Advanced Aircraft Seat Design: Designing Features for Improving Comfort and Ergonomy

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ABSTRACT

This design project examines scientific, creative and innovative means to improve passenger comfort in commercial airplane tourist-class seats during long haul flights. These means have been studied, designed, manufactured and tested consistent with the current size, space and safety constraints.

The project involved three phases. In the first phase, the human factors research area, which includes ergonomics, human physiology and anthropometry, was studied. Moreover, passenger survey and quality function deployment were implemented. For the second phase of the design project a second passenger survey and a product design matrix were used for determining the design concepts that later were manufactured and evaluated. Finally, the features of the two design concepts that improve the ergonomy and the comfort of the seat, and their construction and evaluation have been presented analytically.

The test observations showed that the use of an adjustable lumbar support with an adjustable winged headrest could increase the comfort of the aircraft seat, while the use of a height adjustable tray can significantly increase the ergonomy of the seat.

Table of Contents

List of Figures

List of Tables

List of Appendices

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Finally, most of all I would like to thank my parents for their selfless support and their useful advice.

1 Introduction

Personal experiences while flying in commercial airplanes during long haul flights reveal that current economy-class aircraft seats are not comfortable. The goal of this design project was to find scientific, creative and innovative ways to alleviate passenger discomfort during these flights, through the design of an advanced tourist-class aircraft seat that satisfies existing size, space and safety constraints.

Studies have been focused in three major areas. Increasing passenger personal space, improving the ergonomy of the seat, and increasing comfort. The above goal has been achieved in four phases:

- In the first phase, an initial passenger survey has been performed for characterizing the problem, and a quality function deployment has been analyzed for identifying the user's needs.
- In the second phase, an extensive literature research in the areas of anthropometry, ergonomy, psychology and physiology has been performed. Research for previous and current work concerning aircraft seat design was also conducted. Furthermore a product design matrix has been analyzed.
- The information gathered has been used in the third phase for innovation and implementation, taking into account design constraints.
- The fourth phase included the evaluation of the prototypes by using human subjects.

Finally, further objectives of this project were to achieve a design that will advance the aircraft industry, to provide greater competitive advantage for airlines and seat manufacturers, and meet or exceed all expectations of the project stakeholders.

Five graduate MIT students worked at this project for a six month period, resulting in five independent theses concerning the different aspects of the design project.

2 Initial analysis of the problem

The preliminary analysis of the advanced aircraft seat design has been divided in four parts. In the first part, visits were made to aircraft seat manufacturers where the design and development of aircraft seats were explained. At the second part, a questionnaire was distributed to passengers and responses analyzed. Third, a Functional Flow Diagram (FFD) was constructed and finally, the technical requirements were analyzed with the use of a Quality Function Deployment (QFD).

2.1 Seat manufacturers

Two aircraft seat manufacturers responded to the request for technical advisors. These were BE Aerospace and Oregon Aerospace. All members of the design team visited BE Aerospace's factory, and two also visited Oregon Aerospace.

BE Aerospace is one of the major aircraft seat manufacturers and Mr. John Williamson of BE Aerospace was the main technical advisor for our project. During our visit to the factory, a detailed briefing describing all the stages of the design, production and testing of an aircraft seat was provided. The major seat features and constraints were also analyzed, and the phases of the production were explained. Finally, three sets of aircraft seats were provided for study, analysis and reverse engineering.

Oregon Aerospace is involved in the design and manufacture of cushions for aircraft seats and especially in the use of conformal foam. Based on their experiments, conformal foam cushions support the body better, distribute forces equally resulting in decreasing the pressure concentration points. The occupant can sit for an entire flight without needing to shift positions often, something that is a major cause for discomfort. On the other hand, the manufacture of conformal foam is more difficult and more expensive.

In addition to the seat and cushion manufactures, Northwest Airlines responded to the same request and provided useful information on the airlines point of view and interests.

2.2 Survey Analysis

In order to determine the specific areas of an aircraft seat that need improvement, a customer survey was send out to students and faculty of the university. This survey can be found in Appendix 1. After analyzing this survey, many interesting aspects came to light, which were eventually used for weighting the different design concepts during the QFD.

Statistical data were gathered from the analysis of the first three questions. Analysis showed that the information gathered from this questionnaire was acceptable for further analysis, since it showed that this sample of people are flying at an average of two to five times per year (Figure 1), the flight duration is between three and ten hours (Figure 2) – the average duration of a long haul flight, and eighty five per cent of this sample of people are flying in the economy class (Figure 3).

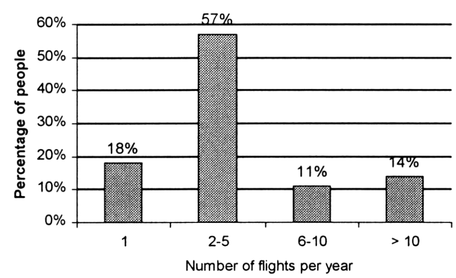


Figure 1: Percentage of times flying per year

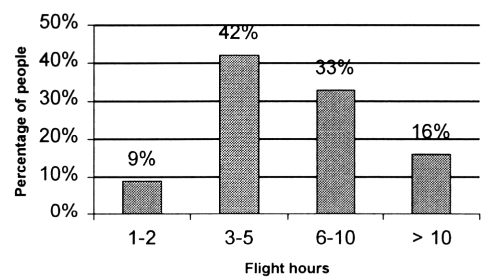


Figure 2: Average duration of flight

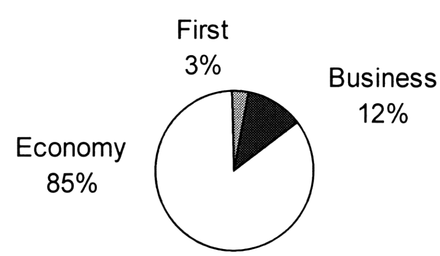


Figure 3: Class that passengers are usually flying

The following questionnaire questions were about the different aspects of the current aircraft seat that require the most improvement, and the features that a passenger would like to find on a seat. The current passenger space, the back support and the headrests of the existing aircraft seats are the features that dissatisfied most the customers (Figure 4). So, these three features, according the passengers, should be improved in a new design concept (Figure 5).

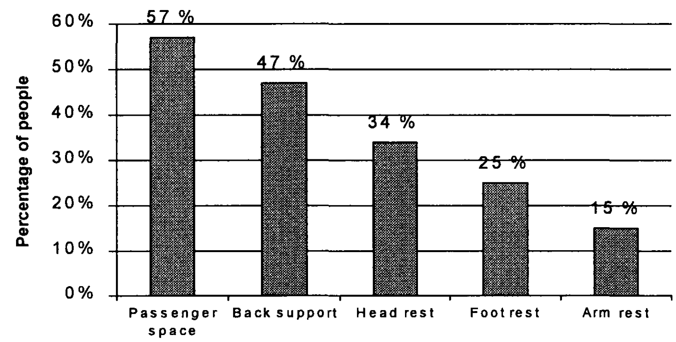


Figure 4: Aspects of the aircraft seat that require the most improvement

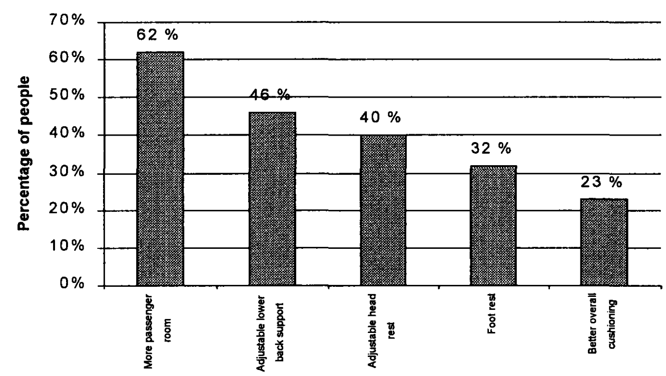


Figure 5: Customer's preferences for an improved aircraft seat

Finally, the increased amount of money that customers were willing to pay for a more comfortable seat was determined. As Figure 6 shows, while the majority of the passengers demanded a more comfortable seat, less than 32% were willing to pay more than a 5% increase in the airfare, and only 6% more than 10%.

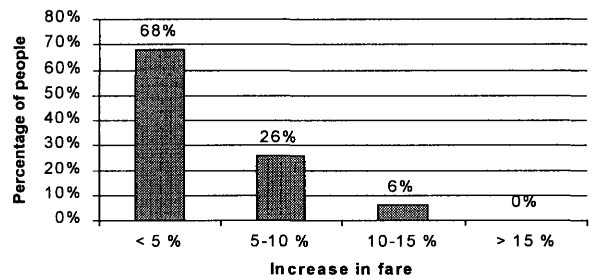


Figure 6: Percentage of increased fare for a more comfortable seat

2.3 Functional Flow Diagram (FFD)

For the third part of the initial analysis of the problem, a Functional Flow Diagram (FFD) was constructed. The FFD is a pictorial scheme used as a mechanism for portraying system design requirements, illustrating series and parallel relationships, and establishing a hierarchy of system functions. The reason for using the FFD was to highlight the different activities that a passenger is involved in during a flight and how the different seat aspects can affect these activities positively or negatively, and finally, which features should be improved in order to increase the total comfort of the aircraft seat during these activities.

The FFD provides a detailed map of the passenger activities during the flight, and it is a tool for ideas generation and visualization. Moreover, it can be expanded for a dynamic comfort analysis. It can be seen at Figure 7

2.4 Technical requirements analysis

The final step of the initial phase was to look into the technical requirements for the aircraft seat design. These requirements were derived from the customer and industry needs. The customer needs were extracted from the customers' survey and the analysis of the FFD, and the industry needs from our technical advisors.

For the best analysis and evaluation of the technical requirements a Quality Functional Deployment (QFD) matrix was constructed and analyzed. The QFD matrix is a graphical technique that translates customer needs into parameters or attributes of the product. A weighting coefficient is assigned to each customer and industry need. In total, eighteen customer and industry needs were considered.

2.4.1 Customer needs

The Customer needs that resulted from the survey and the FFD, can be seen in the following Table 1:

Customer Needs	Weight
Provide More Personal Space	10
Improved Physical Comfort	10
Higher Adaptability	8
Aesthetic Appeal	7
Better Entertainment	7
Additional Functionality	7
Better Environment	4
Better ingress/egress	3
User Friendly / Easy of Use	1

Table 1: Customer Needs

The weighting coefficients resulted from the degree that each one of these customer needs affected the comfort of the passenger. Provide more personal space, rated as the most important, because according the survey results, it was the most demanding from the passengers' point of view. Improved physical comfort was also important, since it was the driving need for our design.

FUNCTIONAL FLOW DIAGRAM FOR A TYPICAL AIRCRAFT TOURIST-CLASS PASSENGER

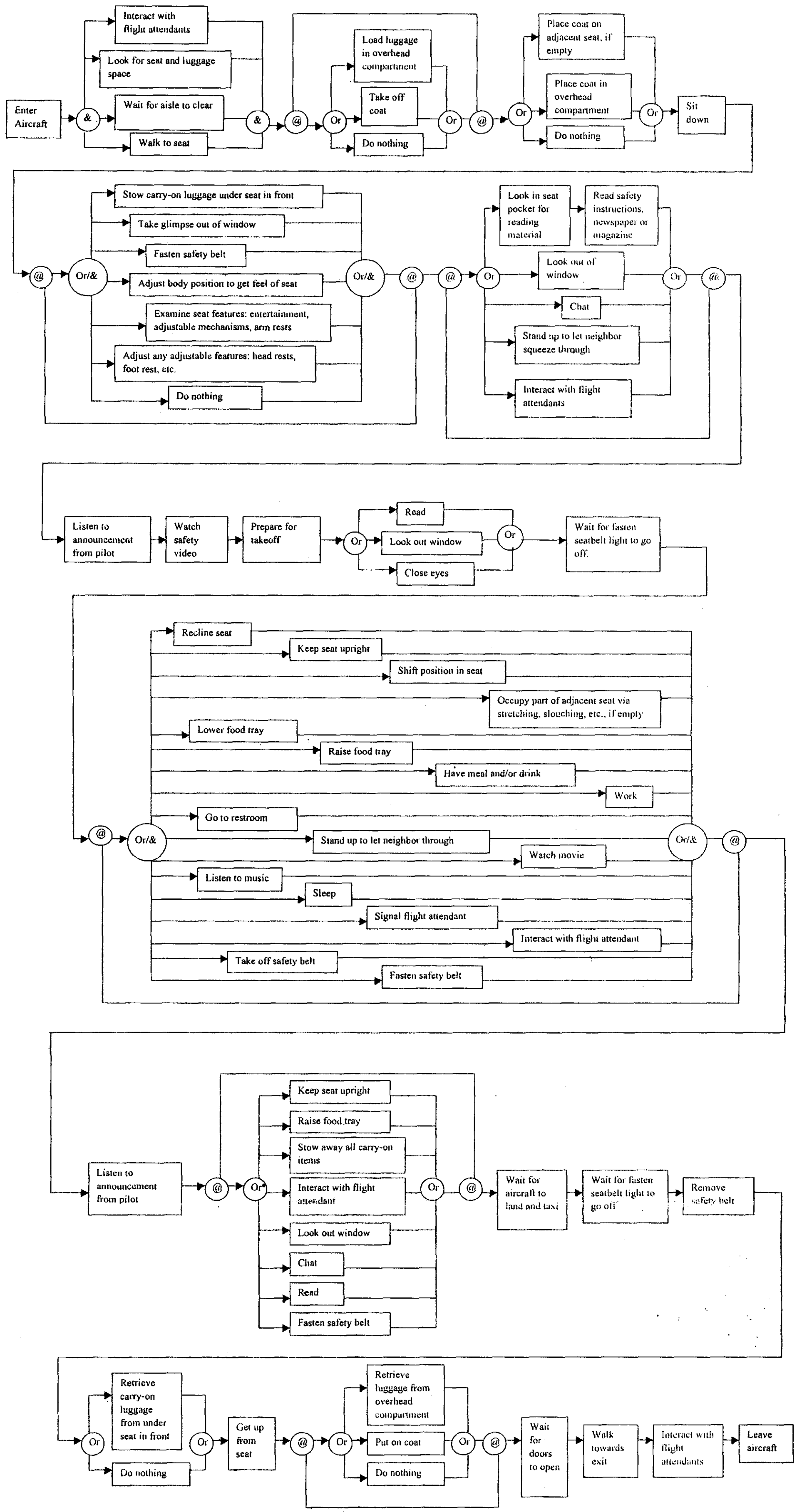


Figure 7: Functional Flow Diagram

2.4.2 Industry needs

The industry needs that were recommended by the technical advisors can be seen in Table 2:

Industry Needs	Weight
Provide More Personal Space	10
Improved Physical Comfort	10
Lower Cost of Ownership	10
High Reliability	8
Improved Maintainability	8
Anthropometric Design	8
More Robust Design	7
Aesthetic Appeal	7
Low Weight	6
Good Fleet Compatibility	5
High Upgradability	5
Spares Provisioning	4

Table 2: Industry Needs

The weighting coefficients are based on industry importance. As can be seen, three of the industry needs are common with the customer needs. This was another reason for their higher weightings. Considering the industry needs, lower cost of ownership was the most important. The survey showed that the passengers are not willing to pay a higher airfare for a more comfortable seat, so, keeping the total cost low was very important.

2.4.3 Quality Functional Deployment (QFD)

Different technical requirements that satisfied these customer and industry needs have been evaluated. The QFD matrix made it possible to select the most important technical requirements that were considered in the second part of the project, by minimizing human biases, prioritizing technical requirements and providing requirements traceability. Moreover, conflicts between the technical requirements were traced.

The different elements of the QFD matrix are explained in Figure 8. The customer and industry needs are listed on the left of the matrix. The different technical requirements that satisfy the needs are listed on the top. In the relationship matrix, the strength of the relationship is indicated. Moreover, in the priorities section, the final ranking for each technical requirement is calculated. Finally, conflicts between the technical requirements are indicated in the correlation matrix. Figure 9 shows the final QFD used for the technical requirement analysis of the aircraft seat design and all the technical requirements that were considered.

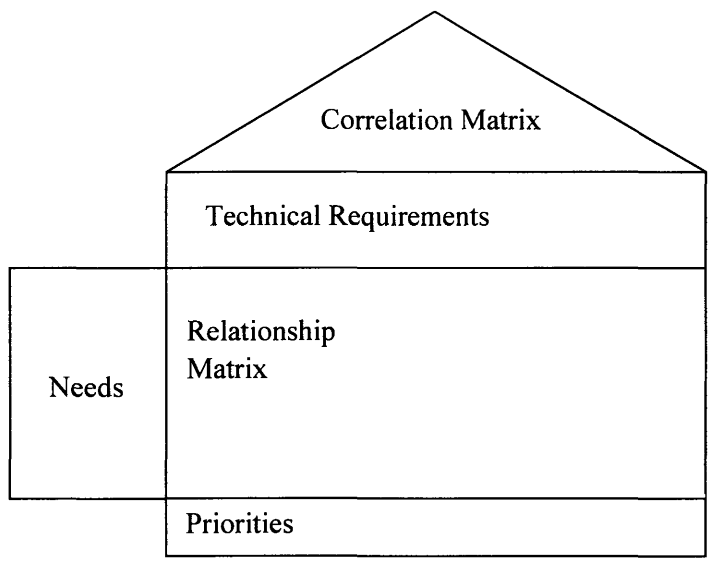


Figure 8: Elements of a QFD matrix

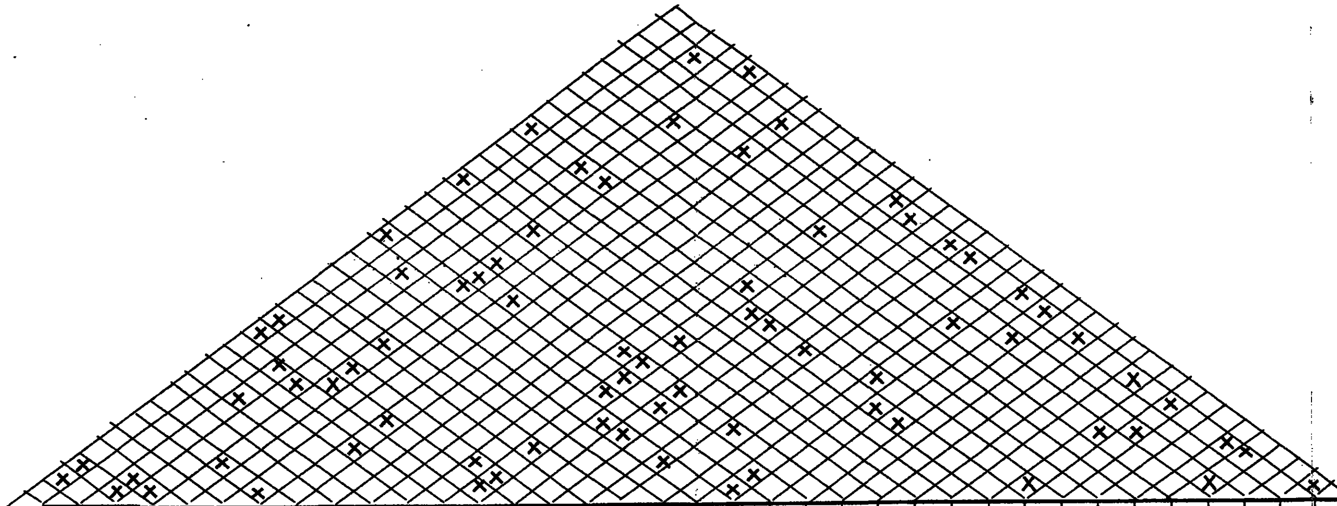
The top seven technical requirements that resulted from this analysis where:

- Simplicity of engineering
- Accessory arrangement minimization
- Ergonomic / anthropometric design
- Minimize number of parts
- Continuous adjustability
- Common internal parts
- Ease of maintenance

Other technical requirements with close rankings have been retained. These technical requirements were used for identifying the most important seat attributes that should be implemented in the aircraft seat for increasing comfort.

2.5 Approach for second phase

The results of the first phase of the project were used to identify different areas for research. Then, a second customer survey was conducted and by the analysis of a Product Design Matrix (PDM) the design concepts were defined. The third phase of the project included the construction of the design concepts with the implementation of the different design features, and finally the fourth phase included the evaluation of the designs.



	Weighting	Minimize accessories and arrangement	Improved seat arrangement	Electrical controls	Mechanical controls	Simplicity of engineering	Durable materials	Reduced seat volume	Ergonomic/anthropometric design	Easily obtainable parts	Common internal parts	Low MTBF	Commonality of design	Minimize number of parts	Versatile design	Adjustable mechanims	Aesthetic design	Environmental controls	Light structural materials	Comfortable material	Ease of maintenance (cleaning too)	Personal avionics	Adjustable geometry	Variable loads absorption	Variable degree of firmness	Facilitate work	Intuitive controls	Isolation	Minimize controls	Powered adjustments	Modern appearance	Visual patterns	Material texture	Continuous adjustability	Fixed geometry	Modularity of design	Cost-effective design	Integrated funtionality	***CONSTRAINTS***	*Engineering standard*	*Compliance to regulations*
Customer needs																																									
Higher adaptability	8															9		3					9	3	1									9							
Better entertainment	7																					9						3													
Better environment	4	1	1	3														9				3						3													
Better ingress/egress	3	3	3					9															3																		
Additional functionality	7			9	9										9	3					3					9								3							
User friendly / Easy of use	1	3		1														1									9		9	9											
Customer/Industry needs																																									
Aesthetic appeal	7		1						3								9			3		1									3	9	3								
More personal space	10	9	3					9																																	
Improved physical comfort	10	3	3					3	9							3		1		9			3	3	3									9							
Industry needs																																									
Lower cost of ownership	10				3	9	9			3	3	3	3	3					1		9																9	3			
Low weight	6	9		3		3								1					9																3						
High reliability	8	9		1	3	9	3					9		3																											
Spares provisioning	4	3				9	3			9	9	3		3																											
More robustness (stiffness, strength)	7					9								9																											
Improved maintainability	8				3	9					9		1	3							9																				
Good fleet compatibility	5					3					9		9	3	3																										
High upgradability	5					3									9																					9					
Anthropometric (wider population fit)	8								9							9																									
Total		274	80	102	141	381	126	147	183	66	183	114	83	174	123	195	63	71	64	111	183	82	111	54	38	63	9	33	9	9	21	63	21	183	18	45	90	30		N/A	N/A

Figure 9: Quality Functional Deployment

3 Main areas of research

The first part of the second phase of the project was the accomplishment of detailed research in different areas. The areas of anthropometry, psychology, materials, ergonomics, were studied and general and specific principles of seat design were analyzed

3.1 Anthropometry

The most important aspects of designing a seat involved determining the proper sitting position, the need for variations in sitting positions, and the different chair settings. The major results from the research in anthropometry are presented in the following paragraphs. A more detailed analysis of the findings in anthropometry can be found in Ref. 1

For the proper sitting position, five main areas must be considered according to Ref. 5. First, the feet of the passenger must be flat on the floor with knees at an angle of 90 degrees or slightly more. Second, the chair should be at an ideal height according the person who is sitting, otherwise, if it is too high the pressure under the thighs reduces the circulation to the lower part of the leg; while if it is too low, lower back pain may occur. Both cases correspond to discomfort for the passenger. Third, the back of the knees must be two to three inches forward of the chair's front edge. This eliminates any pressure in the popliteal area, which contains many blood vessels and nerves. Fourth, the shoulders need to be relaxed, and finally, the arms should be kept close to the body without having to be held away from the body.

The need for variations in the sitting position and the posture changes are as important as the posture correctness, especially regarding the intervertebral discs in the spine. The reason is that the discs are losing fluid over the course of time because of the weight they carry. The posture changes are essential for helping fluid return to the discs.

There are three major chair considerations that are important for passenger's comfort. First, a chair should minimize, or even avoid pressure concentrations at sensitive parts of the human body. Second, the backrest must support the natural inward curve of the lumbar area. Finally, an inadequate lumbar support places excess pressure on the spine.

3.2 Psychology

In many cases, discomfort can be credited to psychology and especially to the environment that surrounds the passenger. Proper environment control can reduce these effects. Another aspect also in psychology, is the distraction of the passenger from the causes of dissatisfaction, by averting his senses to other, more pleasurable objects. The use of different colors and a correct lighting condition can also improve the feeling of comfort. A more detailed analysis of the psychological aspects can be found in Ref. 2.

3.3 Materials

During the research phase, conformal foam properties were studied, as a material substitute for the construction for the seat cushions. A conformal foam cushion has many advantages.

- It is available in varying degrees of flexibility and rigidity
- It has great shock absorbing properties that can reach 97% of the impact energy in case of an accident
- It conforms to the body shape
- It is breathable; thus it is able to dissipate moisture and perspiration, and
- It has a slow recovery of its original shape from several seconds up to three and a half minutes.

The conformal foam has also the following disadvantages.

- It is very sensitive in temperature and pressure
- It is very difficult to obtain laminate with precision
- The foams of varying degrees of flexibility have to be layered together
- The conformal foam is less durable in shear stresses, and
- It has high cost.

A more detailed analysis in the characteristics of the conformal foam and the possible uses in aircraft seat design can be read in Ref. 3.

3.4 Ergonomics

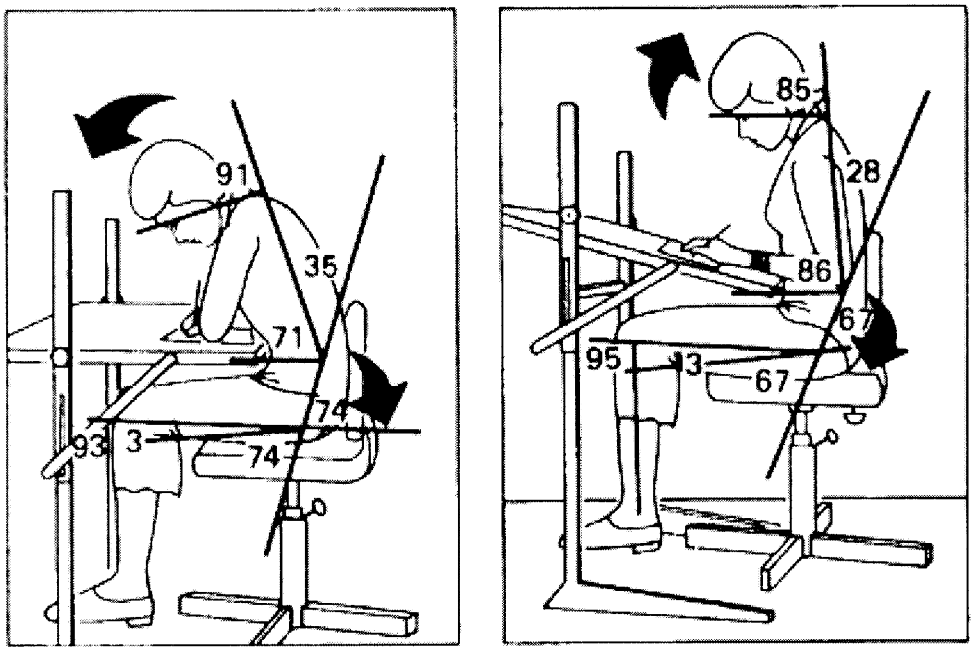
The word ergonomics is defined as the science of designing for people. It includes the design of workplace equipment to optimize productivity and to reduce the potential for physical illness or injury. Initially, all the areas concerning ergonomics were studied and then the most important of them were implemented in conjunction with the constraints imposed.

For designing an ergonomic seat it is unlikely that discomfort can be avoided by simply matching each body dimension with the equivalent seat dimension, as if the interface were static. What seems to be critical is the relation of any one dimension with the others and with the expected seated position. So, it is important to determine not only the correct dimensions for each seat feature that would increase the seat's ergonomy, but also the adjustability needed to accommodate the different positions that a passenger takes during the flight for the accomplishment of each task.

Initially, it was important to determine which aspects of the aircraft seat have a direct impact on the ergonomy of the seat. These are the work-surface; the seated work-surface height and arm posture; the seated work-surface height and thigh clearance; and the seated work-surface height and the nature of task, according Ref. 4.

3.4.1 Work surface

Work-surface is defined as the upper surface of a table, bench, desk, counter, measured from the floor. For an aircraft seat this corresponds to the upper surface of the tray. There are two main characteristics of the work-surface; the height and the position with the horizontal. If a work surface is too low, the back may be bent over too far. If it is too high, the shoulders must be raised above their relaxed posture, thus triggering shoulder and neck discomfort. On the other hand, the orientation relative to horizontal is very important, because a slanted surface results in less bending of the neck, more upright trunk, and less flexion than does the horizontal surface, as can be seen in Figure 10.



(a) Horizontal surface (b) Slanted surface

Figure 10: Comparison of typical postures when horizontal or slanted surfaces are used. (Taken from Ref. 4)

3.4.2 Seated work-surface height and arm posture.

The work surface height must permit relaxed postures of the upper arms. Working with relaxed upper arms and elbows at about 90° provides comfort and helps maintain straight wrists, which can be beneficial when performing repetitive tasks.

3.4.3 Seated work-surface and thigh clearance

Basing seated work surface height on arm posture alone can lead to problems. Work surface height is also influenced by seat height, the thickness of the work surface and the thickness of the thighs. The clearance between the seat and the underside of the work surface should accommodate the thighs of the largest user. If the height of the work surface is designed for a larger user, then the smaller users have to raise their seat, so their elbow height is equal to the working height. In so doing, their feet can not touch the floor. So a footrest is also needed to support their feet. With adjustable height work surfaces, small users can adjust the height so that the working level is at elbow height with their feet on the floor.

3.4.4 Seated work-surface height and nature of the task

Table 3 presents some recommendations for the work-surface heights from various sources based on representative anthropometric data.

Type of Task	From	To
Reading and Writing	27.5 inches	31 inches
Range for typing desks	23.5 inches	27.5 inches
Computer keyboard use	23 inches	28 inches

Table 3: Recommendations for seated work-surface heights for various types of tasks. (Taken from Ref. 4)

3.5 General principles of seat design

Many principles must be followed during the design of a seat.

3.5.1 Promote lumbar lordosis

According Ref. 4, when a person is standing erect, the lumbar portion of the spine is naturally curved inward, *lordotic*, as can be seen at Figure 11. Natural lumbar lordosis aligns the vertebrae of the spine in a near vertical axis, through the thigh and pelvis. However, when one is sitting with the thighs at 90°, the lumbar region of the back flattens out and may even assume an outward bend, *kyphotic*, as can also be seen at Figure 11. Lumbar kyphosis results in increased pressure on the discs located between the vertebrae of the spine. There are two main ways to maintain the lordotic posture of the spine. By using a lumbar support (Ref. 5) or by providing a forward tilting seat (Ref. 4). A forward tilting seat opens the angle between the hip and the upper torso, thus producing a more relaxed posture (Figure 12).

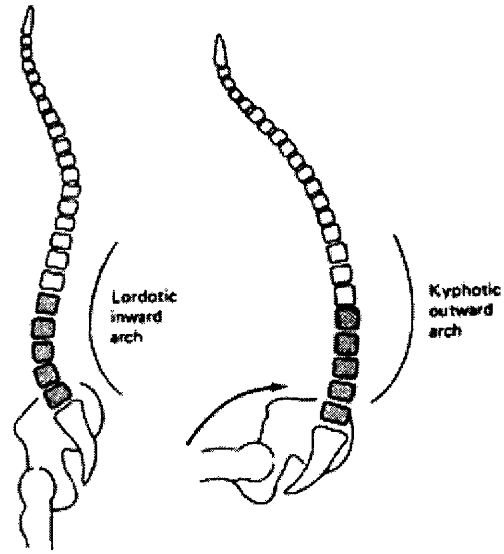


Figure 11: Lordotic and kyphotic posture of the spine. (Taken from Ref. 4)

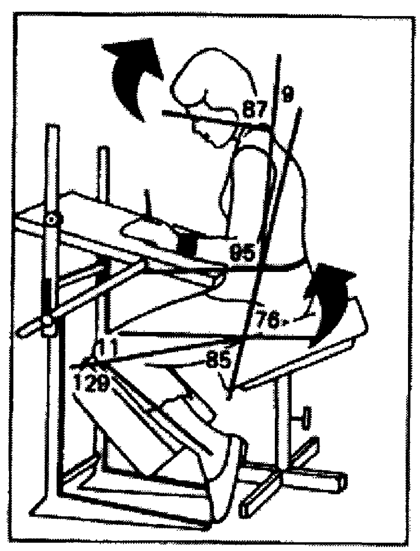


Figure 12: Forward tilting seat. (Taken from Ref. 4)

3.5.2 Minimize disc pressure

The discs between the vertebrae can be damaged by excessive pressure. Unsupported sitting increases disc pressure considerably over that experienced while standing. A reclined backrest at an angle from 100° to 110° can decrease disc pressure. Pressure is also decreased by the use of a lumbar support.

3.5.3 Reduce postural fixity

Postural fixity is the problem that occurs when sitting in one position for long periods without significant postural movement. The human body is not made to sit in one position for long periods of time. The discs between the vertebrae depend on changes in pressure to receive nutrients and remove waste products. Since discs have no blood supply, fluids are exchanged by osmotic pressure. Sitting in one posture will result in reduced nutritional exchange and in the long term may promote degenerative processes in the discs. Chair design can reduce postural fixity by allowing the user to rock in the chair and assume a variety of postures.

3.6 Specific design recommendations

The basic recommendations for a seat design, according Ref. 4 to Ref. 6, can be seen in Figure 13. A good seat design must accommodate from the fifth percentiles of Asian female body dimensions (which on average consists the smallest size of the world population), to the ninety-fifth percentile of North European male body dimension (which on average consists the largest size of the world population). Figure 13 provides the optimum seat dimensions.

1:	Seat height:	14.5" -- 19"
2:	Seat Back height:	30.8" -- 39.3"
3:	Seat depth:	16" -- 17"
4:	Work surface height:	23" -- 31"
5:	Work surface - seat back:	18.3" -- 24.5"
6:	Seat back angle:	90° -- 110°
7:	Seat slope:	5° -- (-10°)
8:	Work surface slope:	0° -- 15°

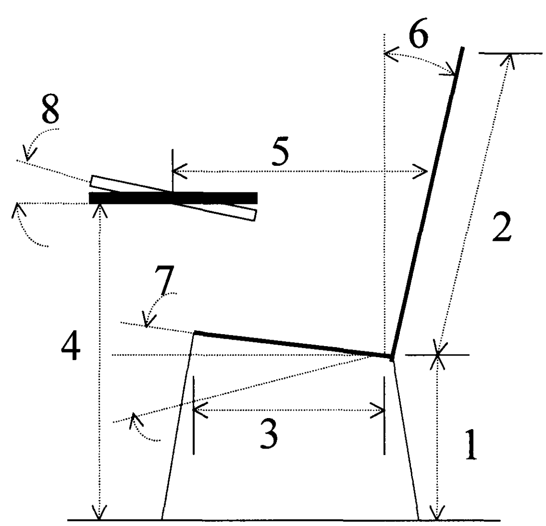


Figure 13: Optimum seat dimensions

4 Design concepts

4.1 Seat design attributes for increased comfort

After the end of the research phase, the different seat requirements were established. From these requirements, many different seat features were considered and later evaluated with the Product Design Matrix. The seat features that can improve the comfort of the seat were:

- Seat height adjustability

This feature, allows the user to adjust the height of the seat bottom, so that the passenger's feet are flat on the floor

- Seat back angle adjustability

This refers to changing the angle of the backrest relative to the angle of the seat. It allows the chair to support different degrees of recline, which in turn transfers some upper-body weight to the chair backrest and lightens the load on the lower back's intervertebral discs. The backrest angle adjustability also increases the angle between the torso and the thighs, resulting in less pressure on the discs.

- Tiltable seat bottom

This feature refers in changing the angle of the seat relative to the floor, and so, again some upper-body weight can be transferred to the chair backrest.

- Height adjustable armrests

A high armrest results in elevated shoulders and pressure on the undersides of the elbows and forearms. On the other hand, a low armrest causes the passenger to slump or lean to one side to use them. By the use of height adjustable armrests these problems can be avoided

- Padded armrests

Padded armrests eliminate uncomfortable pressure on the undersides of the forearms and elbows

- Lumbar support adjustability

A lumbar support should be adjustable in height and in depth. A height adjustable lumbar support can fit a higher percentile of passengers, while depth adjustability can control the size and the firmness of the lumbar support

Beyond the features that improve the comfort of the aircraft seat, three more features that improve the ergonomy of the seat were also considered. These features correspond to the optimum position of the tray in accordance with the passengers' position, and they are:

- Height adjustable tray
- Tiltable tray
- Sliding in/out tray

4.2 Survey analysis

A second passenger survey was prepared in order to examine in-flight activities of the passengers and their preferences for some specific seat features. The complete questionnaire can be found in Appendix 2. The first question involved rating the level of comfort for getting in and out of the seat in four different conditions. As it can be seen at Figure 14, a major reason for discomfort is a reclined forward seat, since it reduces the passengers' personal space significantly.

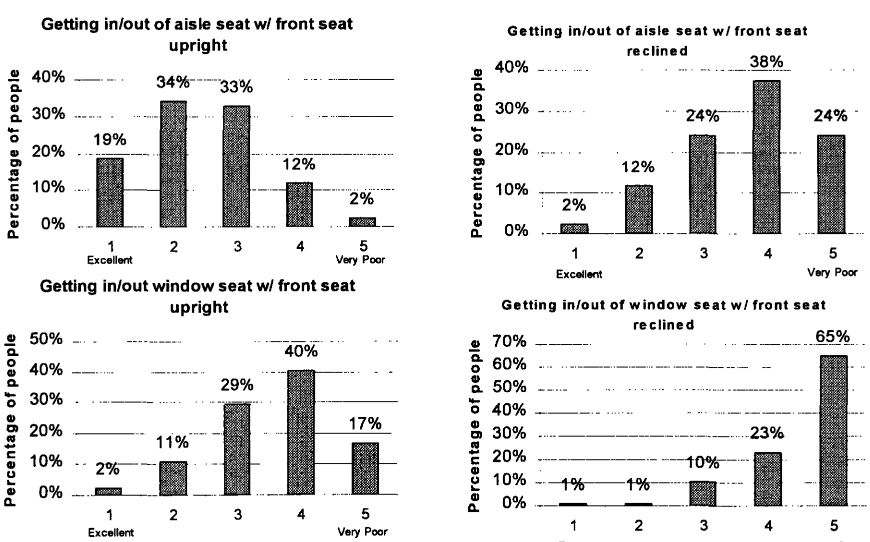


Figure 14: Level of comfort when getting in/out of a seat with front seat upright or reclined

As it was realized from the FFD analysis, during the flight a passenger is involved in many different activities, and the ease of performing these activities has a positive or negative effect on the total level of comfort for the seat. Figure 15 shows the percentage of time for the different activities that a passenger does during the flight, and Figure 16 shows the level of comfort for each activity. The percentage of time corresponds to the real time that a passenger spends during a flight, and not the time that he/she would want to spend. Because the level of comfort for sleeping and working is very low, it is very difficult for a passenger to perform these tasks, and that's why he/she spends more time in reading, a task that is much easier.

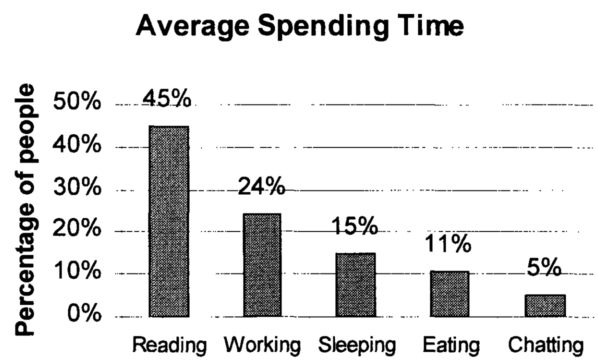


Figure 15: Average time for flight activities

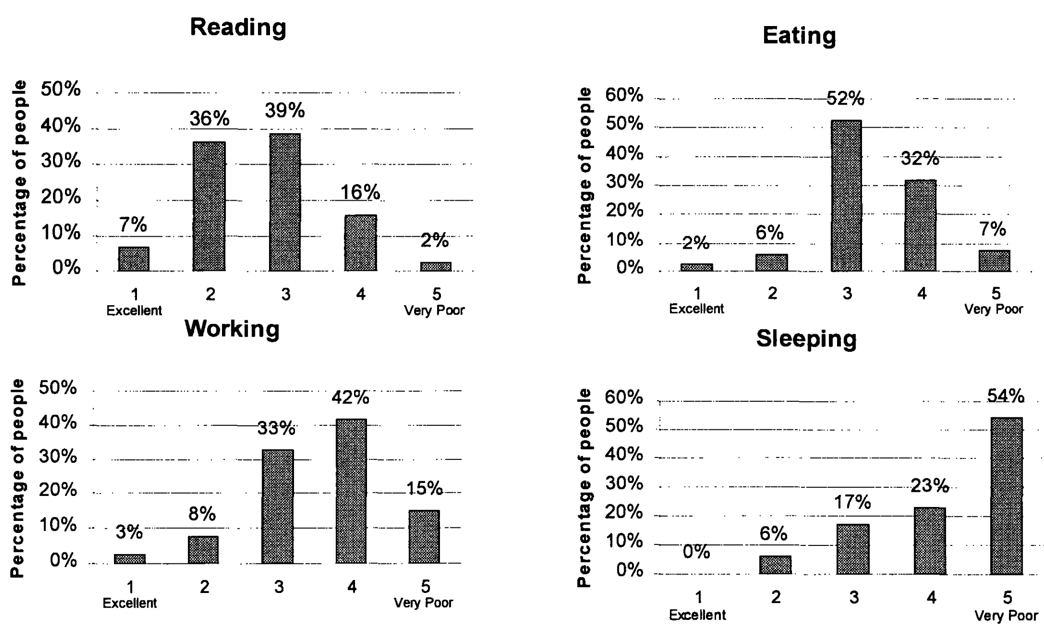


Figure 16: Level of comfort for flight activities

Moreover, as it has been found from the research phase, the features of the working surface have a major contribution for the level of comfort considering the ergonomy of the seat. So, for the survey the passenger rated the most important features that he/she would like to see in a future design. Figure 17 shows that the most preferred feature is a height adjustable tray, then a sliding in-out tray and finally a tiltable tray.

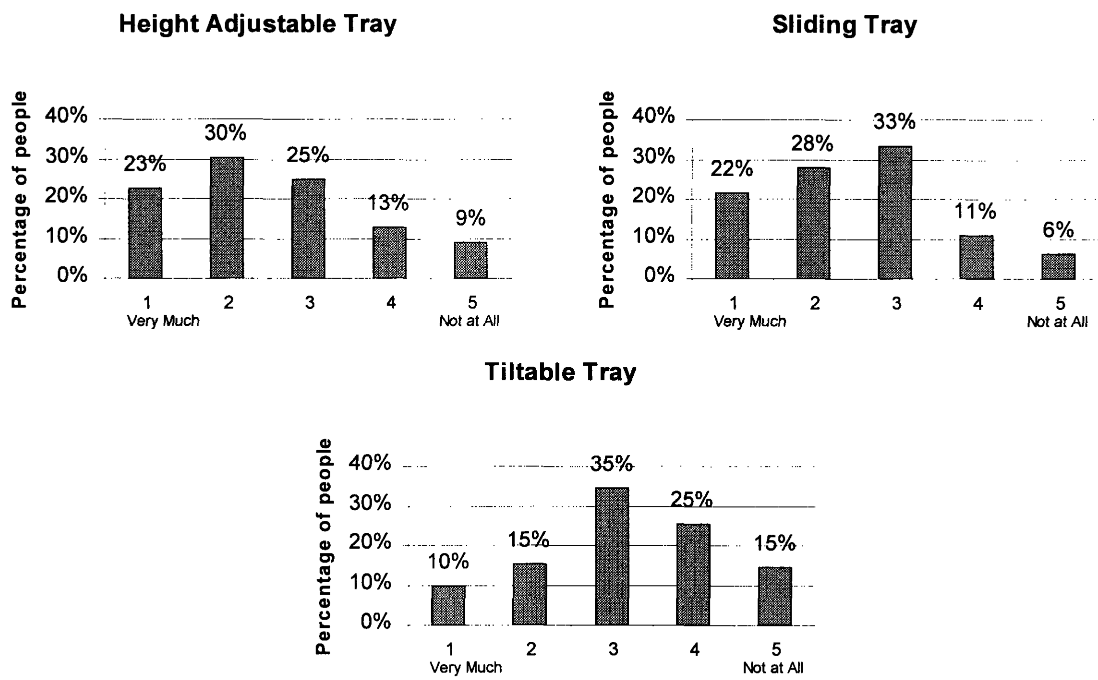


Figure 17: Preferences for the seat tray

Finally, since a reclined seat has a major negative effect on ingress and egress, the survey asked the respondents to rate their preference between a reclinable seat and the existence of a lumber support. The analysis of the survey shows, that there is a small preference for a lumbar support versus a reclinable seat (Figure 18).

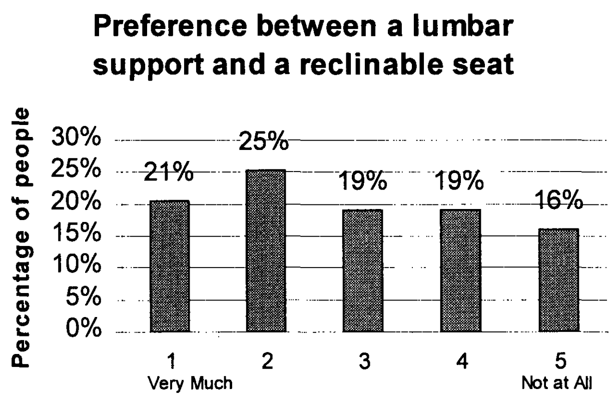


Figure 18: Preference between a reclinable seat and a lumbar support

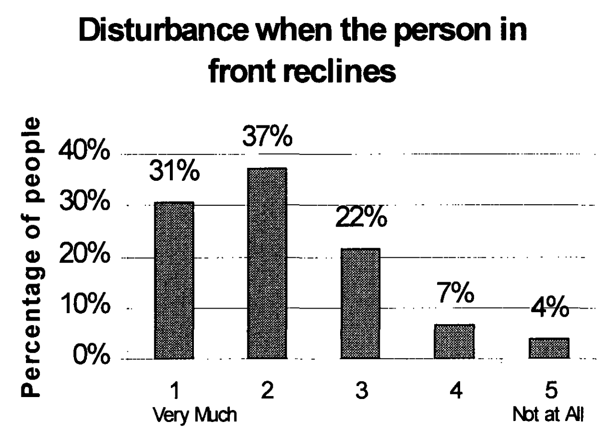


Figure 19: Disturbance when the person in front reclines

4.3 Product Design Matrix (PDM)

The product design matrix is the second step of the QFD. With this matrix, the different seat features considered to improve the comfort and ergonomy of the aircraft seat were evaluated in accordance with the resulting weightings of the technical requirements from the QFD. Figure 20 shows the detailed PDM. In total, seventy-six different seat attributes were considered. Since the scores resulting from the PDM did not take into account the research weightings, these scores for each seat feature have been moderated according to their relative merits for providing comfort according the information gathered during research. For that reason, even the "Thin Diaphragm Seats without Cushion" ranked third in the PDM, since it does not contribute directly to increase ergonomy or comfort. In the revised scores it ranked sixth. Table 4 shows the seat attributes that were considered with the corresponding research weightings and their final scores. The final top five design seat features were:

- Non – Reclinable seats
- Webbing as cushioning substitute
- Sliding trays
- Height adjustable trays, and
- Adjustable foot rest.

4.4 Design concepts

The last part of the second phase of the project includes the definition of the final design concepts. After having the resulting rating for each seat attribute, these ratings have been divided in three categories. These categories were:

- Provide more personal space
- Facilitate in-flight activities
- Provide better support

Then, at least one seat feature was chosen from each category.

4.4.1 Design Concept #1

For the first design concept, to provide more space, a non-reclinable seat was chosen. A reclinable seat is able to support different degrees of recline, to transfer some of the upper body weight to the back rest, it lightens the load on the lower back's intervertebral disks and increases the angle between the torso and the thighs. This results in lordosis. On the other hand, a reclinable seat is responsible for intrusion into other passenger's space behind the seat. It is impossible for the passenger to effectively use the tray when the front seat is reclined. Recline also reduces the ease of ingress and egress and finally it has a more complex design.

Technical Requirements	Weighting	1 Patterns on fabric that give feeling of greater space	2 Aesthetically pleasing patterns of fabric	3 Colors that are pleasing to the eyes	4 Light colors to convey better sense of depth	5 Dark colors to make stains less visible	6 Space-age colors	7 "Slides" at the back of trays depicting sunset, mountain, etc. (selectable)	8 Logo/symbol on seat back to draw attention away from peripheral vision	9 Soft and comfortable fabric (nice to the touch)	10 Smooth fabric	11 Textured fabric	12 Durable and longlasting fabric	13 Zip-up seat covers (to facilitate cleaning)
Simplicity of engineering	20	9	9	9	9	9	9	3	9	3	9	9	3	9
Accessory arrangement/minimization	16													
Adjustable mechanisms	13							3						
Ergonomic/anthropometric design	10													
Ease of maintainance	10	3	3	3	3	9	3	1	3		3		9	9
Continuous adjustability	10													
Common internal parts	10													
Reduced seat volume	9													
Minimize number of parts	9													
Mechanical controls	7							1						
Durable materials	7											1	9	
Versatile design	6	3	3	3	3	3	3	3	3					
Low MTBF	6					1							9	
Comfortable materials	6	3	3	3	3				3	9				
Adjustable geometry	8													
Electrical controls	5													
Easily obtainable parts	5	3	3	3	3				3	1	1	1		
Cost-effective design	5	3	3	3	3	3	1		3	1	3	3	1	
Integrated functionality	5	1	1	1	1	1	1	1	1	1			1	
Improved seat arrangement	5													
Commonality of design	4													
Personal avionics	4													
Environmental controls	4													
Modularity of design	4	1	1	1	1	1	1		1	1			1	
Light structural materials	3													
Visual patterns	3	9	9						3			3		
Aesthetic design	3	3	9	9	3	3	3	9	3					
Facilitate work (laptops included)	3													
Variable loads absorption	3													
Variable degree of firmness	2													
Isolation	2							1	3					
Modern appearance	1		3	1			9	3	1	1				
Material texture	1									9	3	9		
Fixed geometry	1													
TOTAL:		331	352	323	304	337	270	181	320	153	243	235	291	280

Technical Requirements	Weighting	14 Protruding seat edges to symbolically mark personal boundaries	15 Protruding head rest edges for more privacy	16 Retractable screens that block other passengers from field of vision	17 Seats arranged diagonally	18 Middle seats offset backwards to facilitate 3-way/4-way conversation	19 Theatre-style seating	20 Sliding trays	21 Tiltable trays	22 Height-adjustable trays	23 Height-adjustable arm rests	24 Inflatable arm rests	25 Arm rests that swing out to facilitate conversation (when seats are offset)	26 Width adjustable arm rest
Simplicity of engineering	20	3	3	3				3	3	1	1	3	3	3
Accessory arrangement/minimization	16													
Adjustable mechanisms	13			9				9	9	9	9	9	9	9
Ergonomic/anthropometric design	10							9	9	9	9	3		3
Ease of maintainance	10	3	3											
Continuous adjustability	10			9				9	3	9	3	3	9	3
Common internal parts	10													
Reduced seat volume	9													
Minimize number of parts	9													
Mechanical controls	7			9				9	9	9	9	1	9	3
Durable materials	7													
Versatile design	6	3	3		3	9							9	
Low MTBF	6													
Comfortable materials	6													
Adjustable geometry	8										1	3	1	9
Electrical controls	5													
Easily obtainable parts	5				1	1		1	1	1	1		1	
Cost-effective design	5													
Integrated functionality	5	1	1					3	3	9	3	1	1	3
Improved seat arrangement	5				9	9	3							
Commonality of design	4													
Personal avionics	4													
Environmental controls	4													
Modularity of design	4													
Light structural materials	3													
Visual patterns	3													
Aesthetic design	3						3		1					
Facilitate work (laptops included)	3	1	3			1		9	9	9	3	3	1	
Variable loads absorption	3											3		
Variable degree of firmness	2											3		
Isolation	2	3	3	9	3									
Modern appearance	1			3	1	3	3		3			3	1	
Material texture	1													
Fixed geometry	1	1	3											
TOTAL:		133	141	361	85	120	37	477	423	467	365	304	414	337

Technical Requirements	Weighting	27 Cup holder on arm rest	28 Cushioned arm rest	29 Sinkable (all the way) arm rest (instead of upwards rotation)	30 Contour head rest	31 Height-adjustable head/neck rest (mechanical)	32 Inflatable head rests	33 "Wings" to rest head on	34 Foldable head rest to facilitate front-back conversation	35 Adjustable foot rest	36 Adjustable leg rest	37 Vertically adjustable seat back	38 Horizontally adjustable backrest	39 Flat seat back
Simplicity of engineering	20	9	9		3	1	1	3		3				9
Accessory arrangement/minimization	16			3										
Adjustable mechanisms	13			3		9	9	9	9	9	9	9	9	
Ergonomic/anthropometric design	10		3		9	9	3	1		9	9	9	3	
Ease of maintainance	10	9	1		9									9
Continuous adjustability	10			3		3	3	9	9	9	9	3	3	
Common internal parts	10													
Reduced seat volume	9													3
Minimize number of parts	9				1									
Mechanical controls	7			3		9	1	3	3	9	9	9	9	
Durable materials	7													
Versatile design	6	9		9				9	9					
Low MTBF	6				3									3
Comfortable materials	6		1											
Adjustable geometry	8			9		1	3		9	1	1	9	1	
Electrical controls	5													
Easily obtainable parts	5	1	1			1		1		1				3
Cost-effective design	5							1						9
Integrated functionality	5	9	1	1		3	3					9	3	
Improved seat arrangement	5													
Commonality of design	4													
Personal avionics	4													
Environmental controls	4													
Modularity of design	4													
Light structural materials	3													
Visual patterns	3													
Aesthetic design	3		3		3			3						
Facilitate work (laptops included)	3	3	1						1				9	
Variable loads absorption	3		3				3							
Variable degree of firmness	2						3							
Isolation	2				1			3						
Modern appearance	1		1	1	1	1	3	9			3			
Material texture	1		3											
Fixed geometry	1				9									9
TOTAL:		393	271	262	298	357	265	396	349	441	379	409	298	394

Technical Requirements	Weighting	40 Contoured seat back	41 Concave contouring	42 Edge contouring	43 Pillow secured to the seat with velcro (position adjustable)	44 Electronic massage pillows	45 Adjustable lumbar support (mechanical)	46 Adjustable lumbar support (electrical)	47 Inflatable lumbar support	48 Pelvic support	49 Adjustable seat height (mechanical)	50 Inflatable seat bottom	51 Tiltable seat bottom (entire)	52 Downward foldable seat bottom (front edge) to facilitate ingress/egress
Simplicity of engineering	20	3	3	1	9					3				
Accessory arrangement/minimization	16				1									
Adjustable mechanisms	13				3	3	9	9	9		9	9	9	3
Ergonomic/anthropometric design	10	9	9	9	3	3	9	9	9	9	9	3	3	1
Ease of maintainance	10	9	9	9	3									
Continuous adjustability	10						3	9	3		3	3	9	3
Common internal parts	10													
Reduced seat volume	9			3										1
Minimize number of parts	9	1												
Mechanical controls	7						9		1		9	1	9	3
Durable materials	7													
Versatile design	6				1									9
Low MTBF	6	3			3					3				
Comfortable materials	6													
Adjustable geometry	8						1	1	1		1	3	3	9
Electrical controls	5					9		9						
Easily obtainable parts	5				9		1							
Cost-effective design	5				1									
Integrated functionality	5	3					1	1	1	9	3	1	1	
Improved seat arrangement	5													
Commonality of design	4													
Personal avionics	4													
Environmental controls	4													
Modularity of design	4				1									
Light structural materials	3													
Visual patterns	3													
Aesthetic design	3	3	1	1		1							9	
Facilitate work (laptops included)	3										3		9	
Variable loads absorption	3				3				3			3		
Variable degree of firmness	2								3			3		
Isolation	2													
Modern appearance	1	9	3	9		3			3	3		3	1	
Material texture	1				1									
Fixed geometry	1	9	3	3						9				
TOTAL:		319	259	252	393	130	326	363	283	235	340	235	388	227

Technical Requirements	Weighting	53 Tiltable seat bottom (front edge)	54 Sliding-out seats	55 Foldable seat bottom	56 Flip-over seat bottom	57 Lower seat bottoms (no luggage space)	58 Sideways rocking seat bottom	59 Non-reclinable seats	60 Thin diaphragm seats without cushions	61 Webbing as cushioning substitute	62 Sandwich structure in the cushion	63 Store hand items below seat (remove front pocket)	64 Bag/pocket hanging from seat bottom edge (remove front pocket)
Simplicity of engineering	20				3	9		9	3	9		9	9
Accessory arrangement/minimization	16							9	9	9		9	9
Adjustable mechanisms	13	9	9	3	3		1						
Ergonomic/anthropometric design	10	3	1	1		1	1						
Ease of maintainance	10							9	9	9			
Continuous adjustability	10	9	9	3			9						
Common internal parts	10								1				
Reduced seat volume	9			1					9	9		3	3
Minimize number of parts	9							9	3				
Mechanical controls	7	9	9	3									
Durable materials	7								9	9			
Versatile design	6			9	3		3						
Low MTBF	6							9	3	3			
Comfortable materials	6												
Adjustable geometry	8	3	3	9									
Electrical controls	5												
Easily obtainable parts	5							9					
Cost-effective design	5							9	1	1			
Integrated functionality	5	3		1	1	1				1			
Improved seat arrangement	5												
Commonality of design	4							9					
Personal avionics	4												
Environmental controls	4												
Modularity of design	4							9					
Light structural materials	3								9	9	3		
Visual patterns	3												
Aesthetic design	3		9										
Facilitate work (laptops included)	3	3	9					9					
Variable loads absorption	3										9		
Variable degree of firmness	2				1						3		
Isolation	2												
Modern appearance	1						3						
Material texture	1												
Fixed geometry	1					9		9	3	3			
TOTAL:		352	362	232	134	214	144	757	529	626	52	361	361

Technical Requirements	Weighting	65 Knee cushions	66 Seat to diagonal bed transformation	67 Personal entertainment system	68 Variable light intensity	69 Confor foam	70 Conventional foams	71 One type of foam	72 One type of structural material	73 One-type adjustment mechanisms (inflatable)	74 One-type adjustment mechanisms (mechanical)	75 One-type adjustment mechanisms (pneumatic/hydraulic)	76 One-type adjustment mechanisms (electrical)
Simplicity of engineering	20	9					9	9	9				
Accessory arrangement/minimization	16									1			3
Adjustable mechanisms	13		9	3	9					9	9	9	9
Ergonomic/anthropometric design	10	1	1							9	9	9	9
Ease of maintainance	10	1					3	3	3	1	1	1	1
Continuous adjustability	10		3		9					3	3	9	9
Common internal parts	10							9	9	9	9	9	9
Reduced seat volume	9												
Minimize number of parts	9												
Mechanical controls	7		9							1	9	3	
Durable materials	7						3						
Versatile design	6		9	9									
Low MTBF	6												
Comfortable materials	6	1				3							
Adjustable geometry	8		9							3	1	1	1
Electrical controls	5			9									9
Easily obtainable parts	5	1					9	1	1		1	1	
Cost-effective design	5						9	9	9	1	1	1	
Integrated functionality	5		1	9									
Improved seat arrangement	5												
Commonality of design	4						9	9	9	3	3	3	3
Personal avionics	4			9									
Environmental controls	4				9								
Modularity of design	4						1	3	3				
Light structural materials	3						1						
Visual patterns	3												
Aesthetic design	3			9									
Facilitate work (laptops included)	3				9								
Variable loads absorption	3	3	1			9							
Variable degree of firmness	2					9							
Isolation	2			9									
Modern appearance	1		3	9									
Material texture	1	3											
Fixed geometry	1												
TOTAL:		233	349	283	280	73	374	327	327	324	357	375	437

Figure 20: Product Design Matrix

Rank	Feature	Score	Research Weighting	Revised Score	Average Score
1	Non-reclinable seats	757	0	757	757
2	Webbing as cushioning substitute	626	3	686	656
3	Thin diaphragm seats without cushions	529	0	529	529
5	Sliding trays	477	8	637	557
10	Height-adjustable trays	467	8	627	547
6	Adjustable foot rest	441	9	621	531
7	One-type adjustment mechanisms (electrical)	437	4	517	477
4	Tiltable trays	423	7	563	493
8	Arm rests that swing out to facilitate conversation (when seats are offset)	414	4	494	454
9	Vertically adjustable seat back	409	12	649	529
11	"Wings" to rest head on	396	7	536	466
12	Flat seat back	394	0	394	394
13	Cup holder on arm rest	393	0	393	393
14	Pillow secured to the seat with velcro (position adjustable)	393	4	473	433
15	Tiltable seat bottom (entire)	388	12	628	508
16	Adjustable leg rest	379	9	559	469
17	One-type adjustment mechanisms (pneumatic/hydraulic)	375	4	455	415
18	Conventional foams	374	0	374	374
19	Height-adjustable arm rests	365	12	605	485
20	Adjustable lumbar support (electrical)	363	15	663	513
21	Sliding-out seats	362	9	542	452
22	Retractable screens that block other passengers from field of vision	361	5	461	411
23	Store hand items below seat (remove front pocket)	361	0	361	361
24	Bag/pocket hanging from seat bottom edge (remove front pocket)	361	0	361	361
25	Height-adjustable head/neck rest (mechanical)	357	12	597	477
26	One-type adjustment mechanisms (mechanical)	357	4	437	397
27	Aesthetically pleasing patterns of fabric	352	2	392	372
28	Tiltable seat bottom (front edge)	352	12	592	472
29	Foldable head rest to facilitate front-back conversation	349	5	449	399
30	Seat to diagonal bed transformation	349	3	409	379
31	Adjustable seat height (mechanical)	340	11	560	450
32	Dark colors to make stains less visible	337	0	337	337
33	Width adjustable arm rest	337	6	457	397
34	Patterns on fabric that give feeling of greater space	331	2	371	351
35	One type of foam	327	0	327	327
36	One type of structural material	327	0	327	327
37	Adjustable lumbar support (mechanical)	326	15	626	476
38	One-type adjustment mechanisms (inflatable)	324	4	404	364
39	Colors that are pleasing to the eyes	323	2	363	343
40	Logo/symbol on seat back to draw attention away from peripheral vision	320	3	380	350
41	Contoured seat back	319	5	419	369
42	Light colors to convey better sense of depth	304	3	364	334
43	Inflatable arm rests	304	10	504	404
44	Contour head rest	298	0	298	298
45	Horizontally adjustable backrest	298	9	478	388
46	Durable and longlasting fabric	291	0	291	291
47	Inflatable lumbar support	283	14	563	423
48	Personal entertainment system	283	5	383	333
49	Zip-up seat covers (to facilitate cleaning)	280	0	280	280
50	Variable light intensity	280	3	340	310
51	Cushioned arm rest	271	5	371	321
52	Space-age colors	270	1	290	280
53	Inflatable head rests	265	9	445	355
54	Sinkable (all the way) arm rest (instead of upwards rotation)	262	2	302	282
55	Concave contouring	259	2	299	279
56	Edge contouring	252	4	332	292
57	Smooth fabric	243	0	243	243
58	Textured fabric	235	0	235	235
59	Pelvic support	235	4	315	275
60	Inflatable seat bottom	235	10	435	335
61	Knee cushions	233	0	233	233
62	Foldable seat bottom	232	3	292	262
63	Downward foldable seat bottom front to facilitate ingress/egress	227	3	287	257
64	Lower seat bottoms (no luggage space)	214	0	214	214
65	"Slides" at the back of trays depicting sunset, mountain, etc. (selectable)	181	4	261	221
66	Soft and comfortable fabric (nice to the touch)	153	0	153	153
67	Sideways rocking seat bottom	144	9	324	234
68	Protruding head rest edges for more privacy	141	2	181	161
69	Flip-over seat bottom	134	2	174	154
70	Protruding seat edges to symbolically mark personal boundaries	133	2	173	153
71	Electronic massage pillows	130	2	170	150
72	Middle seats offset backwards to facilitate 3-way/4-way conversation	120	5	220	170
73	Seats arranged diagonally	85	4	165	125
74	Confor foam	73	0	73	73
75	Sandwich structure in the cushion	52	0	52	52
76	Theatre-style seating	37	0	37	37
	Average:	308			
	Max:	757			
	Max - Average:	449			
	Weighting to assign to each research area:	20			

Revised score = Score + (research weighting) x 20

Table 4: Research weighting coefficient and final averaged scores for each seat attribute

The non-reclinable seat concept eliminates these disadvantages, but in order to have the same effects as the reclined seat for the recline posture of the human body, an inflatable and height adjustable lumbar support must be considered. Other attributes that were used for providing better support were a height and tilt adjustable head/neck rest (preferably the one from a dentist chair) and a seat bottom constructed with conformal foam. Finally, for improving seat ergonomy, a height adjustable tray was chosen. A sketch of this concept can be seen at Figure 21.

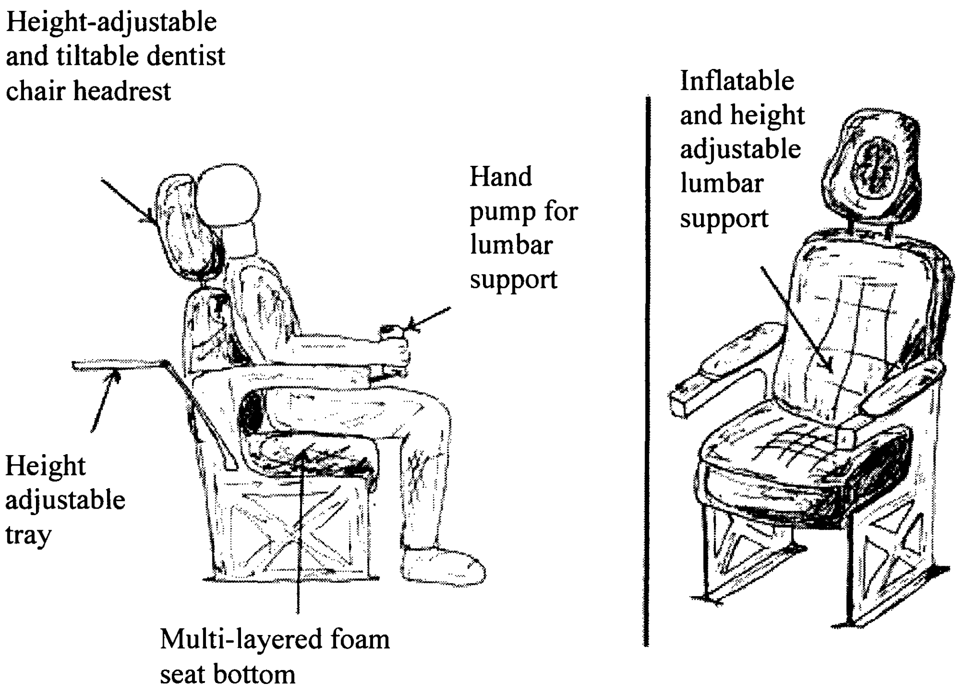


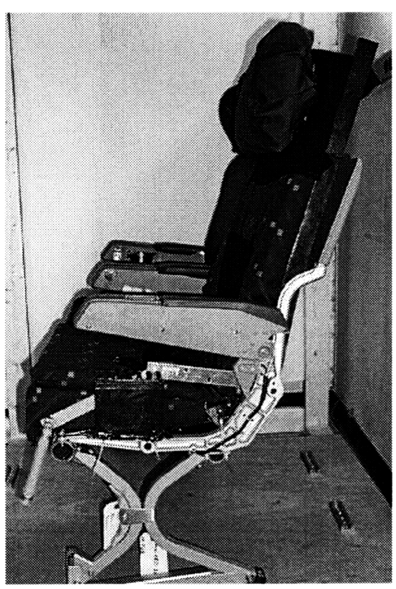
Figure 21: Design Concept #1: Non-Reclinable seat

During the manufacture of this concept, many difficulties surfaced and necessary modifications were implemented. These modifications were:

- A lumbar support that would have the same effects as a reclined backrest, had to be very big and so, very difficult to implement. The initial non-reclinable seat concept was changed to a forward sliding seat. In that way, if the backrest is kept at the upright position, it has the same advantages as the non-reclinable backrest. On the other hand, when the low end of the backrest slides forward, the seat has the same effect as a reclinable seat without its disadvantages. By doing that modification, a smaller lumbar support could be used.

- The existing tiltable mechanisms for the headrest are very expensive, so, considering the limitations in the total final cost of our design, this mechanism was not used.
- The headrest of a dentist chair provides the best support for the head and the neck, but only in one specific posture. A passenger takes many different postures during the flight, so, this kind of headrest was not practical.
- Finally, because a forward sliding concept was chosen, a seat bottom with conformal foam could not be fitted.

After these modifications, the final design concept was considered. It consisted of a forward sliding seat, with a height adjustable tray, a height adjustable headrest and an inflatable and height adjustable lumbar support. This final constructed seat concept can be seen in Figure 22. The manufacture of the mechanism that allowed the backrest to slide is described in Ref. 2. In general, the backrest has two frames, one external permanently attached at the seat frame, and one internal. The lower part of the internal frame is allowed to slide to preset positions while the upper part has a pivoting point that allows the internal frame to pivot and slide. This mechanism allows the seat to achieve the same angles (100° and 115° degrees) between the backrest and the seat bottom as a reclined seat. Figure 23 shows the sliding mechanism details. The construction of the other features will be described in the following chapters.



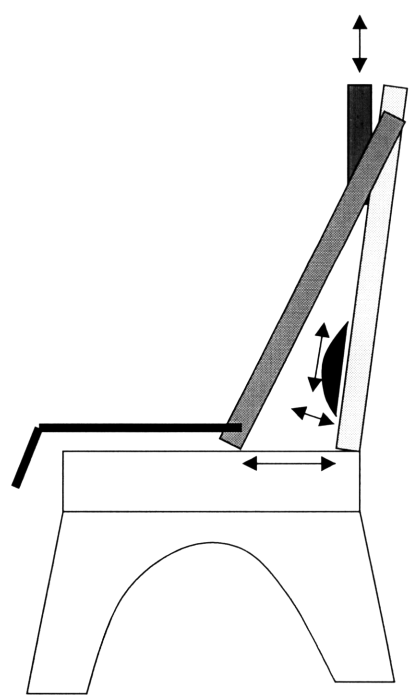


Figure 22: Modified design concept #1

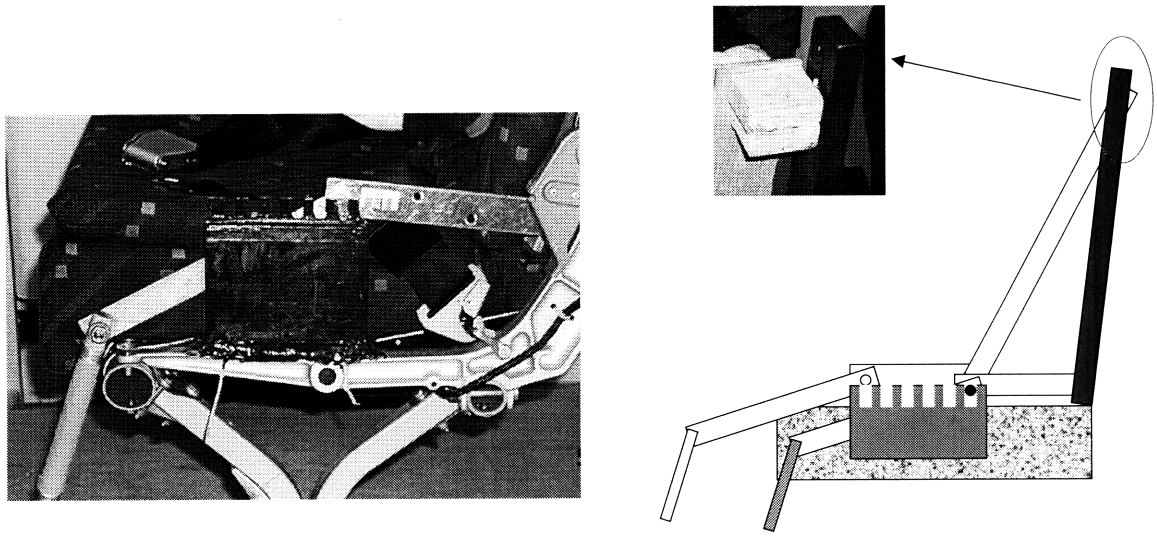


Figure 23: Sliding mechanism

4.4.2 Design Concept #2

For the second design concept, a webbing backrest was chosen as the main feature for providing more space. By eliminating the thickness of the cushion of the backrest, a direct increase in passenger personal space can be achieved. A web backrest also provides better seat ventilation, and has a lower flammability. On the other hand, a cushioned seat bottom was chosen to be implemented for three reasons. First, the space restrictions are horizontal and not vertical. Second, a foam seat bottom can be used as a floatation device in case of an emergency. Finally, by substituting only the cushion backrest with a web backrest, there is a gradual introduction of a radical technology. The other features that accompanied the specific concept were again a height adjustable tray for improving the in-flight activities, and a height adjustable winged headrest and a mechanical lumbar support for providing better support. A sketch of this concept can be seen at Figure 24.

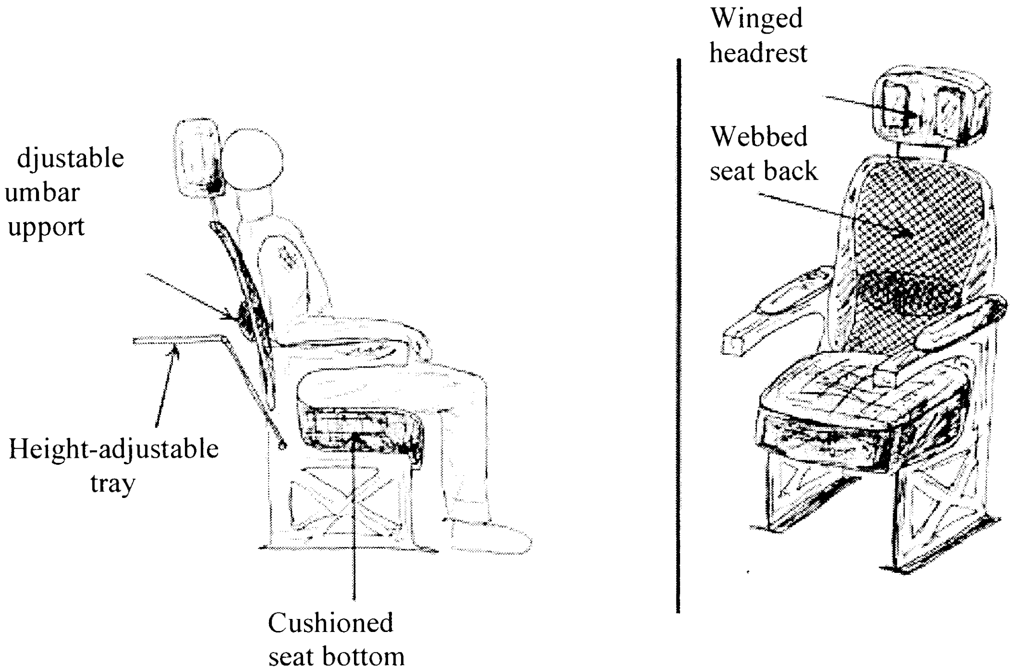


Figure 24: Design Concept #2: Web-Cushion hybrid

The biggest problem that was faced during the construction of this concept was the attachment of the height adjustable headrest in the webbed backrest. So, an existing head/neck rest was used at the final design. Moreover, since the webbed backrest provided more space it was possible to use a conformal foam seat bottom. For the construction of this concept, a Herman Miller Aeron-chair was acquired. The backrest of this chair was disassembled from the seat bottom, and was attached to the main frame of a current aircraft seat with exactly the same mechanism, allowing the backrest to recline. The headrest is from a current aircraft seat, with a small modification in order to be attached at the webbed backrest. Figure 25 shows the Herman Miller's Aeron-chair and the final web-cushion hybrid concept. More details on the manufacture and evaluation of this concept can be found in Ref. 7.

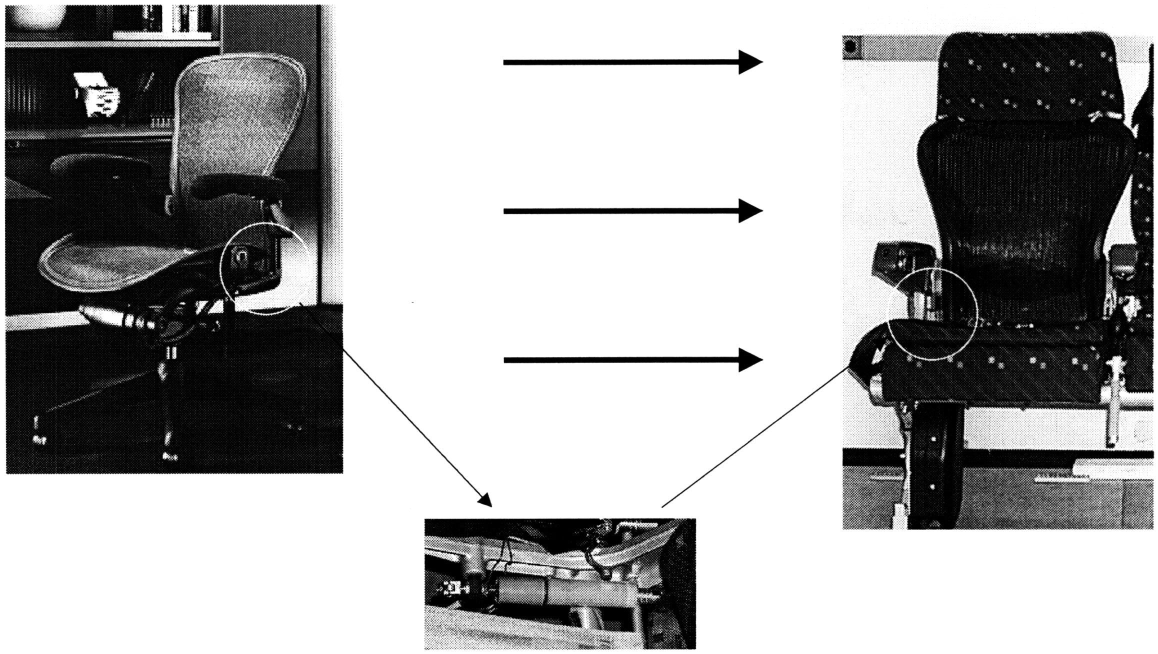


Figure 25: Web-Cushion hybrid

4.5 Construction of the design concepts

The primary purpose for the construction of the prototypes was to test how the implementation of these features can improve the passengers' comfort during long haul flights. For that reason, the designed mechanisms and the materials that were used for their implementation and test have not been checked for compliance with the existing safety regulations, or optimized for being easy in use.

5 Improving the ergonomy

In both concepts, the seat aspect that improves the ergonomy of the seat is the height adjustable tray. Before manufacturing the height adjustable tray, it was necessary to calculate the limits for the adjustability for the fifth percentile of Asian women (lower limit) to ninety-fifth percentile of North European men (upper limit).

5.1 Baseline tray

As has been analyzed in the research phase, there are two principle dimensions for the proper ergonomic design of a seat, the seat bottom height and the work surface height. With the proper combination of these two principal dimensions, it is possible for the passenger to have the proper arm posture and thigh clearance while working in the aircraft seat. The current dimensions of installed airplane seats are 19" for the seat bottom height and 24.25" for the work surface height. By subtracting these two values, and taking into account the thickness of the tray (0.5"), the current thigh clearance for the passenger is only 4.75". According Ref. 6, the thigh clearance for the fifth percentile of women is 4.6" and for the fiftieth percentile is 6.1", while the corresponding clearance for the male population is 4.8" and 6.3". So, it can be noticed that the baseline tray can accommodate properly only a very small percentile of the female population.

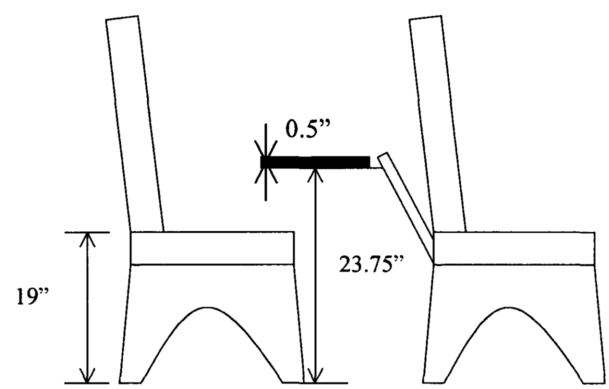


Figure 26: Seat bottom and work surface heights for the baseline aircraft seats

5.2 Height adjustable tray

A height adjustable tray was implemented in the design concepts. For best results, a height adjustable seat bottom would also be welcomed, but due to restrictions in space and volume under the seat for baggage storage, this feature was not pursued.

5.2.1 Optimum adjustable tray

For designing the height adjustable tray, it was initially necessary to determine the optimum height and the optimum adjustability range. For calculating the optimum adjustability, the dimensions of the two extreme percentiles of human population (fifth percentile of female population and the ninety-fifth percentile of male population) were considered. Initially the minimum allowable heights were determined in accordance with the constraint of thigh clearance. So, having that the seat bottom height is constant at 19”, then the work surface height can not be less than 24.1” for the fifth percentile of the female population, and less than 27.3” for the ninety-fifth percentile of the male population.

The second important constraint is the arm posture. If the work surface height was very high, then the angle of the elbow would be less than the acceptable limit of 75 degrees. According Ref. 6, the work surface height should not be higher than 29” for the small percentile of the female population, with an optimum height of 26.5”, and more than 32” for the largest percentile of male population, with an optimum height of 29.75”.

Considering the results from these two constraints, for the smallest female percentile, a work surface height between 24.1” and 29” would be acceptable, with an optimum height of 26.5”. Similarly, for the largest male percentile, a work surface height between 27.3” and 32” would be also acceptable, with an optimum height of 29.75”. So the optimum adjustability of the tray should be between 26.5” and 29.75” (the seat bottom height held constant at 19” for the calculations).

5.2.2 Implemented adjustable tray

The initial problem that had to be solved in the design was that the height of the baseline tray was very low. Thus it was necessary to increase it at least up to 27.3”, which is the lower limit for the thigh clearance of the ninety-fifth percentile of the male population. Moreover, the lower limit should be kept as in the baseline, in order to use the same locking device for the tray while in the closed position. For these two reasons, the height adjustability of the tray had to be at least between 24.25" (the work surface height of the baseline tray) and 27.3". These values are not the optimum, as discussed in the previous paragraph, but they still are acceptable. Furthermore, another requirement was that the new design had to be able to be attached in the baseline seat's frame. Finally, the height adjustability that was used in the implemented design was between 24.25" and 27.75". Even if this range is not the optimum, (the optimum is between 26.5" and 29.75"), it is still acceptable for the ninety-five percentile of the total world population.

5.2.3 Manufacturing of the tray

For achieving the above-mentioned requirements, a baseline tray was used as a base for the final design. By using the baseline tray, the existing seat back locking device and the existing mechanism for attaching the tray to the main frame, could be used. So, the extra requirement that had to be met was the height adjustability.

For the height adjustability, the connection point for attaching the tray bracket to the seat's frame was cut out (Figure 27). The upper part was kept the same, while two metal rods were attached to the lower part leaving in between them enough space for the upper bracket to slide in. By this mechanism, the up and down movement of the tray was possible. Moreover, a pinstop was used to secure the tray at predetermined heights of 24.25", 24.75", 25.75", 26.75" and 27.75", preventing it from sliding down (Figure 28). The two metal rods were connected to the lower part of the bracket with epoxy glue. Because of an increase in thickness in the base of the bracket due to the attachment of the rods, it was necessary to trim the interior side of the armrest slightly, without affecting its width. (Figure 28). The total material cost (metal rods, epoxy glue) for the construction of the sliding mechanism was only $5 for each tray, and one person needed approximately one labor hour to manufacture it.

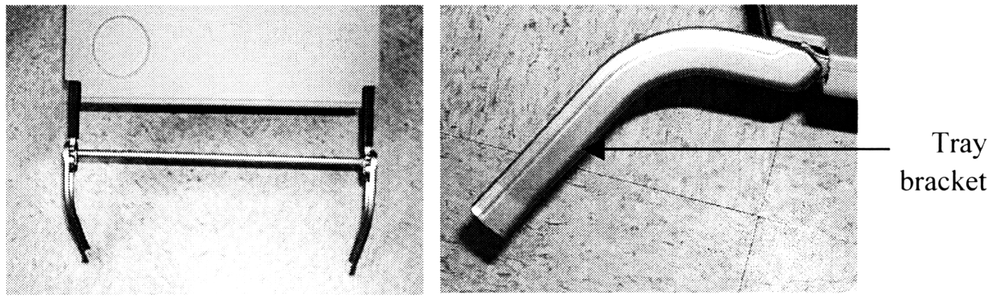


Figure 27: Tray bracket without the connection point.

The sliding mechanism that was constructed was able to support the weight of a laptop computer. Moreover, for the height adjustment, it was necessary for the passenger to use both hands, something that is not desirable in a good design. Finally, the whole mechanism would not satisfy the safety criteria according the FAA regulations (sharp edges, use of a pinstop etc). As it has been mentioned in the previous chapter, the primary purpose of the construction of this mechanism was to test how the implementation of a height adjustable tray can improve the passengers' comfort during long haul flights. Figure 29 shows the tray with the sliding mechanism in the lower and upper position.

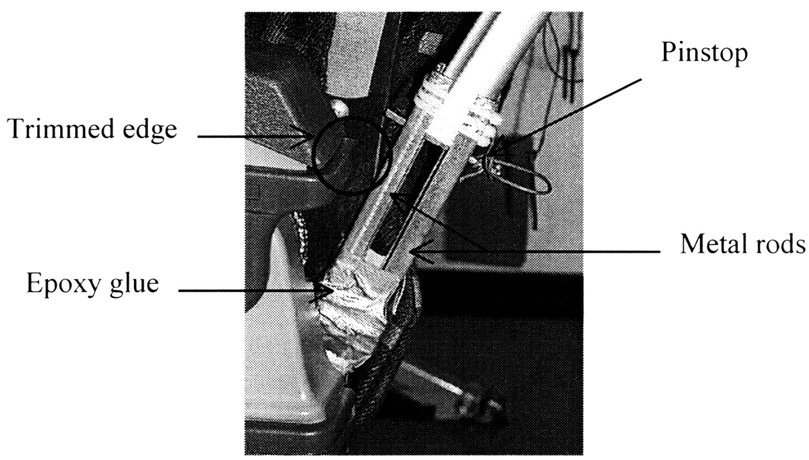


Figure 28: Sliding mechanism

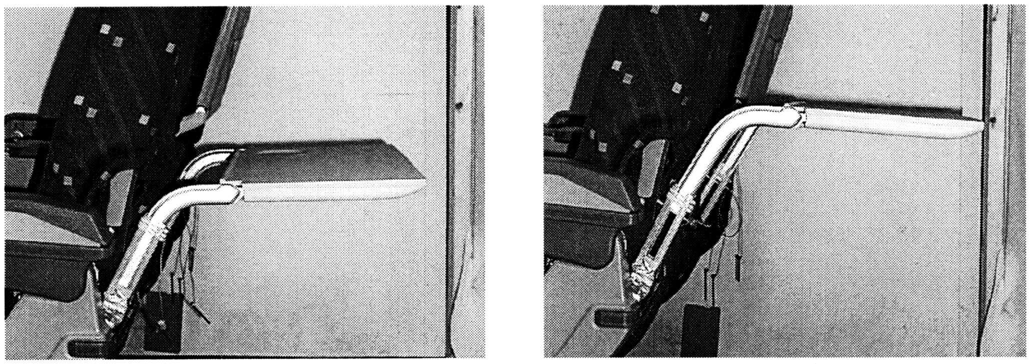


Figure 29: Height adjustable tray in the lower and higher position.

Simple, secure and easy adjustable mechanisms are already available in the market and with a simple modification can also be adopted for the height adjustability of an airplane seat tray. One mechanism is the height adjustable head rest for car seats, which uses a spring to secure the head rest at predetermined heights, while by releasing the spring, the head rest can move back to the lowest position. Moreover, many patents are available for height adjustable tables, and some of them can also be used for an aircraft tray. One example is patent number 4,492,170 where a description is given for a "locking mechanism for a vertically adjustable table." (Ref. 20)

6 Improving comfort

Two main features were considered for improving comfort. The first one was an inflatable and height adjustable lumbar support, while the second one was a height adjustable winged headrest.

6.1 Inflatable and height adjustable lumbar support

The baseline aircraft seat had no lumbar support. The attachment of a permanent lumbar support on a seat is not recommended, since each person needs a lumbar support that differs in thickness and height.

6.1.1 Design concept

The major concept for the design of the lumbar support was that it should be inflatable and height adjustable. The inflatable lumbar support provides an adjustable thickness, able to accommodate the differences in the lumbar radius for the ninety-fifth percentile of the population. Moreover, the height adjustability is important to accommodate differences in lumbar height.

In order for the lumbar support to accommodate the ninety-fifth percentile of the male population it must have 13" of horizontal length. Since a longer lumbar support can accommodate even the smaller percentiles, there is no need for an upper limit, or adjustability of the horizontal length. On the other hand, the vertical length of the lumbar support must not be larger than 8", since a smaller lumbar support in the vertical length can also accommodate the larger percentiles. Furthermore, an optimum lumbar support must be height and width adjustable. The height adjustability depends on the lumbar height of the different percentiles of the world population and it must be between 7" and 11.5", while the width adjustability depends on the lumbar radius, and it must be between 0.5" and 2.7"

6.1.2 Implementation

A simple mechanism from a blood pressure measurement device (Figure 30) was the main core for the construction of the inflatable lumbar support. Initially, the inflatable device was separated from the rest of the mechanism by cutting apart the cloth cover and the mechanism for securing the measuring device on a patient's hand. For removing the pressure gauge, the connecting pipe was cut off and was sealed with sealant glue for air tightness. The rest of the blood pressure measuring device was glued on a wooden surface covered by a thin layer of foam. Finally, an elastic cloth was used to cover and protect the mechanism. A picture of the constructed lumbar support can be seen in Figure 31.

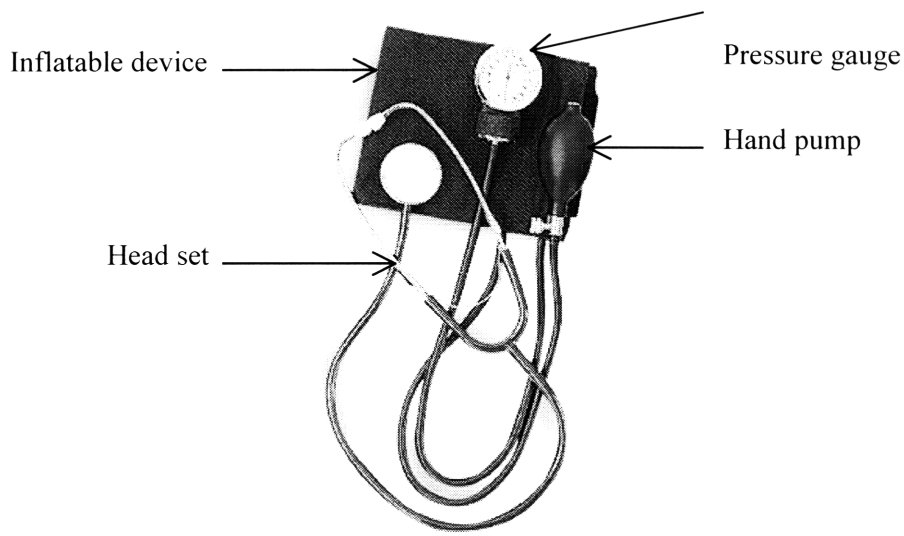


Figure 30: Blood pressure measuring device

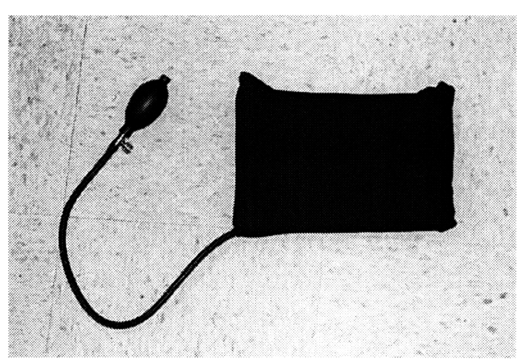


Figure 31: Inflatable lumbar support

Because of the limited dimensions of the blood pressure measuring device, the final dimensions of the constructed lumbar support were 7" in vertical length, 9.5" in horizontal length and between 1"and 3" in width. Since the minimum width had to be 0.5", a pocket of 9.5" of length, 10.5" of height and 0.5" depth was opened in the backrest cushion, resulting in a final width adjustability between 0.5"and 2.5". Figure 32 shows the principal dimensions of the constructed lumbar support.

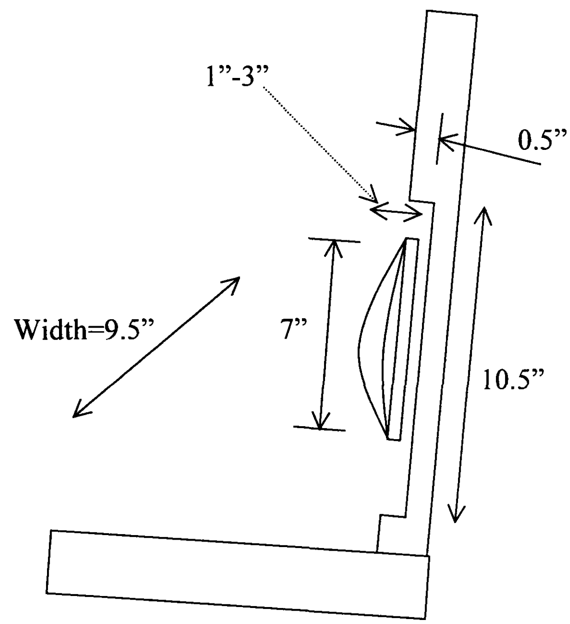


Figure 32: Principal dimensions of the lumbar support mechanism

For making the lumbar support mechanism height adjustable, two strips of VELCRO® were attached in the backside of the mechanism and the pocket at the seat cushion, allowing a 3.5" of height adjustability. The hand pump for inflating the lumbar support was secured underneath the armrest, so a passenger could easily use it, and also it was able to follow the armrest movements. Figure 33 shows the lumbar support attached to the seat back cushion. Finally, the total cost for the construction of the lumbar support was $20.

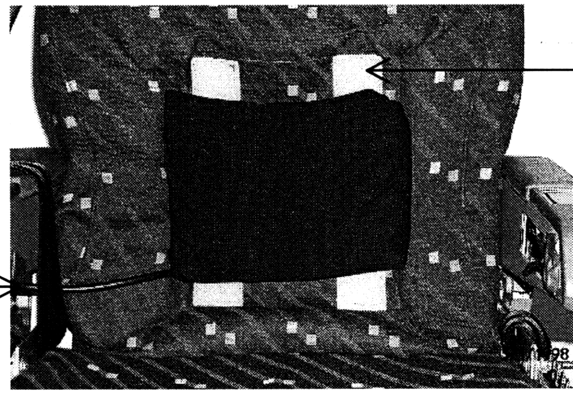


Figure 33: Lumbar support attached on the seat

6.2 Height adjustable winged head rest for forward sliding seat

A second feature for improving the comfort of the seat, was the attachment of a height adjustable winged headrest to the forward sliding seat.

6.2.1 Design concept

From the specifications for an aircraft seat design, the total height of the backrest with the headrest in the lowest position can not exceed 45". Moreover, at the proper sitting position, according Ref. 6, the sitting height is between 26.3" for the fifth percentile of the female population and 34.6" for the ninety-fifth of the male population. So, for a correct design, the headrest must have 8.3" of height adjustability.

6.2.2 Implementation

For the construction of the height adjustable winged headrest, an existing winged headrest, provided by BE Aerospace, was modified. The headrest was 2" thick and 4" height adjustable. Modifications were made in the mechanism for the height adjustability and the thickness of the cushion.

The seat back height is only 27" with the headrest in the lowest position, and this provides good support only to a small percentile of the population. So, it was important to increase the adjustability to the maximum. The mechanism that was used had an initial adjustability of 4". By removing a stopping device from the back of the mechanism, an increase in the adjustability by 2" was achieved, making the headrest 6" height adjustable. In that case, the final height of the seat back could reach 33" providing a proper support for the majority of the population, except the extremes of the male population. This is a significant improvement, since the adjustability of the headrest before the modification was not able to accommodate even the higher percentile of the female population. A graphical representation of the designed headrest is shown in Figure 34.

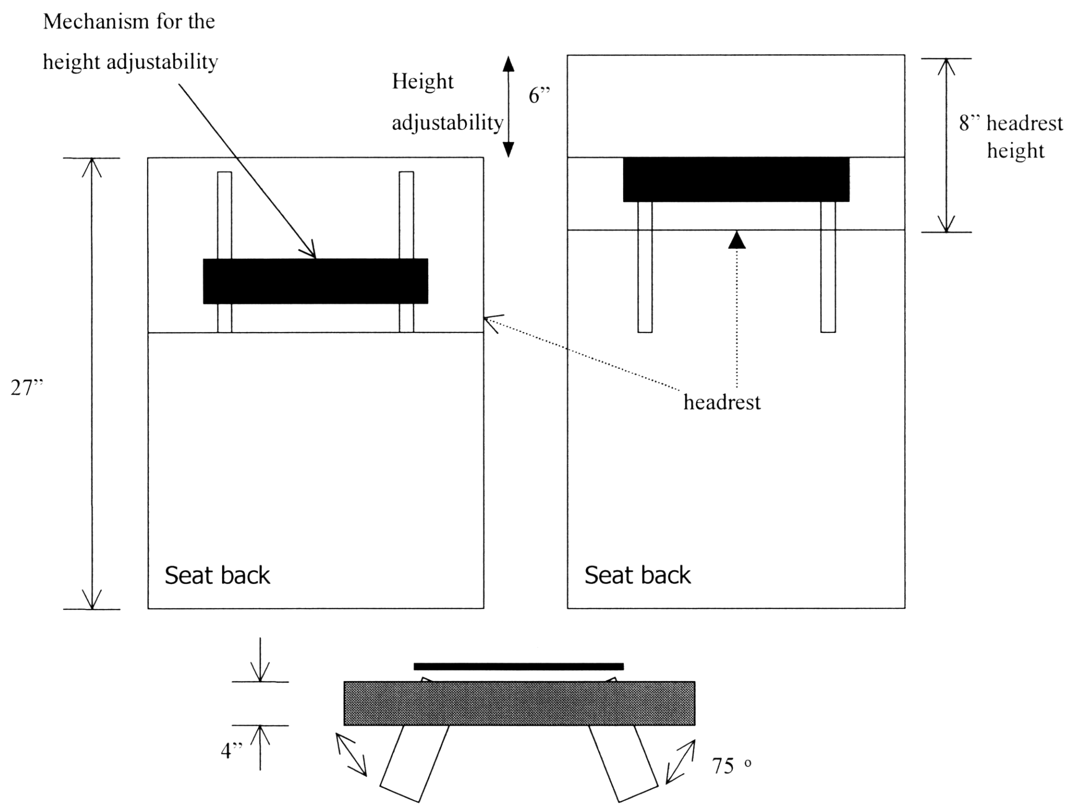


Figure 34: Graphical representation of the winged headrest

The second modification was the increase in thickness of the headrest. A suggested backrest must be inclined by 105° to shoulder height. It then provides proper head support. In our design, since the backrest did not have this discontinuity in the angle, it was necessary to increase the thickness of the headrest to provide the correct support. The initial thickness was 2" and after the modification it was increased to 4". For this increase, a second cushion layer was added. Finally, the material cost for the modification of the winged headrest was only $1 (cost of the second layer of cushion).

7 Evaluation of the design concepts

After the construction of the two prototypes, the last phase of the design project involved evaluation. For an objective evaluation, two areas had to be considered.

a. The testing environment for the prototypes should be as similar as possible to the original airplane cabin and especially the simulation of the space restrictions.

b. The test procedure must simulate all the tasks that a passenger participates in during a long haul flight.

7.1 Environment

Since a model of a real airplane cabin was not available, a simple cabin environment was constructed taking into consideration the space restrictions of a real cabin. The principal dimensions that were considered were the pitch between the seat rows, the ceiling height over the seats, the width of the aisle, and finally the height of the ceiling over the aisle.

The testing environment had three rows of twin seats. The pitch between the seat rows in an airplane is 28" to 36" for the economy class, with an average of 32". For that reason, the pitch that was used in the testing environment was 32". Two baseline seats without any modification were placed in the first row. Two baseline seats were also placed in the second row, with the difference that two height adjustable trays were installed on the backsides of these seats. The seat near the aisle, was the actual baseline seat that was tested and compared with the two prototypes. Finally, the two prototypes were positioned in the rear seat row. A sketch of the testing environment can be seen in Figure 35.

To reduce testing environment cost, only the frame, the floor and the ceiling were built out of wood. The simulated window side was placed near the wall of the room where the experiment took place, while curtains were placed for the simulation of the three other sides. The principal dimensions of the testing environment were consistent with a twin seat airplane cabin, without taking into consideration the curvature of the fuselage. Figure 36 shows the front view of the testing environment with the principal dimensions that were used.

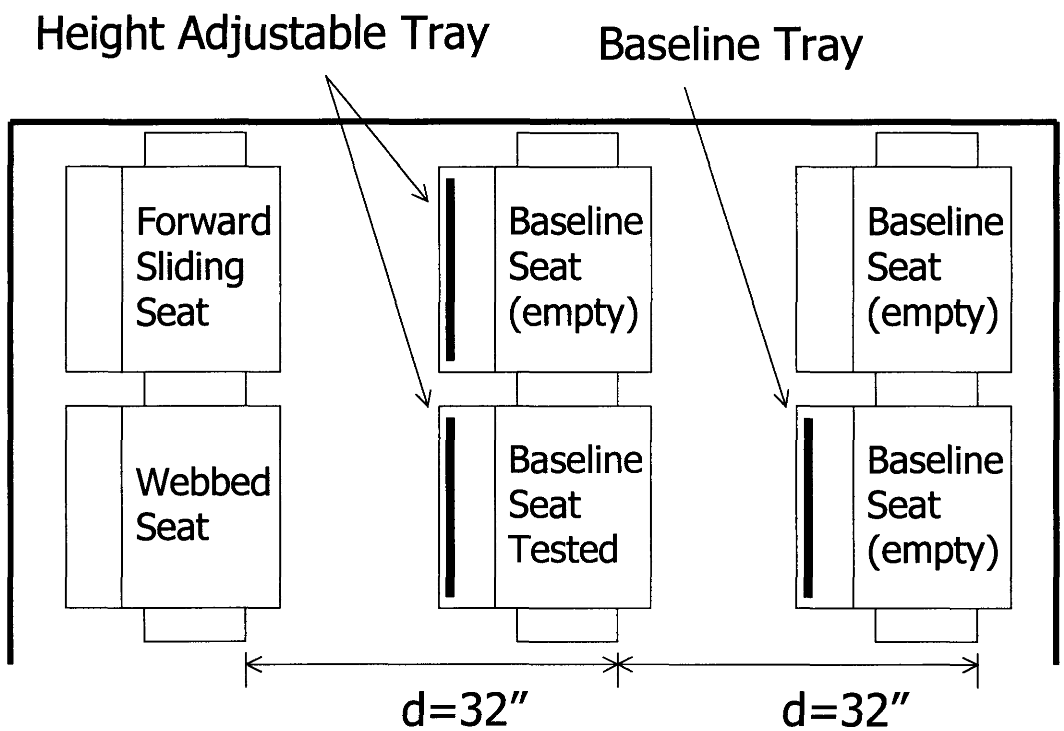


Figure 35: Graphical overview of the testing environment

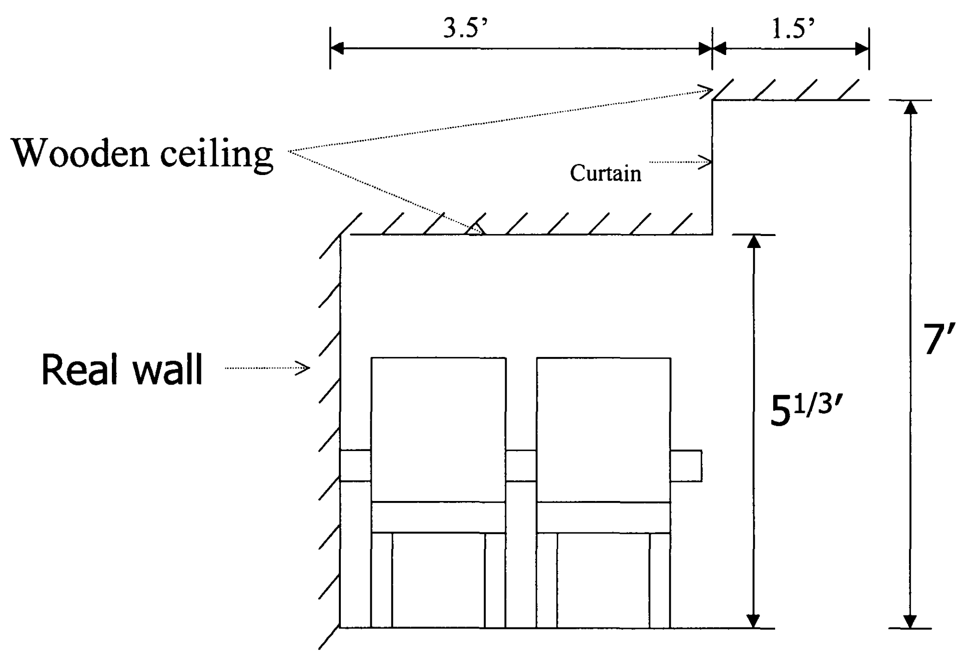


Figure 36: Front view of the testing environment (dimensions are in feet)

The seats were secured to the floor of the testing environment by the same mechanism as in an airplane fuselage in order to prevent them from sliding and changing the pitch between them. Finally, three white lights were attached on the sides of the testing environment. Two were attached at the side near the wall, over the second and third row, providing light for the subjects testing the seats, while the third one was attached at the artificial ceiling over the simulated aisle. A picture of the final testing environment can be seen on Figure 37

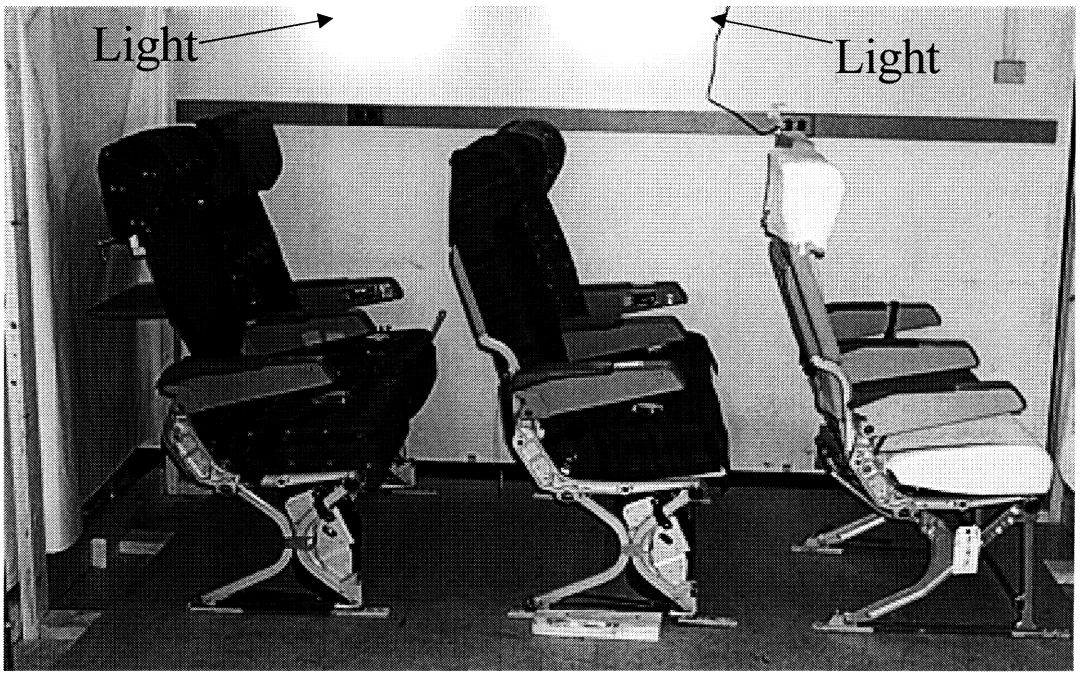


Figure 37: Testing environment

The baseline seats were provided by BE Aerospace. Since small differences existed between the different baseline seat designs (cushion firmness, curved backrest), the one that was tested and compared with the two prototypes was the one that felt more comfortable. The material cost of the testing environment was $200. Specifically, the cost of wood was $130, the lights $40, the electrical connections (extension chord, cables, socket) was $20, and finally $10 the cloth.

7.2 Procedure

The objective of the test was to compare the baseline seat with the two prototypes and validate the implemented features. Two types of tests were implemented. For the first test, each subject had to sit on each one of the three seats for three hours in total. During this period of time test subjects were required to perform some tasks and they answered four questionnaires. Moreover, pressure maps were taken in three different positions. Sitting upright, working and in the slouched position. The pressure maps allow a visualization of the pressure distribution exerted by the human body on the seat bottom and the seat backrest. Later these pressure maps were used to correlate with answers from the questionnaires. Figure 38 shows the timeline of the testing procedure that was followed.

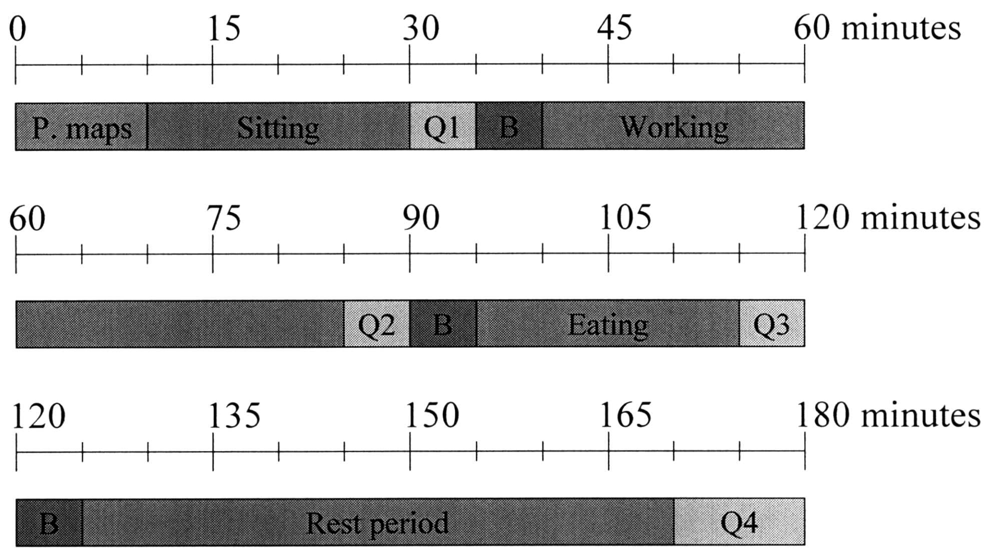


Figure 38: Timeline of the testing procedure

Twelve subjects from the Department of Aeronautics and Astronautics were recruited via emails. The complete experiment protocol, which was within M.I.T. rules and approved for test of human subjects, as well as the corresponding questionnaires can be found in Appendix 3. These subjects were chosen to have the highest distribution in the sizes. Table 5 shows their average data and Figure 39 shows their corresponding height distribution.

Data	Average	Standard Deviation
Age	24 years	3.8 years
Height	172 cm / 5′ 8″	13 cm / 4.3″
Weight	75 kg / 167 lbs	20 kg / 43.5 lbs

Table 5: Average statistical data of the subjects

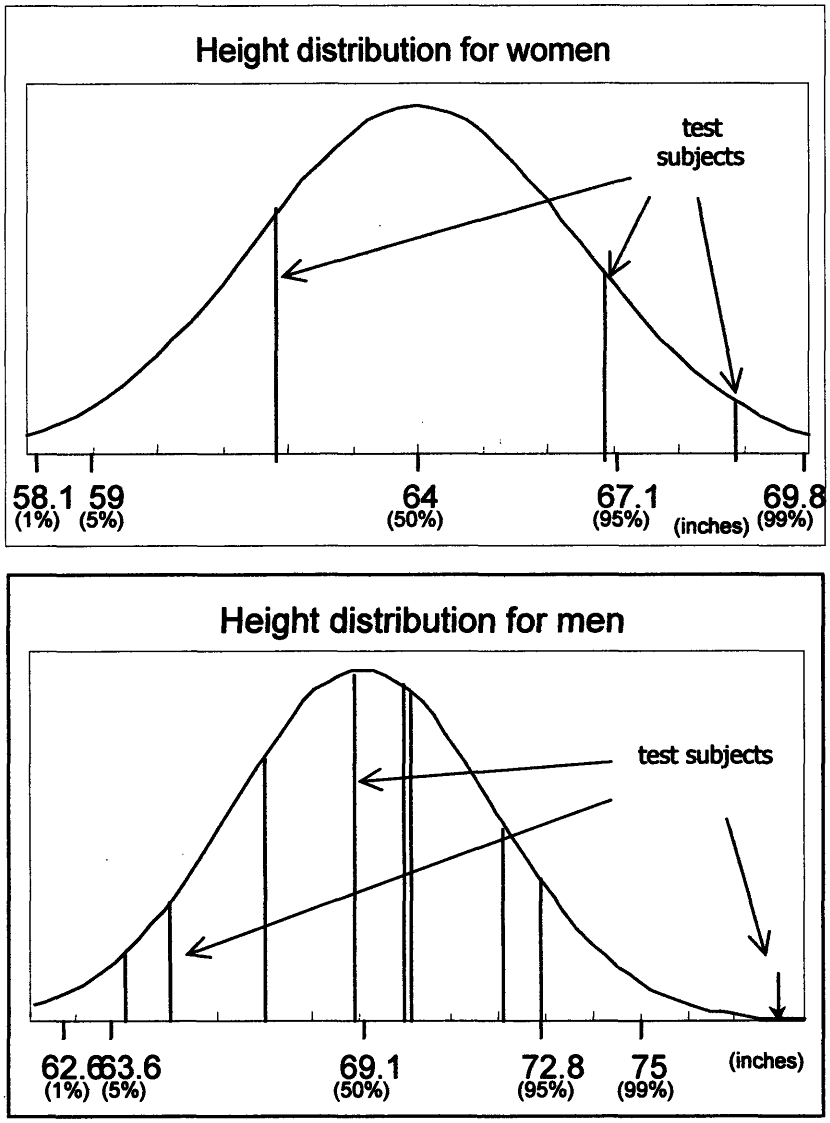


Figure 39: Height distribution for the female and male subjects

7.3 Dynamic test

The second test type that was considered was the dynamic test. The purpose of the dynamic test was to study dynamic comfort by comparing the changes in pressure distribution on the different seat bottoms during time. For that test, the baseline seat was used with the baseline and the conformal foam seat cushions. The subjects sat for ninety minutes on each cushion without doing anything while pressure maps of the seat bottom were taken continuously. According to Ref. 13, more frequent changes in posture occurred in uncomfortable seats.

8 Test results

After analyzing the questionnaires and the pressure maps it was concluded that both the prototypes ranked higher than the baseline seat.

8.1 Forward sliding seat

More specifically, the forward sliding seat ranked higher than the baseline in all thirteen-seat aspects that were considered in the questionnaires. Moreover, five out of the twelve subjects preferred the concept of the forward sliding seat. Four of them found it comparable. Finally, the overall discomfort rating for the forward sliding seat was 2.3, compared to 2.8 for the baseline. The seat aspects that contribute most to the higher ranking of the forward sliding seat were the lumbar support, the leg support and the neck support. A more detailed analysis of the forward sliding seat and an analytical comparison with the baseline seat can be found in Ref. 2.

8.2 Webbing seat

The webbing seat also ranked higher than the baseline in all the thirteen seat aspects, and especially in the back support and lumbar support. Furthermore, nine out of the twelve subjects preferred the concept of the webbing seat. One of them found it comparable, and only two found it worse than the baseline. Finally, the overall discomfort ratings for the webbing seat compared to the baseline seat was 2.1 and 2.8 respectively. The detailed test results for the webbing seat and the analytical comparison with the baseline can be found in Ref. 7.

8.3 Pressure maps

A comparison between the different ranking for the seat aspects from each subject and the corresponding pressure maps showed the validity of these results. The detailed comparison and analysis of the pressure maps can be found in Ref. 1.

Finally, Appendix 4 shows all the results from the questionnaires for all the three seats with comments from the test subjects.

8.4 Dynamic test results

During the dynamic test, plots of forces at each quarter of the seat bottom versus time were constructed and compared. The results showed that the seat bottom made of conformal foam (Figure 41) resulted in fewer posture changes compared to the baseline foam (Figure 40), thus it was more comfortable than the baseline seat cushion.

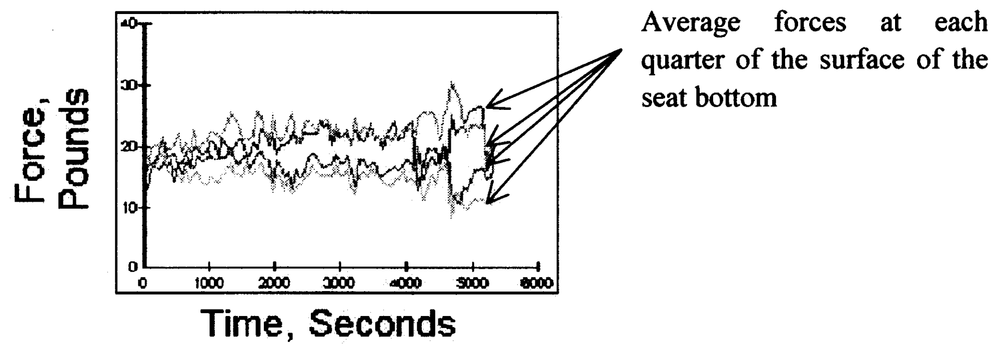


Figure 40: Forces vs Time for the baseline foam

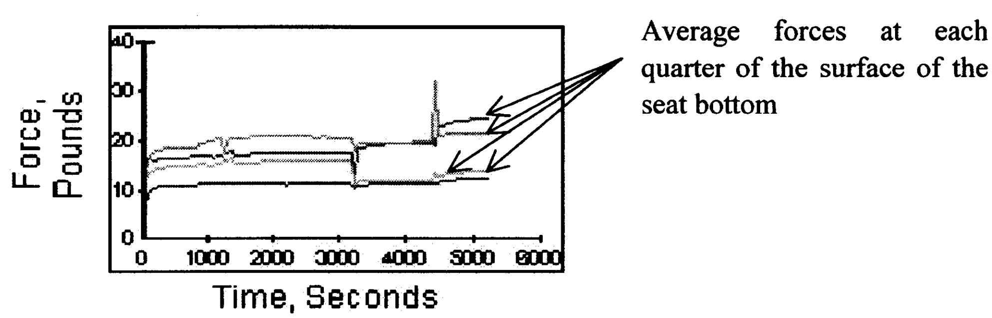


Figure 41: Forces vs Time for the conformal foam cushion

A complete analysis of the dynamic tests is given in given in Ref. 2 and Ref. 3.

8.5 Height adjustable tray

The height adjustable tray was the only advanced seat feature common to both design concepts and contributed the most to the increase in comfort for the two prototypes. In both the design concepts, the average level of discomfort for the tray was 1.8, while for the baseline seat it was 3.7. This was also the highest difference among all the seat features between the design concepts and the baseline seat.

8.6 Inflatable and height adjustable lumbar support

The inflatable and height adjustable lumbar support was the second seat aspect that ranked higher in the comparison with the baseline after the height adjustable tray. As it can be seen inFigure 42, even after the first fifteen minutes of the test, the increase in comfort due to the lumbar support is significant. For these graphs the t-test for statistical significance was used, in order to eliminate any discrepancies.

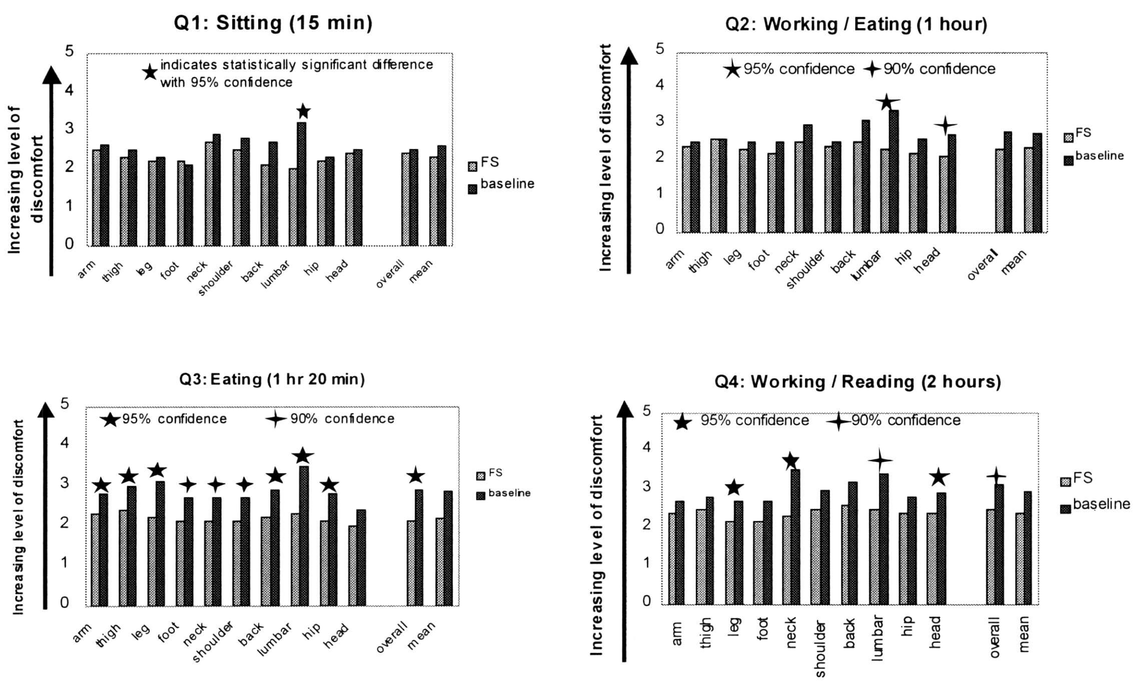


Figure 42: Comparison of the level of discomfort for each seat aspect between the forward sliding seat and the baseline seat

8.7 Height adjustable winged head rest

The height adjustable winged headrest also improved the level of comfort of the forward sliding seat, but not significantly. As Figure 42 shows, the headrest ranked significantly higher than the baseline only in the second and fourth questionnaire.

9 Conclusions

The purpose of this project was to implement new seat attributes in an aircraft seat for improving the overall ergonomy and comfort. After an initial research and evaluation of different seat attributes, six of them were chosen and two design concepts were implemented. A forward sliding seat and a webbing seat.

The forward sliding seat proved to be slightly better than the baseline seat with the following additional benefits derived from eliminating the recline capability:

- It is not possible to compromise the rear's passenger space
- It improves passenger's ingress and egress
- It provides seat depth adjustability for a small percentile of the population, and
- It protects the leg and knee room for a large percentile of the population.

The webbing seat ranked significantly better than the baseline seat. Moreover, it provided the following additional benefits because of the elimination of the cushion from the backrest:

- There is a significant decrease in the weight of the seat, which could lead to a reduction in fuel consumption for the airplane, and
- There are less non-biodegradable wastes.

Closing this report the following conclusion must be mentioned:

a. The webbed seat concept appears to be the best.
b. The forward sliding seat concept prevents space intrusion, and it might best be used for daytime flights when passengers are spending more time moving around in the airplane or working on the tray.
c. A height adjustable tray is strongly recommended, because it showed a great improvement in the total comfort and ergonomy of the seat.
d. The adjustable lumbar support rated as a significant improvement.
e. The height adjustable winged headrest slightly improved seat comfort. It might best be used for long haul or overnight flights, because it facilitates sleep.

f. The multilayer conformal foam cushion provides significant long-term comfort and it could be incorporated for long haul flights. It is not recommended for short flights, because the dynamic test showed (Ref. 3) that there is not an increase in comfort for small time periods, and at the same time it has an increased cost.

Clearly, there are still many aspects in the airplane seat that can be improved. The most comfortable and ergonomic seat would be the one that incorporates all the features from both of the design concepts presented herein. But at the same time, this seat would have a significant increase in cost. So trade offs must be done between improving the comfort and ergonomy and increasing the cost.

10 Recommendations

The primary purpose of implementing these seat attributes on an aircraft seat was to examine the improvement of ergonomy and comfort. FAA regulations were not taken into consideration. Before adopting these features in a final seat design, a more detailed analysis and investigation should be performed in the following areas:

- Fire Safety: The materials that were used for the construction of the mechanisms were common and in cases very flammable. A thorough examination must be done for the selection of alternative and fire safe materials. Selection should be followed by detailed fire tests.
- Durability: The seat attributes were constructed in order to endure the time and the loads during the experimental period. Detailed structural analysis and tests for each feature must be performed in order to ensure their durability under extreme conditions during a typical flight.
- Passenger's Safety: Redesign of the proof of concept design developed during this thesis is required in order to ensure the passengers safety.

Another area that needs to be investigated is ease of use. The different seat attributes must be redesigned according the following guidelines from Ref. 4 that were not followed during the proof of concept design:

1. Controls must be easily reached and adjusted from the standard seated position
2. The controls are easy to find and interpret
3. Few motions are required to use the controls, and
4. Adjustments should require the use of only one hand.

Finally, during this project six main seat features were incorporated in the two design concepts, while many others are pending examination and could be considered in a final design.

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Appendix 1: First Customer Survey

Appendix 2: Second Customer Survey

Appendix 3: Experiment Protocol

Appendix 4: Experiment results

APPENDIX 1

First Customer Survey

Biographical Data:

Age ___ Height ____ Weight ___ Gender: Male / Female

Flying Habits

1. How many times do you fly in a year? 1 2-5 6-10 >10

2. On average, how many hours is each flight? 1-2 3-5 6-10 >10

3. What class do you normally fly? First Business Economy

Opinions

4. Do you think the current seats can be improved? Yes No

5. How much are you willing to pay for improvement (as a percentage of your fare)? <5% 5-10% 10-15% >15%

6. Which aspects of the seats do you think requires the most improvement? Head Rest Foot Rest Arm Rest Back Support Passenger Room

Problems in Flight

8. Any physical effects at the end of the flight?

Seat Aspects

9. Rate the following aspects of the seats according to Excellent (1), Good (2), Satisfactory (3), Fair (4) or Mediocre (5).

a. Height	1	2	3	4	5
b. Width	1	2	3	4	5
c. Seat Fabric	1	2	3	4	5
d. Cushioning Comfort	1	2	3	4	5
e. Head Rest	1	2	3	4	5
f. Foot Rest	1	2	3	4	5
g. Arm Rest	1	2	3	4	5
h. Lower Back Support	1	2	3	4	5
i. Functionality for Slumber	1	2	3	4	5
j. General Comfort Level	1	2	3	4	5

10. Which of these features would you most like to see in passenger seats on your next flight?

Adjustable Lower Back Support   Adjustable Head Rest   Foot Rest

Better Overall Cushioning   More Passenger Room

Other ___________________________________

APPENDIX 2

Second Customer Survey

Hi! We are graduate students in the Aeronautics and Astronautics Masters of Engineering program. In January, we sent out questionnaires to you asking for your thoughts on various aspects of the seat. Your responses helped us a lot and we thank you for the assistance. We are now trying to analyze how passenger comfort varies with various activities during flight, for we realize that discomfort is not only caused by the seat per se, but also by the environment that the seat provides to the passenger. Again, we would like your feedback. This is an anonymous questionnaire and any information you provide will only be made available to persons involved in this project.

1. Biographical Data:

Age ___ Height ____ Weight ___ Gender: Male / Female

2. Flying Habits

i. How many times do you fly in a year? 1 2-5 6-10 >10

ii. What is the most common flight duration? 1-2 3-5 6-10 >10 hrs

iii. What class do you normally fly? First Business Economy

3. Flight Activities

Rate the level of comfort experienced during these activities:
(Excellent – 1, Good – 2, Satisfactory – 3, Poor – 4, Annoying – 5, Very Annoying – 6)

Stowing luggage under seat in front	1	2	3	4	5	6
Checking if there are any adjustable mechanisms on seat	1	2	3	4	5	6
Adjusting head rest (if applicable)	1	2	3	4	5	6
Adjusting foot rest (if applicable)	1	2	3	4	5	6

Adjusting lumbar support (if applicable)	1	2	3	4	5	6
Reclining seat	1	2	3	4	5	6
Getting seat upright	1	2	3	4	5	6
Reacting to the person in front reclining seat	1	2	3	4	5	6
Inserting hand items in seat pocket	1	2	3	4	5	6
Retrieving hand items in seat pocket	1	2	3	4	5	6
Getting in/out of aisle seat	1	2	3	4	5	6
Getting in/out of window seat (with adjacent seat occupied)	1	2	3	4	5	6
Getting in/out of window seat (with adjacent seat unoccupied)	1	2	3	4	5	6
Letting person next to you get in/out of his/her seat	1	2	3	4	5	6
Getting in/out of seat with seat in front reclined	1	2	3	4	5	6
Reading	1	2	3	4	5	6
Working	1	2	3	4	5	6
Eating	1	2	3	4	5	6
Sleeping	1	2	3	4	5	6

What is your level of comfort when

Adjacent seat is occupied by stranger?	1	2	3	4	5	6
Adjacent seat is occupied by person you know?	1	2	3	4	5	6
Adjacent seat is unoccupied?	1	2	3	4	5	6

APPENDIX 3

Experimental Study on the comfort of a passenger aircraft seat

EXPERIMENTAL PROTOCOL

Objective

To evaluate the comfort of two seat concepts designed by the team of MEng students from the Aero/Astro Department and compare them to an actual aircraft seat.

The first concept is a non-reclinable seat, the second one uses webbing instead of cushioning.

Four seats in total will be used for the experiments: two seats designed by the team and two actual seats. Aircraft environment is to be represented as precisely as possible. See attached figures.

Setup

Recruiting of experimental subjects will begin in April 1999. 12 subjects will be solicited (18 years or older) by e-mails to faculty members and students from all engineering school at MIT and by posters around MIT.

Here is a draft of the e-mail and the poster that will be sent:

"Hi!

We are a group of MIT Master of Engineering students from the Department of Aeronautics and Astronautics. We are working on a project to design aircraft passenger seats more comfortably than the ones already existing in aircraft today.

We have designed and built two new seat concepts and we need to know if we really achieved our goal: a truly comfortable seat!

We are looking for people to test the seats.

You would have to spend 9 hours in total, 3 hours in each seat (our two seats and an actual aircraft seat) in three separate days. For each seat you will be asked to perform specific tasks : sitting, reading, eating, sleeping. And filling in questionnaires!

You will be paid $10/hour.

If you are interested, please send us an e-mail specifying your height, your age, your sex and the time you would be available to come and test the seats. The tests should go from April, 16 to April, 23.

All data will be collected in a confidential manner and you may decline to participate to this experiment.

Thank you!"

Subjects may be accepted or rejected according to their height, because we need to cover the same spectrum of sizes the airline companies do (i.e. from the 5^{th} percentile to the 95^{th} percentile of the human population)

They will be paid $10 an hour as a compensation.

Experiments will be conducted at MIT. Two to three subjects will participate to the test at the same time.

Procedures

For each experiment subjects will spend three hours per day for three days. There will be two to three subjects at a time. They will be asked to perform the tasks described below for each of the three seats. The questionnaires (which are attached) are aimed at determining how comfortable they felt during those tasks.

A final questionnaire will be distributed to rank the overall comfort of the seat.

1. **Pressure mapping**: the subject will sit on a pad (pressure pad) and the experimenter will take maps of the pressure distribution directly on a computer. Three maps will be taken: one while the subject is sitting correctly, the second one in a slouched position and then in a working position.

2. **Sitting**: the subject will be asked to do nothing but remain seated and try to find his/her most comfortable sitting position.

3. **Questionnaire 1**: the subject will fill in questionnaire 1.

4. **Break**: the subject will be allowed a short break to get up and take a walk if he/she likes.

5. **Working**: the subject will be asked to perform any work task (reading, writing, using a computer) which requires the use of the tray.

6. **Questionnaire 2**: the subject will fill in questionnaire 2.

7. **Break**.

8. **Eating**: refreshments will be served.

9. **Questionnaire 3**: the subject will fill in questionnaire 3.

10. **Break**.

11. **Rest period**: the subject will be asked to rest on the seat and test the comfort of the lumbar support.

12. **Questionnaire 4**: the subject will fill in questionnaire 4 and give general comments on the seat.

The timeline is attached.

All twelve tasks will then be repeated in each of the next two seat types.

Subjects will be free to leave and use the restroom at any point in the study.

Personal data

Sample personal data to be taken for each subject (on a voluntary basis) include age, height and gender. Under no circumstances will these be linked to the names of the subject (anonymity preserved).

Experimental Study

on the comfort of a passenger aircraft seat

INFORMATION ON EXPERIMENT

Participation in this study is voluntary. You are free to withdraw your consent and to discontinue participation in the project or activity at any time, without prejudice. Please feel free to refer to the above contact if you have any question concerning the purpose, procedures, or risks associated with this experiment.

All data will be collected in a confidential manner, and will not be linked in any way to your identity. You will remain anonymous in any report that describes this work.

This study is designed to evaluate the comfort of two economy class aircraft seats with new features, and to test these features. You will be asked to perform the following tasks:

1. **Pressure mapping**: you will sit on a pad (pressure pad) and the experimenter will take maps of the pressure distribution directly on a computer. Three maps will be taken: one while you are sitting correctly, the second one in a slouched position and then in a working position.
2. **Sitting**: you will be asked to do nothing but remain seated and try to find your most comfortable sitting position. The safety belt will be fastened.
3. **Questionnaire 1**: you will fill in questionnaire 1.
4. **Break**: you will be allowed a short break to get up and take a walk if you like.
5. **Working or Rest Period**: you will be asked to perform any work task (reading, writing, using a computer) which requires the use of the tray. You are also welcome to sleep if you like.
6. **Questionnaire 2**: you will fill in questionnaire 2.
7. **Break**.
8. **Eating**: refreshments will be served.
9. **Questionnaire 3**: you will fill in questionnaire 3.
10. **Break**.
11. **Working or Rest period**: you will be asked to rest on the seat and test the comfort of the lumbar support. You will also be able to work.
12. **Questionnaire 4**: you will fill in questionnaire 4 and give general comments on the seat.

You are welcome to get up and stretch your legs during break periods. You may go to the restroom at any point during the study.

But please, if possible, remain seated during the other periods.

Refreshments will be provided.

You will be paid $10 an hour.

Each sequence presented above is expected to take three hours and will be repeated for each of the three seats.

The experimenter will be in your presence during the entire experiment.

Spending several hours in an airplane is known to be uncomfortable so some discomfort is expected. But if this feeling of discomfort happens to be unbearable, feel free to interrupt the test right away and inform the experimenter. If you decide to terminate the experiment, you will receive $10 for each hour you participated.

INFORMED CONSENT

In the unlikely event of physical injury resulting from participation in this research, I understand that medical treatment will be available from the MIT Medical Department, including first aid, emergency treatment and follow-up care as needed, and that my insurance carrier may be billed for the cost of such treatment. However, no compensation can be provided for medical care apart from the foregoing. I further understand that making such medical treatment available, or providing it, does not imply that such injury is the Investigator's fault. I also understand that by my participation in this study I am not waiving any of my legal rights.*

I understand that I may also contact the Chairman of the Committee on the Use of Humans as Experimental Subjects, MIT 253-6787, if I feel I have been treated unfairly as a subject.

I volunteer to participate in this experiment, with the understanding that I may discontinue my participation at any time. I have been informed as to the nature of this experiment and the risks involved, and agree to participate in the experiment.

Date___________Name_____________________Signature_________________

* Further information may be obtained by calling the Institute's Insurance and Legal Affairs Office at 253-2822.

Experimental Study on the comfort of a passenger aircraft seat

Personal data

Age:

Height:

Sex:

For the experimenter use

Seat type:

Subject number:

Seat type:

Subject number:

Questionnaire 1: sitting

Overall comfort	very comfortable	1	2	3	4	5	very uncomfortable
arm	very comfortable	1	2	3	4	5	very uncomfortable
thigh	very comfortable	1	2	3	4	5	very uncomfortable
leg	very comfortable	1	2	3	4	5	very uncomfortable
foot	very comfortable	1	2	3	4	5	very uncomfortable
neck	very comfortable	1	2	3	4	5	very uncomfortable
shoulder	very comfortable	1	2	3	4	5	very uncomfortable
back	very comfortable	1	2	3	4	5	very uncomfortable
lumbar	very comfortable	1	2	3	4	5	very uncomfortable
hip	very comfortable	1	2	3	4	5	very uncomfortable
head	very comfortable	1	2	3	4	5	very uncomfortable

How was the level of comfort hen the front seat aws reclined (if applicable)?:

Comments (if any):

Seat type:

Subject number:

Questionnaire 2: working/resting

What tasks have you performed and how long did these tasks take?

Overall comfort	very comfortable	1	2	3	4	5	very uncomfortable
arm	very comfortable	1	2	3	4	5	very uncomfortable
thigh	very comfortable	1	2	3	4	5	very uncomfortable
leg	very comfortable	1	2	3	4	5	very uncomfortable
foot	very comfortable	1	2	3	4	5	very uncomfortable
neck	very comfortable	1	2	3	4	5	very uncomfortable
shoulder	very comfortable	1	2	3	4	5	very uncomfortable
back	very comfortable	1	2	3	4	5	very uncomfortable
lumbar	very comfortable	1	2	3	4	5	very uncomfortable
hip	very comfortable	1	2	3	4	5	very uncomfortable
head	very comfortable	1	2	3	4	5	very uncomfortable
use of tray	very easy	1	2	3	4	5	very unesay
comfort with tray	very comfortable	1	2	3	4	5	very uncomfortable

If those answers differ from task to task, please state it here:

Did the recline of the seat affect your abiliy to work?

Comments (if any):

Seat type:

Subject number:

Questionnaire 3: eating

Overall comfort	very comfortable	1	2	3	4	5	very uncomfortable
arm	very comfortable	1	2	3	4	5	very uncomfortable
thigh	very comfortable	1	2	3	4	5	very uncomfortable
leg	very comfortable	1	2	3	4	5	very uncomfortable
foot	very comfortable	1	2	3	4	5	very uncomfortable
neck	very comfortable	1	2	3	4	5	very uncomfortable
shoulder	very comfortable	1	2	3	4	5	very uncomfortable
back	very comfortable	1	2	3	4	5	very uncomfortable
lumbar	very comfortable	1	2	3	4	5	very uncomfortable
hip	very comfortable	1	2	3	4	5	very uncomfortable
head	very comfortable	1	2	3	4	5	very uncomfortable
use of tray	very easy	1	2	3	4	5	very unesay
comfort with tray	very comfortable	1	2	3	4	5	very uncomfortable

Comments (if any):

Seat type:

Subject number:

Questionnaire 4: working/resting

What tasks have you performed and how long did these tasks take?

____

____

____

____

Overall comfort	very comfortable	1	2	3	4	5	very uncomfortable
arm	very comfortable	1	2	3	4	5	very uncomfortable
thigh	very comfortable	1	2	3	4	5	very uncomfortable
leg	very comfortable	1	2	3	4	5	very uncomfortable
foot	very comfortable	1	2	3	4	5	very uncomfortable
neck	very comfortable	1	2	3	4	5	very uncomfortable
shoulder	very comfortable	1	2	3	4	5	very uncomfortable
back	very comfortable	1	2	3	4	5	very uncomfortable
lumbar	very comfortable	1	2	3	4	5	very uncomfortable
hip	very comfortable	1	2	3	4	5	very uncomfortable
head	very comfortable	1	2	3	4	5	very uncomfortable

If applicable:

use lumbar support	very easy	1	2	3	4	5	very unesay
lumbar support	very comfortable	1	2	3	4	5	very uncomfortable

If those answers differ from task to task, please state it here:

How was the level of comfort when the front seat was reclined (if applicable):

Comments (if any):

Seat type:

Subject number:

General comments about the seat

What was your general feeling about the seat you have just tried?

For the webbed seat and the forward-sliding seat: how does this seat compare to a tourist-class seat in use?

_________	_____	_________	_____	_________
Much better	Better	Comparable	Worse	Much worse

APPENDIX 4

Experiment Results: Baseline Seat – Questionnaire 1

		Biographical				Questions											Comments	
Subject number	*Exp number*	*Age*	*Height*	*Weight*	*Gender*	*Overall comfort*	*arm*	*thigh*	*leg*	*foot*	*neck*	*shoulder*	*back*	*lumbar*	*hip*	*head*	*comfort w/ seat reclined*	*others*
C					M	4	3	3	3	4	5	4	5	5	4	5		
1	1	23	6'6	285	M	3	2	4	3	2	4	5	4	3	4	3		head rest at shoulder level
2	3	27	5'11 3/4	180	M	2	2	1	1	1	3	2	2	3	1	2		very familiat feel. Diff to make first impressions. Seat back a little too firm
3	3	22	5'2	120	F	2	1	1	1	1	1	1	3	4	1	2		very comfy - head rest in a very nice position/location
4	3	32	5'4	145	M	2	2	2	3	2	2	2	1	1	1	2		front edge of seat a little bit too hard. Should be softer than center
5	1	21	5'5	178	M	3	4	4	2	1	3	4	3	3	3	2		
6	3	20	5'10	178	M	2	2	2	2	1	3	1	2	2	2	1		neck supp not adequate - shoulder supp much better in this chair than in fs - overall comfort close to 1.8 - no noticeable pressure point in discomfort
7	2	23	5'9	150	F	2	2	1	1	1	1	2	2	3	1	1		surprisingly, feel very comfy in this seat (attributing to early comfort familiarity w/ this type of seat). Immediately after sitting, felt as if was actually sitting in an aircraft. Nice lteg/foot room. Noticeable difference in back support dut to lack of ulmbar support
8	1	24	6'1	190	M	4	5	3	4	3	4	5	3	5	3	4		
9	3	21	5'10	165	M	2	3	3	3	3	3	2	2	3	3	2	=	
10	3	21	5'7	145	M	2	2	2	2	3	2	2	2	3	2	2		
11	1	30	5'6.5	120	F	3	3	3	3	2	4	4	3	3	2	5		
12	3	24	5'9	150	M	2	3	3	2	3	3	3	3	3	3	2		

Average	2.5	2.6	2.5	2.3	2.1	2.9	2.8	2.7	3.2	2.3	2.5

Experiment Results: Baseline Seat – Questionnaire 2

		Biographical				Questions														Comments	
Subject number	*Exp number*	*Age*	*Height*	*Weight*	*Gender*	*Tasks*	*Overall comfort*	*arm*	*thigh*	*leg*	*foot*	*neck*	*shoulder*	*back*	*lumbar*	*hip*	*head*	*use of tray*	*comfort with tray*	*comfort w/ seat reclined*	*others*
C					M	reading (40mn)	4	3	3	4	4	5	4	5	5	4		4	4		
1	1	23	6'6	285	M	reading (20mn) resting (25mn)	3	2	3	4	3	5	4	4	3	3	4	5	4		tray table hard to use with any leg comfort
2	3	27	5'11 3/4	180	M	read (45mn). Seat up, tray down	2	2	1	1	1	4	2	2	3	2	2	1	4		tray table too low
3	3	22	5'2	120	F	slept and just sat (45mn)	2	1	1	1	1	1	1	2	3	1	1	5	5		tray too low, can't cross legs or maneuver at all when down
4	3	32	5'4	145	M	sleeping (30mn)	3	2	2	2	2	4	3	2	2	2	5	2	3		
5	1	21	5'5	178	M	talking / reading / relax	3	3	3	3	3	2	2	4	4	4	3	2	4	=	
6	3	20	5'10	178	M	rested/slept (45mn)	2	2	2	1	2	2	1	2	3	3	1	1	1		with time, lower back (lumbar) got sore
7	2	23	5'9	150	F	homework	3	2	3	2	2	1	1	2	3	1	1	1	4		overall comfort went down due to tray table along w/ thighs and legs. Tray uncomfy: sat low on and put pressure on thighs. Lower back support decreasing
8	1	24	6'1	190	M	working (55mn)	4	5	4	4	3	3	4	5	5	3	3	4	5	-	
9	3	21	5'10	165	M	reading (30mn)	3	3	3	3	3	3	3	3	3	3	3	3	4		
10	3	21	5'7	145	M	resting (30mn)	2	2	3	2	3	2	2	3	3	2	2	2	3		
11	1	30	5'6.5	120	F	sleepng(15mn), reading(45mn)	3	3	3	3	3	4	3	3	3	3	4	3	5		
12	3	24	5'9	150	M	rested	2	3	3	2	2	3	3	3	4	3	3	3	3		

Average	2.8	2.5	2.6	2.5	2.5	3.0	2.5	3.1	3.4	2.6	2.7	2.8	3.8

Experiment Results: Baseline Seat – Questionnaire 3

		Biographical				Questions													Comments	
Subject number	*Exp number*	*Age*	*Height*	*Weight*	*Gender*	*Overall comfort*	*arm*	*thigh*	*leg*	*foot*	*neck*	*shoulder*	*back*	*lumbar*	*hip*	*head*	*use of tray*	*comfort with tray*	*comfort w/ seat reclined*	*others*
C					M	4	4	4	4	3	5	4	4	5	4		5	5		
1	1	23	6'6	285	M	3	3	3	4	4	3	4	3	4	3	3	2	4		legs cramped being under the tray table especially feet and ankles
2	3	27	5'11 3/4	180	M	3	3	1	1	1	3	2	3	4	2	2	1	3		tray ok but a but low. Tall person and have to slouch way over to reach food. Very little maneuverability ofr legs beneath tray. Very tight space to eat in. hard surface under arms and elbows cause discomfort
3	3	22	5'2	120	F	2	3	4	4	3	1	1	2	2	2	3	5	5		tray very low - eating diff b/c tray so low (like eating from your lap) - otherwise seat comfy for sitting upright
4	3	32	5'4	145	M	2	2	2	2	2	2	2	2	2	2	2	2	3		tray little bit too low
5	1	21	5'5	178	M	4	4	4	3	3	3	3	3	3	3	3	2	2		not too bad for a coach class
6	3	20	5'10	178	M	2	2	2	2	1	2	2	4	3	3	1	1	1		back hurts even more while eating and leaning over - front seat rec was in the way significantly for any activity, esp eating - overall comfort 2 b/c tray is 1 but chair irself closer to 3
7	2	23	5'9	150	F	3	2	3	3	3	2	2	2	4	2	2	1	4		miss lumbar support and moveable tray. Believe decrease in head/shoulder rating due to leaning fwd for homework. When front seat reclined, extremely cramped in this seat area
8	1	24	6'1	190	M	5	4	4	4	4	4	5	4	5	4	3	3	4		
9	3	21	5'10	165	M	2	3	3	3	3	2	2	2	3	3	2	4	4		
10	3	21	5'7	145	M	2	2	2	3	2	2	2	2	3	2	2	2	3		
11	1	30	5'6.5	120	F	3	2	4	4	3	3	3	3	3	4	3	4	5		
12	3	24	5'9	150	M	3	3	3	3	3	3	3	4	4	3	3	3	3		tray too low

Average	2.9	2.8	3.0	3.1	2.7	2.7	2.7	2.9	3.5	2.8	2.4	2.7	3.5

Experiment Results: Baseline Seat – Questionnaire 4

		Biographical				Questions														Comments	
Subject number	*Exp number*	*Age*	*Height*	*Weight*	*Gender*	*Tasks*	*Overall comfort*	*arm*	*thigh*	*leg*	*foot*	*neck*	*shoulder*	*back*	*lumbar*	*hip*	*head*	*use of lumbar support*	*lumbar support*	*comfort w/ seat reclined*	*others*
C					M	sleeping(30mn) reading(30mn)	4	4	4	4	4	5	5	5	5	5					
1	1	23	6'6	285	M	reading (35mn) resting (10mn)	4	4	3	4	4	4	4	4	3	3	3				very hard to rest - uncomfortable esp. neck - no head support
2	3	27	5'11 3/4	180	M	read, seat slightly rec, tray down. Front seat fully rec	3	3	1	1	1	4	2	2	3	2	3			-	choice of tasks made it diff to be comfy w/ fron seat rec. very little room to read, trya too low. Arm tired having to hold paper at eye level
3	3	22	5'2	120	F	rested, sat, talked (45mn)	2	1	1	1	1	1	1	2	2	1	2				
4	3	32	5'4	145	M	sleeping (30mn), relaxing (20mn)	2	2	2	2	2	4	2	2	2	2	4			fine	
5	1	21	5'5	178	M	talking / relaxing	3	3	2	3	4	3	3	3	3	3	4				neck very sore because head rest not adjustable
6	3	20	5'10	178	M	wrote (20mn), read (30mn).	3	2	2	1	2	3	2	3	3	2	1			-	front seat annoying when writing
7	2	23	5'9	150	F	homework	3	2	4	3	3	2	2	4	4	2	2			-	space extremely resticted w/ front seat rec. diff to have drink on table. Back achy, tray uncmofy b/c pressure on thighs
8	1	24	6'1	190	M	working (1h30)	5	3	5	4	4	5	5	4	5	3	4			-	tray to low
9	3	21	5'10	165	M	sleeping (1hour)	3	3	3	3	3	4	4	3	3	3	3			fine	neck and shoulders felt good when not sleeping
10	3	21	5'7	145	M	chatting (1h)	2	2	2	3	2	3	2	3	3	2	2				
11	1	30	5'6.5	120	F	reading, resting (1h1/2)	3	3	3	3	2	4	3	4	4	4	4				resting: head and neck uncomfortable
12	3	24	5'9	150	M	rested	3	3	4	3	3	3	4	3	4	4	3				tray definitely too low

Average	3.1	2.7	2.8	2.7	2.7	3.5	3.0	3.2	3.4	2.8	2.9

Experiment Results: Forward Sliding Seat – Questionnaire 1

		Biographical				Questions											Comments	
Subject number	*Exp number*	*Age*	*Height*	*Weight*	*Gender*	*Overall comfort*	*arm*	*thigh*	*leg*	*foot*	*neck*	*shoulder*	*back*	*lumbar*	*hip*	*head*	*comfort w/ seat reclined*	*others*
N					M	3	3	4	3	3	2	3	3	2	3	1		
1	2	23	6'6	285	M	2	3	4	3	3	2	2	3	2	3	2		wish lumbar supp were taller - a little too narrow - head rest an inch too short - sliding back hard to use and eliminates leg room
2	2	27	5'11 3/4	180	M	2	2	1	1	1	3	1	2	2	2	2		much better lumbar support than webbed seat
3	1	22	5'2	120	F	2	1	1	1	1	2	2	2	2	1	2		large lumbar support --> body too straight --> can not use head rest
4	2	32	5'4	145	M	3	2	2	3	3	4	3	2	2	2	5		head support makes head very uncomfy b/c pushed too much forward
5																		
6	2	20	5'10	178	M	2	2	1	2	1	1	3	1	1	2	1		overall comfort 1.5 (not 1 b/c not perfect). Pump in neck would be wonderful, would make shoulders feel more comfy b/c wouldn't be floating as much. Arms felt crampy (cushion not good?)
7	1	23	5'9	150	F	1	2	2	2	3	1	1	1	1	1	1		left foot align with the seat bracket in front of me, does not allow me to put foot where it would go naturally
8	3	24	6'1	190	M	2	3	3	2	2	3	2	1	3	3			lumbar support very comfy - headrest a little far when seated properly - armrest too small - seat not wide enough
9	2	21	5'10	165	M	4	4	2	3	3	5	4	4	2	3	4		
10	1	21	5'7	145	M	2	3	3	2	2	2	3	1	2	2	1		like the inflatable back support most - head rest a little low, would be great if adjustable
11	3	30	5'6.5	120	F	4	4	3	3	3	3	3	4	4	3	4		webbed seat obviously ths most comfy
12	1	24	5'9	150	M	2	2	3	2	2	4	3	2	1	2	1		head too much backwards

Average	2.4	2.6	2.4	2.3	2.3	2.7	2.5	2.2	2.0	2.3	2.2

Experiment Results: Forward Sliding Seat – Questionnaire 2

		Biographical				Questions														Comments	
Subject number	*Exp number*	*Age*	*Height*	*Weight*	*Gender*	*Tasks*	*Overall comfort*	*arm*	*thigh*	*leg*	*foot*	*neck*	*shoulder*	*back*	*lumbar*	*hip*	*head*	*use of tray*	*comfort with tray*	*comfort w/ seat reclined*	*others*
N					M	reading brochure, taking notes	2	3	4	3	3	3	3	2	2	3			2		
1	2	23	6'6	285	M	reading (25mn), resting (20mn)	3	3	4	3	3	2	3	4	2	3	2	3	2		adj tray height good, mechanism could be improvred - good lumb support - okay for shoulders - bad in-between
2	2	27	5'11 3/4	180	M	chatting (15mn), reading w/ tray raised (40mn)	2	2	1	1	1	3	1	2	2	1	3	2	2		lumbar pillow nearly deflated when seat reclined. Reclining does not allow much leg room, and effective seat becomes very shallow. Bad design
3	1	22	5'2	120	F	studying, talking	2	1	1	1	1	2	2	3	3	1	1	4	1		tray difficult to adjust, once adjusted it was excellent (much more than a standard one)
4	2	32	5'4	145	M	reading (20mn), resting (10mn)	2	2	2	2	2	3	3	3	3	3	4	2	2		
5																					
6	2	20	5'10	178	M	reclined seat, talked, rested. Fiddled with tray	2	2	2	2	1	2	2	1	1	2	1	4	3		seat adjustments pretty awkward. Perhaps more convex head rest would feel bettre for neck. Tray diff to adjust, makes it bothersome to use. Rating actually about 2.4
7	1	23	5'9	150	F	talking (20mn), working (40mn)	1	2	2	2	3	1	2	1	1	1	1	2	2		working with tray down --> head/neck/shoulders had no contact with seat - excellent lumbar support, seem to place most of my weight on it
8	3	24	6'1	190	M	reading (30mn), restting(10mn)	3	3	4	3	3	3	3	2	2	3	2	1	2		fs position makes use of head rest easier but decreases leg room
9	2	21	5'10	165	M	working (30mn) sleeping (5mn)	3	3	3	3	3	3	3	3	2	3	3	2	2		seat would be a lot more comfortable if the headrest was pushed back some
10	1	21	5'7	145	M	studying (20mn)	2	3	4	3	2	3	2	1	2	2	2	3	2		seat too small (the part you sit on) - lot of pressure on the seat at the thigh
11	3	30	5'6.5	120	F	reading	3	3	3	3	3	3	3	4	4	3	2.5	3	3		
12	1	24	5'9	150	M	reading (1h10)	2	2	3	2	2	2	2	3	3	3	2	1	1		in slouched position: back hurts a bit, bottom part of seat too short. Good tray

Average	2.3	2.4	2.8	2.3	2.3	2.5	2.4	2.4	2.3	2.3	2.1	2.5	2.0

Experiment Results: Forward Sliding Seat – Questionnaire 3

		Biographical				Questions													Comments	
Subject number	*Exp number*	*Age*	*Height*	*Weight*	*Gender*	*Overall comfort*	*arm*	*thigh*	*leg*	*foot*	*neck*	*shoulder*	*back*	*lumbar*	*hip*	*head*	*use of tray*	*comfort with tray*	*comfort w/ seat reclined*	*others*
N					M	3	3	4	3	3	2	3	2	2	3			2		
1	2	23	6'6	285	M	2	3	3	3	2	2	3	4	2	2	2	2	2		much better than conventional tray
2	2	27	5'11 3/4	180	M	2	2	1	1	1	2	1	2	2	2	2	3	1		tray nice and high, though small. Nice to maneuver legs beneath tray while in use. Thanks for food! Excellent service
3	1	22	5'2	120	F	1	1	1	1	1	1	1	1	3	1	1	4	1		(not for eating) difficult to recline the seat - leg room greatly diminished with seat reclined - in reclined position, head rest works very well & is quite comfortable, lumbar support feels better
4	2	32	5'4	145	M	2	3	2	3	3	2	2	2	2	2	2	2	2		
5																				
6	2	20	5'10	178	M	2	1	2	1	1	2	2	1	1	2	1	3	2		
7	1	23	5'9	150	F	1	2	2	2	2	1	1	1	1	1	1	1	1		felt very comfortable with tray (have been using it entire flight) - lumbar support excellent - did not try to adjust tray
8	3	24	6'1	190	M	3	3	3	3	3	3	3	2	3	3	3	1	1		use of tray helps for a better eating position
9	2	21	5'10	165	M	3	3	3	3	3	3	3	4	4	3	3	2	2		
10	1	21	5'7	145	M	2	2	3	2	2	2	2	1	2	2	2	2	1		height of tray adjustable : great, would be better if even higher (always had problems eating in planes before, because food is so far away !!)
11	3	30	5'6.5	120	F	3	3	3	3	3	3	3	4	4	3	3	3	3		
12	1	24	5'9	150	M	2	2	3	2	2	2	2	2	1	2	2	1	1		

Average	2.2	2.3	2.5	2.3	2.2	2.1	2.2	2.2	2.3	2.2	2.0	2.2	1.6

Experiment Results: Forward Sliding Seat – Questionnaire 4

		Biographical					Questions													Comments	
Subject number	*Exp number*	*Age*	*Height*	*Weight*	*Gender*	*Tasks*	*Overall comfort*	*arm*	*thigh*	*leg*	*foot*	*neck*	*shoulder*	*back*	*lumbar*	*hip*	*head*	*use of lumbar support*	*lumbar support*	*comfort w/ seat reclined*	*others*
N					M	reading, sleeping	2	3	3	3	3	2	3	1	2	3	1	2	2		ranks for sleeping
1	2	23	6'6	285	M	writing (30mn), reading (!0mn), resting (5mn)	3	3	4	3	3	2	3	4	3	3	2	3	2		thigh less comfy when trying to lean back and rest
2	2	27	5'11 3/4	180	M	read (5mn), sleep (40mn). Seat reclined to position 3 the whole time and tray raised	1	2	1	1	1	2	2	1	2	1	1	1	2		not much room leaft when reclined. Feels like sliding off the seat
3	1	22	5'2	120	F	reading, studying & sleeping (45mn)	3	1	1	1	1	3	3	4	4	2	3	3	4		see previous
4	2	32	5'4	145	M	sleeping (30mn)	2	3	2	2	2	2	2	3	3	2	4				
5																					
6	2	20	5'10	178	M	class work and reading	2	2	2	1	1	2	2	1	1	3	2	1	1		should have shoulder support, neck support further forward. Seat sliding too complex backwards
7	1	23	5'9	150	F	studying, talking	2	2	2	2	2	2	2	1	1	1	2	1	1		deflate the lumbar support bc lower back became sore, decreasing pressure absolved the discomfort - chair not comfortable at all in reclined position
8	3	24	6'1	190	M	resting (90mn)	3	3	3	3	3	2	3	3	3	3	2	2	2		side head rest very useful and comfy in this position
9	2	21	5'10	165	M	studying (40mn)	4	3	3	3	3	3	4	4	3	3	3	2	3		
10	1	21	5'7	145	M	working (2h)	2	2	3	2	2	2	2	1	1	2	2	2	1		
11	3	30	5'6.5	120	F	chatting	3	3	3	3	3	3	3	4	4	4	3	4	4		worst comfort level of the 3 types of seats
12	1	24	5'9	150	M	reading(1h30), talking(1h)	2	2	4	3	3	2	2	3	2	2	2	1	1		knees hurt but probably beacause didn't get up and walk. Will next time

Average													
	2.4	2.4	2.6	2.3	2.3	2.3	2.6	2.5	2.4	2.4	2.3	2.0	2.1

Experiment Results: Webbing Seat – Questionnaire 1

		Biographical				Questions											Comments	
Subject number	*Exp number*	*Age*	*Height*	*Weight*	*Gender*	*Overall comfort*	*arm*	*thigh*	*leg*	*foot*	*neck*	*shoulder*	*back*	*lumbar*	*hip*	*head*	*comfort w/ seat reclined*	*others*
XT					M	3	2	2	2	2	4	4	4	2	3	5		head rest too high
1*	3	23	6'6	285	M	2	3	3	3	3	2	2	1	2	3	2	-	reclined bad for legs and esp knees - back support really comfy
2	1	27	5'11 3/4	180	M	2	3	2	2	2	3	1	1	4	2	2		I have an easily aggrevatible lower back, and although I like the springiness of the tight mesh, the lumbar support is WAY TOO LUMPY
3	2	22	5'2	120	F	3	1	1	1	1	1	1	2	4	2	3		
4	1	32	5'4	145	M	3	4	3	4	3	2	2	2	2	2	2		arm rest low, face of arm rest should be softer and larger
5*	2	21	5'5	178	M	2	3	3	2	3	4	2	1	2	3	4		back support excellent. Feels really good for middle back
6	1	20	5'10	178	M	2	2	3	2	1	4	2	1	3	3	4	+	head rest too far from person (should be moved forward) - too much pressure on the lumbar area (nothing more than a slight discomfort) - hip/buttocks area too flat (more comfortable with deeper thigh/butt indentions ?)
7*	3	23	5'9	150	F	1	1	1	1	1	1	1	1	1	1	2		webbed back offers increased support to upper back and shoulders - head rest not as comfy as lumbar seat head rest, too low
8	2	24	6'1	190	M	3	4	3	3	3	4	4	2	4	3	2		webbed seat a little hard at beginning, but quite comfy; No lumbar support: hurts; Head rest comfy but too small; Should be a neck support; (if sitting straight, comfy, but if slouched, neck not supported anymore); Arm rests not wide enough and not comfy at all; hurts shoulders
9	1	21	5'10	165	M	2	3	2	3	3	2	1	1	3	3	2		webbed backing very comfortable
10*	2	21	5'7	145	M	2	2	2	2	2	3	3	1	1	2	3		lumbar supp is fine but head and neck have nothing to rest on unless slouched
11	2	30	5'6.5	120	F	2	3	3	4	4	3	3	2	3	3	3		
12*	2	24	5'9	150	M	1	2	2	2	2	3	3	2	2	3	3		
Average						2.2	2.5	2.3	2.4	2.3	2.8	2.2	1.6	2.5	2.5	2.8		

Experiment Results: Webbing Seat – Questionnaire 2

	Biographical					Questions														Comments	
Subject number	Exp number	Age	Height	Weight	Gender	Tasks	Overall comfort	arm	thigh	leg	foot	neck	shoulder	back	lumbar	hip	head	use of tray	comfort with tray	comfort w/ seat reclined	others
XT					M	sleeping, chat (15mn)	4	2	2	2	2	5	4	4	2	3		2	2		head rest too high
1*	3	23	6'6	285	M	reading (35mn), resting (10mn)	2	4	4	3	4	2	2	1	1	3	2	3		-	very little room to lean forward to work - hard to lean chair back to be comfy
2	1	27	5'11 3/4	180	M	reading (10mn), chat (20mn), rest (5mn)	2	3	2	2	1	4	2	1	5	1	3	2	1		lumbar "rock" should be removed or softened - height adjustment tray increased comfort and ease of filling out this form
3	2	22	5'2	120	F	slept (45mn)	1	1	1	1	1	1	2	2	2	1	4	4	1		a bit distracted to have knee up against front seat
4	1	32	5'4	145	M	reading (15mn)	2	2	3	2	2	2	2	1	2	3	2	1	2		tray okay fot thigh, but looks likely to break if heavy stuff on it
5*	2	21	5'5	178	M	talking, nap, pulled out tray table	3	2	3	3	3	4	1	1	1	2	4	3	4		neck support not adjust so hits head and not neck. Adjusting tray is very difficult
6	1	20	5'10	178	M	working (45mn)	3	3	4	4	3	2	1	1	1	4	2	2	2	-	not enough arm & leg space - interfernce of room with the second passenger
7*	3	23	5'9	150	F	reading, working	1	1	1	1	1	2	1	2	2	1	2	3	1		decrease in head/neck comfort due to leaning forward - tray table very comfy - back a little bit uncomfy
8	2	24	6'1	190	M	working (1hour)	2	4	3	3	3	3	4	2	3	3	3	3	1		can't use head rest when working b/c leaning forward, tray very useful and comfy (don't have too lean too much so back better and arms better b/c on the tray and not on arm rests)
9	1	21	5'10	165	M	homework (40mn)	2	4	3	3	3	3	2	2	3	3	2	2	1	=	
10*	2	21	5'7	145	M	reading (15mn), sleeping (10mn)	2	2	2	2	2	3	2	1	2	2	2	2	2		neck support would be great
11	2	30	5'6.5	120	F	reading	3	3	3	3	4	3	3	2	3	3	3	2	3	-	no foot rest. Did not know for the tray adjustability
12*	2	24	5'9	150	M	reading (1hr)	2	2	2	2	2	3	2	2	2	3	3	1	1		pillow would be a good idea
						Average	2.2	2.5	2.5	2.4	2.4	2.8	2.2	1.7	2.2	2.5	2.7	2.3	1.8		

Experiment Results: Webbing Seat – Questionnaire 3

		Biographical				Questions													Comments	
Subject number	*Exp number*	*Age*	*Height*	*Weight*	*Gender*	*Overall comfort*	*arm*	*thigh*	*leg*	*foot*	*neck*	*shoulder*	*back*	*lumbar*	*hip*	*head*	*use of tray*	*comfort with tray*	*comfort w/ seat reclined*	*others*
XT					M	2	1	2	2	2	3	3	3	2	3		2	2		
1*	3	23	6'6	285	M	2	3	4	3	3	3	2	2	2	3	3	3	3		
2	1	27	5'11 3/4	180	M	2	1	1	2	1	4	2	2	5	2	2	3	1		
3	2	22	5'2	120	F	1	1	1	1	1	1	1	1	1	1	1	4	1		very comfortable b/c tray adjustable. (difficult to adjust)
4	1	32	5'4	145	M	2	2	2	3	3	2	2	2	3	3	2	2	2		
5*	2	21	5'5	178	M	2	3	3	2	3	2	1	1	2	3	4	3	4		neck support not adjust so hits head and not neck. Adjusting tray is very difficult
6	1	20	5'10	178	M	2	4	3	2	2	2	2	3	2	3	1	1	1		seat & tray very well suited for eating process - does not require use of head rest (for eating) - space is less of a problem when eating except for arm/elbows which still interfere heavily
7*	3	23	5'9	150	F	2	1	1	1	1	2	1	2	2	1	2	3	1		
8	2	24	6'1	190	M	2	3	3	2	2	2	3	2	3	3	2	2	1		tray helps for good position. Head rest useless
9	1	21	5'10	165	M	2	3	3	3	3	3	2	2	3	3	2	1	1		
10*	2	21	5'7	145	M	2	2	2	2	2	2	2	1	1	2	2	2	2		
11	2	30	5'6.5	120	F	2	3	2	3	4	3	3	2	2	2	3	3	3		
12*	2	24	5'9	150	M	1	2	3	2	2	2	2	1	2	2	4	1	1		head rest too much backwards

Average													
	1.8	2.2	2.3	2.2	2.2	2.4	2.0	1.8	2.3	2.4	2.3	2.3	1.8

Experiment Results: Webbing Seat – Questionnaire 4

		Biographical				Questions														Comments	
Subject number	*Exp number*	*Age*	*Height*	*Weight*	*Gender*	*Tasks*	*Overall comfort*	*arm*	*thigh*	*leg*	*foot*	*neck*	*shoulder*	*back*	*lumbar*	*hip*	*head*	*use of lumbar support*	*lumbar support*	*comfort w/ seat reclined*	*others*
XT					M	sleeping	5	2	2	2	2	5	3	3	2	4					
1*	3	23	6'6	285	M	reading (45mn)	2	3	4	4	3	3	2	2	2	4	2				
2	1	27	5'11 3/4	180	M	chat (20mn), reading (20mn)	2	2	1	1	1	4	2	1	5	2	2				really like the mesh back
3	2	22	5'2	120	F	slept, talked	2	2	1	1	1	3	3	4	4	4	4			-	knees against seat
4	1	32	5'4	145	M	talkgin(50mn), reading(30mn)	2	2	2	3	3	2	2	2	2	2	2				
5*	2	21	5'5	178	M	relaxed and talked	2	3	3	4	3	4	2	1	2	3	4			+	loved that tray did not move forward when front seat was reclined
6	1	20	5'10	178	M	studying, talking (30mn), resting	2	4	3	2	2	1	2	3	2	2	1				discomfort did not increase appreciably after several hours in the seat
7*	3	23	5'9	150	F	working, talking	2	1	1	1	1	2	1	3	3	1	2			=	lower back and back in gen became more and more uncomfy w/ time - when front seat rec, failry comfy but a small protion of table area reduced
8	2	24	6'1	190	M	working (1hour)	2	3	4	3	2	3	3	2	2	2	3				tray helps for good position. But too much pressure on thighs
9	1	21	5'10	165	M	homework (1h)	2	3	3	3	3	3	2	2	3	3	3				
10*	2	21	5'7	145	M	studying (1hour)	2	2	2	2	2	3	2	1	1	2	2				
11	2	30	5'6.5	120	F	reading, resting, thunb-doodling	3	3	2	3	4	3	3	2	2	2	3			-	less space, less comfy
12*	2	24	5'9	150	M	reading (2hr)	2	2	3	3	2	3	2	2	4	3	3			=	okay w/ front seat rec: enough space - using inflatable lumb supp and adj head rest would be perfect
						Average	2.3	2.5	2.4	2.5	2.2	3.0	2.2	2.2	2.6	2.6	2.6				