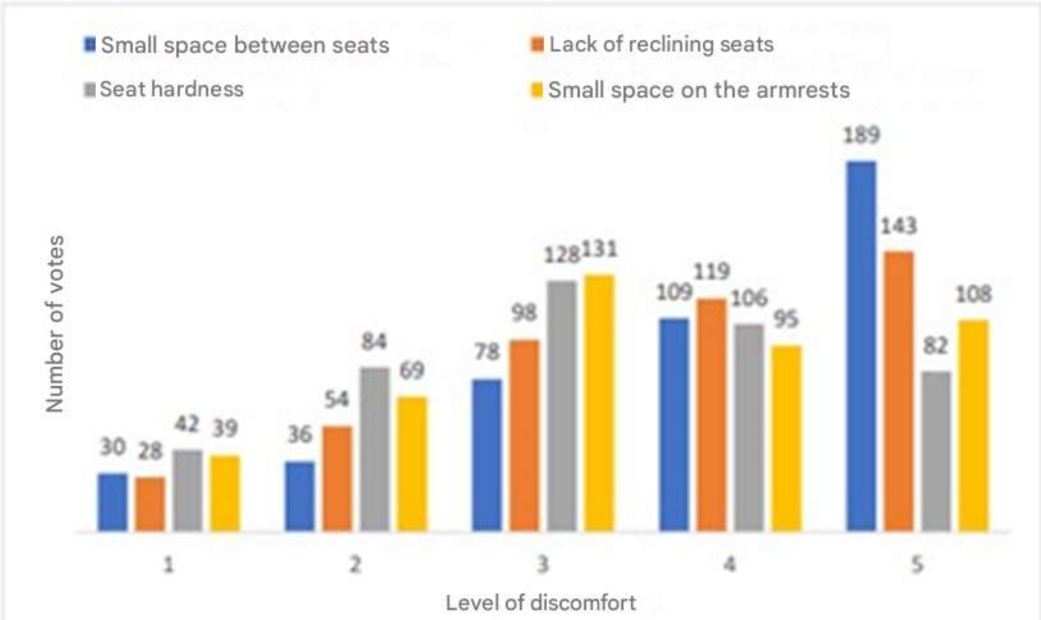
Figure 13 – User satisfaction level



Source: (AUTHORS, 2018)

Figure 14 presents the results obtained from the user's levels of discomfort

Figure 14 – User nuisance level



Source: (AUTHORS, 2018)

In relation to the variable "Small space between your seat and the one in front of you", the number of voters grows with each level of discomfort.

Considering the variable "Little recline of the chair", the answers followed the same pattern as in the previous question, few votes in the options that represent low discomfort and a greater number of votes in the options that indicate high discomfort.

When asked about "Seat hardness", users answered in different ways, with the majority focusing on the options of nuisance levels 2, 3 and 4, as shown in Figure 1.

Finally, the travelers answered how uncomfortable they feel in relation to the "Small space in the armrests of the chairs", obtaining level 3 as the most recurrent.

With the travelers' answers in relation to each of the characteristics, the weighted average of the variables was made so that it became possible to verify which one is more critical. The calculation was made by establishing a weight of 1 for a situation of "I am not bothered" and a weight of 5 for a situation in which the user feels "Extremely uncomfortable" (Table 1).

Table 1 - Criticality of the variables

Condition	Criticality
Small space between seats	114,5
Low recline of the seat	108,1
Seat hardness	95,2
Small space on the armrests	99,3

Source: (AUTHORS, 2018)

Thus, it was possible to understand that the variables of the airplane seat (currently used in the economy class of aircraft) that cause the most discomfort for the passenger, in ascending order, are the little space between the seat and the one in front, followed by the low inclination of the latter, the short space for armrests and, finally, the hardness of the seats.

3.2. Results of RULA simulations

After performing the simulations in the 3D Experience Ergonomics for Car Design software, a RULA analysis report was extracted for each digital mannequin used. Remembering that the RULA analysis scale ranges from 1 to 9.

The average American male studied had a 5-point result in the RULA analysis, indicating that the seat was inadequate for a man of such size and should be changed soon. The members of the male avatar that were most affected due to the position determined by the airplane seat were his forearm, arms, shoulders, and legs.64

After an analysis in the simulation, it was realized that the small distance between one armrest and the other was largely responsible for the discomfort generated in the man's arms and shoulders. With the distance between the supports of 480 mm, presented in the seats currently used on the Airbus A320, the average American passenger is forced to shrug his shoulders and twist his arms inappropriately (Figure 15).

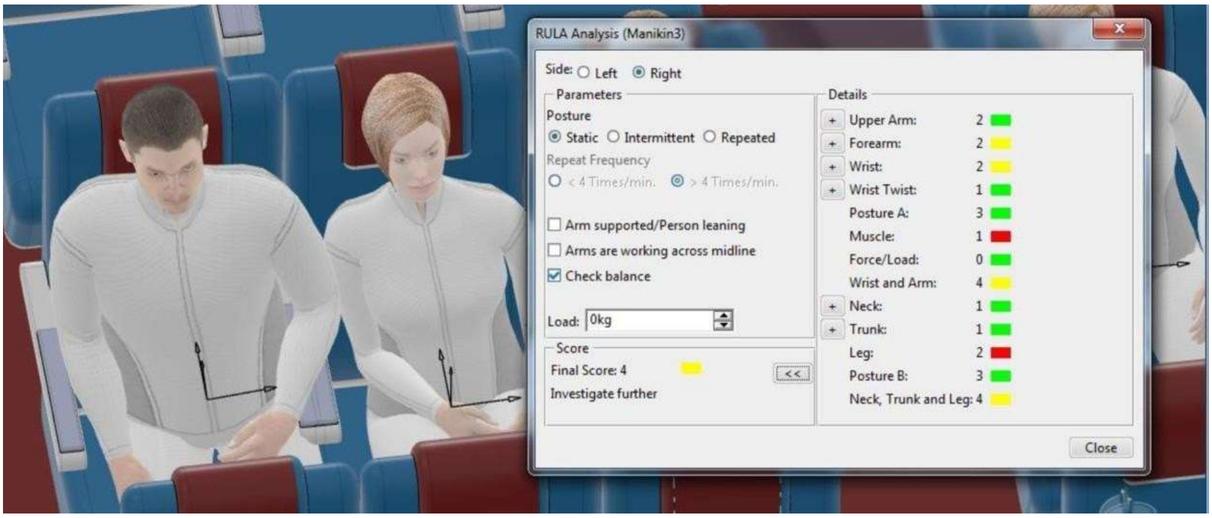
Figure 15 - Simulation in male American avatar

Source: (AUTHORS, 2018)

In the second simulation, performed on the average American female mannequin, the result obtained in the RULA analysis was a score of 4. From the analysis, it was noticed that the limbs that showed the most discomfort were the legs and posterior muscle of the avatar's arms. Since this mannequin is smaller than the one previously presented, the score generated in the RULA analysis was lower.

However, the fact that the avatar sat next to a larger avatar made him shrink his right shoulder and legs, so as to harm these limbs of his body, as shown in Figure 16.

Figure 16 - Simulation in American female avatar

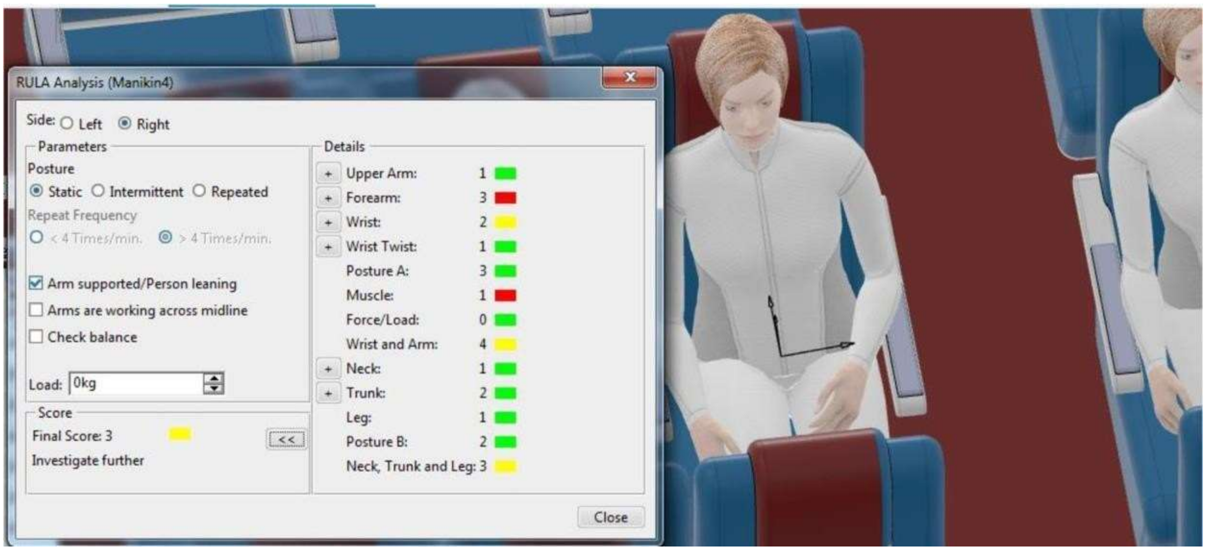


Source: (AUTHORS, 2018)

The next mannequin analyzed, of French nationality and female, presented 3 points in the RULA analysis, also indicating the need for investigation in the seat in question.

Given that the place next to this avatar was occupied by another avatar of not so large size, the first one had greater mobility when supporting its arms, which made the RULA analysis generate a lower result, indicated in Figure 17.

Figure 17 - Simulation in a female French avatar

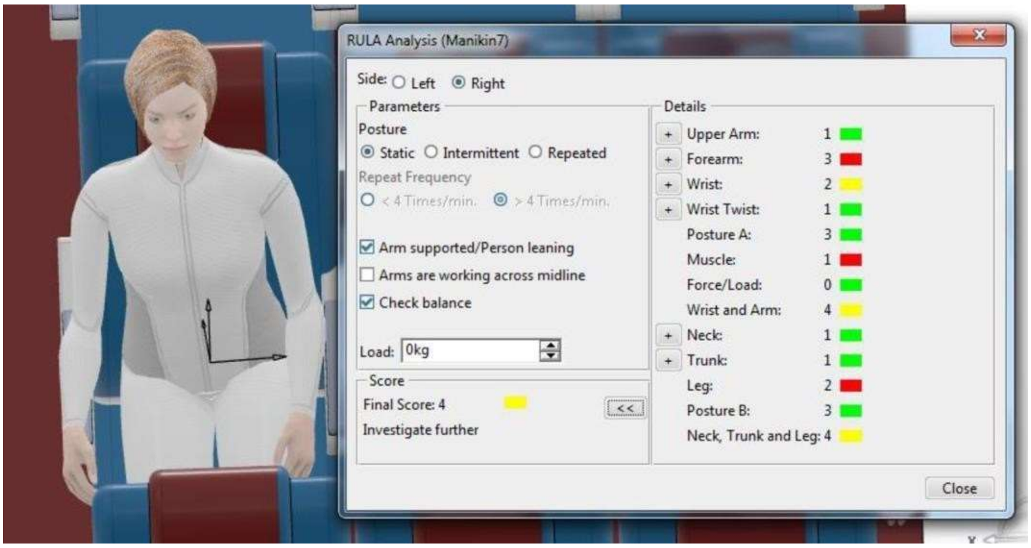


Source: (AUTHORS, 2018)

The RULA analysis carried out on the female mannequin of Indian nationality generated a result of 4 points, which reinforces the need to investigate the causes of the bad posture provided by the armchair studied.

The members of this avatar subject to the highest risk of musculoskeletal pain, in this case, were: forearm, posterior muscle of arms and legs. By analyzing the results, it can be observed that the armchair in which the Indian mannequin is seated in Figure 18 is too narrow for her.

Figure 18 - Simulation in Indian female avatar

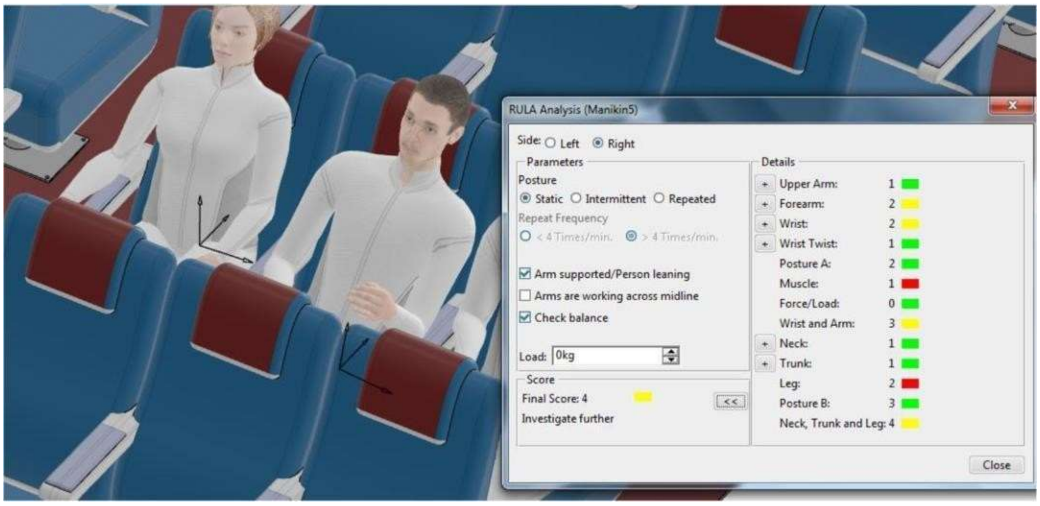


Source: (AUTHORS, 2018)

The following analysis was performed on a Japanese male mannequin (Figure 19). The RULA performed on this manikin indicated a level 4 risk, as well as on the previously described manikin.

Due to the fact that a Japanese man is, on average, smaller than an American man, the score generated in the RULA analysis in this simulation was lower. However, the most affected limbs, in both cases, were the same.

Figure 19 - Simulation in Japanese male avatar

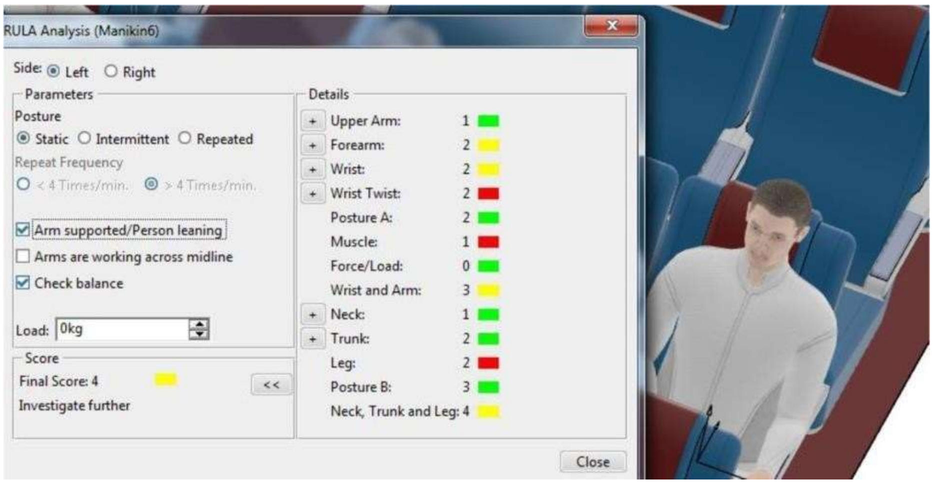


Source: (AUTHORS, 2018)

Finally, the ergonomic study carried out on the German male mannequin generated a result of 4 in the RULA analysis.

Unlike the Japanese mannequin, presented above, the German mannequin studied needed to twist its arms and wrists inappropriately to fit in the airplane seat, as seen in Figure 20. This fact is due to his larger stature and the need for him to shrink to support his arms on the side rests.

Figure 20 - Simulation in male German avatar



Source: (AUTHORS, 2018)

After performing the RULA analysis on the 6 avatars described above, it can be seen that the seat, currently used on Airbus A320 aircraft, needed to be investigated and undergo changes soon in order to adapt to all or most of its users.

In addition, it was possible to notice that those larger avatars, such as the American and the German, had their limbs affected more intensely than the others during the simulations.

The study carried out on these six avatars also allowed the researchers of this theme to determine the main causes by which the members of the mannequins were affected during the simulations. After checking all the simulations performed, it was concluded that the main reason for discomfort was the small width of the seat, which caused passengers to shrink their shoulders and legs, to accommodate themselves in the airplane seat.

Table 2 - Results of the RULA simulations

Nationality	Gender	RULA Method Result
American	Male	5
American	Female	4
Frenchwoman	Female	3
Indiana	Female	4
Japanese	Male	4
German	Male	4

Source: (AUTHORS, 2018)

3.3. Result of the new seat model and aircraft layout

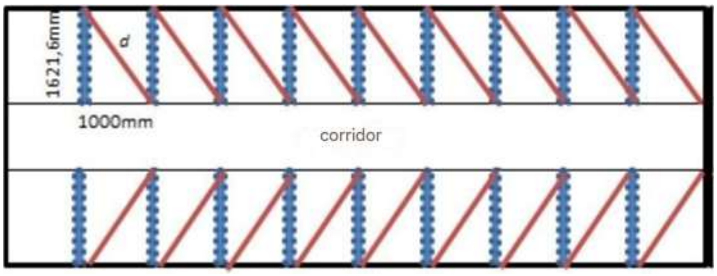
After performing the RULA simulations, presented above, it was possible to verify that the width of the airplane seat studied was inadequate for almost all the avatars analyzed. It was also noted that the increase in this dimension caused a significant reduction in the RULA score, so that the need for change in this measure became clear.

In order to determine how much the dimension of the armchair width could increase, the following analyses and calculations were carried out:

The layout of the Airbus A320 consists of the rows arranged horizontally, with two rows blocks separated by an aisle between them. Each of the rows is composed of three side-by-side seats, and the total value of the length of a row (considering the three seats and their respective armrests) is 1,621.65mm, while the *seat pitch* (distance between an armchair and the seat in front) measures 1,000.00mm, see Figure 10.

It was observed that, if the rows were arranged diagonally, the total distance of the length of a row could be greater (diagonal value), which would allow an increase in the width of each seat and a great ergonomic improvement, according to simulations studied. Figure 21 illustrates the geometric study carried out to determine the space available for the relocation of the seats so that the aisle measurement was kept the same, so as not to hinder the passage of passengers and the meal cart.

Figure 21 - New arrangement of the rows of seats on the aircraft

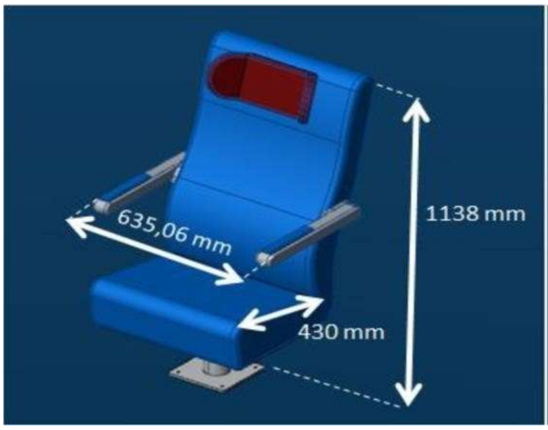


Source: (AUTHORS, 2018)

From the results shown above, the new width and the new *seat pitch* of the seat in preparation were defined. The value of the distance d found, of 1905.19 mm, made it possible to allocate 3 seats, each with 635.06 mm in width, considering the armrests. In this way, the new seat is now almost 100 mm larger than the previous one, which measured 540.55 mm in width. In addition, the new *seat pitch* value of 851.12mm continues to be part of the seat pitch class A established by ANAC (values above 730mm).

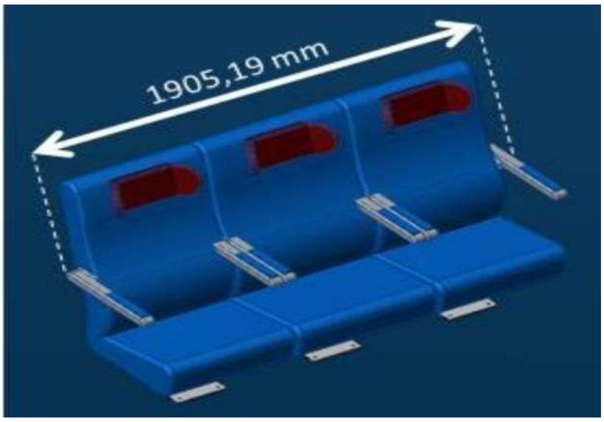
After making the necessary changes to the Airbus A320 seat, in order to reduce the risks presented in the RULA simulations, presented above, the following seat model was obtained, shown in Figure 22 and Figure 23.

Figure 22 - Measurements of the new armchair



Source: (AUTHORS, 2018)

Figure 23 - Measurements of a new row



Source: (AUTHORS, 2018)

With the new layout, it was possible to increase the width of the seat by 94.51 mm, with 50 mm of the upholstery being added and the rest used to insert individual armrests, in order to avoid sharing it, as in the previous model. In this way, it was possible to increase the interior space for the passenger to sit in just over 10% of its old dimension. This change solved most of the discomfort caused by the old seat, since in the new seat passengers no longer need to shrink their shoulders and legs to accommodate themselves in the seat.

According to the Kroemer Table shown in Figure 28, the maximum values found in the sample study for hip width with the body sitting, according to the 95% percentile of women, were in the range of 459.40 mm. In addition, the mean shoulder width found in the study was 435.00 mm. In this way, the new seat is also consistent with this analysis, and promises to bring more space and comfort to the traveler.

Another important factor that was analyzed during the design of the new seat was the height of the seat, since the correct sitting position requires the feet resting completely on a surface, it is important that the height of the seat is the same distance from your knee to the floor (Dul & Weerdmeester, 2012). In addition, projecting the lumbar forward in order to be able to support the feet on the floor can be extremely harmful to health.

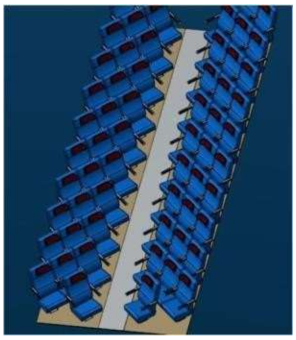
Thus, in order to prevent shorter people from having their legs "floating" in the air, the height of the seat should be designed considering the lowest values of leg length, which corresponds, according to Kroemer's analysis, to 400mm. The height measurement of the old armchair already met this requirement, which remained intact for the new armchair.

In addition, in relation to the length of the seat, the correct measurement should represent the lowest value found for thigh length, in order to avoid pressure on the bottom of it. Adequate dimensions to accommodate buttocks and thighs should leave only the leftovers of the knee out (Iida & Buarque, 2016). The value indicated in the study was 430 mm, thus adopted for the length of the new seat (ROEBUCK, J. A. Jr.; KROEMER, K. H. E.; THOMSON, 1975).

Finally, a lateral headrest was inserted that serves as a cushion, increasing the passenger's comfort when leaning back to the sides and minimizing possible neck and spine pain during long trips.

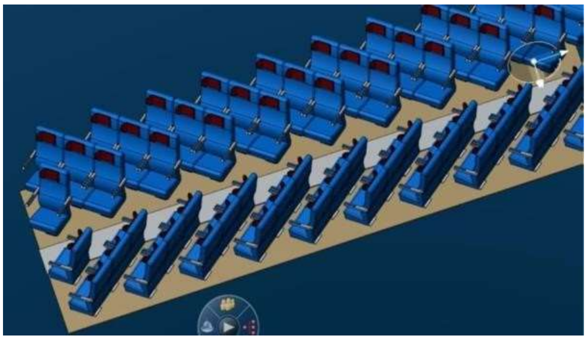
The new distribution of seats inside the aircraft can be seen in Figure 24 and Figure 25. It can be noted that in the last row there were only two seats on each side. In order not to change the number of seats inside the aircraft, these remaining seats were inserted, one on each side, in the front of the plane.

Figure 24 - New seating distribution top view



Source: (AUTHORS, 2018)

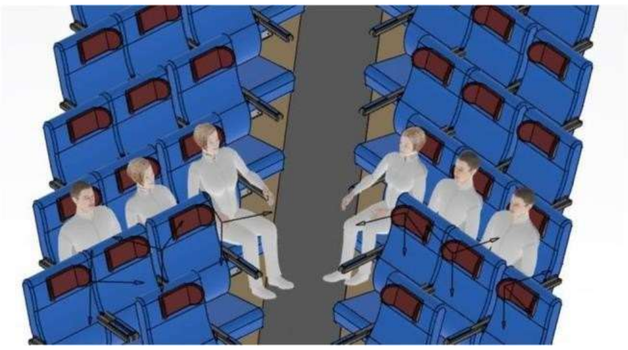
Figure 25 - New seating distribution - side view



Source: (AUTHORS, 2018)

The results of the simulations made with the six digital mannequins, using the new seat and the new layout of the aircraft, in the same way as they were previously carried out with the Airbus A320 air seat model, will be presented, in order to visualize the changes and possible ergonomic improvements acquired. Figure 26 illustrates the positioning of the mannequins in the new seat.

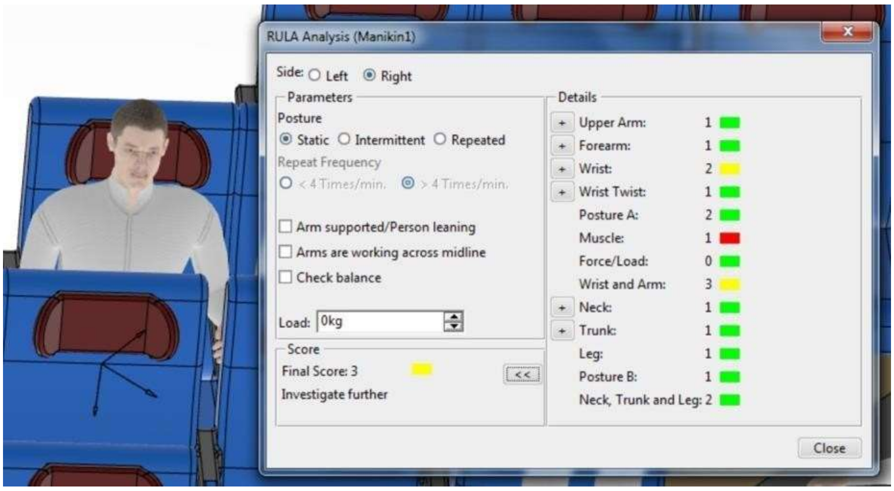
Figure 26 - Avatars positioned in the new airplane seats



Source: (AUTHORS, 2018)

The first mannequin analyzed was the American man, who had previously presented a score of 5 in the RULA ergonomic analysis, indicating an extreme need for change. Using the new seat, the analysis returned a value of 3 for this avatar, pointing to a great ergonomic improvement, although there are still a few points of attention. The factor that contributed most strongly to this improvement was the increase in the distance between the armrests of the armchair, which allowed the avatar greater mobility, so that he did not need to shrink his arms and shoulders while seated. Figure 27 shows the results obtained in this new simulation.

Figure 27 - Simulation of a male American avatar in the new armchair



Source: (AUTHORS, 2018)

The second mannequin analyzed was an American woman, female (Figure 28), which obtained result 4 in the ergonomic analysis of the old armchair. This value was reduced to 3 with the use of the new seat, which demonstrates acceptable conditions for people of this physical type, although there are still some points of attention.

In the first analysis carried out with this avatar, it was observed that the main problem was located in the legs and posterior muscle of the arms, because he was sitting next to a larger avatar (American man described earlier), which made it necessary to shrink his shoulder and legs. With the increase in the width of the seat, the avatar now has enough space to support its limbs properly without being influenced by the physical type of the avatars next to it, which explains the improvement obtained.

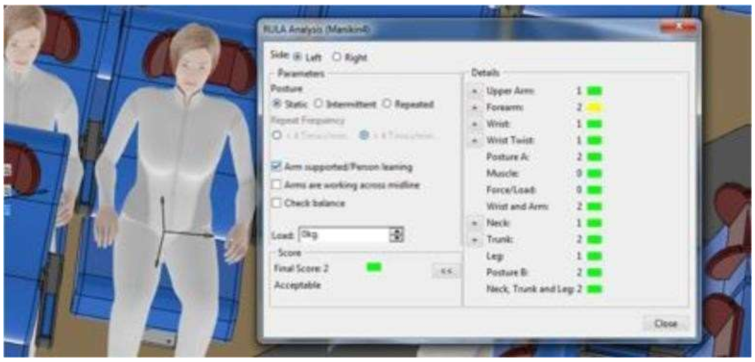
Figure 28 - Simulation of a female American avatar in the new armchair

Source: (AUTHORS, 2018)

Next, RULA analysis was performed on the French female mannequin (Figure 29). The simulation on this mannequin generated a score of 2 on the RULA scale, indicating that the position of this avatar in the new seat is in acceptable conditions for this body type.

In the previous simulation performed with this mannequin, the RULA result presented had generated a score of 3, indicating the need for seat investigation.

Figure 29 - Simulation of a female French avatar in the new armchair



Source: (AUTHORS, 2018)

The next mannequin analyzed was of Indian nationality, female, which had also obtained a result of 4 in the analysis of the old armchair. As shown in Figure 30, the result generated using the new armchair was 2, with all limbs in acceptable ergonomic conditions, with the exception of the forearm, which still has some point in need of improvement. This result again proves how the changes of the new seat have really contributed to the ergonomic improvement.

Figure 30 - Simulation of a female Indian avatar in the new armchair

Source: (AUTHORS, 2018)

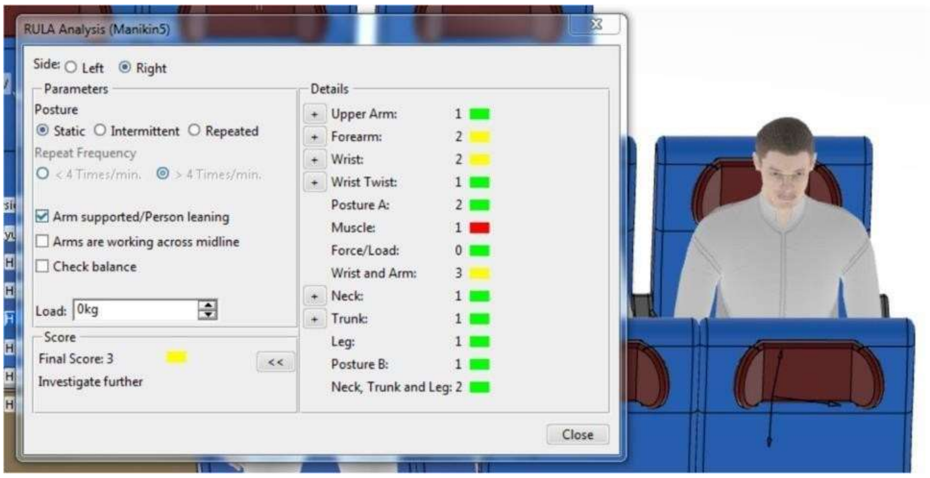
Subsequently, the analysis was performed on a Japanese male mannequin. The RULA performed on this manikin had indicated a score of level 4, and in the present analysis, as shown in Figure 31, the result became level 2, with only the forearm and wrist showing points of possible improvement, while the other limbs were in acceptable ergonomic conditions.

Figure 31 - Simulation of a Japanese male avatar in the new armchair

Source: (AUTHORS, 2018)

The last simulation performed was on the male mannequin of German nationality, which had obtained a result of level 4 and became level 3 in the new seat analyzed. The result obtained was very similar to that of the American avatar, as both have similar large physical types. Figure 32 shows the results of this simulation.

Figure 32 - Simulation of a German male avatar in the new armchair



Source: (AUTHORS, 2018)

After performing all the simulations in the new airplane seat using the different avatars and comparing them with the results previously obtained with the old seat, it was observed that in all cases there was an improvement in the ergonomic result, as expected. Table 3 shows that the values obtained in the simulations of the two seats analyzed can be compared.

Table 3 - Comparison of the results of the RULA analysis of the simulations made in the two armchair models

Nationality	Gender	Airbus A320 armchair	Engineered Armchair
American	Male	5	3
American	Female	4	3
Frenchwoman	Female	3	2
Indiana	Female	4	2
Japanese	Male	4	2
German	Male	4	3

Source: (AUTHORS, 2018)

Only in the result of the largest avatars, American man, German and American woman, although they also show improvements, there are still some points of attention. This is because, due to their larger dimensions, their limbs continue to be affected more intensely than the other mannequins analyzed.

Another notable aspect is the fact that in ergonomics, small changes can mean big improvements in the result. The airplane seat was an example of this, considering that these positive results were achieved through small changes made to some dimensions of the Airbus A320 seat.

4. Conclusion

This work aimed to develop an ergonomic analysis of the standard seat, currently used in commercial aircraft in economy class, to understand the main causes of discomfort experienced by passengers, and to design a new seat model capable of better meeting the needs of users, bringing comfort and safety to them during flights.

The hypothesis that the current model of armchair is not ergonomically correct for travelers was strengthened by market research, which showed dissatisfaction of most of them; and confirmed by the ergonomic analysis in the 3D Experience CATIA Ergonomics for Car Design software, carried out on six mannequins of different nationalities and physiognomic types, which revealed the need for an investigation into the Airbus A320 seat and future changes. Thus, it can be concluded that the primary objective of this study was successfully achieved.

Changes made to the layout of the aircraft, with the rows of seats positioned diagonally rather than horizontally, allowed for a 94mm increase in the width of each individual seat. This modification promoted several ergonomic improvements to the seat when compared to its previous model, according to the new simulations performed in the 3D Experience CATIA Ergonomics for Car Design software.

In addition, the main dimensions of the new armchair (height, length and width) were explored and tested in conjunction with Kroemer's anthropometric dimension table, where it was verified that in fact the seat measurements are in accordance with human anatomy.

Due to the lack of information and conditions for the manufacture of the new full-size seat, it was not possible to address and study the issue of weight reduction, for possible lower costs for the airline (secondary objective).

However, given the importance of the subject, and in order to increasingly improve safety, comfort and well-being for passengers during their trips; It is necessary to deepen this study in the seats of the other aircraft supplied today by the airlines.

As a proposal for future work, there is the possibility of carrying out a feasibility study of the new seating arrangement in relation to aviation standards, in addition to a market research to verify and understand the acceptance of passengers in relation to the suggested layout, and thus, ascertain other possible improvements in the object of study.

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