# Advanced Aircraft Seat Design: Solving the Problem of Rearward Space Intrusion with a Sliding-Out Seat Back

by

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ABSTRACT

An aircraft economy-class seat that reclines via a sliding-out backrest was designed, fabricated and tested for comparison with a baseline aircraft seat. The goal was to design a seat that was at least as comfortable as the baseline seat so as to demonstrate the viability of replacing the usual backwards recline feature with a sliding-out mechanism. This would solve the problems of space intrusion associated with seat recline. Three additional features were included on the seat: an adjustable lumbar support, a height-adjustable winged headrest and a height-adjustable tray.

The seat was evaluated via human subject responses and pressure distribution maps. Results obtained from the experiment showed that the seat was as comfortable as a baseline seat, if not better, and there was no statistical indication that subjects found the seat more uncomfortable. Pressure distribution maps corresponded well to the subject responses.

Based on the test results, the concept is deemed viable and its implementation is recommended on daytime flights that are over three hours long.

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## DEDICATION

To my parents and my brother,
for all their love and encouragement.

And to Woo Pei Wei,
for her strong emotional support during those long days and nights working in front of the computer.

## ACKNOWLEDGEMENTS

The author would like to express his sincere gratitude to the following companies:

1) BE Aerospace – for assistance rendered throughout the project that included hardware, information, advice, feedback, a plant tour and participation in design reviews
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3) Northwest Airlines – for the information and feedback rendered, and also for taking part in the final design review
4) Milliken & Co. – for hastily wrapping a backrest frame with elastomeric fiber upon short notice, and for attending the final design review.

"Without your participation, there would not have been a project!"

A special word of thanks also goes to the faculty advisors that provided valuable guidance and encouragement throughout the project

"Thanks for always being there to steer us in the right path!"

Last but not least, the author would like to thank his sponsor organization, the Economic Development Board of Singapore.

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# 1. INTRODUCTION

Air travel has become a very unpleasant experience of late. From the endless wait in the security lines to the clogged up aisles during stowage of overhead baggage, the economy-class passenger is usually exhausted by the time he or she gets to sit down. To make matters worse, instead of a comfortable seat to sink into, the passenger is greeted by a seat either one size too big or one size too small, designed to fit the hypothetical $50^{th}$ percentile human being (those above the $50^{th}$ percentile will find the seat small, while those below it will find the seat big). It is hence not suprising, that with the hectic travelling schedules of today's businessmen, the number of media-dubbed "air rage" incidents has been steadily increasing. In fact, there are hundreds of physical assault and verbal abuse incidents on record. A Virgin Atlantic Airtours flight attendant was attacked with a broken vodka bottle when she asked a passenger to be seated, requiring her to get 18 stitches. In a British Airways B-747 jet flying at 10,600 m, a man punched a door window so hard that he smashed the inner protective layer.

While the lack of comfort in aircraft seats cannot be solely to blame for the occurrence of air rage, it is certainly true that not enough attention has been given to the complex and intricate task of aircraft seat design. In fact, snubbed by certain quarters as nothing more than the design of "flying furniture," the progress made in this industry has largely gone unnoticed. Yet, passengers continue to complain about the lack of comfort in their seats, and with the roughly 600 million passenger enplanements each year (see Appendix I), one might find it surprising that the problem of uncomfortable seats still lingers on.

When the Advanced Aircraft Seat project was first conceived, the team had no idea what aircraft seat designed entailed, and thought it a fairly straightforward process. The team presumed that aircraft seats were not comfortable because airlines and seat manufacturers, in their frantic bid to increase profit margins and stay afloat in today's deregulated air travel industry, had simply overlooked the importance of providing better seats. However, the folly of this presumption was very quickly uncovered as the team began to sink its teeth into the problem. A visit to the BE Aerospace seat manufacturing plant in Litchfield, Connecticut, provided a glimpse into the level of sophistication and detail that went into each seat design. Indeed, in order to design seats effectively, one has to consider not only the mechanics of the seat, but also the human factors that govern its dimensions and contours. On top of that, the seat designer literally has one hand tied between the back by stringent FAA safety regulations. (Each time an airline introduces a change to its seats, however miniscule, the airline has to resubmit the seats through the scrutinous eyes of the FAA, a process which takes a matter of years. Even changing the fabric color on a seat that had been previously approved would be in violation of FAA regulations.) Airlines on the other hand, have consistently demanded for lower and lower cost seats because airfarers hardly take seat comfort into account when purchasing tickets; customers base their decisions primarily on price and itinerary. Such are the challenges faced by aircraft seat designers. The team felt nevertheless, that there were still avenues left open to explore, and the project goal was outlined as follows:

> "To find scientific, creative, and innovative means to improve passenger comfort
> in economy-class seats during long haul flights."

This thesis focuses on one of the two concepts that the project team selected, designed, fabricated and tested: the forward-sliding seat.

# 2. BACKGROUND

## 2.1 DEFINING SEAT COMFORT

Ironic as it may sound, one of the biggest problems facing seat designers in the aircraft, automotive, office or home industry today is finding a way to define and measure seat comfort. It is indeed a very difficult task and is highly subjective. Some definitions of comfort include the following:

- some state of well-being or being at ease (Oborne and Clarke, 1973)
- an occupant's empirical perception of being at ease (Reynolds, 1993)
- the absence of discomfort (Branton, 1969, Corlett, 1973, Hertzberg, 1958).

The latter definition is more prevalent among researchers today because designing for comfort, as Verbrugge (1990) puts it, is "an impossible goal scientifically." It is more logical to eliminate sources of discomfort on a seat than to provide more comfort.

The body regions where discomfort may be felt are generally accepted to comprise of the neck, upper back, middle back, lower back, thighs, buttocks, calves, chest, shoulder and sides. Three modes of comfort have been identified:

1. Initial comfort
   - the initial sensation perceived upon sitting down
   - a comfortable seat should provide a gradual, gentle and cozy sensation.
2. Transient comfort
   - the sensation perceived as one adjusts his or her posture or fidgets around in the seat
   - the seat should provide a gentle damping effect on the transient loading.
3. Dynamic comfort
   - the comfort of the seat under vibrating conditions

Although several tools have been developed to assess seat comfort objectively, none have been able to produce results with enough consistency to be relied upon as the singular predictor of comfort. In the automotive industry, Lee and Ferraiuolo (1993), working for Ford Motor Company, conducted an experiment to correlate EMG (electromyograph) data and seat pressure distribution data with subjective comfort, but were not able to find a significant enough correlation to be a basis for seat design. EMG measures the electrical activity of the muscle action potential. Faced with this problem, the seating industry continues to rely on jury evaluations as the main assessment of seat comfort.

## 2.2 A BROADER DEFINITION OF COMFORT

While the various definitions and modes of comfort described in the above section would, at first glance, be taken in the context of the comfort of the seat per se, the team felt that it would be worthwhile extending the definition to include the comfort of the interfaces between the aircraft seat and the aircraft environment. Such interfaces would include the space around the seats that could be violated, for instance, by the recline of the front seat. Shen and Vertiz (1997), defined physical comfort as the "physiological and psychological state perceived during the autonomic process of relieving physical discomfort and achieving corporeal homeostasis." In other words, comfort is defined as a dynamic attribute, occuring only when the immediate surrounding environment makes a positive change. An example given by Shen and Vertiz to illustrate their point is the case of a person feeling comfortable when he or she takes a shower after spending a few hours out in the hot sun, but soon becomes indifferent to the level of comfort. The person may even feel uncomfortable again due to a different environmental stimulus, such as the lack or air ventilation, sustained medium pressure under the thigh or persistent low back muscle exertion.

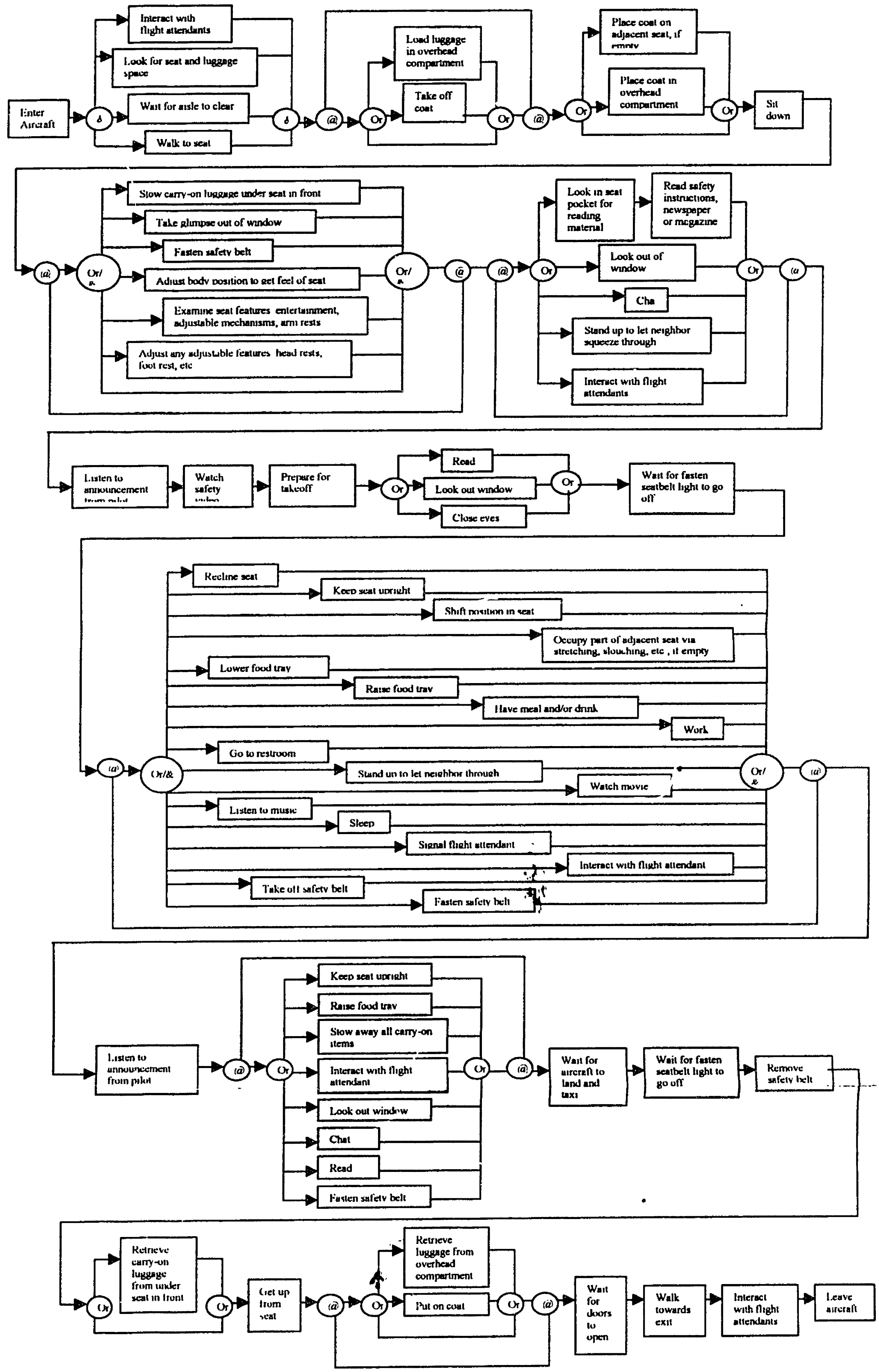
In an aircraft seating environment, various external stimuli exist which may or may not alter a passenger's level of comfort. A personal entertainment system for example, could serve a dual function: first as a souce of entertainment, and second as a source of distraction (from feelings of discomfort). Squeezing past the adjacent passenger – with the front seat reclined – in order to go to the bathroom could also adversely affect the overall comfort level of either passenger. Furthermore, any adjustment mechanism provided to the passenger, if not intuitive to use or too difficult to adjust, may cause the passenger to conclude prematurely that the seat is "bad." Studies have pointed to the fact that people, when sitting at work, tend not to use the manually adjustable features on their chairs (Kleeman and Prunier, 1980).

## 2.3 FUNCTIONAL FLOW DIAGRAM (FFD)

In order to fully capture both the static and dynamic in-flight activities that may affect the passenger's overall level of comfort, a Functional Flow Diagram was created (see Figure 2.3). A brief description of the FFD is provided in Appendix II. This design tool was instrumental in helping the team arrive at the forward-sliding backrest concept. Activities such as getting in and out of the seat, reclining and keeping the seat upright, and standing up to let the adjacent passenger squeeze through could occur many times throughout the flight, and are usually an inconvenience to one or more passengers. The author has had several bad experiences during long haul flights where he was frequently woken up throughout the night by the adjacent passenger who needed to go to the bathroom.

In the FFD, a circle labeled with "&" represents activities that occur concurrently, while a circle with an "Or" means one of the activities in the different branches can be taken. The "@" label represents an iterative loop that may go on for varying durations, and finally an "Or/&" label means a combination of different activities may go on concurrently.

**Figure 2.3: Functional Flow Diagram for a Typical Economy-Class Aircraft Passenger Seat**



## 2.4 THE FIRST CUSTOMER SURVEY

At this stage of the project, the team was still uncertain on what customers really wanted improved in their seats, apart from the fact that they needed more legroom. The average seat pitch, or distance between seats ranges anywhere from 28 to 36 inches, while studies by United Airlines (Roach, 1998) showed that about 48 inches is needed between seats to be able to have a backrest angle that is conducive to sleeping. However, increasing legroom is not a financially viable option for most carriers, as it would drastically cut into their revenues and force them to raise fares. Raising fares could be tantamount to suicide, given today's competitive deregulated industry. Increasing even an inch of legroom would require taking out one or two rows of seats (Roach, 1998). It is the author's understanding that losing a row of seats without increasing fares may cost an airline about $600,000 per airplane per year in flight revenues.

With little room to maneuver as far as seat dimensions and spacing is concerned, the seat designer is left to focus on cushioning, contours and adjustable mechanisms. Changing or adding each new feature would usually increase the cost of the seats. No doubt a very comfortable seat could be designed by adding an adjustable lumbar support, a fancy headrest, a footrest, cushioned armrests, and even an electronic back massage, but this would raise the cost of the seat too much for it to be commercially viable. Clearly, a tradeoff has to be made with regard to each seat feature.

The customer survey is provided in Appendix III. This was distributed to 150 faculty and staff in MIT's Department of Aeronautics and Astronautics, and a further 100 were sent by team members to their respective home countries, that included Singapore, China, Greece and France.

For this survery, there were 132 respondents in total: 51 female and 71 male. Their attributes are summarized in Table 2.4.

**Table 2.4: Attributes of Respondents for First Customer Survey**

| | Average | Median | Standard Deviation |
|---|---|---|---|
| **Age** | 34 years | 31 years | 11.8 years |
| **Weight** | 70 kg | 67 kg | 18 kg |
| **Height** | 172 cm | 172 cm | 12.8 cm |

Figures 2.4.1 and 2.4.2 show the average flight attributes of the respondents. The majority fly 2-5 times each year and between 3-5 hours for each flight. When asked what class they normally flew in, 85% of respondents answered economy class, while 12% and 3% indicated that they flew in business and first class respectively. Although 3-5 hours may not be truly representative of "long haul" flights, as targeted in the project statement, there was a substantial number of respondents in the 6-10 and >10 hour range (45% of respondents), which lends credibility to the results.

**Figure 2.4.1: "How many times do you fly in a year?"**

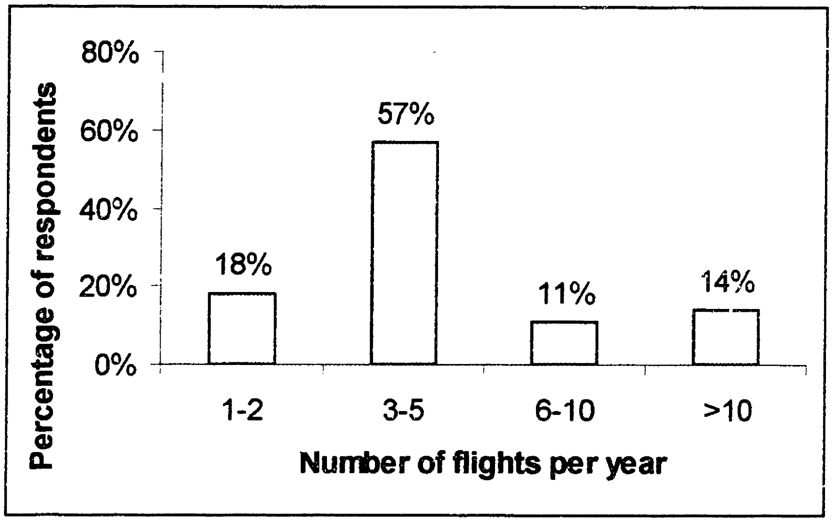
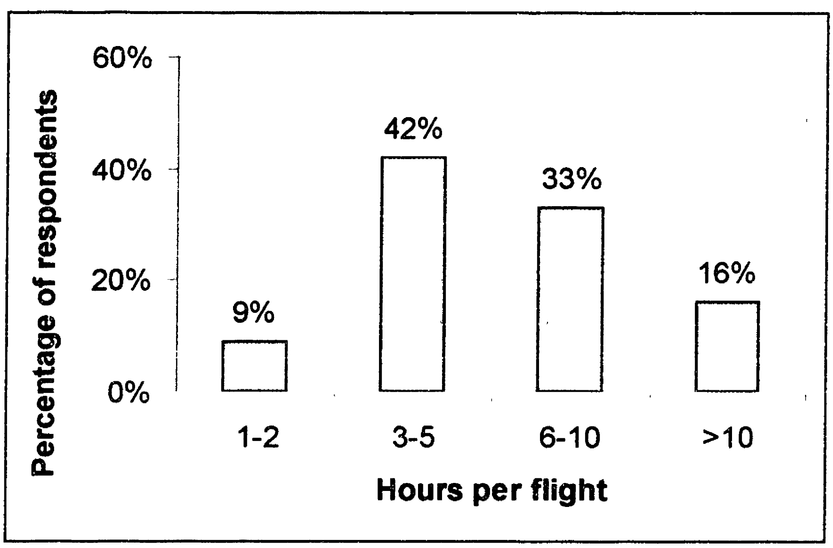
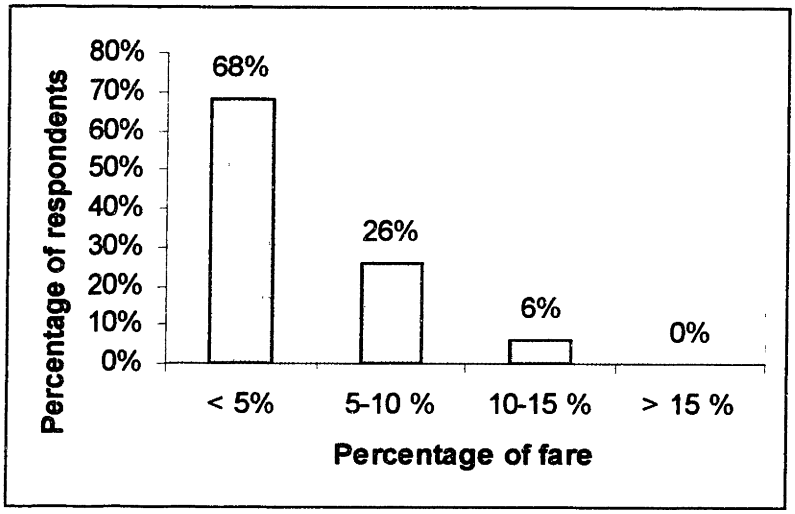



**Figure 2.4.2: "On Average, How Many Hours Does Each Flight Take?"**



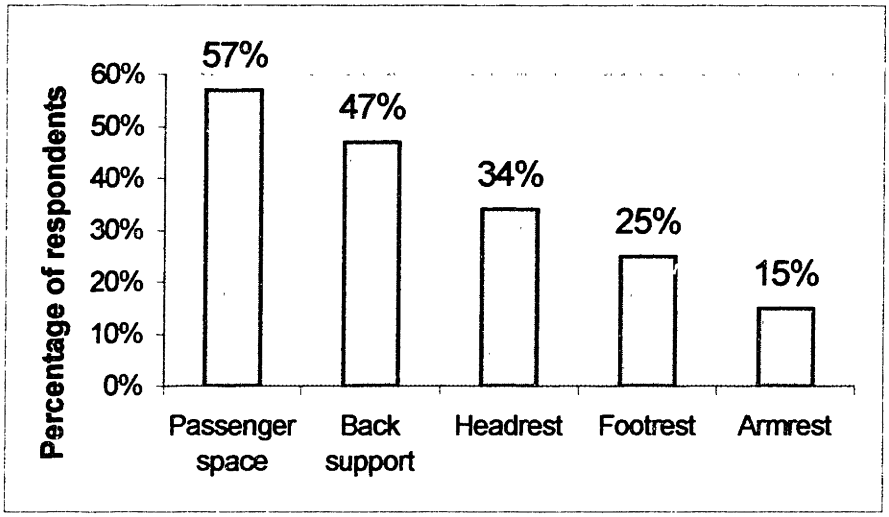
In response to the question, "Do you think the current seats can be improved?" an overwhelming 98% of respondents answered "Yes." However, when asked how much more they were willing to pay for improvement as a percentage of their fare, 68% responded "less than 5%," 26% "between 5-10%," and 6% "between 10% to 15%" (see Figure 2.4.3). These results illustrate clearly the problem faced by airlines and seat manufacturers: people generally want seats improved, but are not willing to pay for improvement.

**Figure 2.4.3: "How Much of Your Fare Are You Willing To Pay for Improvement (As A Percentage of Your Fare)?"**



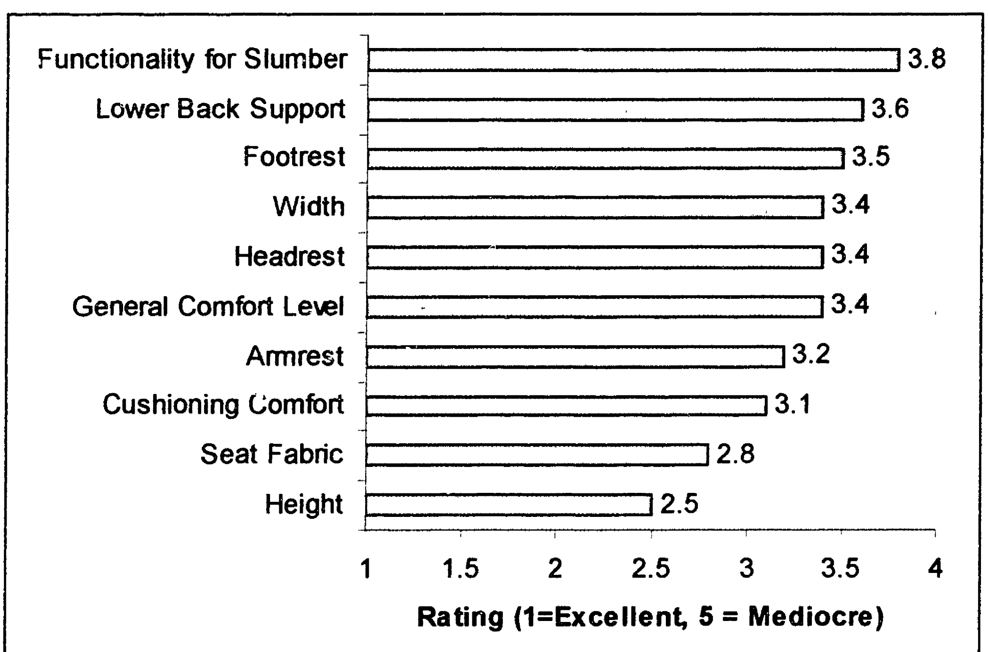

The responses to the question, "Which aspects of the seats do you think requires the most improvement?" are shown in Figure 2.4.4. Unsurprisingly, "passenger space" was selected the most number of times. Following this was "back support," "headrest," "foot rest," and "armrest."

**Figure 2.4.4: "Which aspects of the seats do you think requires the most improvement?"**




Those surveyed were also asked to rate several key seat aspects according the their level of comfort: Excellent (1), Good (2), Satisfactory (3), Fair (4) and Mediocre (5). The results are summarized in Figure 2.4.5. "Functionality for Slumber" and "Lower Back Support" received the poorest ratings.

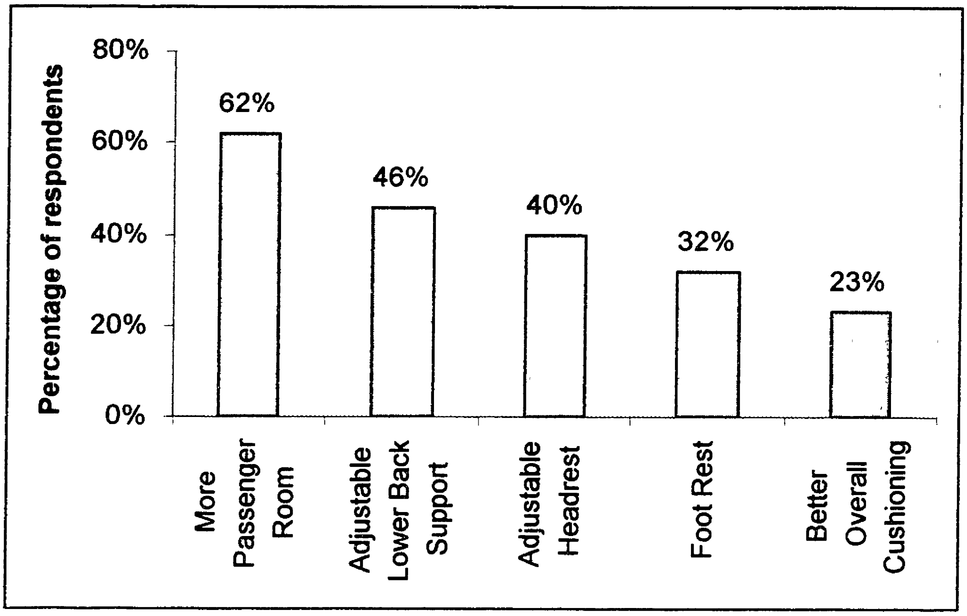
**Figure 2.4.5: "Rate the following seat aspects."**



Finally, from a given list of seat features, respondents were asked which they would most like to see on their next flight.

The top three features are respectively "more passenger room," "adjustable lower back support," and "adjustable head rest" (see Figure 2.4.6).

**Figure 2.4.6: "What features would you like to see most on your next flight?"**




As will be seen later in the discussion of the two selected concepts, the results of this survey helped generate the ideas that led to the team's prototypes.

## 2.5 THE QUALITY FUNCTION DEPLOYMENT (QFD) REQUIREMENTS MATRIX

With the customer needs identified, the team contacted representatives from BE Aerospace and Northwest Airlines for their input on what the needs of seat manufacturers and airlines were. The responses received included lower cost of ownership, low weight, high reliability, spares provisioning, more robustness, improved maintainability, good fleet compatibility, high upgradability and wider population fit. The industry advisors were also asked to rank the relative importance of these needs on a scale of one to ten, ten being the most important. The rankings for the customer needs were assigned based on the results of the survey detailed in Section 2.4.

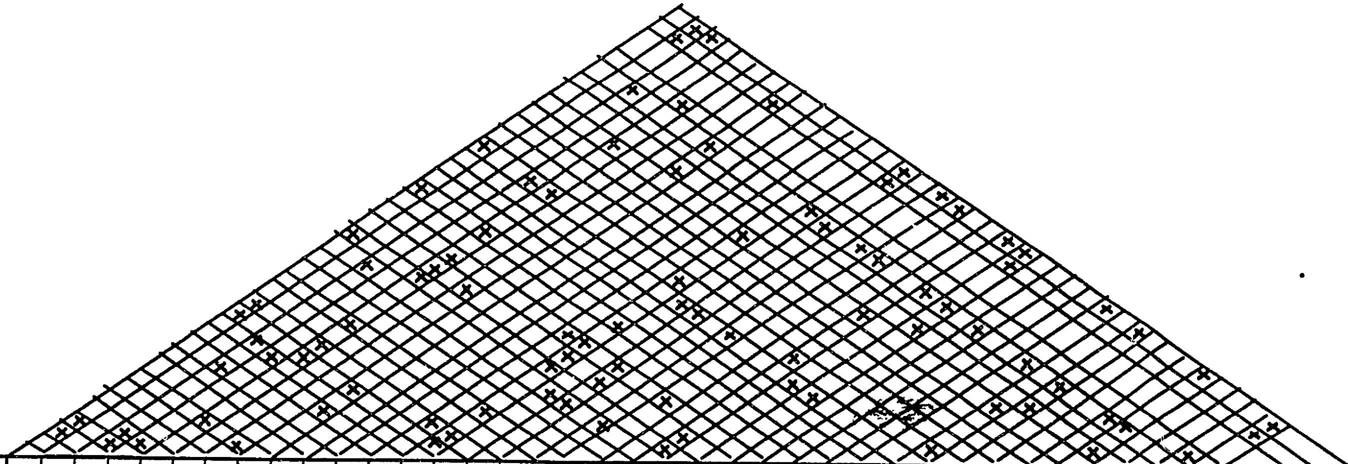
Next, the team went through each customer and industry need and brainstormed technical requirements that would fulfill these needs. The technical requirements were tabulated against the customer/industry needs in the form of a QFD Requirements Matrix (see Figure 2.5). Appendix II.B gives a more detailed description of the QFD.

The top ten technical requirements and their scores are summarized in Table 2.5. These results prove logical, for the top ten requirements address simultaneously both the airlines' need for low cost and low weight, and customers' need for more space, more comfort and higher adaptability.

**Table 2.5: Top Ten Technical Requirements**

| Rank | Technical Requirement | Score |
|---|---|---|
| 1 | Simplicity of Engineering | 381 |
| 2 | Accessory Arrangement/Minimization | 305 |
| 3 | Adjustable Mechanisms | 255 |
| 4 | Ergonomic/Anthropometric Design | 183 |
| 4 | Ease of Maintenance | 183 |
| 4 | Common Internal Parts | 183 |
| 4 | Continuous Adjustability | 183 |
| 8 | Reduced Seat Volume | 175 |
| 9 | Minimize Number of Parts | 174 |
| 10 | Mechanical Controls | 141 |

Figure 2.5: Quality Function Deployment Requirements Matrix



| | Weighting | Accessory arrangement/minimization | 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 | Varaible 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 | | 1 | | | 3 | | | | | 9 | | | | | | | | 3 | | | | | | | |
| User friendly / Easy of use | 1 | 3 | | 1 | | | | | | | | | | | | | | 1 | | | | | | | | | 9 | | 9 | 9 | | | | | | | | 3 | | | |
| **Customer/Industry needs** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Aesthetic appeal | 7 | 1 | 1 | | | | | | 3 | | | | | | | | 9 | | | 3 | | 1 | | | | | | | | | 3 | 9 | 3 | | | | | | | | |
| More personal space | 10 | 9 | 3 | | | | | 9 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 3 | | | |
| Improved physical comfort | 10 | 3 | 3 | | | | | 3 | 9 | | | | | | | 9 | | 1 | | 9 | | | 3 | 3 | 3 | | | | | | | | | 9 | | | | | | | |
| **Industry needs** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Lower cost of ownership | 10 | | | | 3 | 9 | 9 | 1 | | 3 | 3 | 3 | 3 | 3 | | | | | 1 | | 9 | | | | | | | | | | | | | | | | 9 | 3 | | | |
| Low weight | 6 | 9 | | 3 | | 3 | | 3 | | | | | | 1 | | | | | 9 | | | | | | | | | | | | | | | | 3 | | | 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 | | | 3 | 9 | | | | 3 | 9 | | 1 | 3 | | | | | | | 9 | | | | | | | | | | | | | | | 3 | | 1 | | | |
| Good fleet compatibility | 5 | | | | | 3 | | | | | 9 | | 9 | 3 | 3 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| High upgradability | 5 | | | | | 3 | | | | | | | | | 9 | | | | | | | | | | | | | | | | | | | | | 9 | | | | | |
| Anthropometric (wider population fit) | 8 | | 1 | | | | | | 9 | | | | | | | 9 | | | | | | | | | | | | | | | | | | | | | | | | | |
| **Total** | | 305 | 88 | 102 | 141 | 381 | 126 | 175 | 183 | 90 | 183 | 114 | 83 | 174 | 123 | 255 | 63 | 78 | 64 | 111 | 183 | 82 | 111 | 54 | 38 | 63 | 9 | 33 | 9 | 9 | 21 | 63 | 21 | 183 | 18 | 69 | 90 | 89 | | N/A | N/A |

## 2.6 RESEARCH AND DISCOVERY

The next phase of the project called for team members to research several key areas of seat design and identify any promising avenues that may have been overlooked by industry designers. These areas were:

1. Physiology
   - Involves the functional processes in the human body
   - Includes the study of posture, spinal alignment, pelvic rotation, and the mechanisms that cause pain, injury and fatigue.
2. Ergonomics
   - Defined as the science of designing for people
   - Includes the design of workplace equipment to
     (i) optimize productivity
     (ii) reduce the potential for physical illness or injury.
3. Anthropometry
   - Broadly defined as the measurement of human beings
   - In the context of seat design, each seat aspect would be sized to fit a predetermined population size .
4. Materials
   - Confor™ foam, a pressure and temperature sensitive conformal foam already being utilized for cushioning in forklifts, trucks, helicopters and military aircraft was identified as a promising material that could improve passenger comfort.
   - The team also identified elastomeric fibers as a potential replacement for seat cushions (to increase passenger space and reduce weight) .
5. Psychology
   - Relevant areas in this field include concepts of territoriality, crowding and personal space, and the use of visual illusions and color to improve the passenger's perception of comfort.

4) Physical Design Features
   - Improvement to current seat features, including better tray designs and seat arrangements, as well as features used in seats from other industries – automobile seats, office chairs and dentist chairs – fall under this category.

The key findings for the above areas of research are provided in Appendix IV.

## 2.7 THE SECOND CUSTOMER SURVEY

While the research phase was underway, the team sent out a second customer survey, this time to 700 faculty and staff from the various departments at MIT (see Appendix V). The purpose of this survey was to analyze how passenger comfort varies with different in-flight activities. There was a total of 135 respondents: 40 female and 95 male. Their attributes are summarized in Table 2.7.

**Table 2.7: Attributes of Respondents for Second Customer Survey**

| | Average | Median | Standard Deviation |
|---|---|---|---|
| **Age** | 47 years | 47 years | 13 years |
| **Weight** | 77 kg | 75 kg | 17.6 kg |
| **Height** | 176.7 cm | 177.7 cm | 35.7 cm |

As indicated in Figures 2.7.1 and 2.7.2, the majority of respondents travel more than ten times a year (46%) on flights between three to five hours long (66%). Also, ninety-four percent of respondents indicated that they usually travel in economy class (94%), while five and one percent travel in business and first class respectively.

**Figure 2.7.1: "How many times do you fly in a year?"**

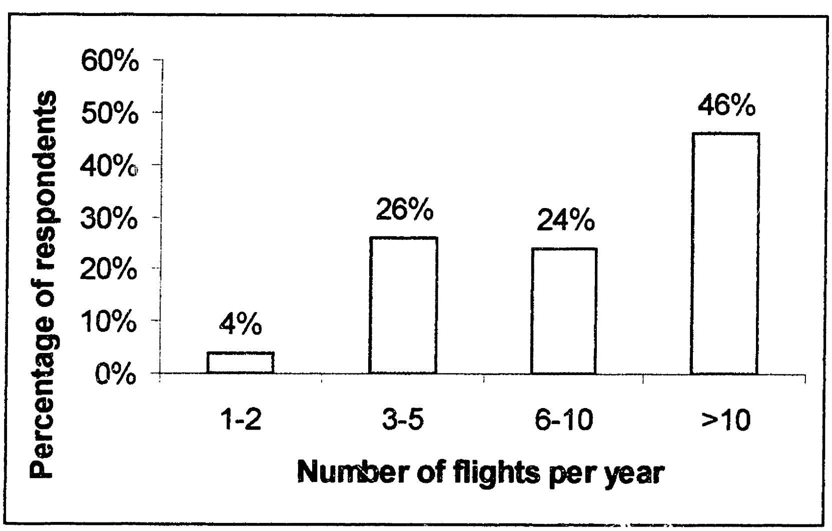
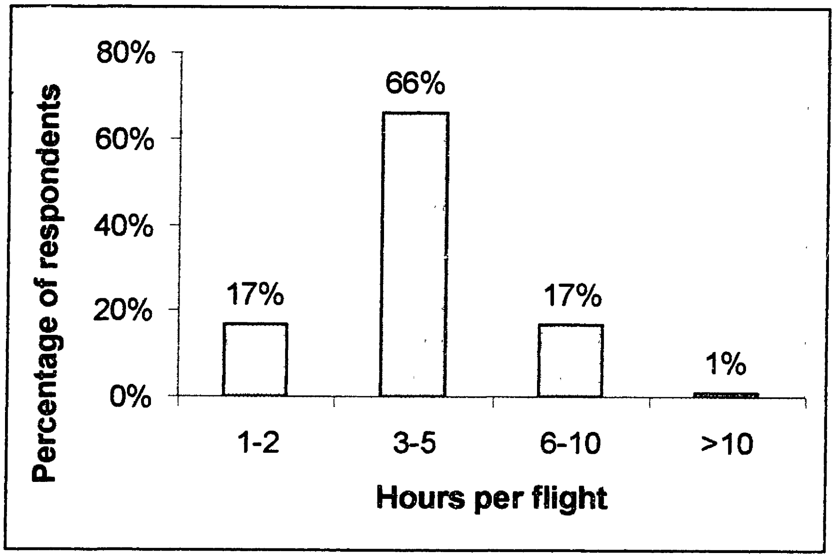


**Figure 2.7.2: "On Average, How Many Hours Does Each Flight Take?"**




Respondents were asked to rate the level of comfort experienced during the most common flight activities – reading, working, eating, sleeping and chatting, as detailed in the FFD (see Section 2.3) and also to indicate the percentage of time spent on each activity. As Figure 2.7.3 shows, respondents spent the most time reading, followed by working, sleeping, eating and chatting. With regard to the comfort felt while performing these activities (see Figures 2.7.4 – 2.7.7), sleeping received the worst ratings, with 54% of respondents rating sleeping "Very Poor." This could be the reason why respondents spent most of their time reading and working instead.

**Figure 2.7.3: Amount of Time Spent on Various In-Flight Activities**

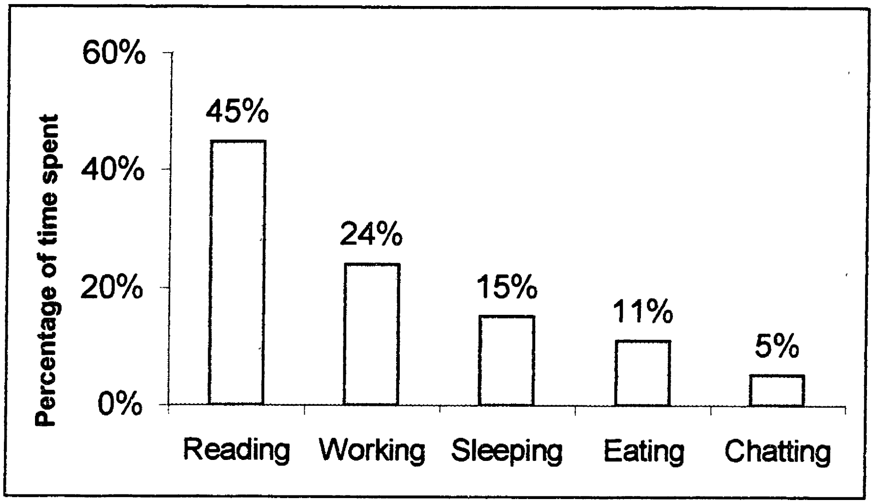



**Figure 2.7.4: Comfort Ratings for Reading**

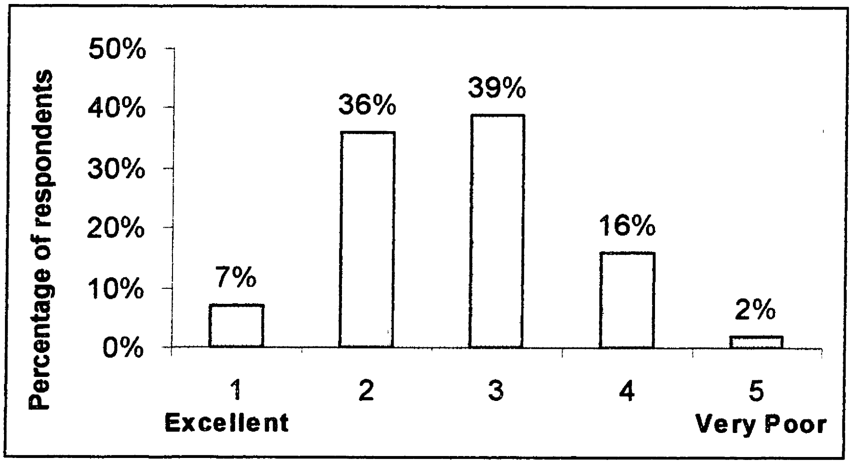



**Figure 2.7.5: Comfort Ratings for Working**

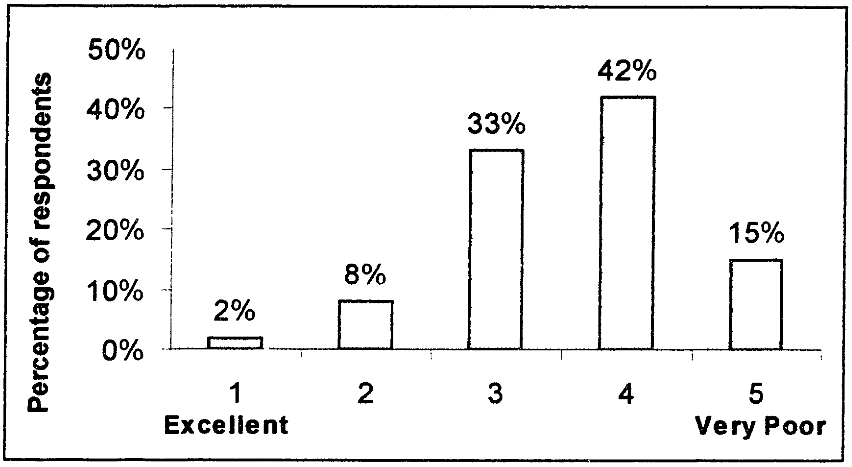


**Figure 2.7.6: Comfort Ratings for Sleeping**

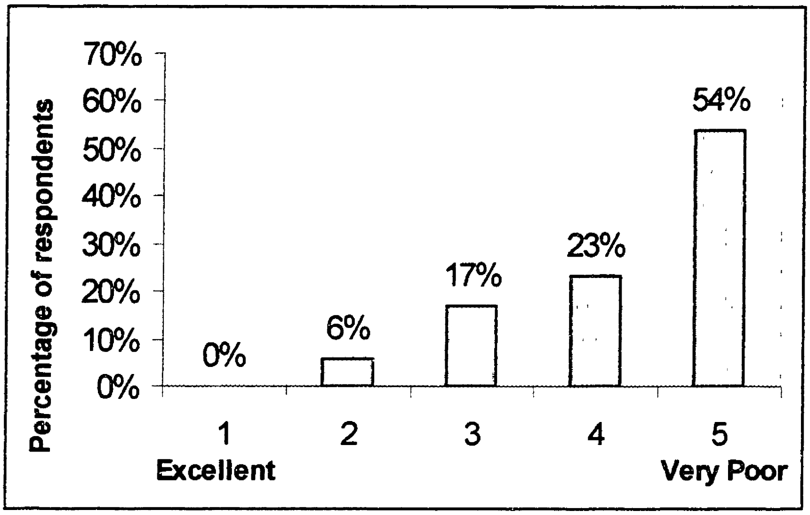
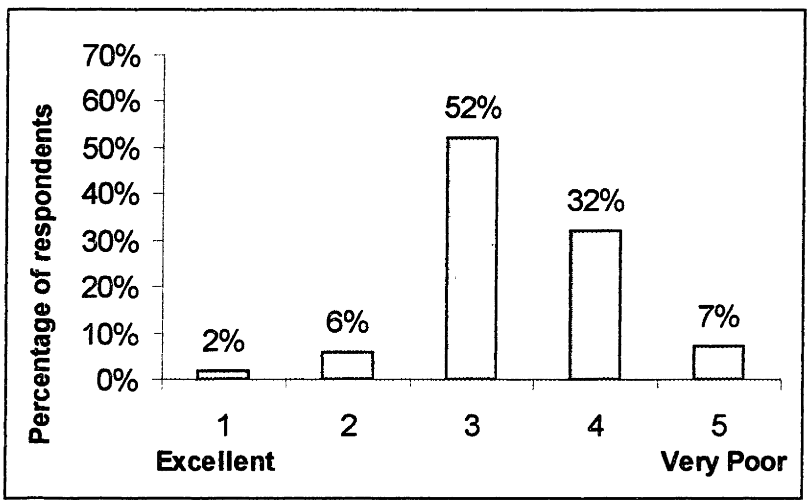



**Figure 2.7.7: Comfort Ratings for Eating**




The team found, through its research, that three different tray features could be implemented – depth adjustability (sliding in/out), slope adjustability (tiltable) and height adjustability (see Appendix IV, Section A.6). When asked to rate how much they would desire each feature (see Figures 2.7.8-2.7.10), respondents indicated that they favored height adjustability and depth adjustability over slope adjustability.

Figure 2.7.8: "How much would you desire a height-adjustable tray?"

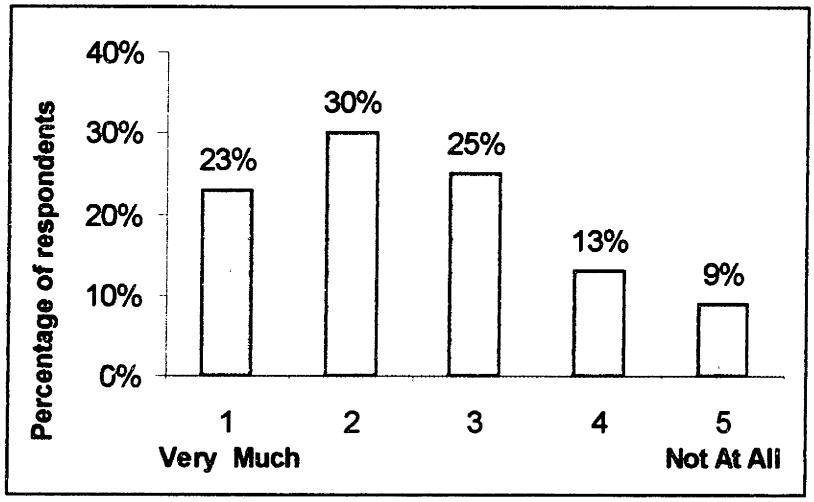



Figure 2.7.9: "How much would you desire a sliding in/out tray?"

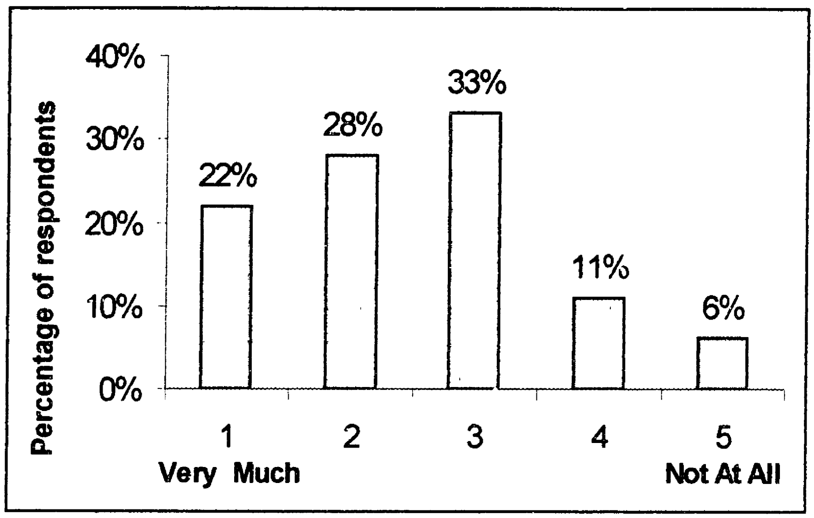
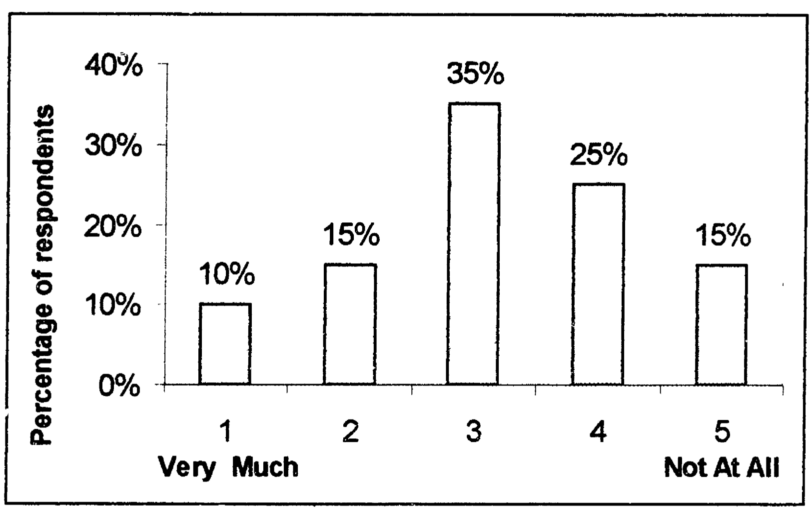



Figure 2.7.10: "How much would you desire a tiltable tray?"



It was mentioned earlier on in Section 2.2 that the team was looking to improve not only the comfort of the seat per se, but also the interfaces between the seat and the cabin environment. Through the FFD (see Section 2.3), customer feedback and much discussion, the team felt that the recline of seats could be a significant source of discomfort, at least in the psychological sense. Therefore, a series of questions that focused on the recline of seats was included in the survey.

The first question asked was whether or not respondents usually reclined their seats during flights. 65% of respondents gave a positive response (that they reclined their seats) while 35% answered negatively.

Next, respondents were asked to rate the level of comfort experienced while getting in or out of an aisle seat in two situations: 1) with the seat in front upright, and 2) with the seat in front reclined. Respondents were also asked to do the same for getting in or out of a window seat. The results are shown in Figures 2.7.11-2.7.14. A significant deterioration in comfort is seen going from the aisle seat with the front seat upright to the aisle seat with the front seat reclined. The deterioration is even more noticable for the window seat, with 65% of respondents rating the level of comfort "Very Poor" when the front seat is reclined.

**Figure 2.7.11: Comfort rating for getting in/out of aisle seat with front seat upright**

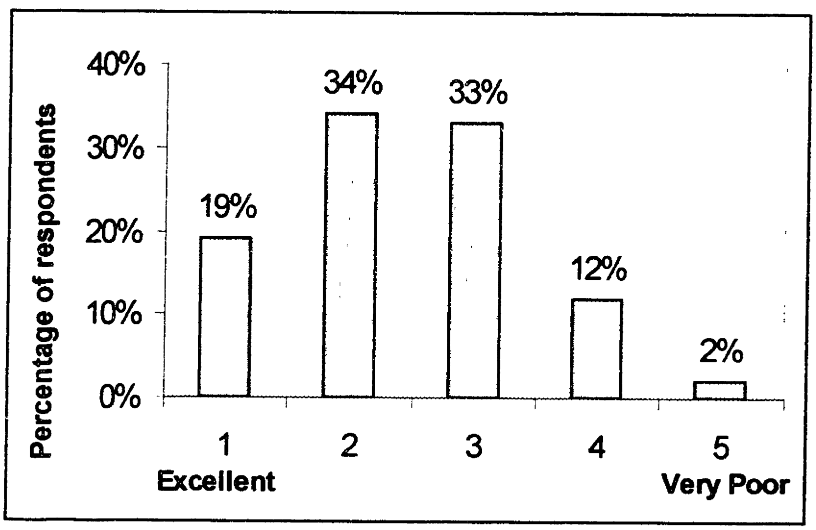


**Figure 2.7.12: Comfort rating for getting in/out of aisle seat with front seat reclined**

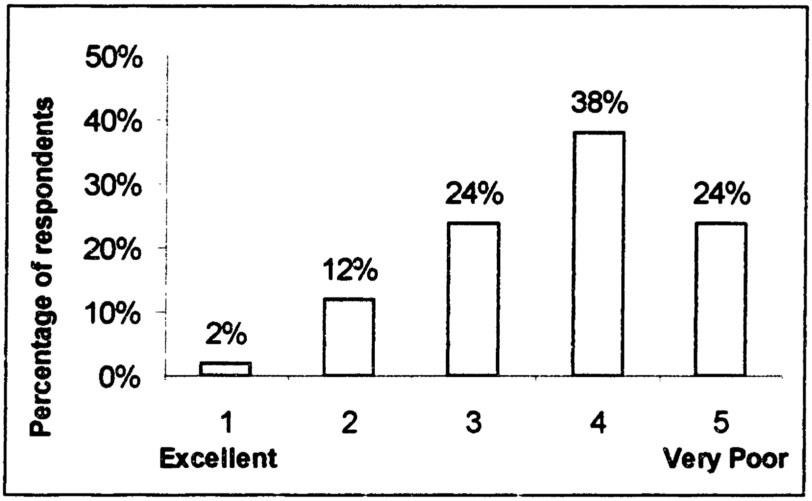



**Figure 2.7.13: Comfort rating for getting in/out of window seat with front seat upright**

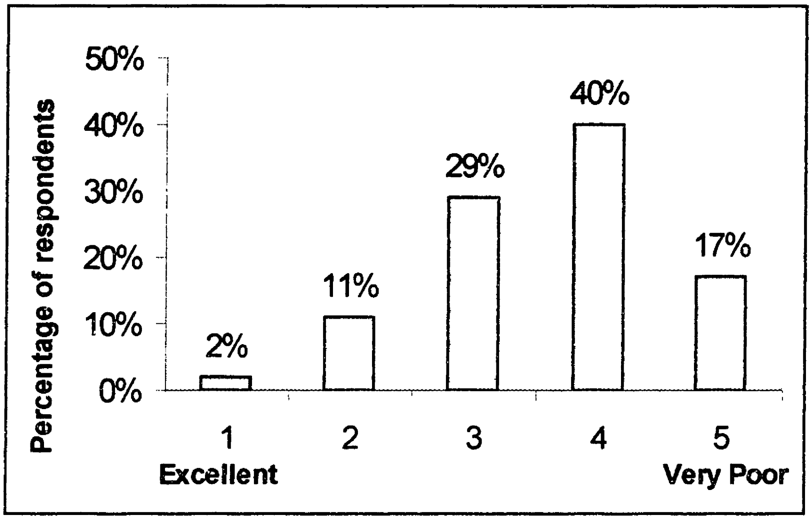
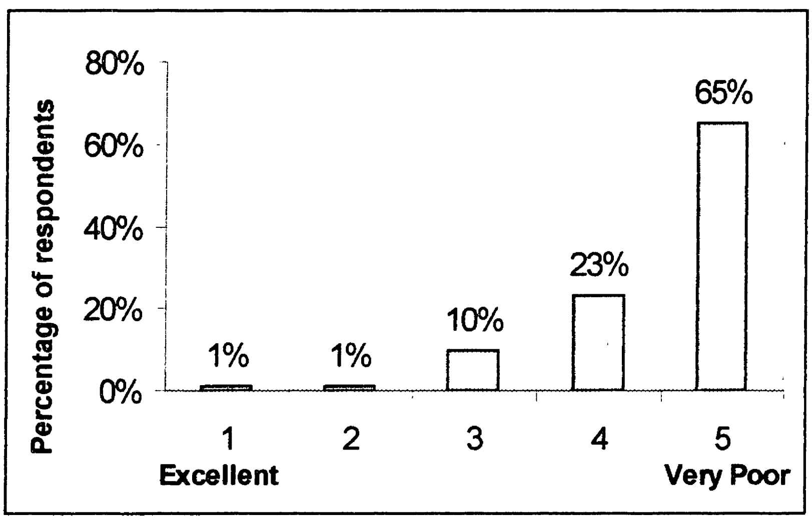


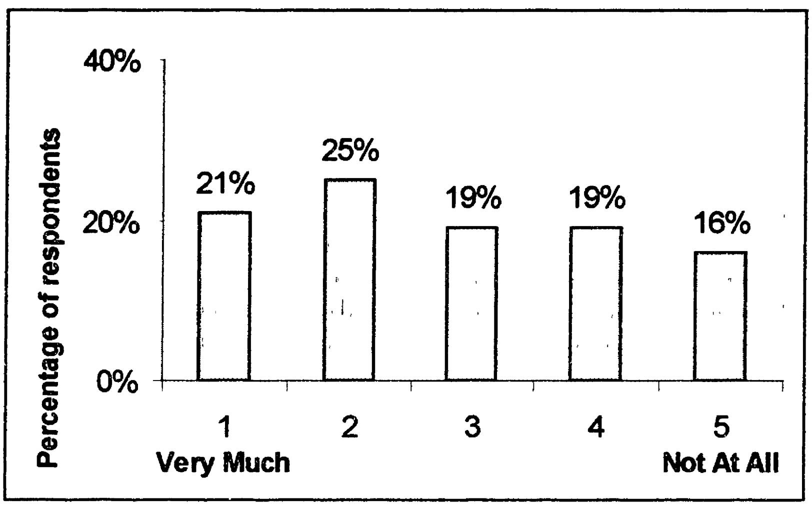

**Figure 2.7.14: Comfort rating for getting in/out of window seat with front seat reclined**



When asked how disturbed they felt when the person in front reclines his/her seat, 68% of respondents indicated that they felt disturbed, with 31% indicating that they were "Very Much" disturbed.

Lastly, to the question "How much would you be willing to trade off the recline feature of the seat for an adjustable back support?", responses received were quite evenly spread out, with a slight trend indicating that more people were willing to trade off the recline feature (see Figure 2.7.15).

**Figure 2.7.15: Willingness to trade off recline feature of seat for an adjustable back support**



## 2.8 THE QUALITY FUNCTION DEPLOYMENT (QFD) PRODUCT DESIGN MATRIX

Having identified the technical requirements via the QFD Requirements Matrix (Section 2.5) and the customer needs via the two surveys (Sections 2.4 and 2.7), and researching the relevant areas of seat design, the team was ready to focus its efforts on identifying key design specifications. The team went through the technical requirements listed in the QFD Requirements Matrix and brainstormed design specifications or features that would meet each requirement. A QFD Product Design Matrix was then generated (see Figure 2.8) and the team went through the same scoring process that was done with the Requirements Matrix (see Appendix II.B).

The scores from the QFD allowed the team to draw up a list of prioritized design specifications. This list however, primarily reflected the degree to which each design specification met the various technical requirements, that could be dominated by industry needs such as simplicity of engineering and minimization of parts; it did not adequately take into account any physiological or psychological considerations. The team felt it necessary to incorporate its research findings into the results. Table 2.8 shows the final design specification rankings while Appendix VI details the revisions made to the scores.

**Table 2.8: Design Specification Rankings**

| Rank | Feature | Average Score |
|---|---|---|
| 1 | Non-reclinable seats | 757 |
| 2 | Webbing as cushioning substitute | 656 |
| 3 | Sliding trays | 557 |
| 4 | Height-adjustable trays | 547 |
| 5 | Adjustable foot rest | 531 |
| 6 | Thin diaphragm seats without cushions | 529 |
| 7 | Vertically adjustable seat back | 529 |
| 8 | Adjustable lumbar support (electrical) | 513 |
| 9 | Tiltable seat bottom (entire) | 508 |
| 10 | Tiltable trays | 503 |

**Figure 2.8: Quality Function De**

| | 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. (selecta | 8. Logo/symbol on seat back to draw attention away from peripheral vis | 9. [illegible] 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) | 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Simplicity of engineering | 20 | 9 | 9 | 9 | 9 | 9 | 9 | 3 | 9 | 3 | 9 | 9 | 3 | 9 | 3 | 3 | 3 | |
| 2 | Accessory arrangement/minimization | 16 | | | | | | | | | | | | | | | | | |
| 3 | Adjustable mechanisms | 13 | | | | | | | 3 | | | | | | | | | 9 | |
| 4 | Ergonomic/anthropometric design | 10 | | | | | | | | | | | | | | | | | |
| 5 | Ease of maintainance | 10 | 3 | 3 | 3 | 3 | 9 | 3 | 1 | 3 | | 3 | | 9 | 9 | 3 | 3 | | |
| 6 | Continuous adjustability | 10 | | | | | | | | | | | | | | | | 9 | |
| 7 | Common internal parts | 10 | | | | | | | | | | | | | | | | | |
| 8 | Reduced seat volume | 9 | | | | | | | | | | | | | | | | | |
| 9 | Minimize number of parts | 9 | | | | | | | | | | | | | | | | | |
| 10 | Mechanical controls | 7 | | | | | | | 1 | | | | | | | | | 9 | |
| 11 | Durable materials | 7 | | | | | | | | | | | 1 | 9 | | | | | |
| 12 | Versatile design | 6 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | | | | | | 3 | 3 | | 3 |
| 13 | Low MTBF | 6 | | | | | 1 | | | | | | | 9 | | | | | |
| 14 | Comfortable materials | 6 | 3 | 3 | 3 | 3 | | | | 3 | 9 | | | | | | | | |
| 15 | Adjustable geometry | 6 | | | | | | | | | | | | | | | | | |
| 16 | Electrical controls | 5 | | | | | | | | | | | | | | | | | |
| 17 | Easily obtainable parts | 5 | 3 | 3 | 3 | 3 | | | | 3 | 1 | 1 | 1 | | | | | | 1 |
| 18 | Cost-effective design | 5 | 3 | 3 | 3 | 3 | 3 | 1 | | 3 | 1 | 3 | 3 | 1 | | | | | |
| 19 | Integrated functionality | 5 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | 1 | | 1 | 1 | | |
| 20 | Improved seat arrangement | 5 | | | | | | | | | | | | | | | | | 9 |
| 21 | Commonality of design | 4 | | | | | | | | | | | | | | | | | |
| 22 | Personal avionics | 4 | | | | | | | | | | | | | | | | | |
| 23 | Environmental controls | 4 | | | | | | | | | | | | | | | | | |
| 24 | Modularity of design | 4 | 1 | 1 | 1 | 1 | 1 | 1 | | 1 | 1 | | | 1 | | | | | |
| 25 | Light structural materials | 3 | | | | | | | | | | | | | | | | | |
| 26 | Visual patterns | 3 | 9 | 9 | | | | | | 3 | | | 3 | | | | | | |
| 27 | Aesthetic design | 3 | 3 | 9 | 9 | 3 | 3 | 3 | 9 | 3 | | | | | | | | | |
| 28 | Facilitate work (laptops included) | 3 | | | | | | | | | | | | | | 1 | 3 | | |
| 29 | Variable loads absorption | 3 | | | | | | | | | | | | | | | | | |
| 30 | Variable degree of firmness | 2 | | | | | | | | | | | | | | | | | |
| 31 | Isolation | 2 | | | | | | | 1 | 3 | | | | | | 3 | 3 | 9 | 3 |
| 32 | Modern appearance | 1 | | 3 | 1 | | | 9 | 3 | 1 | 1 | | | | | | | 3 | 1 |
| 33 | Material texture | 1 | | | | | | | | | 9 | 3 | 9 | | | | | | |
| 34 | Fixed geometry | 1 | | | | | | | | | | | | | | 1 | 3 | | |
| | TOTAL: | | 331 | 352 | 323 | 304 | 337 | 270 | 181 | 320 | 153 | 243 | 235 | 291 | 280 | 133 | 141 | 361 | 85 |

| | Technical Requirements | Weighting | 18. Middle seats offset backwards to facilitate 3-way/4-way conversation | 19. Theatre-style seatin | 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 o | 26. Width adjustable arm rest | 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 headneck rest (mechanical) | 32. Inflatable head rests | 33. "Wings" to rest head on |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Simplicity of engineering | 20 | | | 3 | 1 | 1 | 1 | 3 | 3 | 3 | 9 | 9 | | 3 | 1 | 1 | 3 |
| 2 | Accessory arrangement/minimization | 16 | | | | | | | | | | | | 3 | | | | |
| 3 | Adjustable mechanisms | 13 | | | 9 | 9 | 9 | 9 | 9 | 9 | 9 | | | 3 | | 9 | 9 | 9 |
| 4 | Ergonomic/anthropometric design | 10 | | | 9 | 9 | 9 | 9 | 3 | | 3 | | 3 | | 9 | 9 | 3 | 1 |
| 5 | Ease of maintainance | 10 | | | | | | | | | | 9 | 1 | | 9 | | | |
| 6 | Continuous adjustability | 10 | | | 9 | 9 | 9 | 3 | 3 | 9 | 3 | | | 3 | | 3 | 3 | 9 |
| 7 | Common internal parts | 10 | | | | | | | | | | | | | | | | |
| 8 | Reduced seat volume | 9 | | | | | | | | | | | | | | | | |
| 9 | Minimize number of parts | 9 | | | | | | | | | | | | | 1 | | | |
| 10 | Mechanical controls | 7 | | | 9 | 9 | 9 | 9 | 1 | 9 | 3 | | | 3 | | 9 | 1 | 3 |
| 11 | Durable materials | 7 | | | | | | | | | | | | | | | | |
| 12 | Versatile design | 6 | 9 | | | | | | | 9 | | 9 | | 9 | | | | 9 |
| 13 | Low MTBF | 6 | | | | | | | | | | | | | 3 | | | |
| 14 | Comfortable materials | 6 | | | | | | | | | | | 1 | | | | | |
| 15 | Adjustable geometry | 6 | | | | | | 1 | 3 | 1 | 9 | | | 9 | | 1 | 3 | |
| 16 | Electrical controls | 5 | | | | | | | | | | | | | | | | |
| 17 | Easily obtainable parts | 5 | 1 | | 1 | 1 | 1 | 1 | | 1 | | 1 | 1 | | | 1 | | 1 |
| 18 | Cost-effective design | 5 | | | | | | | | | | | | | | | | 1 |
| 19 | Integrated functionality | 5 | | | 3 | 3 | 9 | 3 | 1 | 1 | 3 | 9 | 1 | 1 | | 3 | 3 | |
| 20 | Improved seat arrangement | 5 | 9 | 3 | | | | | | | | | | | | | | |
| 21 | Commonality of design | 4 | | | | | | | | | | | | | | | | |
| 22 | Personal avionics | 4 | | | | | | | | | | | | | | | | |
| 23 | Environmental controls | 4 | | | | | | | | | | | | | | | | |
| 24 | Modularity of design | 4 | | | | | | | | | | | | | | | | |
| 25 | Light structural materials | 3 | | | | | | | | | | | | | | | | |
| 26 | Visual patterns | 3 | | | | | | | | | | | | | | | | |
| 27 | Aesthetic design | 3 | | 3 | | 1 | | | | | | | 3 | | 3 | | | 3 |
| 28 | Facilitate work (laptops included) | 3 | 1 | | 9 | 9 | 9 | 3 | 3 | 1 | | 3 | 1 | | | | | |
| 29 | Variable loads absorption | 3 | | | | | | | 3 | | | | 3 | | | | 3 | |
| 30 | Variable degree of firmness | 2 | | | | | | | 3 | | | | | | | | 3 | |
| 31 | Isolation | 2 | | | | | | | | | | | | | 1 | | | 3 |
| 32 | Modern appearance | 1 | 3 | 3 | | 3 | | | 3 | 1 | | | 1 | 1 | 1 | 1 | 3 | 9 |
| 33 | Material texture | 1 | | | | | | | | | | | 3 | | | | | |
| 34 | Fixed geometry | 1 | | | | | | | | | | | | | 9 | | | |
| | TOTAL: | | 120 | 37 | 477 | 443 | 467 | 365 | 304 | 414 | 337 | 393 | 271 | 262 | 298 | 357 | 265 | 396 |

## eployment Product Design Matrix

| 34 | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 | 48 | 49 | 50 | 51 | 52 | 53 | 54 | 55 | 56 | 57 | 58 | 59 | 60 | 61 | 62 | 63 | 64 | 65 | 66 | 67 | 68 | 69 | 70 | 71 | 72 | 73 | 74 | 75 | 76 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Foldable head rest to facilitate front-back conversation | Adjustable foot rest | Adjustable leg rest | Vertically adjustable seat back | Horizontally adjustable backrest | Flat seat back | Contoured seat back | Concave contouring | Edge contouring | Pillow secured to the seat with velcro (position adjustable) | Electronic massage pillows | Adjustable lumbar support (mechanical) | Adjustable lumbar support (electrical) | Inflatable lumbar support | Pelvic support | Adjustable seat height (mechanical) | Inflatable seat bottom | Tiltable seat bottom (entire) | Downward foldable seat bottom (front edge) to facilitate ingress/egress | Tiltable seat bottom (front edge) | Sliding-out seats | Foldable seat bottom | Flip-over seat bottom | Lower seat bottoms (no [illegible]) | Sideways erecting seat bottom | Non-reclinable seats | Thin diaphragm seats without cushions | Webbing as cushioning substitute | Sandwich structure in the cushion | Store hand items below seat (remove front pocket) | Bag/pocket hanging from seat bottom edge (remove front pocket) | Knee cushions | Seat to diagonal bed transformation | Personal entertainment system | Variable light intensity | Comfor foam | Conventional foams | One type of foam | One type of structural material | One-type adjustment mechanisms (inflatable) | One-type adjustment mechanisms (mechanical) | One-type adjustment mechanisms (pneumatic/hydraulic) | One-type adjustment mechanisms (electrical) |
|  | 3 |  |  |  | 9 | 3 | 3 | 1 | 9 |  |  |  |  | 3 |  |  |  |  |  |  |  | 3 | 9 |  | 9 | 3 | 9 |  | 9 | 9 | 9 |  |  |  |  | 9 | 9 | 9 |  |  |  |  |
|  |  |  |  |  |  |  |  |  | 1 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 9 | 9 | 9 |  | 9 | 9 |  |  |  |  |  |  |  |  | 1 |  |  | 3 |
| 9 | 9 | 9 | 9 | 9 |  |  |  |  | 3 | 3 | 9 | 9 | 9 |  | 9 | 9 | 9 | 3 | 9 | 9 | 3 | 3 |  | 1 |  |  |  |  |  |  |  | 9 | 3 | 9 |  |  |  |  | 9 | 9 | 9 | 9 |
|  | 9 | 9 | 9 | 3 |  | 9 | 9 | 9 | 3 | 3 | 9 | 9 | 9 | 9 | 9 | 3 | 3 | 1 | 3 | 1 | 1 |  | 1 | 1 |  |  |  |  |  |  | 1 | 1 |  |  |  |  |  |  | 9 | 9 | 9 | 9 |
|  |  |  |  |  | 9 | 9 | 9 | 9 | 3 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 9 | 9 | 9 |  |  |  | 1 |  |  |  |  | 3 | 3 | 3 | 1 | 1 | 1 | 1 |
| 9 | 9 | 9 | 3 | 3 |  |  |  |  |  |  | 3 | 9 | 3 |  | 3 | 3 | 9 | 3 | 9 | 9 | 3 |  |  | 9 |  |  |  |  |  |  |  | 3 |  | 9 |  |  |  |  | 3 | 3 | 9 | 9 |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 1 |  |  |  |  |  |  |  |  |  |  | 9 | 9 | 9 | 9 | 9 | 9 |
|  |  |  |  |  | 3 |  |  | 3 |  |  |  |  |  |  |  |  |  | 1 |  |  | 1 |  |  |  |  | 9 | 9 |  | 3 | 3 |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  | 1 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 9 | 3 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 3 | 9 | 9 | 9 | 9 |  |  |  |  |  |  | 9 |  | 1 |  | 9 | 1 | 9 | 3 | 9 | 9 | 3 |  |  |  |  |  |  |  |  |  |  | 9 |  |  |  |  |  |  | 1 | 9 | 3 |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 9 | 9 |  |  |  |  |  |  |  |  | 3 |  |  |  |  |  |  |
| 9 |  |  |  |  |  |  |  |  | 1 |  |  |  |  |  |  |  |  | 9 |  |  | 9 | 3 |  | 3 |  |  |  |  |  |  |  | 9 | 9 |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  | 3 | 3 |  |  | 3 |  |  |  |  | 3 |  |  |  |  |  |  |  |  |  |  | 9 | 3 | 3 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 1 |  |  |  | 3 |  |  |  |  |  |  |  |
| 9 | 1 | 1 | 9 | 1 |  |  |  |  |  |  | 1 | 1 | 1 |  | 1 | 3 | 3 | 9 | 3 | 3 | 9 |  |  |  |  |  |  |  |  |  |  | 9 |  |  |  |  |  |  | 3 | 1 | 1 | 1 |
|  |  |  |  |  |  |  |  |  |  | 9 |  | 9 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 9 |  |  |  |  |  |  |  |  | 9 |
|  | 1 |  |  |  | 3 |  |  |  | 9 |  | 1 |  |  |  |  |  |  |  |  |  |  |  |  |  | 9 |  |  |  |  |  | 1 |  |  |  |  | 9 | 1 | 1 |  | 1 | 1 |  |
|  |  |  |  |  | 9 |  |  |  | 1 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 9 | 1 | 1 |  |  |  |  |  |  |  |  | 9 | 9 | 9 | 1 | 1 | 1 |  |
|  |  |  | 9 | 3 |  | 3 |  |  |  |  | 1 | 1 | 1 | 9 | 3 | 1 | 1 |  | 3 |  | 1 | 1 | 1 |  |  |  | 1 |  |  |  |  | 1 | 9 |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 9 |  |  |  |  |  |  |  |  |  |  | 9 | 9 | 9 | 3 | 3 | 3 | 3 |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 9 |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 9 |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  | 1 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 9 |  |  |  |  |  |  |  |  |  |  | 1 | 3 | 3 |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 9 | 9 | 3 |  |  |  |  |  |  |  | 1 |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  | 3 | 1 | 1 |  | 1 |  |  |  |  |  |  | 9 |  |  | 9 |  |  |  |  |  |  |  |  |  |  |  |  | 9 |  |  |  |  |  |  |  |  |  |
| 1 |  |  |  | 9 |  |  |  |  |  |  |  |  |  |  | 3 |  | 9 |  | 3 | 9 |  |  |  |  | 9 |  |  |  |  |  |  |  |  | 9 |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  | 3 |  |  |  | 3 |  |  | 3 |  |  |  |  |  |  |  |  |  |  |  | 9 |  |  | 3 | 1 |  |  | 9 |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  | 3 |  |  | 3 |  |  |  |  |  | 1 |  |  |  |  |  | 3 |  |  |  |  |  |  | 9 |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 9 |  |  |  |  |  |  |  |  |  |
|  |  | 3 |  |  |  | 9 | 3 | 9 |  | 3 |  |  | 3 | 3 |  | 3 | 1 |  |  |  |  |  |  | 3 |  |  |  |  |  |  |  | 3 | 9 |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  | 1 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 3 |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  | 9 | 9 | 3 | 3 |  |  |  |  |  | 9 |  |  |  |  |  |  |  |  | 9 |  | 9 | 3 | 3 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 349 | 441 | 379 | 409 | 298 | 394 | 319 | 259 | 252 | 393 | 130 | 326 | 363 | 283 | 235 | 340 | 235 | 388 | 227 | 352 | 362 | 232 | 134 | 214 | 144 | 757 | 529 | 626 | 52 | 361 | 361 | 233 | 349 | 283 | 280 | 73 | 374 | 327 | 327 | 324 | 357 | 375 | 437 |

## 2.9 CONCEPT GENERATION AND SELECTION

The top two seat specifications generated by the QFD in the above section ranked significantly higher than the other specifications in the matrix. Both addressed the most important customer need identified in the first customer survey: more passenger space (see Section 2.4). The non-reclinable seat serves to protect passengers' space from intrusion by the recline of the seat in front. The webbing seat on the other hand, provides more space by replacing the seat cushion with a thin textile material (also known as elastomeric fibers) such as the *M-Flex* produced by Milliken & Company (see Appendix XI, Section XI.III). The team decided to explore two concepts based on these features.

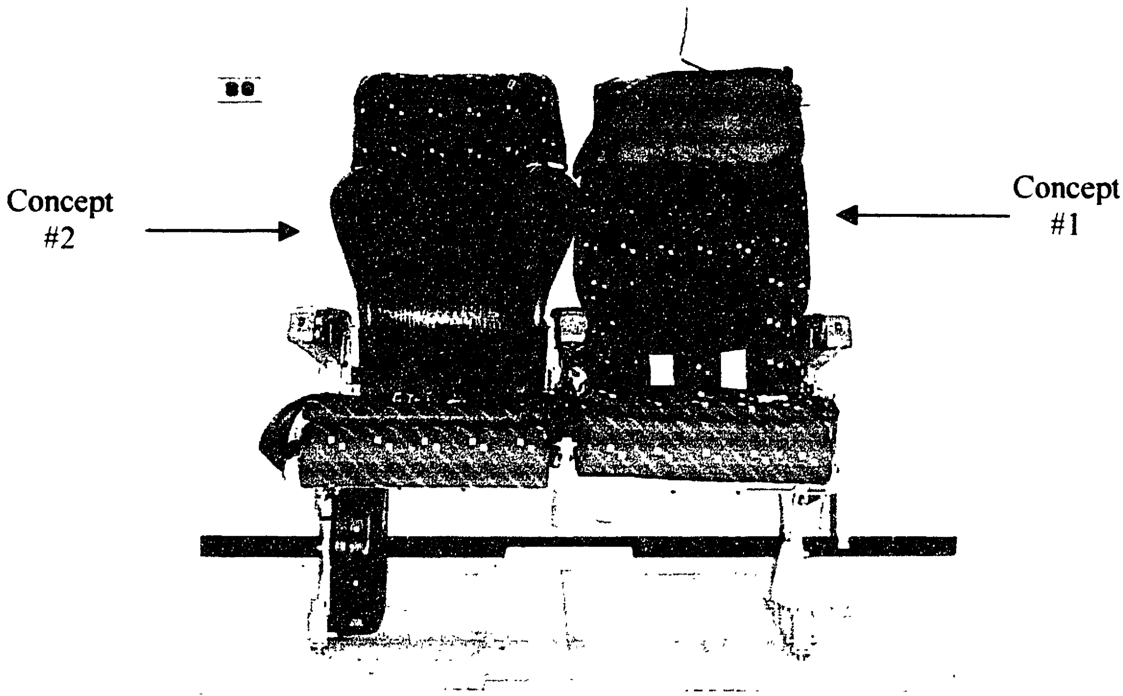
In generating its two concepts, the team split the design specifications into three categories: "provide more space," "facilitate in-flight activities," and "provide better support." The team experimented with different combinations of features that complemented each other, keeping manufacturing complexity and cost in mind. Appendix VII shows the concepts that the team generated. The final two selected concepts are presented in Table 2.9 below.

**Table 2.9: Final Selected Concepts**

| Concept # | Provide more space | Facilitate in-flight activities | Provide better support | Score |
|---|---|---|---|---|
| I | - Non-reclinable seat | - Height-adjustable tray | - Inflatable lumbar support<br>- Height-adjustable headrest<br>- Winged headrest | 2670 |
| II | - Webbing | - Height-adjustable tray | - Height-adjustable headrest<br>- Winged headrest | 2146 |

Concept I was subsequently modified to include a sliding-out backrest. (This makes the "non-reclinable" terminology a misnomer and the concept will be referred to as the "forward-sliding" concept from this point onwards.) The details of this concept will be presented in the next chapter. For detailed analysis and test results of Concept II, the reader is referred to the thesis by Teo (June 1999). Figure 2.9 gives a preview of the construction of the two concepts.

**Figure 2.9: The Two Prototypes**



# 3. THE SLIDING-OUT BACKREST CONCEPT

## 3.1 JUSTIFICATION

### 3.1.1 THE BENEFITS OF RECLINE

Studies have shown that if a person on a seat reclines by as little as twenty degrees, the backrest can support up to 47 percent of the upper body weight (Corlett, 1984). The backrest in the reclined position also helps hold up the torso, reducing forces in the lower back by as much as 20 percent (Anderson, 1991).

In addition to the above, reclining the back induces lordosis, which partially explains why many people like to sit with the buttocks well forward in the seat. It opens up the angle between the trunk and the thigh, thus creating a more natural curve in the lower back. Recline also permits changes in posture, the benefits of which are detailed in Appendix IV: A.4.

### 3.1.2 THE PROBLEMS WITH RECLINE

Although not a problem in first class or business class cabins, the recline of the seat in economy class can be a source of discomfort, due to the small amount of space provided to the passenger. As evidenced by the results of the second customer survey (Section 2.7), getting in and out of the seat becomes significantly more uncomfortable when the front seat is reclined. Psychologically, passengers feel "crowded-in" because of their inability to control or manage their own spaces (see Appendix IV:D1).

Large persons who have their knees up against the front backrest will feel pressure in their knees once the backrest is reclined. Besides limiting the passenger's ability to change postures, this condition restricts blood circulation to the knees and can cause pain over time.

The recline of the seat can also affect passengers' ability to work, and this may prevent them from making productive use of their time in the aircraft. There is a growing trend among business travellers to work on laptop computers during flights. When the front seat is reclined, the reduced angle between the backrest and the tray makes it impossible for passengers to flip open their laptop screens.

### 3.1.3 THE SLIDING-OUT BACKREST

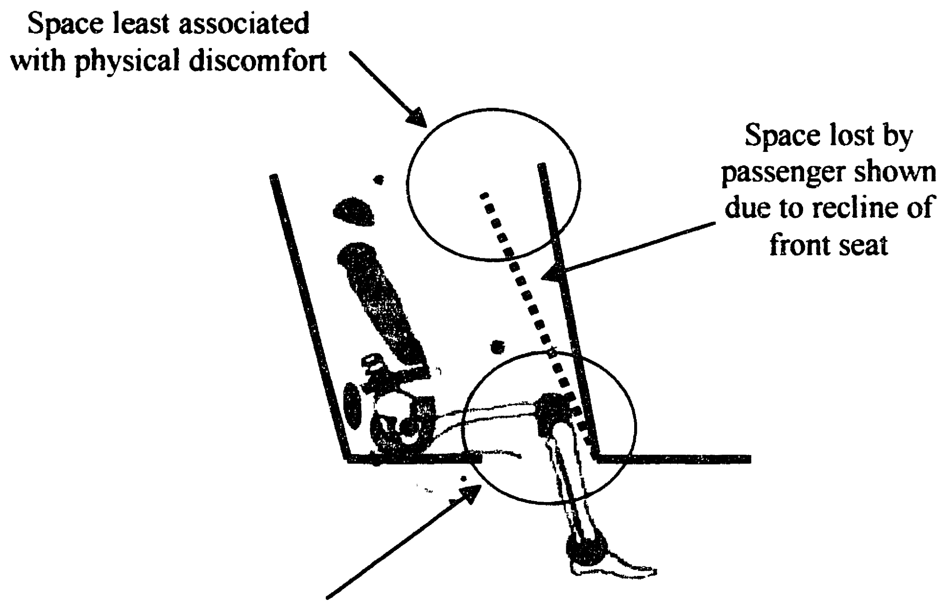
In view of the problems and benefits associated with having the seat reclined, the team believes that the recline feature may not be providing any overall benefit to the passenger; it provides comfort in one area only by creating discomfort in another. An increase in a passenger's space via recline is achieved at the expense of the space of the passenger behind. In this zero-sum situation, all passengers (assuming everyone reclines) end up losing space at the regions that matter the most: at the knees and the legs (see Figure 3.1.1).

The forward-sliding concept can be thought of as a means of "space management." Each passenger has a fixed amount of space that cannot be intruded upon by the passenger in front. This restores a sense of control to the passenger and alleviates the "crowded-in" effect mentioned in the previous subsection. Moreover, the passenger is able to specify the balance between degree of recline, knee space and thigh support according to his or her preferences, keeping in mind that having more recline means less knee space and thigh support, and vice-versa.

The sliding-out backrest is better suited for small people than for large people. This is because smaller people sometimes feel pressure on the thighs and the backs of the knees due to the seats being too high or the backrests being too far back. Such a condition will eventually lead to discomfort and numbness in the legs and feet. In order to ease the excessive pressure on their thighs and to let their feet comfortably reach the floor, they often move forward on the seat, away from the backrest that provides much needed support. This slumped posture, that flattens the lumbar area of the spine, leads to back pain and over time, an increased potential for muscular, ligament or disc injury (Dagostino, 1994). A sliding-out backrest prevents this problem by keeping the occupant's back supported and maintaining lumbar lordosis.

Given the current implementation, larger people may not be able to use this feature to its best advantage, for if they slide the backrest out too far, they may have to perch on the shortened seat bottom, losing support underneath the thighs. They might also have to work their leg muscles harder to prevent themselves from sliding off the seat. However, these people stand to gain the most from the non-recline of the seat in front of them. Between sitting with the backrest upright and having the front seat pressed against the knees all the time, the former is most likely to be prefered.

**Figure 3.1.1: Space lost due to recline**




Adapted from Stumpf et al., "The Kinematics of Sitting," Figure 4.

### 3.1.4 CONCEPT GOALS

The team decided that as a success criteria for the forward-sliding concept, the seat had to be at least as comfortable as a baseline aircraft seat. This would then allow the team to conclude that an improvement over current aircraft seats had been accomplished due to the non-apparent benefits of better ingress/egress, better psychological comfort, protected space and the guaranteed ability to work on laptops. In order to meet its success criteria, the team would provide three other features in addition to the sliding-out backrest: a height-adjustable headrest, an inflatable lumbar support and a height-adjustable tray, to compensate for the loss of backwards recline. The benefits of each of these additional features are documented in Appendix IV.

Formidable as the task may seem, the team felt encouraged by the fact that as much as thirty five percent of respondents for the second customer survey (see Section 2.7) had indicated that they did not usually recline their seats during flights, so it would be left only to convince the remaining sixty five percent that the forward-sliding concept was at least comparable to the baseline.

## 3.2 THE DESIGN PROCESS

Several changes were made throughout the design process. The team had originally hoped to design an inflatable lumbar support that would provide the necessary amount of back support while the buttocks are shifted forward. A 115 degree trunk-to-thigh angle was set as the design goal (equal to the maximum angle permitted during the recline of a baseline seat). Unfortunately, the considerable amount of effort required to inflate the lumbar support to the necessary dimensions and the sheer bulk of such a device made it an infeasible option. A sliding-out backrest was incorporated instead.

The team also made another change to the initial concept generated in Section 2.9, though this change was subsequently reversed. This change came about because the height-adjustable, winged headrest had already been included in the webbing concept (Table 2.9), and the team wanted to experiment with a height-adjustable and tiltable dentist chair headrest The perceived benefit came from the contoured cushion on the dentist chair headrest that gives a cradle support for the head and provides greater relief to the neck muscles.

A modern-day dentist chair headrest was loaned from a sales representative of Sullivan-Schein Dental (a Henry Schein company) that was not only height-adjustable, but tiltable and depth-adjustable (moves in and out horizontally) as well. The team then designed a seat around this headrest (see Section 3.2.1.2). However, this design was deemed unsuitable due to safety issues related to head impact and its inability to accommodate a personal entertainment system.

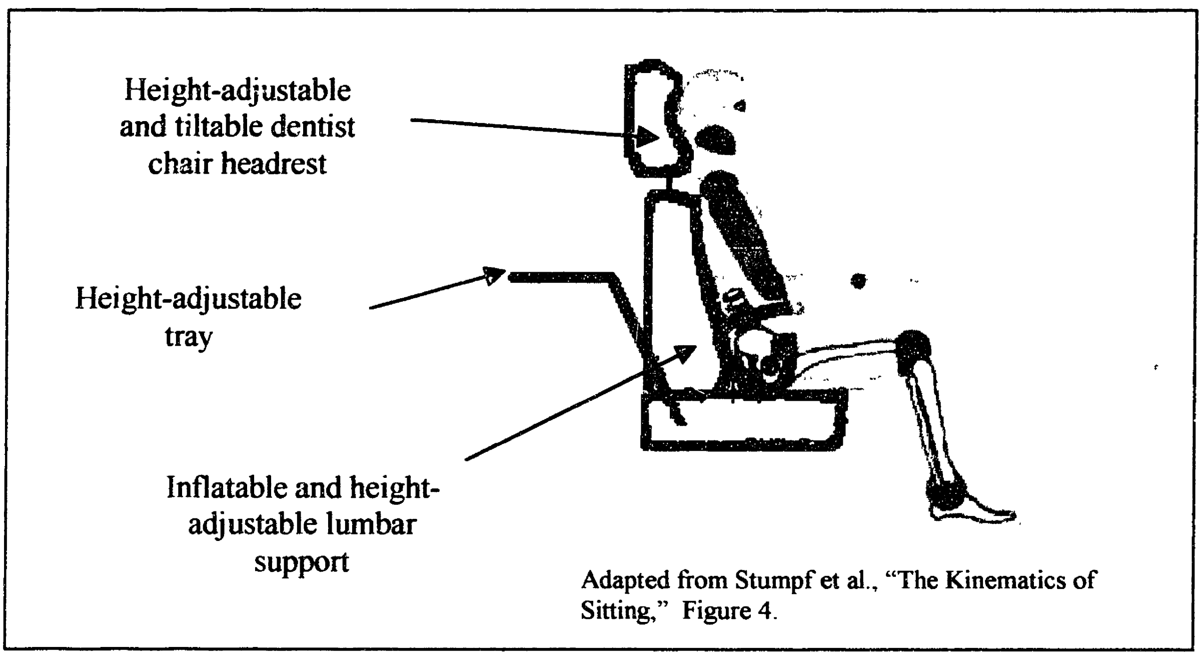
In the end, the team settled on a simple sliding-out backrest mechanism with an adjustable lumbar support and a height-adjustable, winged headrest, as shown in Section 3.2.1.3.

### 3.2.1 CONCEPT SKETCHES

#### 3.2.1.1 Initial Concept Sketch

The first concept generated by the team (see Section 2.9) is sketched in Figure 3.2.1 below. Actuated by a hand pump located at the armrest, the lumbar support would extend outwards from the base and provide the necessary amount of "recline." At the same time, the passenger would adjust the tilt and height of the dentist chair headrest so that the neck is not strained, and the head adequately supported.

**Figure 3.2.1: Initial Concept Sketch**

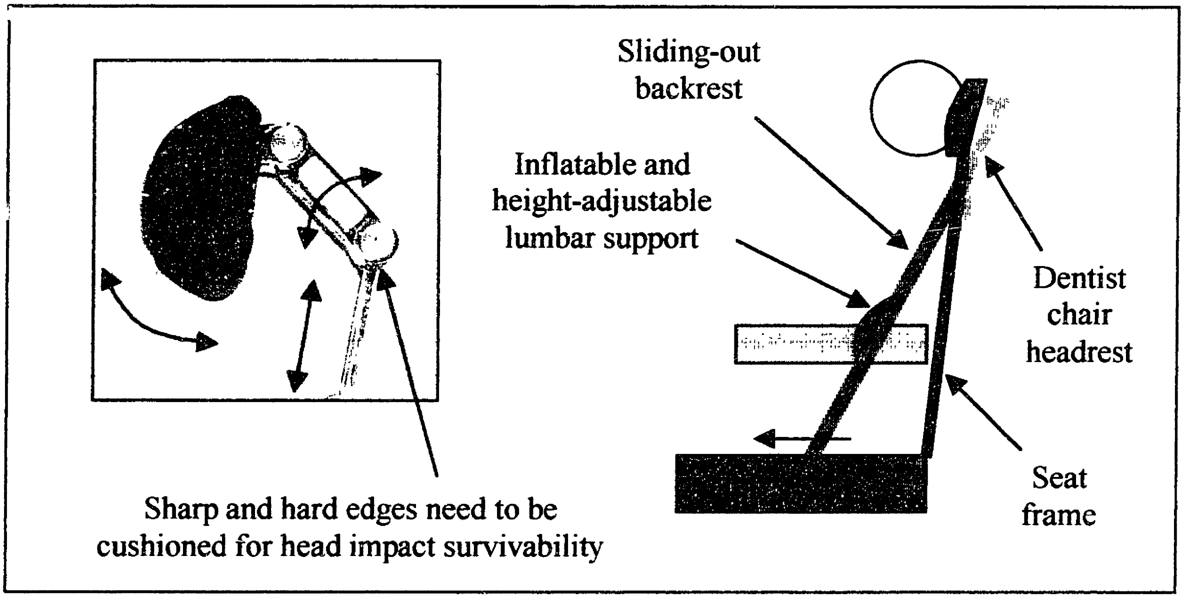



Adapted from Stumpf et al., "The Kinematics of Sitting," Figure 4.

#### 3.2.1.2 Modified Concept Sketch

The concept sketch in Figure 3.2.2 below was modified to include the multi-degree-of-freedom dentist chair headrest that the team obtained from Sullivan-Schein Dental. A sliding-out backrest was also incorporated.

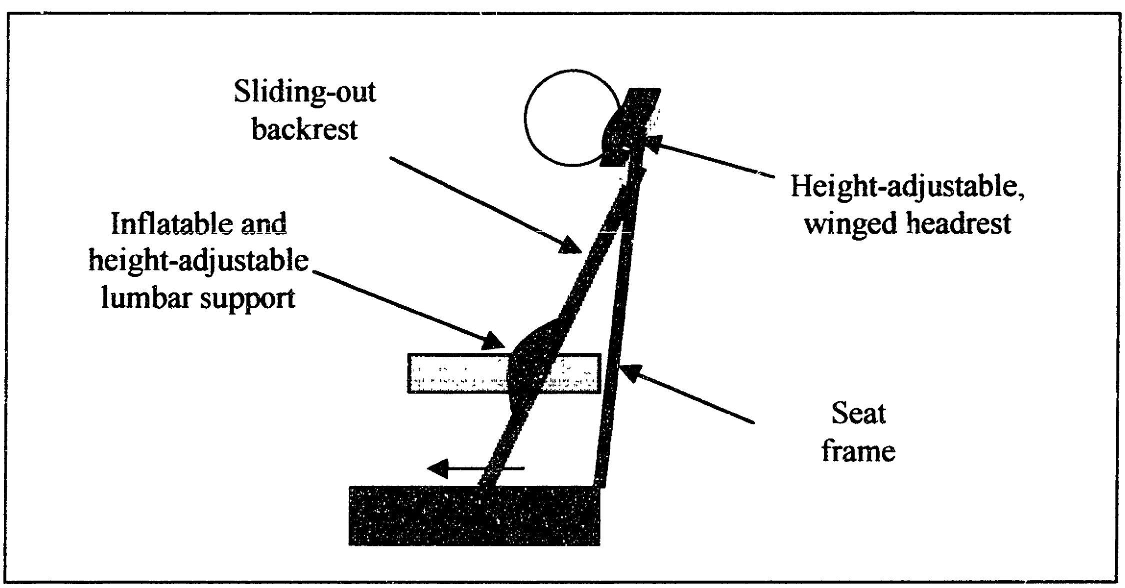
**Figure 3.2.2: Modified Concept Sketch**




### 3.2.1.3 Final Concept Sketch

The only difference between this final concept sketch and the previous sketch is the use of a winged headrest instead of a dentist chair headrest, as shown in Figure 3.2.3 below. Section 3.2.2 will provide the detailed design and construction of the final concepts.

**Figure 3.2.3: Final Concept Sketch**



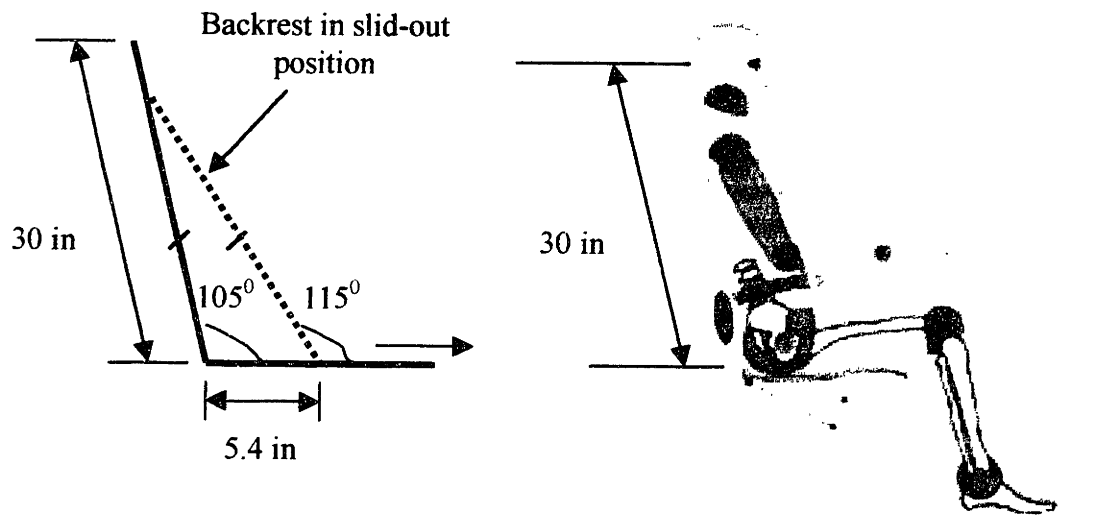
### 3.2.2 DETAILED DESIGN AND CONSTRUCTION

#### 3.2.2.1 Sliding-out backrest

The length of the backrest was sized for a hypothetical person between the 50th percentile US male and the 50th percentile US female, measured from the middle of the ear to the bottom seating surface. This dimension was respectively 31 inches for the 50th percentile US male and 29 inches for the 50th percentile US female (Dreyfus, 1973), giving an average length of 30 inches.

In order to achieve the same upright and recline angles as a baseline seat, the horizontal travel distance would have to be 5.4 inches. This is shown in Figure 3.2.4 below.

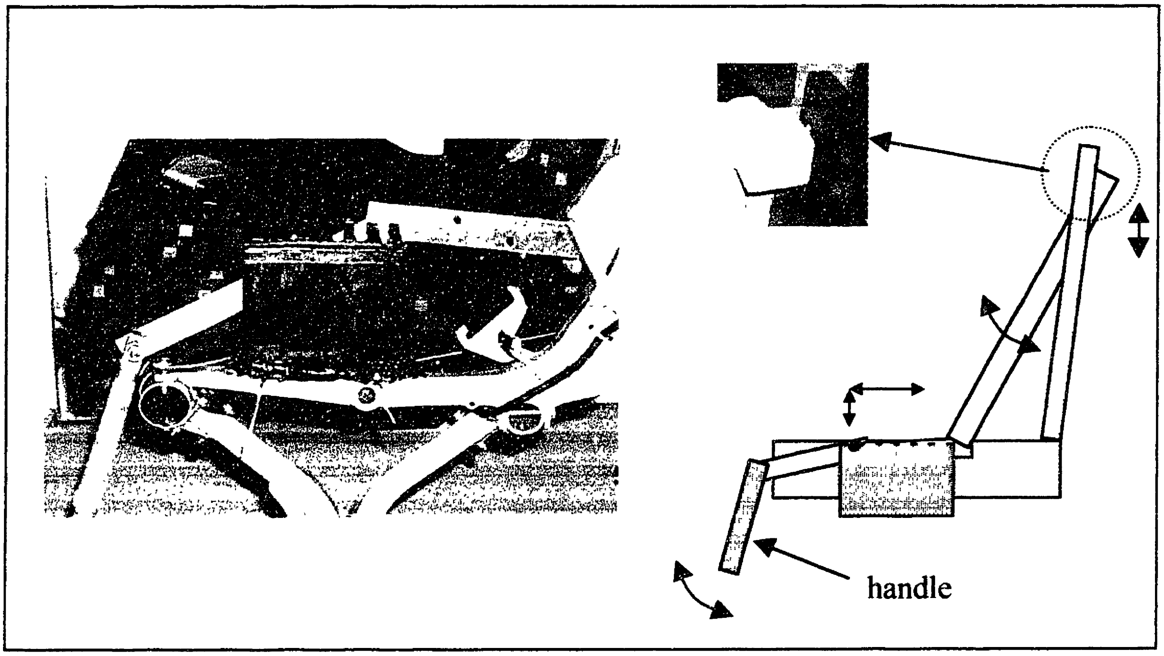
**Figure 3.2.4: Backrest angles**




Adapted from Stumpf et al., "The Kinematics of Sitting," Figure 4.

Figure 3.2.5 shows the sliding out mechanism of the backrest. To move the backrest forward, the occupant shifts his or her buttocks forward, then pulls upwards and forwards on the handle and pushes down when the bolt is above the required slot.

**Figure 3.2.5: The Mechanism for the Sliding-Out Backrest**

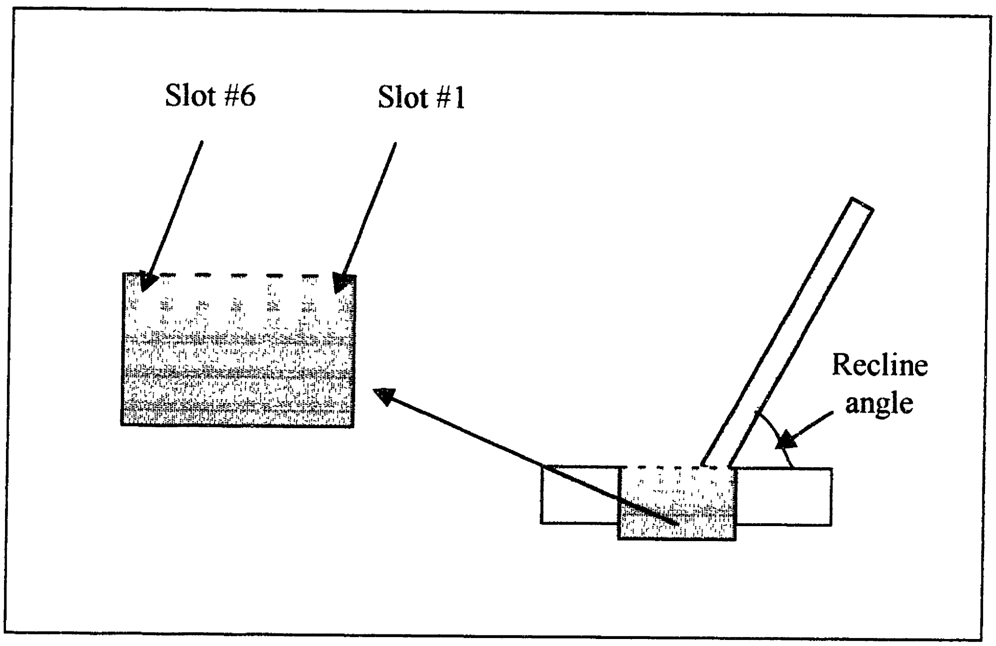



The seat depths and angles (see Figure 3.2.6) afforded by the prototype are listed in Table 3.2. Values for a baseline seat are also included for comparison. Dreyfus (1973), in his book, "The Measure of Man and Woman" recommended that the seat angle (for an office chair) range between 105 to 115 degrees and the seat depth be fixed at sixteen inches. The prototype could only provide a seat depth of fifteen inches in the upright position due to a slight problem with the way the sliding-out mechanism was constructed, but the team believes the depth can be increased with some modifications to the design. Another point to note is that although the team intended to have the recline angle at 115 degrees in the fully reclined position (slot 6), the imprecision of the team's construction methods caused a three degree angle increase.

**Table 3.2: Seat Depths and Angles: Prototype vs. Baseline**

| | Prototype | | Baseline | |
|---|---|---|---|---|
| Slot number | Recline angle (degrees) | Seat depth (inches) | Recline angle (degree) | Seat depth (inches) |
| 1 | 105 | 15.0 | 105 (upright) | 17.0 |
| 2 | 110 | 14.3 | - | - |
| 3 | 112 | 13.5 | - | - |
| 4 | 114 | 12.5 | - | - |
| 5 | 115 | 12.0 | - | - |
| 6 | 118 | 11.0 | 115 (fully reclined) | 17.0 |

**Figure 3.2.6: Backrest Recline Angle and Slot Number Designation**




### 3.2.2.2 Winged Headrest

Little was done to the winged headrest in terms of design. This headrest was taken off a seat provided by BE Aerospace and bolted on to the backrest (see Figure 3.2.7). The height-adjustability for this headrest is six inches which means it provides proper support for anyone ranging from the 1st percentile US female to the 50th percentile US male. (Other nationalities have different percentile ranges.) For a more detailed description of the headrest and its adjustability, the reader is referred to the thesis by Bekiaris (September 1999). Interestingly, seats with winged headrests have appeared in science fiction movies such as "2001: A Space Oddesy," as shown in Figure 3.2.8.

**Figure 3.2.7: Winged Headrest**

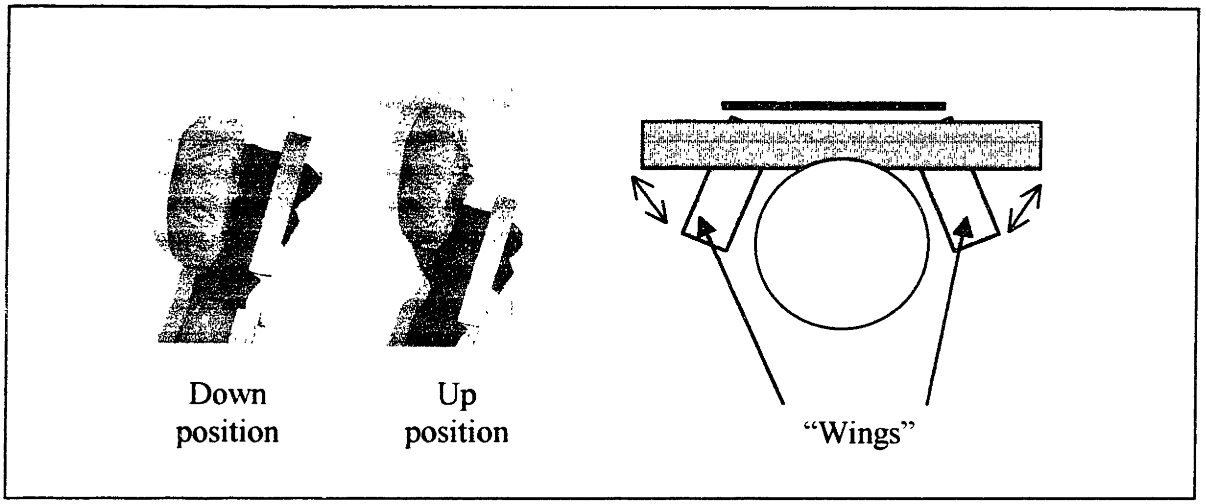



**Figure 3.2.8: Scene from "2001: A Space Odessy"**

### 3.2.2.3 Height-Adjustable and Inflatable Lumbar Support

As the lumbar support is a very popular feature in office and automotive seating, the team performed an extensive patent search on the United States Patent website. Many interesting concepts were discovered. However, after some deliberation, the team adopted a rather simple design, utilizing VELCRO® (for height adjustability) and parts from a blood pressure measuring device commonly used in health clinics (see Figure 3.2.9). Apart from the fact that it is cheap and simple to manufacture, this device would have the flexibility to support various sitting positions via manual adjustment by the passenger.

**Figure 3.2.9: Lumbar Support**

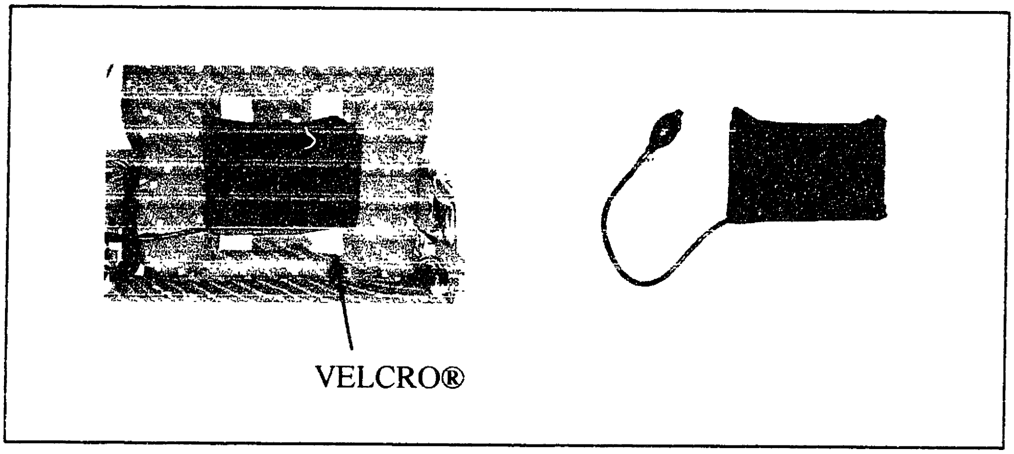
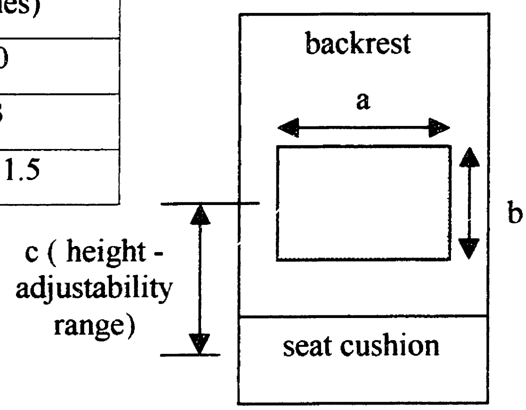



Figure 3.2.10 compares the dimensions of this lumbar support to those recommended by Dreyfus (1973). Dimensions "a" and "b" for the prototype was constrained by the size of the blood pressure measuring device while the height-adjustability range shifted unintentionally during the construction process.

**Figure 3.2.10: Lumbar Support Dimensions**

| Dimension | Prototype (inches) | Recommended (inches) |
|---|---|---|
| a | 7.0 | 8.0 |
| b | 9.5 | 13 |
| c | 8.5-12.0 | 7.0-11.5 |

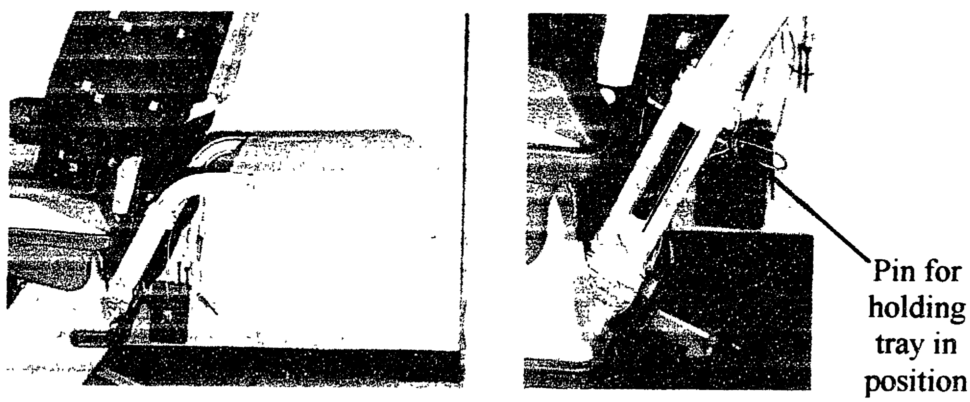



#### 3.2.2.4 Height-adjustable tray

The aircraft seat tray serves not only as an eating surface, but also as a reading surface, and increasingly so nowadays, as a work surface. Each activity requires different surface heights, as described in Appendix IV:A6, and these vary from person to person.

In order to avoid a complete redesign of the tray, a crude and simple latching mechanism was adopted, allowing the team to adapt an existing tray for height-adjustability. This mechanism is shown in Figure 3.2.11. It allows the user to set the tray at three different heights, for a total adjustability of two inches. For a more detailed description of the tray design, the reader is referred to the thesis by Bekiaris (September 1999).

**Figure 3.2.11: Adjustable Tray Height Mechanism**




### 3.3 FAA REGULATIONS

The team was unable to perform any rigorous analysis of the prototype to ensure that it met FAA regulations, both due to the enorminity of the task, and the short five-month timeframe of the project. Nonetheless, before proceeding with the detailed design, the team looked through the whole of Parts 25 and 121 of the Federal Aviation Regulations (FAR), as recommended by industry advisors from BE Aerospace and Northwest Airlines.

Based on the team's understanding of the FAA regulations and feedback received from industry representatives, the team believes the forward-sliding concept has no major regulatory concerns. The headrest, for example, was taken off an existing FAA-certified seat, while the tray was a simple modification to a baseline aircraft seat tray. However, the sliding-out mechanism for the backrest would have to be redesigned, or beefed up in order for the seat to meet FAA's 16-g deceleration requirement (that the seat would be able to withstand a force sixteen times the force of Earth's gravity). Also, the material used for the lumbar support would have to be changed in order for it to meet FAA's flammability and toxic gas emission (while burning or melting) standards.

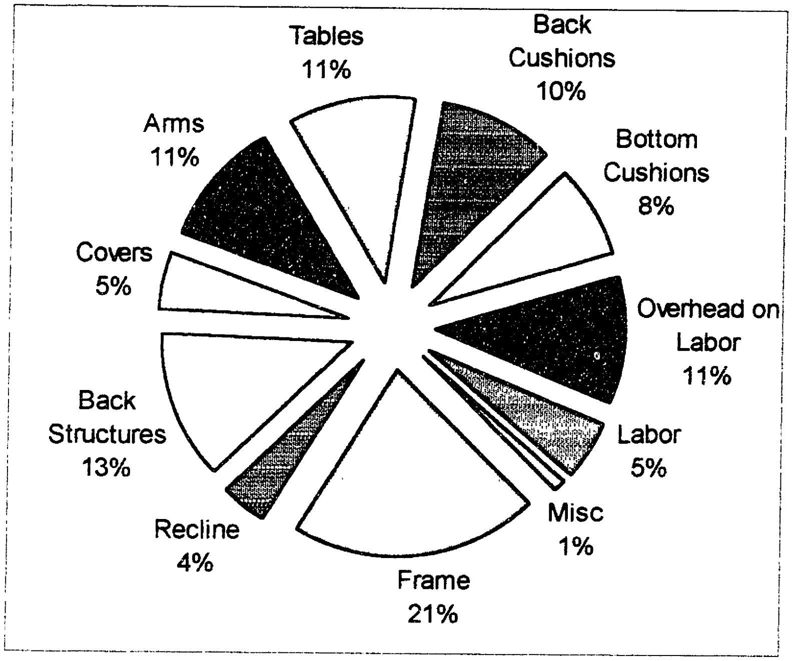
## 3.4 COST CALCULATIONS

The team estimates the additional cost of fabricating this forward-sliding concept to be $150 per seat. This figure was calculated based on the cost breakdown provided by BE Aerospace for a typical economy-class seat (see Figure 3.4). Table 3.4 compares the team's best cost estimate for a production model forward-sliding seat with the cost for a baseline seat. It was assumed for this production model, that the sliding-out backrest, lumbar support and height-adjustable tray have been redesigned for better adjustability via similar or different mechanisms. The total cost for a baseline seat was approximated at $1000 (based on information received from BE Aerospace).

**Table 3.4: Production Model Cost Estimates**

| Component | Baseline | Forward-Sliding | Cost Increase |
|---|---:|---:|---:|
| Frame | $210 | $210 | $0 |
| Recline (backward) | $40 | $0 | -$40 |
| Sliding-out mechanism | $0 | $50 | $50 |
| Back Structures | $130 | $130 | $0 |
| Covers | $50 | $50 | $0 |
| Arms | $110 | $110 | $0 |
| Tables | $110 | $160 | $50 |
| Back Cushions | $100 | $100 | $0 |
| Bottom Cushions | $80 | $80 | $0 |
| Overhead on Labor | $110 | $110 | $0 |
| Labor | $50 | $70 | $20 |
| Lumbar support | $0 | $30 | $30 |
| Adjustable Headrest | $0 | $40 | $40 |
| Miscellaneous | $10 | $10 | $0 |
| **Total** | **$1000** | **$1150** | **$150** |

**Figure 3.4: Cost Breakdown Estimates for a Typical Economy-Class Seat**




Source: BE Aerospace

# 4. CONCEPT EVALUATION

Two approaches were adopted in order to evaluate the effectiveness of the forward-sliding concept: human subject experiments and pressure distribution maps. The purpose of the latter was to examine if subjective ratings obtained from the former could be linked to human-seat interface data (pressure distributions). An advanced tactile pressure measurement system by Tekscan, Inc. (see Appendix XI.V) was used to record the pressure distributions. The following subsections describe these evaluation methods and their results in detail.

## 4.1 EXPERIMENTS

### 4.1.1 THE TEST ENVIRONMENT

A mockup of an aircraft cabin was constructed for the purpose of conducting experiments in a simulated aircraft environment. This mockup, as shown in Figures 4.1.1 and 4.1.2, was made out of wood and the dimensions were replicated from the schematics of a Boeing 737 cabin. A seat pitch (distance between seats) of thirty-two inches was used, which is the average pitch used in the commercial airline industry today. The details of the environment construction can be found in the thesis by Bekiaris (September 1999).

**Figure 4.1.1: Test Environment**

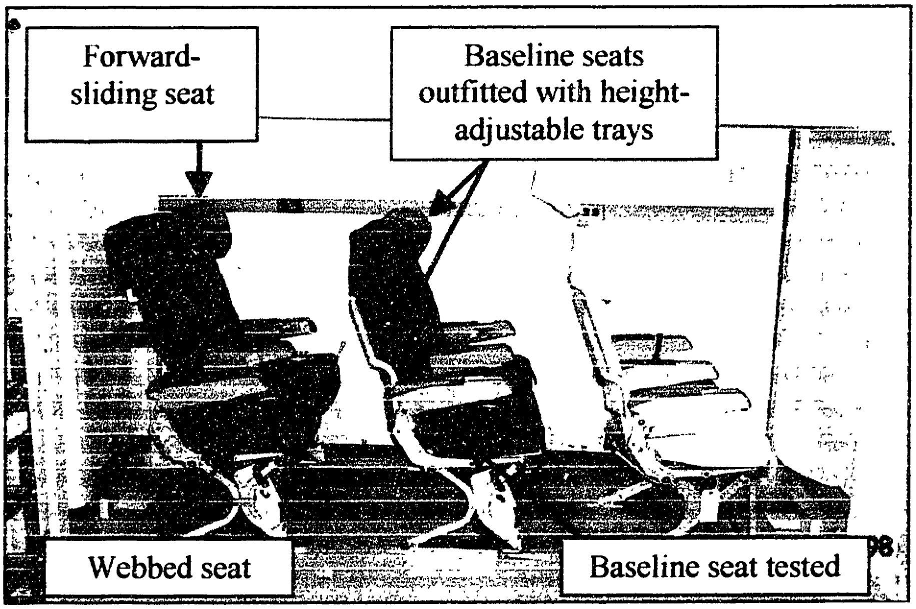
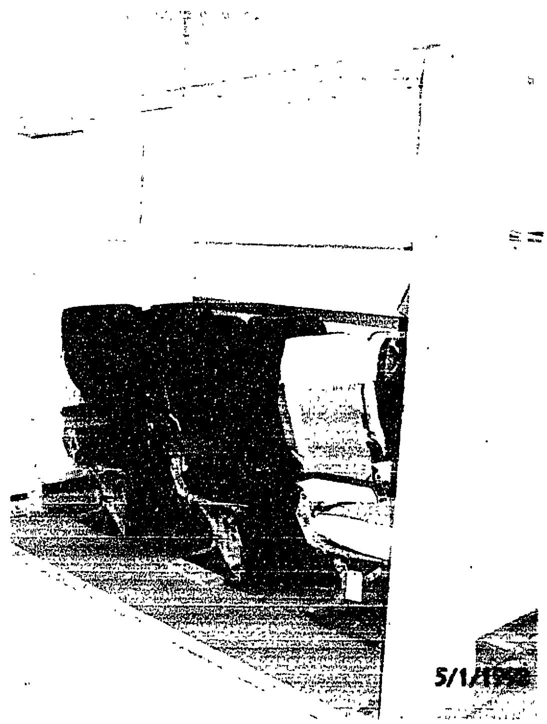


**Figure 4.1.2: Aircraft Cabin Mockup**



## 4.1.2 DETAILS OF THE EXPERIMENT

There were three seats to be tested for the project: the baseline seat, the forward-sliding seat, and the webbed seat (concept #2 described in Section 2.9). Twelve subjects were recruited and the team tried to get as wide a spread of the human population curve as possible. Figures 4.1.3 and 4.1.4 show the position of the twelve subjects on the US population curves for women and men. Subjects number three, nine and eight most closely represent the $5^{th}$ percentile female, the $50^{th}$ percentile male and the $95^{th}$ percentile male respectively. (The pressure maps taken of these subjects will be discussed in Section 4.2.)

**Figure 4.1.3: US Population Curve for Women**

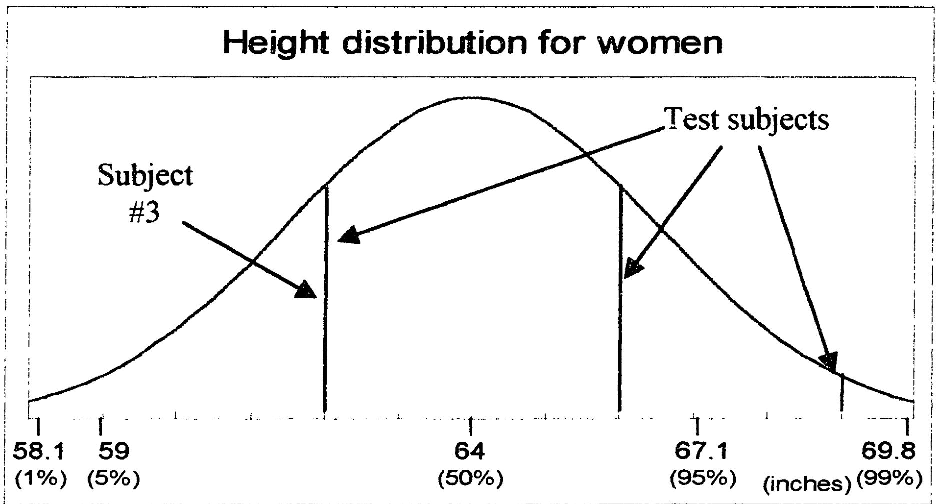
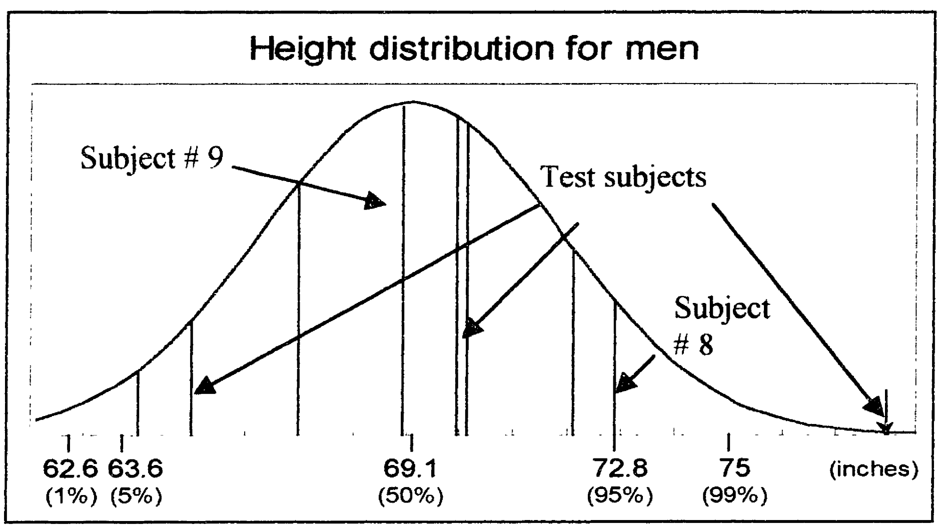



**Figure 4.1.4: US Population Curve for Men**




One dilemma faced by the team was in choosing the duration of each experiment. Although it has been suggested that opinions stabilize after about twenty minutes (LeCarpentier, 1969), subtle discomfort may not be noticeable until about three hours have passed (Jones, 1969). Ergonomists commonly suggest that chairs be evaluated for at least as long as users are expected to sit at one time. Since the project goal was to improve seat comfort for long-haul flights, which typically last between 6-10 hours, the ideal experiment would last no shorter than six hours. However, based on subject availability, and time and cost contraints, the team decided to conduct three hour long experiments, where subjects would sit on each of the three seats over three separate days, totaling nine hours per subject. The detailed experiment protocol is provided in Appendix VIII.

Each experiment was split into four phases. Subjects were allowed to take a short break in between each phase, and pressure maps were taken either at the beginning, or after phase II of the experiment. The details of each phase are listed below:

Phase I – Subjects were asked to sit down for fifteen minutes with their seat belt fastened, simulating preparations for takeoff. At the end of this fifteen minutes, they were asked to fill out Questionnaire 1.

Phase II – This segment lasted forty-five minutes. Subjects were allowed to work, read, sleep or rest. Questionnaire 2 was handed out at the end of this phase.

Phase III - Subjects were provided with breakfast or dinner, depending on the time of day, and given fifteen to twenty minutes to eat. They were asked to fill out Questionnaire 3 after having their meals.

Phase IV - Subjects were allowed to work, read, sleep or rest for forty-five minutes, as in Phase II. Questionnaire 4 was handed out at the end of the experiment.

In order to arrive at comfort ratings, researchers in various industries have tried different techniques for user comfort evaluations. These methods include:

- General comfort ratings, in which participants rate their feelings about a seat on a numeric scale
- Rank ordering of seats for overall comfort
- Body part discomfort ratings, in which participants rate the comfort or discomfort of their legs, lower back, upper back, et cetera.
- Chair feature evaluation checklists, in which participants rate the adequacy of specific chair features such as armrests or backrests, often using scales such as "too soft…too hard" rather than degrees of comfort.

(Source: Herman Miller Inc., "Body Support in the Office," www.hermanmiller.*com*)

The body part discomfort ratings were used in the questionnaires because they provided detail on the level of comfort felt on various parts of the body, thus allowing comparison to be made between the two prototypes and the baseline seat.

For a complete description of the experiment and for general results pertaining to both prototypes, the reader is referred to the thesis by Narmada (June 1999).

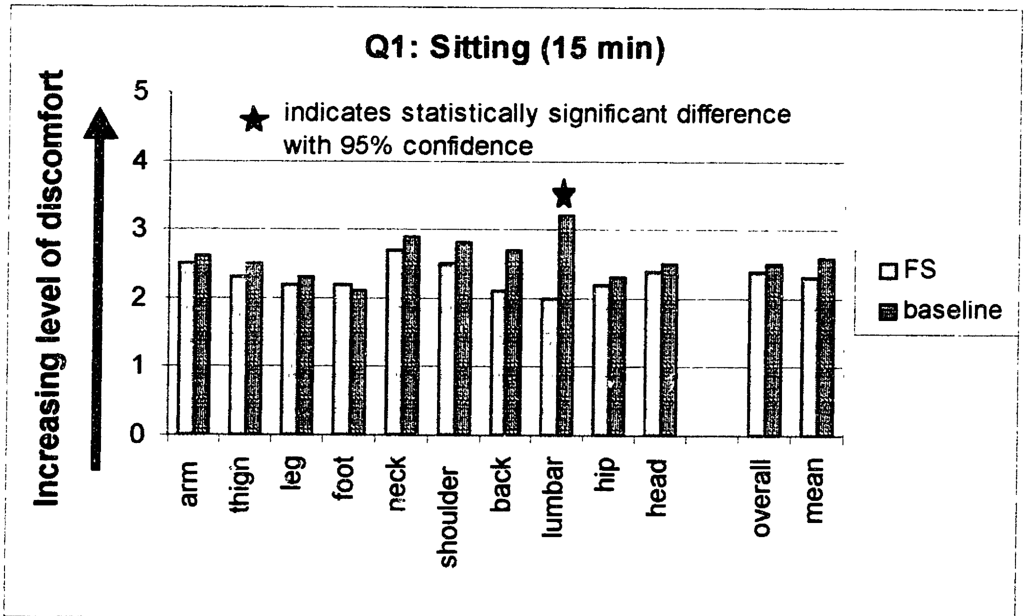
### 4.1.3 EXPERIMENT RESULTS

The data collected from the experiments is tabulated in Appendix IX: Sections A and B. One subject did not complete the experiment, and therefore only results for eleven subjects were obtained. Differences between ratings for the baseline and forward-sliding seats by subject are tabulated in Appendix IX: Section C.

Two statistical tests of significance were performed on the data: the paired t-test and the sign test. The former ranks the differences between values according to levels of significance whereas the latter does not take the magnitude of differences into account, but ranks the significance according to sample size. The team only concluded that any differences between the baseline and forward-sliding seat were statistically significant when both tests produced positive results. Appendix X describes these two tests in detail.

Figure 4.1.5 shows the results obtained for Questionnaire 1. The lumbar region is shown to be significantly more comfortable (with 95% confidence) for the forward-sliding seat compared to the baseline.

**Figure 4.1.5: Results for Questionnaire 1**




The results for Questionnaire 2 are shown in Figure 4.1.6 It is seen that after one hour on the seat (with a possible break after the first fifteen minute segment), the lumbar region remains significantly more comfortable for the forward-sliding seat, while subjects start to feel significantly more comfortable (with 90% confidence) at the head.

**Figure 4.1.6: Results for Questionnaire 2**

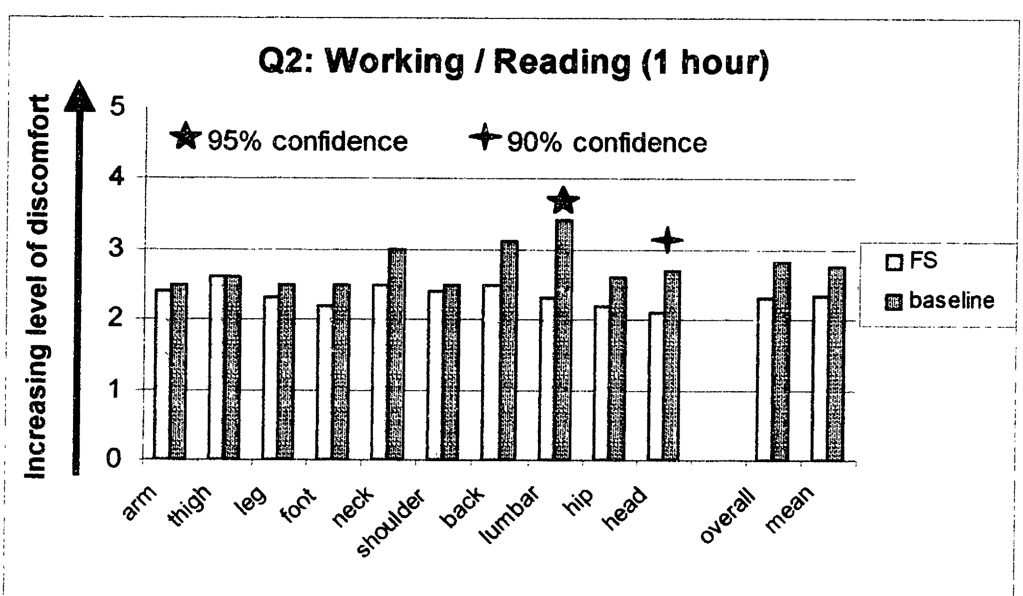
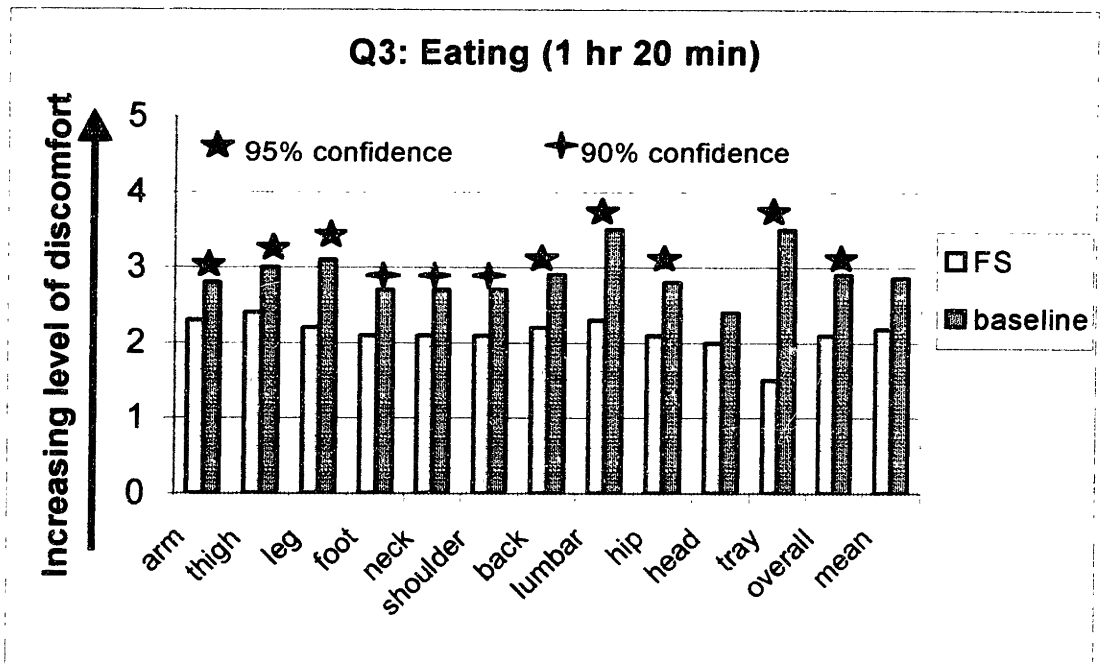


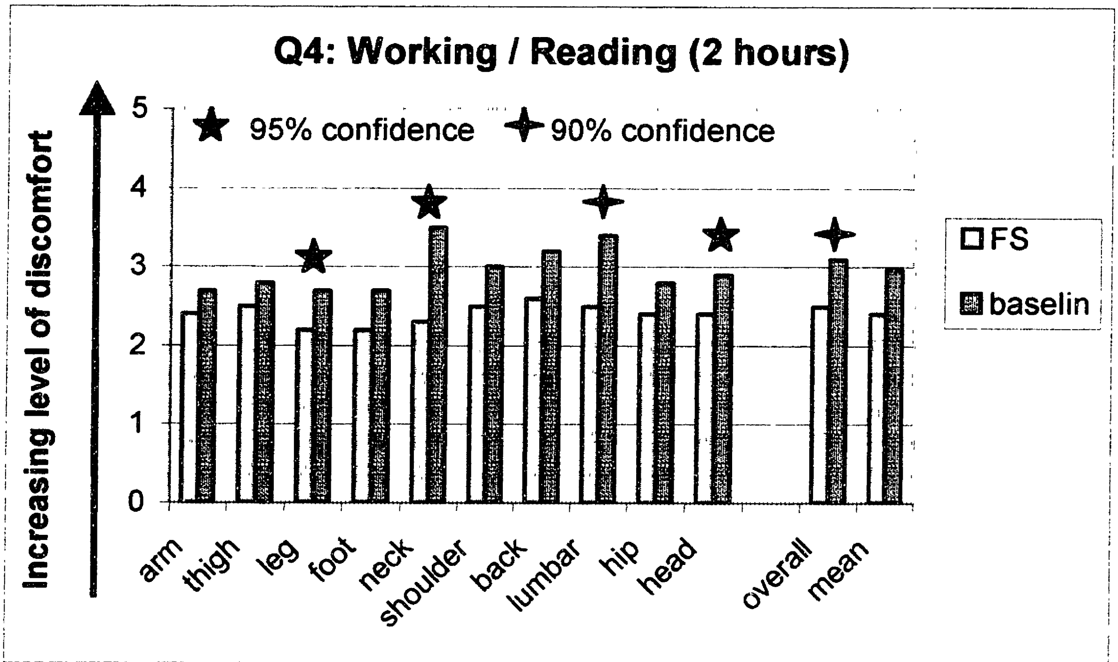
Figure 4.1.7 graphs the results for Questionnaire 3, recorded approximately after one hour and twenty minutes of time spent on the seat. A rather dramatic improvement in comfort is observed during this segment of the experiment. The arm, thigh, leg, back, lumbar, hip and overall comfort all rank significantly better for the forward-sliding seat with 95% confidence. For the tray, the data shows that it ranks significantly more comfortable with up to 99.5% confidence. In addition, the foot, neck and shoulder rank significantly better with 90% confidence.

**Figure 4.1.7: Results for Questionnaire 3**




The results, for Questionnaire 4, are shown in Figure 4.1.8. With a total of two hours on the seat, subjects rated the leg, neck and head significantly more comfortable for the forward-sliding seat with 95% confidence. The lumbar and overall comfort were also rated significantly better with 90% confidence.

**Figure 4.1.8: Results for Questionnaire 4**




When subjects were asked at the end of the experiment how the seat compared to a typical economy-class seat, five subjects rated the forward-sliding seat better, four rated it comparable, while the remaining two rated the seat worse.

### 4.1.4 DISCUSSION OF RESULTS

Significant improvements were seen in both the lumbar and head comfort for the forward-sliding seat. Although the lumbar comfort seemed to deteriorate towards the end of the experiment, it still ranked significantly more comfortable for all four test segments. The head comfort, on the other hand, only began to show after one hour of sitting (Questionnaire 2) and became better over time. (Questionnaire 3 should be ignored for the head, since subjects were leaning forward while eating, hence having no headrest support.) Along with head comfort, neck comfort also became better towards the end of the experiment.

The better lumbar, head and neck comfort can be attributed directly to the features that the team added to the prototype: the lumbar support, the height-adjustable headrest and the "wings" on the headrest. (The winged headrest provides extra support to the head, thus providing relief to the neck muscles. )

A very surprising result was observed for the height-adjustable tray. The tray comfort was ranked significantly higher while it was evaluated during phase III (eating),with up to 99.5% confidence. Furthermore, all body regions except the head were rated significantly better during this phase. The arm and thigh comfort can be attributed to the height-adjustable tray, which provides better support to the arms and more thigh clearance in its proper position. On the other hand, the back and hip comfort can be attributed to both the sliding-out backrest and the lumbar support.

The overall comfort of the forward-sliding seat appeared to improve over time, and making the seat suitable for flights that are at least three hours long.

One thing interesting to note is that although many subjects commented in the questionnaires that the sliding-out backrest diminished much thigh support and was hence a source of discomfort, the data did not show any significant difference in thigh comfort between the baseline and forward-sliding seats. In fact, subjects ranked thigh comfort significantly better with 95% confidence during the third segment of the experiment, possibly due to the backrest being placed in the upright position while eating.

## 4.2 PRESSURE MAPPING

Some researchers have indicated that surface pressure can cause discomfort during prolonged periods of sitting, due to the constriction of blood vessels in underlying tissues that restricts blood flow. These researchers, such as Grandjean et al. (1973), claim that correct pressure distribution is critical to seated comfort.

In the automotive industry, studies of comfort via pressure mapping is fairly commonplace. Using pressure distribution data to evaluate seat comfort, however, is not as straightforward as it seems. People of different body weights and builds distribute their weight in similar patterns, but the pressure intensity and area distribution vary considerably from person to person. The variation in peak pressure patterns makes it difficult to prescribe ideal seat and back contours or cushion softness levels that would minimize uncomfortable pressure points for all seat occupants.

Nonetheless, researchers point out that the skin and fat tissue under the ischial tuberosities, or "sitting bones," are less sensitive to pressure than the muscle tissue surrounding the tuberosities and better suited to carrying load than the other tissues of the buttock and thigh (Reed et al., 1994). Additionally, seats with backrests that show pressure peaks in the lumbar area away from the spine have been deemed more comfortable than seats that exhibit lower pressure gradients in the region of the lower back (Kamijo et al., 1982). It can thus be concluded that a comfortable seat will produce pressure distributions that show peaks in the area of the ischial tuberosities and in the lumbar region, away from the spine. The reader is asked to keep this in mind while going over the pressure maps in the subsections below.

In the interest of brevity, only pressure maps for the three subjects that most closely represent the 5$^{th}$ percentile female (subject #3), the 50$^{th}$ percentile male (subject #9) and the 95$^{th}$ percentile male (subject #8) will be presented. The positions of these subjects on the US population curve were indicated earlier in Figures 4.1.3 and 4.1.4.

### 4.2.1 COMPARISON OF PRESSURE MAPS FOR SUBJECT #3

#### 4.2.1.1 Seats Upright

Figure 4.2.1 shows the seat pressure distributions for subject #3 in the upright position. Overall, the subject rated the forward-sliding seat less comfortable than the baseline. This is reflected by the high pressure concentrations in the middle of the lumbar region where the spine is located and at the neck. There is also an absence of any support at the shoulders. The thigh region for the two seats on the other hand, have similar pressure distributions, which explains the same rating assigned to both.

For the seat cushion of the forward-sliding seat, high pressure concentrations are seen on the ischial tuberosities (sitting bones), away from the spine, which is supposedly better for comfort as described in Section 4.2 above.

Nonetheless, researchers point out that the skin and fat tissue under the ischial tuberosities, or "sitting bones," are less sensitive to pressure than the muscle tissue surrounding the tuberosities and better suited to carrying load than the other tissues of the buttock and thigh (Reed et al., 1994). Additionally, seats with backrests that show pressure peaks in the lumbar area away from the spine have been deemed more comfortable than seats that exhibit lower pressure gradients in the region of the lower back (Kamijo et al., 1982). It can thus be concluded that a comfortable seat will produce pressure distributions that show peaks in the area of the ischial tuberosities and in the lumbar region, away from the spine. The reader is asked to keep this in mind while going over the pressure maps in the subsections below.

In the interest of brevity, only pressure maps for the three subjects that most closely represent the 5$^{th}$ percentile female (subject #3), the 50$^{th}$ percentile male (subject #9) and the 95$^{th}$ percentile male (subject #8) will be presented. The positions of these subjects on the US population curve were indicated earlier in Figures 4.1.3 and 4.1.4.

## 4.2.1 COMPARISON OF PRESSURE MAPS FOR SUBJECT #3

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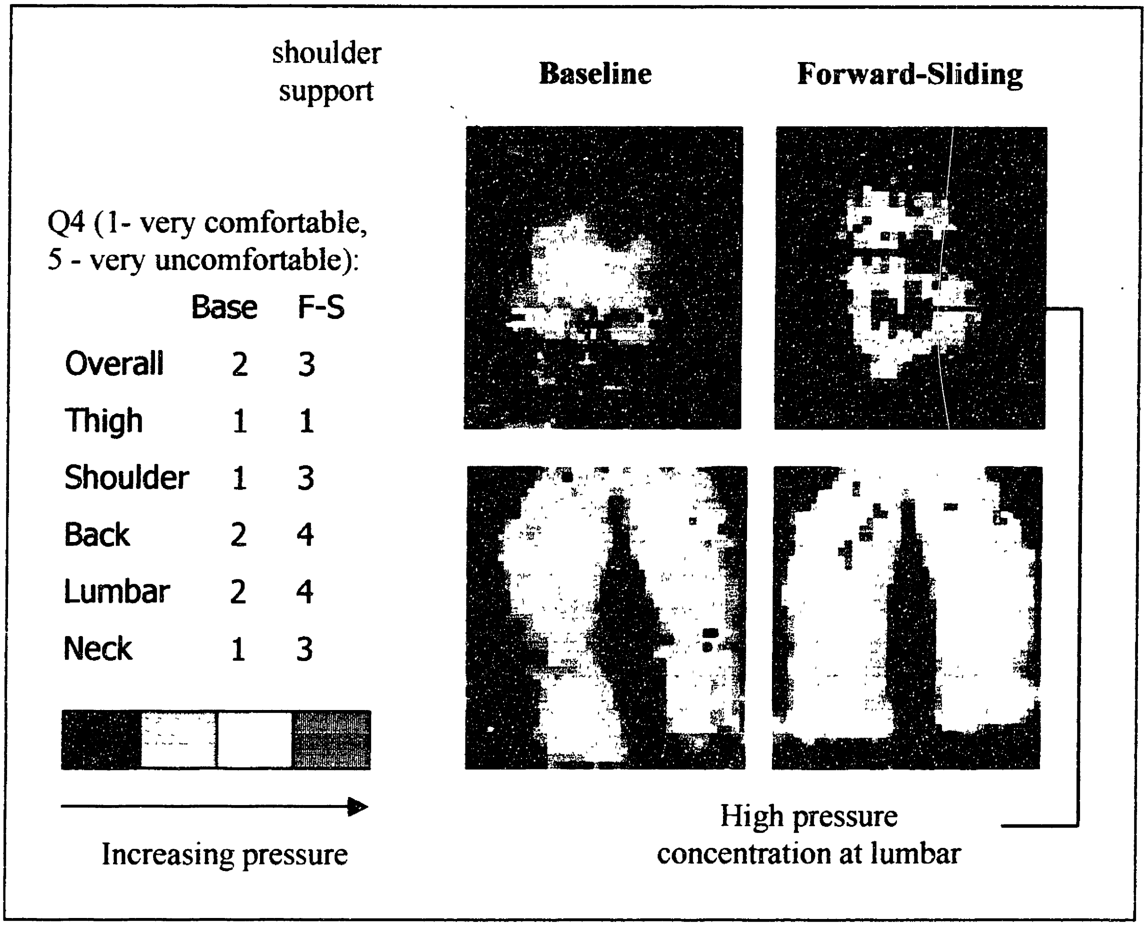
For the seat cushion of the forward-sliding seat, high pressure concentrations are seen on the ischial tuberosities (sitting bones), away from the spine, which is supposedly better for comfort as described in Section 4.2 above.

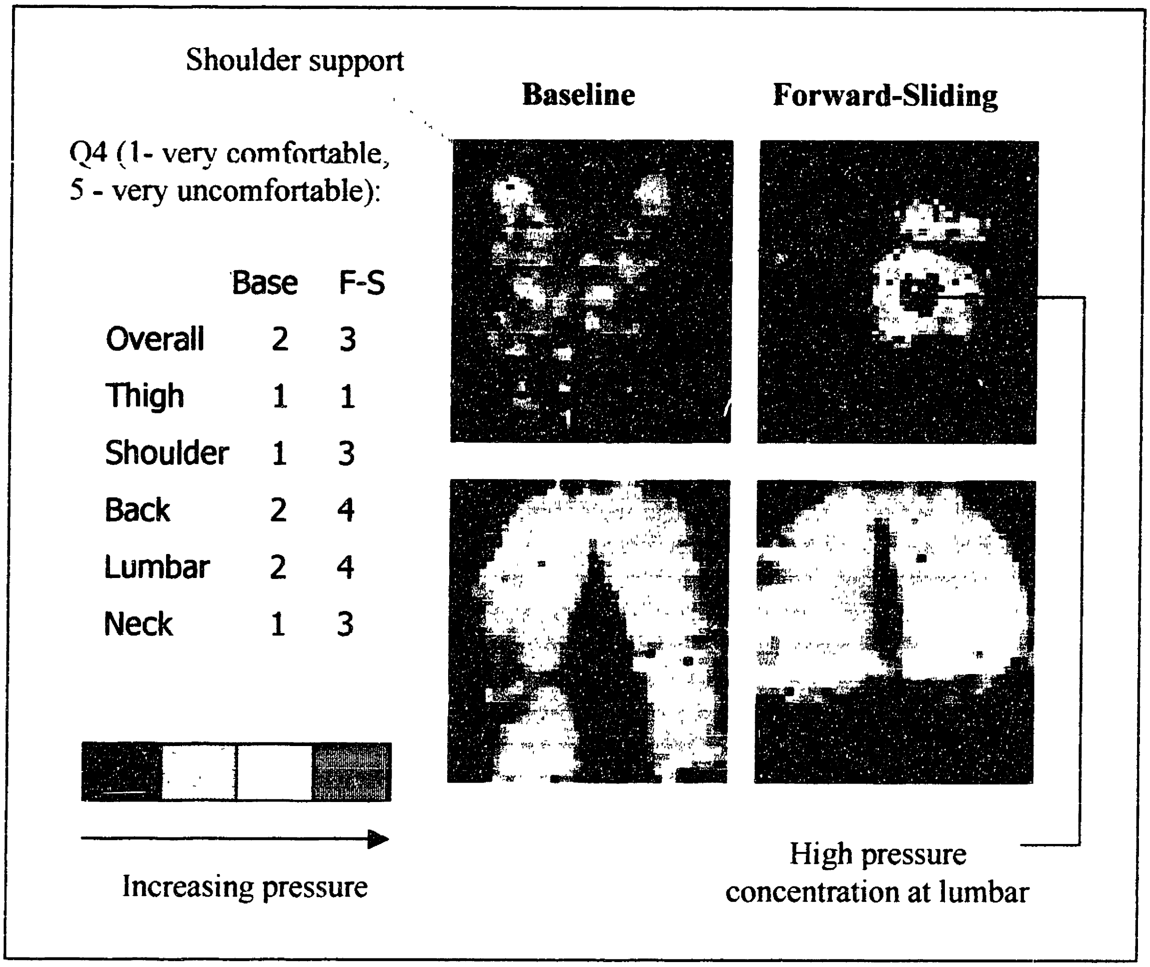
**Figure 4.2.1: Pressure Maps for Subject #3 in the Upright Position**




#### 4.2.1.2 Seats Reclined

The pressure maps in the recline position, as shown in Figure 4.2.2, exhibit similar trends to those in the upright position. The high pressure concentration at the middle of the lumbar region still remains for the forward-sliding seat, while the shoulder support provided by the baseline seat is much more evident here. Interestingly, thigh comfort was given the same rating for both although thigh support was greatly diminished for the forward-sliding seat.

**Figure 4.2.2: Pressure Maps for Subject #3 in the Reclined Position**




## 4.2.2 COMPARISON OF PRESSURE MAPS FOR SUBJECT #9

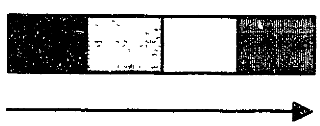
### 4.2.2.1 Seats Upright

This subject generally found both seats comparable to each other (see Figure 4.2.3). Support at the shoulder blades are clearly visible for both seats and this explains the equal rating assigned for the shoulders. Back comfort, however, was rated less comfortable for the forward-sliding seat, as reflected by the high pressure points in the region of the subject's back. Also, a hollow region is noticeable at the neck for the baseline seat, and this could be the reason for the weaker rating received compared to the forward-sliding seat.

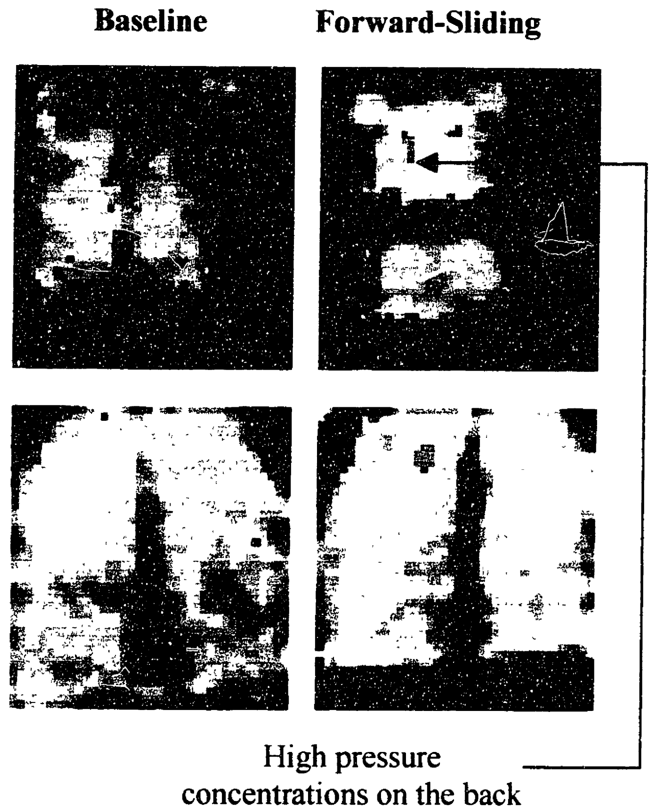
**Figure 4.2.3: Pressure Maps for Subject #9 in the Upright Position**

Q4 (1- very comfortable,
5 - very uncomfortable):

| | Base | F-S |
|---|---|---|
| Overall | 3 | 4 |
| Thigh | 3 | 3 |
| Shoulder | 4 | 4 |
| Back | 3 | 4 |
| Lumbar | 3 | 3 |
| Neck | 4 | 3 |



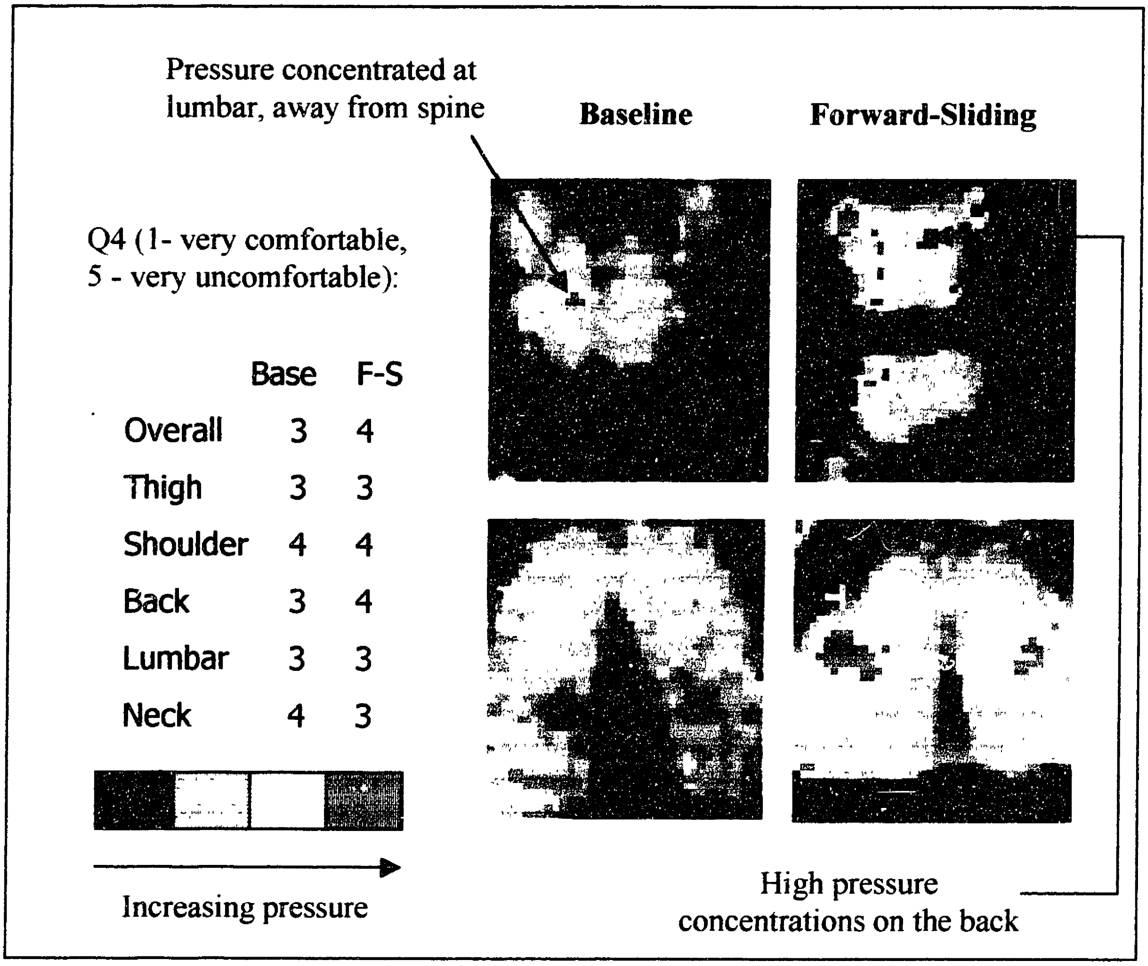
Increasing pressure




### 4.2.2.2 Seats Reclined

Figure 4.2.4 shows the pressure maps for subject #9 in the reclined position. Similar trends to the upright position are observed here, though the pressure concentrations on the back of the forward-sliding seat are more pronounced. The pressure distribution on the baseline backrest can be considered better to that on the forward-sliding backrest due to the distribution of pressure around the lumbar region, away from the spine.

**Figure 4.2.4: Pressure Maps for Subject #9 in the Reclined Position**




### 4.2.3 COMPARISON OF PRESSURE MAPS FOR SUBJECT #8

#### 4.2.3.1 Seats Upright

The forward-sliding seat was rated better than the baseline by this subject (see Figure 4.2.5). Although a high pressure concentration can be seen in the middle of the lumbar region where the spine is located, the subject still rated the lumbar comfort better. This could be due to the baseline seat not providing much support to the lumbar.

There appears to be no contact at the back and neck regions of the baseline seat, which explains the weaker ratings received for these regions compared to the forward-sliding seat.

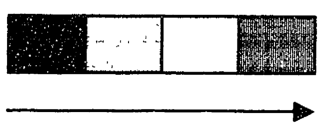
Another point to note is that no pressure concentrations are noticeable at the tailbone for the forward-sliding seat. This could also help explain its better overall rating.

**Figure 4.2.5: Pressure Maps for Subject #8 in the Upright Position**

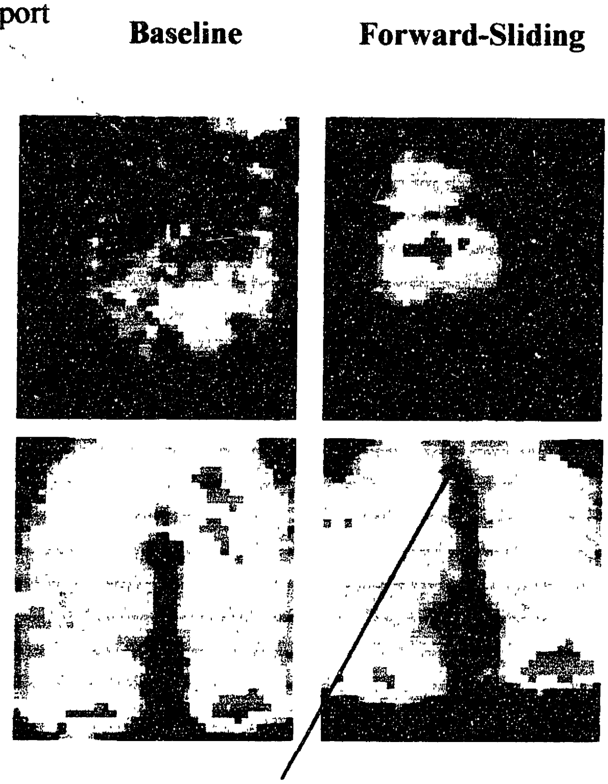
No back and neck support

Q4 (1- very comfortable, 5 - very uncomfortable):

| | Base | F-S |
|---|---|---|
| Overall | 5 | 3 |
| Thigh | 5 | 3 |
| Shoulder | 5 | 3 |
| Back | 4 | 3 |
| Lumbar | 5 | 3 |
| Neck | 5 | 2 |



Increasing pressure



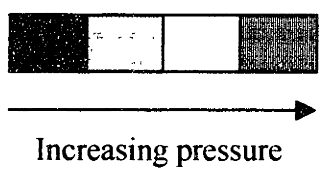

### 4.2.3.2 Seats Reclined

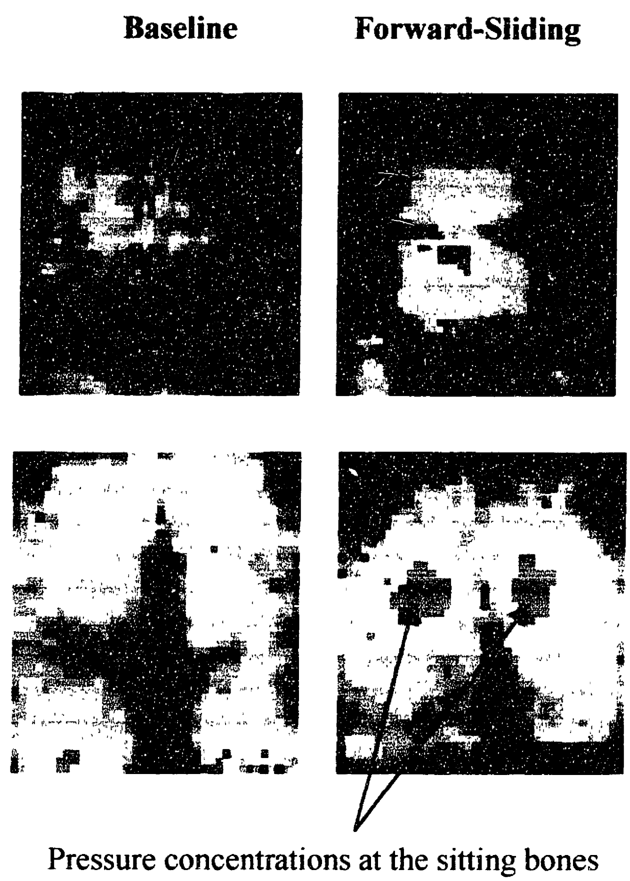
As with the pressure maps for subjects #3 and #9, the upright and reclined maps for this subject exhibit similar trends. The pressure maps for the reclined position are shown in Figure 4.2.6. One key distinction here is the pressure concentrations at the ischial tuberosities (sitting bones), which is one of the two key characteristics of a comfortable seat, as described in Section 4.2 above.

**Figure 4.2.6: Pressure Maps for Subject #8 in the Reclined Position**

Q4 (1- very comfortable,
5 - very uncomfortable):

| | Base | F-S |
|---|---|---|
| Overall | 5 | 3 |
| Thigh | 5 | 3 |
| Shoulder | 5 | 3 |
| Back | 4 | 3 |
| Lumbar | 5 | 3 |
| Neck | 5 | 2 |



# 5. ASSESSMENT AND RECOMMENDATIONS

## 5.1 ASSESSMENT

The team concludes that the forward-sliding concept has met the success criteria that it be at least comparable to a baseline seat in terms of comfort, based on results from the experiments as well as the pressure maps. While there was a trend in the human subject responses that indicated that the forward-sliding seat was better than the baseline in many aspects, there was no indication that they found the forward-sliding seat more uncomfortable to any degree of statistical significance. Moreover, these subjective responses were given credence by the pressure map comparisons, which exhibited trends that corresponded well to the comfort ratings given by the subjects.

Although subjects commented that they preferred the baseline seat recline mechanism to the sliding-out mechanism because the latter diminished both their legroom and the support to their thighs, five out of eleven still rated the forward-sliding seat better, four rated it comparable, while only two rated it worse. This was primarily due to the addition of the lumbar support, the height-adjustable winged headrest and the height-adjustable tray, that were shown to provide significantly better comfort to the seat. A few subjects also commented that they preferred the forward-sliding seat because of one or more of the additional features.

The team was not surprised by this result, because it was acknowledged right from the outset that the sliding-out backrest would not be as comfortable as the usual backwards recline, and its purpose was simply to provide a recline mechanism that was somewhat acceptable to passengers; any discomfort caused by the sliding-out backrest would then be compensated by the lumbar support, the adjustable headrest and the height-adjustable tray.

Having established that the forward-sliding seat is at least as comfortable as the baseline based on experiment results, a case can now be made that the forward-sliding seat is an improvement over the baseline seat in terms of comfort, whichever way one chooses to define it. By preventing rearward space intrusion of the seats via the usual recline mechanism, additional benefits come into play, such as better ease of ingress/egress, better psychological comfort (less effects of being "crowded-in"), seat depth adjustability for small persons, knee and legroom protection for large persons, and the guaranteed ability to operate one's laptop.

## 5.2 RECOMMENDATIONS

The forward-sliding seat seems ideally suited for daytime flights lasting three hours or more. This includes flights from Boston to San Francisco or Los Angeles. Long-haul flights are recommended because passengers usually perform a variety of activities during long flights: reading, working, sleeping or eating. Such behavior would maximize their use of the lumbar support, adjustable headrest and height-adjustable tray, all shown to provide significantly better comfort. Furthermore, for long-haul flights, passengers are likely to get in and out of the seat more than once, and this can get annoying if the front seat is always in recline.

The team also recommends daytime flights because passengers are often more alert and more apt to be disgruntled during the day, by inconveniences such as having their space violated by the passenger in front, feeling the front seat pressing hard against their knees or not being able to open up their laptops.

Finally, even if the forward-sliding concept is not adopted, the team suggests implementing, in order of priority, the height-adjustable tray, the lumbar support, and the height-adjustable, winged headrest.

# 6. CONCLUSIONS

Aircraft seat design is no doubt a complex activity that places many constraints on the designer. Most people have assumed that there is little else that can be done with economy-class seating besides increasing legroom. In fact, when the team first started off, many people the team approached voiced their skepticism about what could be done within the five month time frame that was available. However, via a structured design process and a lot of hard work, the team was able to generate two design concepts that were conceptually different from aircraft seats in use today. The team then succeeded in designing, fabricating and testing these two concepts, and as shown in this thesis, the results for the forward-sliding concept proved encouraging. If nothing else, it is hoped that this thesis will provide ideas, insights, and test results for next-generation economy-class seats.

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# APPENDIX I: PASSENGER ENPLANEMENT DATA

Percentages Based on Information from Air Travel Survey. All numbers are in Thousands.

| | Total Passenger Enplanements | Purpose of Trip | | Percent of Trips | |
|---|---|---|---|---|---|
| | | Business | Personal | Business | Personal |
| 1977 | 240,326 | 124,970 | 115,356 | 52% | 48% |
| 1978 | 274,716 | | | | |
| 1979 | 316,863 | 174,275 | 142,588 | 55% | 45% |
| 1980 | 296,903 | | | | |
| 1981 | 285,976 | 148,708 | 137,268 | 52% | 48% |
| 1982 | 294,102 | | | | |
| 1983 | 318,638 | 162,505 | 156,133 | 51% | 49% |
| 1984 | 344,683 | 165,448 | 179,235 | 48% | 52% |
| 1985 | 382,022 | 191,011 | 191,011 | 50% | 50% |
| 1986 | 418,946 | 192,715 | 226,231 | 46% | 54% |
| 1987 | 447,678 | 214,885 | 232,793 | 48% | 52% |
| 1988 | 454,614 | 227,307 | 227,307 | 50% | 50% |
| 1989 | 453,692 | 222,309 | 231,383 | 49% | 51% |
| 1990 | 465,560 | 223,469 | 242,091 | 48% | 52% |
| 1991 | 452,301 | 208,058 | 244,243 | 46% | 54% |
| 1992 | 475,108 | 175,790 | 299,318 | 37% | 63% |
| 1993 | 488,520 | 234,490 | 254,030 | 48% | 52% |
| 1994 | 528,848 | 248,559 | 280,289 | 47% | 53% |
| 1995 | 547,384 | 224,427 | 322,957 | 41% | 59% |
| 1996 | 558,183 | | | | |
| 1997 | 599,300 (estimated) | | | | |

Source: NBTA Travel Industry Statistics (http://www.nbta.org/industry/stats_index htm)

# APPENDIX II: DESIGN TOOLS EMPLOYED

## A. Functional Flow Diagram (FFD)

The FFD is a common tool used by designers for system behavior analysis and idea generation. By mapping a sequence of activities with time, it provides an initial understanding of the total systems operation. The FFD characterizes which functions can be performed concurrently along with those that must be performed sequentially. This allows the designer to identify alternate paths that might be taken in order to simplify system operations. Among its many other benefits, the FFD provides the first opportunity for designers to implement new and creative ideas, so that the system will not only satisfy, but also "delight" the customer. For a detailed description of functional analysis and functional flow diagrams, the reader is referred to the book "System Engineering and Analysis" by Blanchard & Fabrycky.

## B. Quality Function Deployment (QFD)

The QFD method had its beginnings with the Quality Tables developed by Professor Mizuno at the Tokyo Institute of Technology for the Mitsubishi Kobe Shipyards in 1972. It is the process of translating customer needs into a set of specifications. QFD provides for the prioritization of requirements, the traceability of requirements and the minimization of human biases, among other things. The latter is particularly important in product design projects, where team members tend to over-estimate the importance of their work and designers to advocate only solutions that are familiar to them.

For the case of the requirements matrix, the QFD methodology translates customer needs in a set of technical requirements. This is taken one step further with the product design matrix, where the technical requirement importance weightings are used to determine design specification priorities.

In the QFD Requirements Matrix, the correlation between each technical requirement and customer need was assigned a number according to the following scale: 1 – weak, 3 – moderate, 9 – strong, and those unrelated were not assigned any numbers. These correlation factors were then multiplied by the corresponding needs importance weighting and summed for each technical requirement. Any conflicts between technical requirements were marked with a cross in the top triangle. The QFD Product Design Matrix employs the same rules, but without the conflict identification matrix at the top.

For a more detailed description of the QFD, the reader is referred to the report by Hauser & Clausing, published in the Harvard Business Review in 1988.

# APPENDIX III: 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?

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**Seat Aspects**

A. 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 |

B. 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 IV: RESEARCH FINDINGS

## A. Physiology/Ergonomics

### A.1 Posture/Sitting Position Effects on Comfort

When a person sits, the body is leaned slightly forward and the hips and knees are bent. The armrest, or the seat in front (for the case of an aircraft cabin environment) may be grasped to help hold the torso up to maintain balance. The long thigh bones (femurs) rotate in their pelvic sockets, while the pelvis is tipped back by the ligaments attaching the femurs to the pelvis. This backward tilting motion of the pelvis straightens the lower back, thus moving the spine a few centimeters away from the upper body's center of gravity. In order to keep the now front-heavy torso from slumping forward, the lower back muscles on the outside of the spine contract strongly and steadily (Klausen, 1965). While this is happening, the skin and muscles under the ischial tuberosities – the two hoop-shaped parts of the pelvis that a person sits on – undergo compression. The gluteus maximi, or the large buttock muscles, are pushed aside, leaving the ischial tuberosities resting on a cushion of fat and skin.

As a result of prolonged sitting in one position, the lower back muscles become fatigued (Sjogaard, et. al., 1984). The sitter then tries to relax them and if there is no backrest to keep the lower back straight, the body tends to slump down and forward, causing an outward-curving shape in the lower back. At the same time, the head leans forward, causing the muscles at the back of the neck to work hard to keep the head in its original position (Zacharkow, 1988). With a backrest, the lower back muscles relax with less downward and forward slumping of the torso.

Studies have found that in order to feel comfortable, the lower back vertebrae must not be exerted upon by high pressure. Standing or lying down puts little pressure on the spine, while sitting correctly more than doubles the pressure. In a slumped position, the pressure may increase by up to four times. Too much external pressure for long periods can reduce the blood flow to the skin and other tissues of the buttocks, thighs and back, and cause other kinds of damage. The slumped posture also stretches the ligaments and muscles and extends the back, causing the back extensor muscles to be chronically active. This detrimental combination of responses ultimately lead to pain.

NASA researchers, studying astronauts in zero-G environments, found that in the natural body position (also called the neutral position), the trunk-to-thigh angle is 128 degrees. It is believed that in Earth's 1-G environment, approximating this natural body position could relieve the tension in key muscles (low back, neck, shoulder and forearm) by as much as 75%. The neutral position may not be preferred by all people (Jensen et al., 1992), as the users of these chairs tend to have uncomfortable feelings of sliding forward. They may try to compensate by pushing back with the feet, which can tire the legs easily.

## A.2 The Proper Sitting Position and Seat Dimensions

Researchers provide the following guidelines with regards to the proper sitting position (Woodson, 1981):

- The feet should be placed flat on the floor with the knees at an angle of 90 degrees or slightly more.
- The chair should not be too high or too low; if too high, the pressure under the thighs reduces circulation to the lower leg; if too low, lower back pain may occur.
- The back of the knees should be two to three inches forward of the chairs front edge. This eliminates any pressure in the popliteal area (back of the knee) which contains blood vessels and nerves.
- The shoulders need to be relaxed, not hunched up.
- The arms should be close to the body and not required to make frequent, far reaches, or be held away from the body.
- Where armrests are used, elbows and lower arms should rest lightly so as not to cause circulatory or nerve problems

The following seat settings are recommended:

- The seat bottom should be tilted rearward approximately five degrees so that the upper torso weight is partially supported by the backrest.
- The angle between the seat bottom and the backrest should be approximately 105 degrees so that the torso will be in contact with the backrest, but without causing the occupant to excessively lean forward to balance his or her head.

- The seat bottom and backrest should be at least 485 mm (19 in) wide so that large occupants will not "lap over" beyond the seat edge.
- The fore-aft seat bottom length should be approximately 430 mm (17 in) long to provide adequate support to the occupant thighs, but without contacting the calves.
- The back rest, aside from the head rest, should be at least 510 mm (20 in high).
- The backrest should support the natural inward curve of the lumbar area, or lower spine
- The backrest should either be small enough to fit into the small of the back, clearing the pelvis and back of the rib cage (thoracic region), or curved to provide adequate support

### A.3 Lumbar Support

The spine is one of the most important structures in the body involved in seating. It consists of a chain of vertebrae, each subtly wedge-shaped to form a natural convex curve in the upper back and concave curve in the lower back and the neck. Lumbar support helps maintain a healthy inward (concave) curve of the lower back, described as "lumbar lordosis." Shen and Vertiz (1997) remark as follows:

> "A proper amount of lumbar lordosis is fundamental for maintaining the torso upright or reclined and the eyes at the right vision level. Without lumbar support, back muscles have to work to keep the potentially forward-rotating rib cage upright and overcome the weight. If the lumbar support is appropriate, the lumbar spine will shape into natural lordosis, which helps the pelvis rotate forward. A secured lumbar support carries a large amount of torso load from above the rib cage, and the lumbar support actually serves as a second pivot point, on which the rib cage is caught safely and the abdomen of the occupant opens up. This action in turn, enables the occupant's shoulder to be supported on the upper back and each region on the back can obtain adequate support. A lumbar support also provides stability to the pelvis."

Anderson et al. (1979) found that lumbar lordosis in a seated posture will be reduced as compared to a standing position by as much as 38 degrees on average, due to the tendency of backward rotation of the pelvis under hamstring muscle tension. Porter and Norris (1987) used a wooden test seat to gauge the preferred lumbar prominence and found that a 20 mm prominence was preferred to 40 and 50 mm with both reclined and vertical back angles. Dowell (1995) measured 773 seated persons at a vertical back angle and obtained the apex depth of the lumbar curve. The mean lumbar depth was 25 mm for males and 22 mm for females.

## A.4 Variations in Sitting Position

Although ergonomists make reference to the "ideal" sitting position, one has to be aware that long hours of sitting will eventually make a person feel uncomfortable, regardless on how good the seat is. Posture changes are generally believed to be signs of discomfort, and have been observed to be more frequent in uncomfortable or poorly-adjusted chairs (Mark et al., 1985). Some researchers believe it is due to uncomfortable high-pressure spots on the skin, while others attribute it to trying to achieve low-energy postures when muscle groups become tired. There are also those who believe posture changes are simply due to boredom, temperature and humidity buildup, or even daily cycles of restlessness (Jurgen, 1980). Nonetheless, experts in the rehabilitation field stress the importance of frequent weight shifts (every 15 minutes or so) to prevent tissue breakdown due to inhibited circulation (Casley, 1983). Posture change is essential to help pump fluid back into the intervertebral discs in the spine, which lose fluid over the course of the day because of the weight they carry (Kramer, 1977). (Intervertebral discs are tough lozenges of fibrous cartilage with a thick fluid in the center, separating the broad center plates of the vertebrae from each other.) This phenomenon is a biological means to protect the human tissues from compression damage (Shen and Vertiz, 1997). People who stand all day tend to have back problems, and so do people who sit all day (Magora, 1972). The longer a person sits, the higher the risk of herniated discs and other back troubles (Eklund, 1986). Thus, a well-designed seat has to support a comfortable posture that permits frequent variations in the sitting position through slight body shifts and /or seat adjustments.

## A.5 Reading and Writing

The two main reading postures are the forward position where the book and arms rest on the table, and the reclined position, where the book is held up by the hands. Both of these postures provide good viewing of the reading material and stabilize the body for better relaxation.

Between the two postures, the reclined reading position is generally preferable because the lower back has a better curvature than when sitting forward. The head, while still bent forward is more balanced than in the forward position, where looking down at reading material causes the neck and upper back muscles to work harder. The main drawback of the reclined posture is arm fatigue, which can be alleviated by properly positioned armrests. The forward posture fares no better in this respect, for resting the arms on a hard work surface may cause pressure on the ulnar nerve, either in the elbow or the forearm.

Writing, on the other hand, involves more precise hand-eye coordination than reading, affecting posture in more complicated ways. People generally write in a forward position, though there are some who write while reclined. Unlike in the forward reading posture, people are more apt to sit upright, even to the point of losing support in the back in the forward writing position. This posture leads quickly to lower back fatigue.

(Herman Miller, Inc., www.hermanmiller.*com*, "Body Support in the Office")

## A.6 The Food Tray as a Work Surface

The use of the aircraft seat tray – a provision that allows passengers to be served meals during flights – as a work surface is becoming more and more common nowadays. Rather than resting or trying to fall asleep during flights, business travellers, who make up between 40-50% of yearly aircraft enplanements (see Appendix I) prefer to make full use of their time by reading, writing or working on their laptops. As such, the degree to which the tray helps them perform these tasks would inadvertently be linked to their perception of the overall seat comfort.

The work-surface height is defined simply as the height of the upper surface of a table. Some researchers have recommended that work-surface heights be reduced in order to permit relaxed postures of the upper arms with respect to working height.

Having the upper arms and elbows relaxed, and about 90 degrees to each other helps maintain straight wrists and is widely considered to be the most comfortable work position. If the work-surface is also tiltable, there is less bending of the neck, a more upright trunk, and less trunk flexion than for horizontal work-surfaces. The general principles for seated work-surfaces are as follows:

- If at all possible the work-surface height should be adjustable to fit individual physical dimensions and preferences.
- The work-surface should be at a level that places the working height at elbow height.
- The work-surface should provide adequate clearance for a person's thighs under the work surface.

The table below presents some guidelines for work-surface heights from various sources based on representative anthropometric data.

**Table A.6: Recommended Work-Surface Heights**

| Type of Task | From | To |
|---|---|---|
| Reading and Writing | 27.5 inches | 31.0 inches |
| Range for typing desks | 23.5 inches | 27.5 inches |
| Computer keyboard use | 23.0 inches | inches |

## B. ANTHROPOMETRY

Anthropometry is a science where thousands of people are measured very thoroughly. Through the anthropometic databases, it is possible to determine, for example, how likely a sitting Amercan female is to have thighs wider than 10 inches. Several important measurements used by seat designers are:

- popliteal height (lower leg length)
- seat depth (buttock to popliteal length)
- hip breadth
- midshoulder sitting height (back height)
- elbow height
- lumbar height
- lumbar depth

Commonly accepted anthropometric tables are based on samples of military personnel that, due to entry and retention criteria for size, age, and physical condition, tend to exclude very large and very small persons.

The first percentile female and the $99^{th}$ percentile male are separated by 17 inches in height and 140 pounds in weight (Gordon et al., 1988). (A $50^{th}$ percentile male is 5 feet, 9 inches tall, weighs 171 pounds, and has a popliteal height of 17 inches.) In addition to that, there are gender-related differences in bone structure and weight distribution, and countless variations in limb lengths and body contours. A significant variation in bodily proportions exists even among people of the same gender, age, and stature (Pheasant, 1996). It is common practice in industry to design seats that fit anyone from the fifth percentile South Chinese woman – four feet eight inches tall, smaller than 95 percent of her South Chinese compatriots, to the ninety-fifth percentile northern European male – six feet three inches tall, larger than 95% of his kind. Within this range lies, theoretically, 99.7 percent of the world's population. However, someone who is at the 95$^{th}$ percentile for stature is likely to to be at a different percentile on distribution curves for lower leg length or sitting elbow height; there is no true 5$^{th}$ or 95$^{th}$ percentile person (Pheasant, 1996). The definition of "fit" itself is highly debatable. Herman Miller Inc. (1996), defines a chair that fits as one that allows the user to comfortably rest his or her feet on the floor, with the thighs fully supported and approximately parallel to the floor.

In order to provide fit to as large a population as possible, very little, or almost no contouring is provided on the modern aircraft seat. The more neck and lumbar contouring a seat has, the fewer people it fits. While some modern aircrart seats are flat – almost as flat as a door and perhaps almost as hard, most seats have backrests that are slightly concaved to help reduce the effects of sidesway movements. The concavity of backrests is subject to debate, as they provide points of high pressure that become uncomfortable over long-haul flights.

## C. MATERIALS

The right amount of cushioning is crucial for long-term sitting comfort. By adding just one inch of foam to flat, hard seats, the length of time before discomfort sets in can be tripled (Hertzberg, 1958). However, too much soft padding or seat contouring can cause muscle pain by exerting pressure on the gluteus maximi at the sides of the buttocks (Nola et. al., 1980), the heads of the femur bones (the trochanters) and, possibly, the sciatic nerves next to the trochanters (Hertzberg, 1958).

Domestic economy-class seat cushions for over-water flights must double as floatation devices in the event of a crash. To be specific, the seat cushion must retain at least 14 pounds of buoyancy after eight hours of squeezing. Only a relatively hard grade of foam, referred to as "floatation foam" can meet this requirement. Sitting solely on floatation foam over time could be as painful as sitting on a hard, wooden seat. Hence, the floatation foam is surrounded by a softer grade of foam that provides the needed amount of cushioning. One way around the requirement for floatation would be to install life jackets under the seats, as commonly done on business, first class and international economy class seats. The removal of the floatation foam allows for seats with better cushioning. However, this option is costly, and is seldom exercised on domestic-bound aircraft.

Two promising alternatives to the cushioning materials used in aircraft seats today were identified from the team's research. The first was Confor™ foam, a pressure and temperature sensitive foam that conforms to the occupant's body after a few minutes of seating. The second option was to get rid of the cushions altogether, making use of elastomeric fibers instead.

## C.1 Confor™ Foam

The team first heard of this material when it stumbled upon a website of a small company based in Oregon early on in the project. This company, Oregon Aero makes extensive use of Confor™ foam in their seat cushion designs, and with much success. Cushions designed by Oregon Aero have been used in pilot/co-pilot seats for commercial airplanes such as the Boeing 707, 727 and 737; military airplanes such as the F-22 and F-117 Stealth Fighters, the B-1 and B-2 bombers, the F-15 Eagle and the F-16 Falcon; and helicopters such as the CH47 Chinook and the H-60 Blackhawk. However, conformal-type foam is still relatively unknown to the commercial passenger seating industry.

Confor™ foam was developed by NASA for the Apollo Space Program to increase long term comfort of its astronauts and reduce chances of bodily injury. It is an open-cell polyurethane foam which is sensitive to pressure and temperature. Under sustained loads and increased temperatures, the foam softens and creeps multidirectionally, conforming to the body over the contact area, while keeping the non-contact surfaces firm and supportive. This material also breathes and wicks away body moisture, making it ideally suited for the disabled in wheelchairs, and people who sit for long periods of time at the computer, car, truck or airplane. Confor™ foam is most effective after the second and third hour of sitting in one position, when pressures will be evenly distributed and without any pressure concentrations. On impact, the viscous-damping properties of conformal foams allow them to absorb some of the impact energy which is converted to heat. This takes away some of the energy that would have otherwise been rebounded to the body, thus reducing the risk of serious injury, especially to military pilots in the event of a seat ejection. The foam is twice a durable as conventional foams, and meet current flammability standards.

Confor™ foam does have its drawbacks. It is difficult to cut to precision and is less durable in shear. Passengers who shift in their seats frequently may find the foam's slow rate of deformation recovery annoying and uncomfortable. (It has been argued though, that by conforming to the body and eliminating pressure points, the passenger will not find it necessary to shift positions as often.) These, and the fact that urethane foams are more expensive than conventional foams have served to discourage the large scale use of Confor™ foam in commercial passenger seats.

Nonetheless, Oregon Aero has reportedly been able to overcome some of these drawbacks via proprietary techniques. The company is able to cut the foam to a 0.005 inch precision with a specially designed bun saw (comercial thickness tolerance is currently within 0.125 inches). Cushions fabricated by the company are of multilayer construction, utilizing Confor™ foam of different hardness levels in conjuction with floatation foam. Oregon Aero obliged the team's request that it fabricated and loaned a seat cushion to the team for testing purposes. For results of this testing and detailed information on multilayer foam construction, the reader is referenced to the thesis by Zhang (June, 1999).

## C.2 Elastomeric Fibers

The team was first introduced to this material when it came across the Aeron office chair designed by Herman Miller Inc. This new and expensive office chair uses a specially developed elastomeric fiber that is injection molded onto a seat frame. Impressed by its qualities, the team decided to adopt the use of elastomeric fibers in its "webbing" concept (see Section 2.9 of the main text).

Elastomeric fibers are textile material that can be specially treated to suit various applications. It is completely recyclable and has the strength to provide complete body support in seating environments. This material takes up less space than seat cushions, saves on weight, conforms to the body, and provides cooler seating surfaces by allowing air to pass through.

Milliken & Company, the world's largest manufacturer of body-cloth materials, has fabricated several types of elastomeric fabric for use in aircraft seats. These fibers, such as the *M-Flex* and the *Crystalflex II*, meet current aircraft industry standards, including impact and flammability requirements.

The reader is referred to the thesis by Teo (June 1999) for a detailed discussion on the benefits of elastomeric fibers and its use on the team's "webbing" concept.

## D. PSYCHOLOGY

The team felt that the degree of comfort a person feels is, to some extent, a function of the person's psychological state of mind. One who enters the airplane happy and spends the time chatting with his or her neighbors will quite likely feel more comfortable than one who feels agitated or restless. The quality of service, or the provision of a personal entertainment system, may be all that the passenger needs to divert his or her attention away from any feelings of discomfort caused by the seat. A person's cultural background, age, sex and individual preferences may also come into play.

Among the different areas of research identified by the team, the field of psychology has been largely overlooked in the seat design industry, simply because of its highly subjective nature. The team pursued its research in this field nevertheless, as it would help the team understand aircraft passengers better and possibly gain a new perspective to the problem.

### D.1 Personal Space and Crowding

Personal space has been defined as the area which "has invisible boundaries surrounding a person's body, into which intruders may not come" (Sommer, 1969). The key functions of personal space are (Bell et al., 1990):

(a) to avoid overstimulation

- too close a proximity to others causes excessive social or physical stimuli (e.g. facial details, olfactory cues)

(b) to avoid a variety of stressors associated with too close a proximity

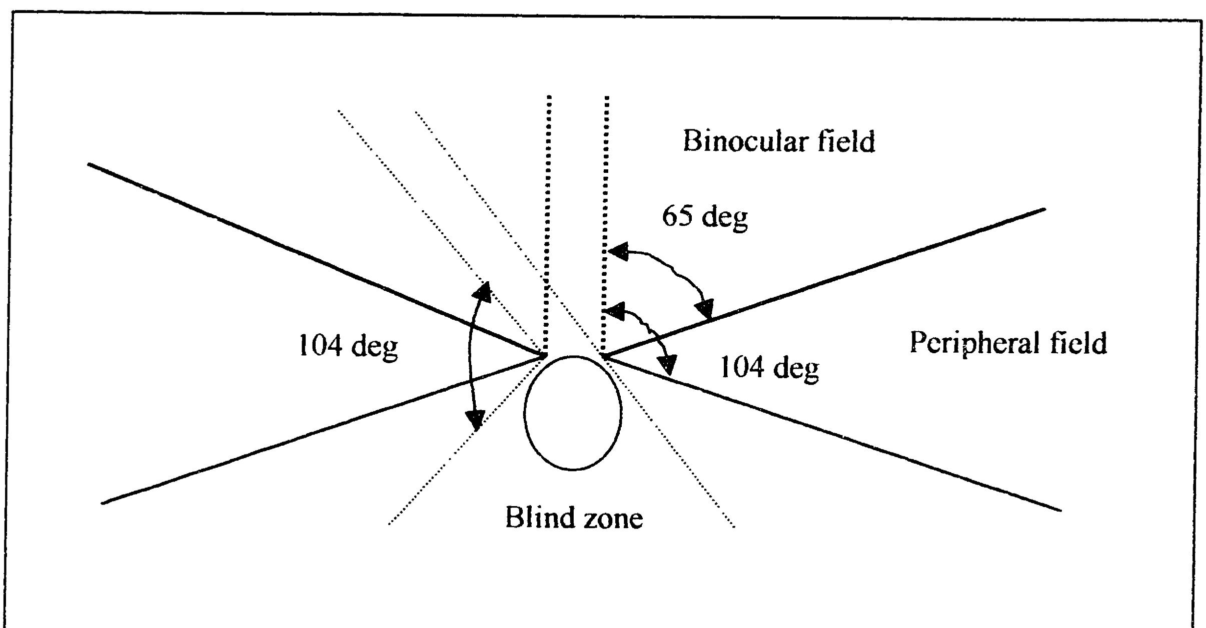
(c) to avoid arousal

- attributions in individuals who are attempting to understand why they are aroused, and the quality of these attributions can determine how people respond to inadequate personal space.

(d) to prevent one's behavioral freedom from being impinged upon.

The amount personal space a person needs varies by culture and race, gender (male-male interactions require greater space than female-female interactions) and age. Research has shown that the personal space bubble around individuals is more egg-shaped than circular, meaning that personal space in smaller at one's back than in front. This is due to the fact that our peripheral vision only extends to about 104 degrees, as shown in the Figure D.1 below (Pirenne, 1967). Hence, people can be placed closer together in a back-to-back arrangement without violating personal space than in a front-to-front arrangement, which is the reason why airport, train, bus and ferry terminals are lined with seats placed back-to-back to one another.

**Figure D.1: The Human Field of Vision**




When personal space is violated, the individual will either consciously or subconsciously, physically move to restore the proper distancing. When this movement is impossible, the individual may erect psychological barriers such as avoiding eye contact, folding the arms, or placing a piece of furniture in front of him. Although these barriers do not restore physical space, they do seem to restore psychological space. Stokols et al. (1981) recommended that room design provide the individual with barriers that need not be permanent or visually impregnable, but simply to give the individual the psychological sense that his or her space is "protected." For the case of an existing aircraft seating environment, the armrests serve as this barrier.

Passengers who sit in the window seats sometimes feel "crowded-in" due to the lack of an open aisle space to which they can move in and out of easily, without needing to interact with the adjacent passenger. This situation is made worse when the front seat is reclined. When individuals are crowded, an essential feature of the experience is that they have lost much of their ability to control what happens to them. The world either becomes unpredictable, or predictably undesirable (Gifford, 1996). One way to lessen the uncomfortable effects of being "crowded-in" is to provide passengers with means to personalize their spaces, and thus regain some sense of control over their environment. Adjustment mechanisms such as adjustable headrests, footrests and lumbar support may well serve this purpose. Certain arrangements of space can also be effective antidotes to crowding. In some cases, optimal arrangements may even be better solutions to crowding than simply providing more space (Gifford, 1996).

Biologist Glen McBride performed a study on the way turkeys behave when they are crowded in a coop. Accidental direct eye contact provoked aggression, which destroyed the turkey society. It is common then to find crowded birds lined up at the fence facing outward so that eye contact will be minimized (Sommer, 1974). This seems similar to the function of the aircraft windows, which provide psychological refuge for those who want to avoid potentially unpleasant visual encounters. Passengers can also retreat into newspapers and magazines, and occupy themselves with in-flight entertainment, if available.

It is to be noted though, that there are numerous situations in which an individual's personal space may be violated but crowding is not experienced Take for example, the spectators at football or basketball games, participants at rock concerts, or new year revelers on the eve of celebrations. These individuals are placed at intimate personal distance with strangers, yet do not usually report being crowded. As soon as individuals are aroused by violations of personal space, they must make attributions about the cause of their arousal. Crowding is experienced when the cause of arousal is attributed to other people being too close to them.

However, if they attribute their arousal to another source, such as the excitement of sports events or concerts, they will not experience crowding (Worchel, 1978).

Although much of the team's research has pointed to the need for more passenger isolation during flights, there were a few sources that indicated otherwise. Sommer (1974) provided the following comments:

> "The spatial experience of flying is nil and the social environment is as bad. The stewardess waits on each passenger individually and there is very little possibility for interaction between passengers. Very few passengers have ever made a friend during an air trip. The usual pattern is to mumble some generalities to the passenger sitting in the next seat, perhaps borrow a newspaper if one is especially bold, and say "Excuse me" as one exits to the restroom and returns. Flying in a commercial airline is as desolate an activity as waiting in an air terminal. The person who starts a trip alone will end the trip alone."

The present aircraft seating environment is most difficult on the elderly, the infirm, families with young children, and gregarious people who like to talk with their neighbors. The lone businessman in contrast, can easily adapt to the isolating arrangement, and may prefer it if he has work to do.

## D.2 Visual Effects: Colors and Patterns

There are a number of airlines that, in trying to project a particular image for the airline, pay a great deal of attention to aesthetics. The colors on their seat fabrics are usually chosen to match the airlines' colors as closely as possible. Some airlines like Cathay Pacific go one step further by ensuring the visible portions of the seat frame have matching colors as well. Studies have shown that different colors can illicit a variety of psychological and physiological responses among different people. It is not a matter of coincidence that seat fabrics are not colored orange, pink, yellow or black.

One aspect of color of traditional interest to psychologists has been the apparent tendency of red surfaces to "advance" and blue surfaces to "recede." In general, the colors whose dominant hues are of the shorter wave-lengths (violet, blue, blue-green, green) are retiring and whose dominant hues are of the longer wave-lengths (yellow, orange, red) are advancing

(Luckiesh, 1965). Acking and Kuller (1972) had subjects rate a series of slides depicting rooms that varied in color. Results indicated that lighter rooms were seen as more open and spacious. Similarly, Baum and Davis (1976) found that different intensities of the same color affected subjects' response to model rooms. Light-green rooms appeared larger and less crowded than identical rooms painted a darker green. Where there is high brightness and warm color, attention will extend outward to an environment, favoring the performance of muscular tasks. Conversely, where there is lower brightness and cooler color, as in an aircraft cabin, the environment will be less distracting and human attention will be directed inward. This reaction will be favorable for more exacting visual and mental tasks (Birren, 1988).

Studies have shown that in human beings, red tends to raise blood pressure, pulse rate, respiration, and skin response (perspiration) and to excite brain waves. There is noticeable muscular reaction (tension) and greater frequency of eye blinks. Blue tends to have reverse effects, lowering blood pressure and pulse rate. Less skin response is noticed, while brain waves tend to decline. The green region of the spectrum is more or less neutral. Orange and yellow incite a similar, though less pronounced reaction to red. The reaction to purple and violet is similar to the reaction to blue (Birren, 1978).

Kurt Goldstein, in his book "The Organism" and in many articles for the medical press argues that color has therapeutic and psychotherapeutic values. Goldstein offers the following generalization:

> "One could say red is inciting to activity and favorable for emotionally-determined actions; green creates the condition of meditation and exact fulfillment of the task. Red may be suited to produce the emotional background out of which ideas and action will emerge; in green these ideas will be developed and the actions executed" [Goldstein's emphasis].

Nonetheless, one must be aware that color effects are always temporary. If the color (and brightness) covers the general field of view, there will be adaptation in which the eye and brain will strive to discount the color and see things to be more or less normal. A good example is for the case of tinted sunglasses. The environment initially looks colored, but as adaptation takes effect, the mind will tend to disregard the tint of the glass. Any increase in blood pressure or pulse rate caused by red and orange only lingers on temporarily, and subsequent responses may be lesser in extent. Therefore, physiological and psychological color reactions, to be actively maintained, require constant change and sequence. This constant change is precisely what will help to counteract sensory deprivation (Birren, 1978). Mental institutions use a variety of colors in order to keep human responses continually active and to avoid visual adaptation or emotional monotony.

There has been dozens of color-preference tests conducted over the years. Infants tend to stare at luminous colors such as yellow, white, pink and red the longest. As the child grows, a liking for yellow begins to subside. At the same time, a greater preference for hues of shorter wavelength (blue, green) than for hues of longer wavelength (red, orange, yellow) develops. This usually leads to the eternal and international ranking for colors: blue, red, green, violet, orange, yellow (Birren, 1978). T.R. Garth found that American Indians preferred red, blue, violet, green, orange, yellow. For Filipinos the order was red, green, blue, violet, orange, yellow. Among Negroes the order was blue, red, green, violet, orange, yellow – the same as for practically everyone else. Even among insane objects, S. E. Katz found almost the same rankings – blue, green, red, violet, yellow, orange. To summarize the whole picture, H. J. Eysenck tabulated a mass of research involving some 21,060 individual judgments. Blue ranked first, then red, green, violet, orange and yellow. The order was basically the same across the sexes, except that, while men put orange in fifth place and yellow in sixth, women put yellow in fifth place and orange in sixth.

Preference for color may also be linked to personalities. The following generalizations are reproduced from the book by Birren, "Color and Human Response," published in 1978.

(a) Red

- Extroverts, impulsive, sexy, quick to speak the mind.
- If there is a dislike for red, which is fairly common, look for a person who has been frustrated, defeated in some way, bitter and angry because of unfulfilled longings.

(b) Pink

- Dilettantes, well educated, indulged, protected. No one of sound and admirable character should be upset by an innocuous color such as pink! Such a dislike would indicate annoyance with if not ire toward those who are pampered and indulged, the rich, the sophisticated, the vain.

(c) Orange

- Social color, cheerful, luminous, warm. Typifies the Irish character, persons of enviable good cheer, friendly, don't like to be left alone. Frequently disliked by those who "can't stand" the hail-fellow-well-met type, the politician, the preacher, backslapper. Life is a serious business.

(d) Green

- Perhaps the most American of colors. Symbolic of nature, balance, normality. Socially well-adjusted, civilized, conventional. Constantly on the go and savor the good things in life, nearly always overweight. Dislike of green is encountered at times. It might indicate a degree of mental disturbance. Such a person may lead a complex, often lonely existence.

(e) Blue-green

- Birren conducted some experiments and was intrigued to find that there were those who disliked blue and green, but liked blue-green. These people were sophisticated and discriminating, had excellent taste, well dressed, sensitive, and refined. Where a dislike of blue-green was met, though seldom, there was an ardent denunciation of conceit in others.

(f) Blue

- The color of conservatism, accomplishment, devotion, deliberation, introspection. Cautious, steady, often admirable. A dislike of blue may signal revolt, guilt, a sense of failure, anger over the accomplishment of others, resent the success of others. A dislike of blue is something to regret, for it may lead to great unhappiness if not neurotic behavior.

(g) Purple and Violet

- Looked upon as elegant by the average person. Vanity may be involved. Those who dislike purple are enemies of pretense, vanity, conceit and will readily disparage things cultural, which to them may be purely artificial.

(h) Brown

- More people dislike brown than like it.

(i) White

- Bleak, emotionless, sterile.

(j) Gray

- To dislike gray is less likely than to be indifferent to it.

(k) Black

- Only the mentally troubled are fascinated by it.

The research findings presented in this subsection seem to indicate that the following three colors are best for seat fabrics: blue, green and blue-green. Table D.2 below summarizes their strong points.

**Table D.2: Desirable Properties of Blue, Green and Blue-Green**

| Blue | Green | Blue-green |
|---|---|---|
| • Receeding<br>• Directs human attention inward<br>• Calming (lowers blood pressure, pulse rate, etc.)<br>• Ranked first in the international color preference ratings | • Receeding<br>• Directs human attention inward<br>• Neutral<br>• Ranked third in the international color preference ratings | • Receeding<br>• Directs human attention inward<br>• Calming, though weaker effects than blue<br>• Dislike for blue-green seldom met |

## E. PHYSICAL DESIGN FEATURES

The team brainstormed ideas and tried to recollect their individual experiences of seats used in various settings. These included seats used in the automobile, the commuter train, the ferry, the high speed train, the office, the classroom, the dental clinic, the cinema and the theater. The major seat features used in the various seating industries are listed below:

1) Seat height adjustability
   - This allows the user to adjust the chair so that his/her feet are on the floor.
   - Pneumatic adjustability works more easily than mechanical adjustability.
   - For an aircraft seat, the most likely mechanism to achieve this is an inflatable seat bottom.
2) Seat depth adjustability

- Achieved either by backrest in-out adjustability or a sliding seat pan, this changes the front-to-back depth of the seat.
- A shorter seat pan is necessary to allow small people to use the chair's backrest, while a deeper one feels more stable to taller individuals.
- The team eventually decided to implement the backrest in-out adjustability as discussed in this thesis, because fabricating a sliding seat pan is considerably more difficult.

3) Backrest angle adjustability
   - Refers to changing the angle of the backrest relative to the angle of the seat.
   - Often done with an adjustment mechanism, though it can also be accomplished via the use of flexing materials or springs in the chair shell.
   - This feature 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 angle between the torso and the thighs is also increased, causing the lower back to curve inward. This inward curve, called "lordosis," results in less pressure on the discs than a flat spinal shape.
   - Backrest angle adjustability can be achieved via a sliding-out backrest.
4) Chair recline, or tilt
   - This changes the angle of the entire seat relative to the floor.
   - As with backrest angle adjustability, a reclined chair transfers some upper-body weight to the backrest of the chair.
   - There are two main tilt geometries: column tilt and knee tilt. In the former, the chair pivots at the top of the base post and lifts the knees slightly while the back descends. The other is knee tilt, in which the pivot point is forward of the post, nearer the knees. In a knee tilt chair, the knee lift is negligible, but the back (and head) descend more than in a column tilt chair.
   - Tilting is used in some of the more recent office chairs; it is not a practical solution for aircraft seats.
5) Seat pan angle adjustability
   - This generally refers to changing the forward-back angle of the seat.
   - It consists of a choice of fixed angle, rather than a free-floating recline.

- This feature more commonly provides forward tilt, in which the thighs slope downward. The main purpose of forward tilt is to open the angle between the trunk and thighs, inducing lordosis and reducing disc pressure.

6) Armrests
   - A person's arms and shoulders typically account for about 15 percent of body weight. Studies show that the use of arm supports reduces the force on the lower back by as much as 26 percent (Occhipinti et al., 1985) to 40 percent (Andersson et al., 1974).
   - Armrests support the arms, reducing the work of the shoulders and possibly the upper arms. They can, however, be used inappropriately by inhibiting free motion of the arms during activities.
7) Armrests height adjustability
   - This helps avoid the problems of armrests that are too high, which result in elevated shoulders and pressure on the undersides of the elbows and forearms, and armrests that are too low, which require the passenger to slump or lean to one side to use them.
   - Height-adjustable armrests also can keep armrests out of the way activities requiring free motion.
   - Armrests on aircraft seats are too low for most people. However, implementing this feature is difficult because passengers have to share at least one armrest with the adjacent passenger.
8) Armrest width adjustability
   - This kind of adjustability changes the distance between armrests.
   - Armrests that are close to the body can help avoid splayed elbows, which in turn cause the wrists to bend to the side during activity.
   - The limited space in aircraft seats makes this an impractical option.
9) Padded armrests
   - These potentially avoid uncomfortable pressure on the undersides of the forearms and elbows.
10) Lumbar support
   - See Section A.3 in this appendix.
   - This is intended to prevent, to the extent possible, the flattening of the lumbar spine that occurs in most people when seated.

- Lumbar support is usually done through gentle curves in the backrest shape.
- The design concept addressed by this thesis includes an inflatable lumbar support.

11) Backrest height adjustability
    - This refers to a change in height of the lumbar support area of the chair backrest, although this feature is often interpreted to mean a change in height of the entire backrest.
    - This feature accommodates preferences by different workers regarding where and how the lumbar support curve contacts the back.
    - The team has implemented this feature into its design.
12) Lumbar depth adjustability
    - This affects the size and sometimes the firmness of the lumbar support curve in a chair's backrest.
    - Like backrest height adjustability, it accommodates different preferences and body shapes.
    - The inflatable lumbar support designed by the team provides lumbar depth adjustability.
13) Headrest height adjustability
    - Fixed height headrests can be either too low or too high for passengers; too low a headrest causes passengers to slump or tilt their heads backwards so as to relieve the strain on the neck; too high also causes the passenger to slump, so that the head rests against the backrest.
14) Winged-headrest
    - Already implemented in major airlines in long-haul, this feature is conducive for sleeping for its allows passengers to rest their heads on the sides, thus relieving the neck muscles.
15) Dentist chair headrest
    - The doughnut-shaped cushioning on this headrest cradles the head and provides very good support.
    - However, due to its very specific contouring, it must be height-adjustable to accommodate people of different heights.

- People who like to tilt their heads sideways while sleeping may find this headrest uncomfortable.

16) Tray height adjustability
   - Current tray heights are too low for most people and cause strain in the neck as they lean forward to eat or work.
   - Leaning too far forward also causes strain in the lower back.
   - A height-adjustable tray would eliminate these problems and also provide clearance for the thighs.

17) Slanted tray surface
   - This feature provides for less bending of the neck, a more upright trunk and less trunk flexion than horizontal tray surfaces.

18) Leg support
   - Widely seen in first and business class seats, this feature supports the calves and is particularly useful while the seat is reclined.
   - Usually used in conjunction with a footrest.
   - Difficult to implement in economy class due to the small distance between seats.

19) Backward-facing seats
   - Seen in most train coaches due to the train moving in reverse directions between destinations.
   - This is a safer seat configuration than forward-facing seats because the backrest prevents the passenger from being thrown forward during aircraft decelerations.
   - Can cause diorientation and discomfort to passengers used to facing forward in moving vehicles.

# APPENDIX V: SECOND CUSTOMER SURVEY

**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, Neutral – 3, Poor – 4, Very Poor – 5)

a. Getting in/out of:

| | | | | | |
|---|---|---|---|---|---|
| (i) aisle seat with front seat upright | 1 | 2 | 3 | 4 | 5 |
| (ii) aisle seat with front seat reclined | 1 | 2 | 3 | 4 | 5 |
| (iii) window seat w. front seat upright | 1 | 2 | 3 | 4 | 5 |
| (iv) window seat w. front seat reclined | 1 | 2 | 3 | 4 | 5 |

(For the activities below, please also indicate the percentage of time spent on each activity.)

| | | | | | | |
|---|---|---|---|---|---|---|
| b. Reading | _____% of time | 1 | 2 | 3 | 4 | 5 |
| c. Working (writing, operating laptop, etc.) | _____% of time | 1 | 2 | 3 | 4 | 5 |
| d. Eating | _____% of time | 1 | 2 | 3 | 4 | 5 |
| e. Sleeping | _____% of time | 1 | 2 | 3 | 4 | 5 |
| f. Chatting | _____% of time | 1 | 2 | 3 | 4 | 5 |

**4. Preferences:**

a) How much would you desire a seat that provides
privacy/isolation? (Very much) 1 2 3 4 5 (Not at all)

b) Do you usually recline your seat during flight? Yes____ No____

c) How disturbed are you when the person in front reclines
his/her seat? (Very much) 1 2 3 4 5 (Not at all)

d) How much would you be willing to trade off the recline feature of the seat for an adjustable back support? (Very much) 1 2 3 4 5 (Not at all)

e) Would you rather have the magazine/safety card storage pocket below your seat than in front of you? Yes____ No____

f) How much would you desire:

(i) a sliding in/out tray? (Very much) 1 2 3 4 5 (Not at all)

(ii) a tiltable tray (Very much) 1 2 3 4 5 (Not at all)

(iii) a height-adjustable tray (Very much) 1 2 3 4 5 (Not at all)

# APPENDIX VI: QFD PRODUCT DESIGN RANKING PROCESS

| Rank | Feature | Score | Weightings based on research (scale: 1-5) | | | | Revised Score | Average of the Original and Revised Scores |
|---|---|---|---|---|---|---|---|---|
| | | | Human Factors I | Human Factors II | Human Factors III | Psychology | | |
| 1 | Non-reclinable seats | 757 | 0 | 0 | 0 | 0 | 757 | 757 |
| 2 | Webbing as cushioning substitute | 626 | 0 | 0 | 0 | 3 | 686 | 656 |
| 3 | Thin diaphragm seats without cushions | 529 | 0 | 0 | 0 | 0 | 529 | 529 |
| 4 | Tiltable trays | 443 | 3 | 3 | 0 | 0 | 563 | 503 |
| 5 | Sliding trays | 477 | 5 | 3 | 0 | 0 | 637 | 557 |
| 6 | Height-adjustable trays | 467 | 5 | 3 | 0 | 0 | 627 | 547 |
| 7 | Adjustable foot rest | 441 | 3 | 3 | 3 | 0 | 621 | 531 |
| 8 | One-type adjustment mechanisms (electrical) | 437 | 1 | 3 | 0 | 0 | 517 | 477 |
| 9 | Arm rests that swing out to facilitate conversation | 414 | 0 | 4 | 0 | 0 | 494 | 454 |
| 10 | Vertically adjustable seat back | 409 | 2 | 3 | 4 | 3 | 649 | 529 |
| 11 | "Wings" to rest head on | 396 | 0 | 3 | 4 | 0 | 536 | 466 |
| 12 | Flat seat back | 394 | 0 | 0 | 0 | 0 | 394 | 394 |
| 13 | Cup holder on arm rest | 393 | 0 | 0 | 0 | 0 | 393 | 393 |
| 14 | Pillow secured to the seat with velcro (position adjustable) | 393 | 2 | 2 | 0 | 0 | 473 | 433 |
| 15 | Tiltable seat bottom (entire) | 388 | 3 | 3 | 4 | 2 | 628 | 508 |
| 16 | Adjustable leg rest | 379 | 3 | 3 | 3 | 0 | 559 | 469 |
| 17 | One-type adjustment mechanisms (pneumatic/hydraulic) | 375 | 1 | 3 | 0 | 0 | 455 | 415 |
| 18 | Conventional foams | 374 | 0 | 0 | 0 | 0 | 374 | 374 |
| 19 | Height-adjustable arm rests | 365 | 0 | 3 | 5 | 4 | 605 | 485 |
| 20 | Adjustable lumbar support (electrical) | 363 | 3 | 3 | 4 | 5 | 663 | 513 |
| 21 | Sliding-out seats | 362 | 3 | 3 | 0 | 3 | 542 | 452 |
| 22 | Retractable screens that block other passengers from field of vision | 361 | 0 | 5 | 0 | 0 | 461 | 411 |
| 23 | Store hand items below seat (remove front pocket) | 361 | 0 | 0 | 0 | 0 | 361 | 361 |
| 24 | Bag/pocket hanging from seat bottom edge (remove front pocket) | 361 | 0 | 0 | 0 | 0 | 361 | 361 |
| 25 | Height-adjustable head/neck rest (mechanical) | 357 | 0 | 3 | 5 | 4 | 597 | 477 |
| 26 | One-type adjustment mechanisms (mechanical) | 357 | 1 | 3 | 0 | 0 | 437 | 397 |
| 27 | Aesthetically pleasing patterns of fabric | 352 | 0 | 2 | 0 | 0 | 392 | 372 |
| 28 | Tiltable seat bottom (front edge) | 352 | 3 | 3 | 4 | 2 | 592 | 472 |
| 29 | Foldable head rest to facilitate front-back conversation | 349 | 0 | 5 | 0 | 0 | 449 | 399 |
| 30 | Seat to diagonal bed transformation | 349 | 0 | 3 | 0 | 0 | 409 | 379 |
| 31 | Adjustable seat height (mechanical) | 340 | 3 | 3 | 0 | 5 | 560 | 450 |
| 32 | Dark colors to make stains less visible | 337 | 0 | 0 | 0 | 0 | 337 | 337 |
| 33 | Width adjustable arm rest | 337 | 0 | 3 | 0 | 3 | 457 | 397 |
| 34 | Patterns on fabric that give feeling of greater space | 331 | 0 | 2 | 0 | 0 | 371 | 351 |
| 35 | One type of foam | 327 | 0 | 0 | 0 | 0 | 327 | 327 |
| 36 | One type of structural material | 327 | 0 | 0 | 0 | 0 | 327 | 327 |
| 37 | Adjustable lumbar support (mechanical) | 326 | 3 | 3 | 4 | 5 | 626 | 476 |
| 38 | One-type adjustment mechanisms (inflatable) | 324 | 1 | 3 | 0 | 0 | 404 | 364 |
| 39 | Colors that are pleasing to the eyes | 323 | 0 | 2 | 0 | 0 | 363 | 343 |
| 40 | Logo on seat back to draw attention away from peripheral vision | 320 | 0 | 3 | 0 | 0 | 380 | 350 |

## APPENDIX VI (CONTINUED)

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 41 | Contoured seat back | 319 | 0 | 0 | 5 | 0 | 419 | 369 |
| 42 | Light colors to convey better sense of depth | 304 | 0 | 3 | 0 | 0 | 364 | 334 |
| 43 | Inflatable arm rests | 304 | 0 | 3 | 3 | 4 | 504 | 404 |
| 44 | Contour head rest | 298 | 0 | 0 | 0 | 0 | 298 | 298 |
| 45 | Horizontally adjustable backrest | 298 | 3 | 3 | 0 | 3 | 478 | 388 |
| 46 | Durable and longlasting fabric | 291 | 0 | 0 | 0 | 0 | 291 | 291 |
| 47 | Inflatable lumbar support | 283 | 3 | 3 | 3 | 5 | 563 | 423 |
| 48 | Personal entertainment system | 283 | 0 | 5 | 0 | 0 | 383 | 333 |
| 49 | Zip-up seat covers (to facilitate cleaning) | 280 | 0 | 0 | 0 | 0 | 280 | 280 |
| 50 | Variable light intensity | 280 | 0 | 3 | 0 | 0 | 340 | 310 |
| 51 | Cushioned arm rest | 271 | 0 | 0 | 0 | 5 | 371 | 321 |
| 52 | Space-age colors | 270 | 0 | 1 | 0 | 0 | 290 | 280 |
| 53 | Inflatable head rests | 265 | 0 | 3 | 3 | 3 | 445 | 355 |
| 54 | Sinkable (all the way) arm rest (instead of upwards rotation) | 262 | 0 | 2 | 0 | 0 | 302 | 282 |
| 55 | Concave contouring | 259 | 2 | 0 | 0 | 0 | 299 | 279 |
| 56 | Edge contouring | 252 | 0 | 0 | 4 | 0 | 332 | 292 |
| 57 | Smooth fabric | 243 | 0 | 0 | 0 | 0 | 243 | 243 |
| 58 | Textured fabric | 235 | 0 | 0 | 0 | 0 | 235 | 235 |
| 59 | Pelvic support | 235 | 0 | 0 | 4 | 0 | 315 | 275 |
| 60 | Inflatable seat bottom | 235 | 2 | 3 | 0 | 5 | 435 | 335 |
| 61 | Knee cushions | 233 | 0 | 0 | 0 | 0 | 233 | 233 |
| 62 | Foldable seat bottom | 232 | 0 | 3 | 0 | 0 | 292 | 262 |
| 63 | Downward foldable seat bottom front to facilitate ingress/egress | 227 | 0 | 3 | 0 | 0 | 287 | 257 |
| 64 | Lower seat bottoms (no luggage space) | 214 | 0 | 0 | 0 | 0 | 214 | 214 |
| 65 | "Slides" at the back of trays depicting sunset, mountain, etc. | 181 | 0 | 4 | 0 | 0 | 261 | 221 |
| 66 | Soft and comfortable fabric (nice to the touch) | 153 | 0 | 0 | 0 | 0 | 153 | 153 |
| 67 | Sideways rocking seat bottom | 144 | 0 | 2 | 4 | 3 | 324 | 234 |
| 68 | Protruding head rest edges for more privacy | 141 | 0 | 2 | 0 | 0 | 181 | 161 |
| 69 | Flip-over seat bottom | 134 | 0 | 2 | 0 | 0 | 174 | 154 |
| 70 | Protruding seat edges to symbolically mark personal boundaries | 133 | 0 | 2 | 0 | 0 | 173 | 153 |
| 71 | Electronic massage pillows | 130 | 0 | 2 | 0 | 0 | 170 | 150 |
| 72 | Middle seats offset backwards to facilitate 3-way/4-way conversation | 120 | 0 | 5 | 0 | 0 | 220 | 170 |
| 73 | Seats arranged diagonally | 85 | 0 | 4 | 0 | 0 | 165 | 125 |
| 74 | Confor foam | 73 | 0 | 0 | 0 | 0 | 73 | 73 |
| 75 | Sandwich structure in the cushion | 52 | 0 | 0 | 0 | 0 | 52 | 52 |
| 76 | Theatre-style seating | 37 | 0 | 0 | 0 | 0 | 37 | 37 |
| | Average: | 308 | Maximum: | 757 | | | | |
| | Maximum - Average: | 449 | | | | | | |
| | Weighting to assign to each research area: | 22.5 | Weighting factor = (Max-Avg)/(Max possible research total) | | | | | |

Note: Four team members were asked to rank each feature on a scale of 1-5 based on their research (3 on human factors and 1 on psychology). To calculate the revised score, the sum of the team member scores are multipled by a weighting factor and added to the original scores. The rational was to allow a feature having the average population score to attain a higher score than the original top ranked feature (757) if it receives the maximum possible score for research while the latter receives nothing. For example, a concept with the average score of 308 could have a total score of 308+(5+5+5+5)*22.5 = 758. (A weighting factor of 20 was finally used for the sake of convenience.)

# APPENDIX VII: CONCEPT GENERATION

| Concept # | Provide more space | Facilitate in-flight activities | Provide better support | Score |
|---|---|---|---|---|
| 1 | - Non-reclinable seat | - Sliding-out seat<br>- Cushioned armrest | - Adjustable lumbar support<br>- Winged headrest | 2472 |
| 2 | - Non-reclinable seat | - Height-adjustable armrest<br>- Cushioned armrest | - Adjustable seat height<br>- Pillow secured to seat with velcro | 2446 |
| 3 | - Non-reclinable seat | - Foldable head rest<br>- Cup holder on armrest | - Adjustable lumbar support<br>- Winged headrest | 2491 |
| **4** | **- Non-reclinable seat** | **- Height-adjustable tray** | **- Inflatable lumbar support**<br>**- Height-adjustable headrest**<br>**- Winged headrest** | **2670** |
| 5 | - Non-reclinable seat<br>- Webbing | - Sliding-out seat<br>- Cup holder on armrest | - Adjustable foot rest | 2789 |
| 6 | - Webbing | - Height-adjustable armrest | - Adjustable leg rest<br>- Adjustable foot rest | 2141 |
| **7** | **- Webbing** | **- Height-adjustable tray** | **- Height-adjustable headrest**<br>**- Winged headrest** | **2146** |
| 8 | - Webbing | - Height-adjustable armrest | - Seat to diagonal bed transformation<br>- Adjustable foot rest | 2051 |
| 9 | - Webbing | - Tiltable seat bottom<br>- Cup holder on armrest | - Height-adjustable headrest | 2034 |
| 10 | - Webbing | - Height-adjustable tray<br>- Inflatable armrest | -Adjustable lumbar support | 2083 |

# APPENDIX VIII: HUMAN SUBJECT EXPERIMENT PROTOCOL

**Experimental Study on the comfort of a passenger aircraft seat**

I. 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. The aircraft environment is to be represented as precisely as possible.

II. 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.*
*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.

III. 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.

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.

IV. 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)

**For the experimenter use**

Seat type:

Subject number:

Questionnaire 1: sitting

| | | | | | | |
|---|---|---|---|---|---|---|
| **Overall comfort** | comfort 1 | 2 | 3 | 4 | 5 | discomfort |
| **arm** | comfort 1 | 2 | 3 | 4 | 5 | discomfort |
| **thigh** | comfort 1 | 2 | 3 | 4 | 5 | discomfort |
| **leg** | comfort 1 | 2 | 3 | 4 | 5 | discomfort |
| **foot** | comfort 1 | 2 | 3 | 4 | 5 | discomfort |
| **neck** | comfort 1 | 2 | 3 | 4 | 5 | discomfort |
| **shoulder** | comfort 1 | 2 | 3 | 4 | 5 | discomfort |
| **back** | comfort 1 | 2 | 3 | 4 | 5 | discomfort |
| **lumbar** | comfort 1 | 2 | 3 | 4 | 5 | discomfort |
| **hip** | comfort 1 | 2 | 3 | 4 | 5 | discomfort |

Comments (if any):

Seat type:

Subject number:

Questionnaire 2: working

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

______________________________________________________________________________
______________________________________________________________________________
______________________________________________________________________________
__________________________________________________

| | | | | | | |
|---|---|---|---|---|---|---|
| **Overall comfort** | comfort | 1 | 2 | 3 | 4 | 5 discomfort |
| **arm** | comfort | 1 | 2 | 3 | 4 | 5 discomfort |
| **thigh** | comfort | 1 | 2 | 3 | 4 | 5 discomfort |
| **leg** | comfort | 1 | 2 | 3 | 4 | 5 discomfort |
| **foot** | comfort | 1 | 2 | 3 | 4 | 5 discomfort |
| **neck** | comfort | 1 | 2 | 3 | 4 | 5 discomfort |
| **shoulder** | comfort | 1 | 2 | 3 | 4 | 5 discomfort |
| **back** | comfort | 1 | 2 | 3 | 4 | 5 discomfort |
| **lumbar** | comfort | 1 | 2 | 3 | 4 | 5 discomfort |
| **hip** | comfort | 1 | 2 | 3 | 4 | 5 discomfort |
| **use of tray** | easy | 1 | 2 | 3 | 4 | 5 uneasy |
| **comfort with tray** | comfort | 1 | 2 | 3 | 4 | 5 discomfort |

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

Comments (if any):

Seat type:

Subject number:

## Questionnaire 3: eating

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Overall comfort** | comfort | 1 | 2 | 3 | 4 | 5 | discomfort |
| **arm** | comfort | 1 | 2 | 3 | 4 | 5 | discomfort |
| **thigh** | comfort | 1 | 2 | 3 | 4 | 5 | discomfort |
| **leg** | comfort | 1 | 2 | 3 | 4 | 5 | discomfort |
| **foot** | comfort | 1 | 2 | 3 | 4 | 5 | discomfort |
| **neck** | comfort | 1 | 2 | 3 | 4 | 5 | discomfort |
| **shoulder** | comfort | 1 | 2 | 3 | 4 | 5 | discomfort |
| **back** | comfort | 1 | 2 | 3 | 4 | 5 | discomfort |
| **lumbar** | comfort | 1 | 2 | 3 | 4 | 5 | discomfort |
| **hip** | comfort | 1 | 2 | 3 | 4 | 5 | discomfort |
| **use of tray** | easy | 1 | 2 | 3 | 4 | 5 | uneasy |
| **comfort with tray** | comfort | 1 | 2 | 3 | 4 | 5 | discomfort |

Comments (if any):

Seat type:

Subject number:

## Questionnaire 4: resting

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

_______________________________________________

_______________________________________________

_______________________________________________

________________________________

| | | | | | | |
|---|---|---|---|---|---|---|
| **Overall comfort** | comfort | 1 | 2 | 3 | 4 | 5 discomfort |
| **arm** | comfort | 1 | 2 | 3 | 4 | 5 discomfort |
| **thigh** | comfort | 1 | 2 | 3 | 4 | 5 discomfort |
| **leg** | comfort | 1 | 2 | 3 | 4 | 5 discomfort |
| **foot** | comfort | 1 | 2 | 3 | 4 | 5 discomfort |
| **neck** | comfort | 1 | 2 | 3 | 4 | 5 discomfort |
| **shoulder** | comfort | 1 | 2 | 3 | 4 | 5 discomfort |
| **back** | comfort | 1 | 2 | 3 | 4 | 5 discomfort |
| **lumbar** | comfort | 1 | 2 | 3 | 4 | 5 discomfort |
| **hip** | comfort | 1 | 2 | 3 | 4 | 5 discomfort |
| **use of lumbar support** | easy | 1 | 2 | 3 | 4 | 5 uneasy |
| **lumbar support** | comfort | 1 | 2 | 3 | 4 | 5 discomfort |

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

General comments about the seat:

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

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

| | | | | |
|---|---|---|---|---|
| Much better | Better | Comparable | Worse | Much worse |

# APPENDIX IX: EXPERIMENT RESULTS

## IX.A.1: Results for Forward-Sliding -- 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 |
| 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 uncomfortable because 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 comfortable |
| 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 | 2.5 | 2.3 | 2.2 | 2.2 | 2.7 | 2.5 | 2.1 | 2.0 | 2.2 | 2.3 |
|---|---|---|---|---|---|---|---|---|---|---|---|

## APPENDIX IX: EXPERIMENT RESULTS

## IX.A.2: Results for Forward-Sliding -- Questionnaire 2

| | | Biographical Data | | | | 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 |
| 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 6 | 2.3 | 2.2 | 2 5 | 2.4 | 2 5 | 2.3 | 2.2 | 2.1 | 2.5 | 2.0 | | |

# APPENDIX IX: EXPERIMENT RESULTS

## IX.A.3: Results for Forward-Sliding -- Questionnaire 3

| | | Biographical Data | | | | 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 |
| 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 | Overall comfort | arm | thigh | leg | foot | neck | shoulder | back | lumbar | hip | head | use of tray | comfort with tray |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Average | 2.1 | 2.3 | 2.4 | 2.2 | 2.1 | 2.1 | 2.1 | 2.2 | 2.3 | 2.1 | 2.0 | 2.2 | 1.5 |

# APPENDIX IX: EXPERIMENT RESULTS

## IX.A.4.1: Results for Forward-Sliding -- Questionnaire 4

| | | Biographical Data | | | | 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 |
| 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 comfortable 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 left 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 | | deflated 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 comfortable 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 do so next time |
| | | | | | | **Average** | 2.5 | 2.4 | 2.5 | 2.2 | 2.2 | 2.3 | 2.5 | 2.6 | 2.5 | 2.4 | 2.4 | 2.0 | 2.1 | | |

# APPENDIX IX: EXPERIMENT RESULTS

## IX.A.4.2: Results for Forward-Sliding -- Questionnaire 4 (continued)

| | | Biographical | | | | Comments | Compare with. | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Subject number | Exp number | Age | Height | Weight | Gender | General feeling | Much better | Better | Comparable | Worse | Much Worse |
| 1 | 2 | 23 | 6'6 | 285 | M | Overall fairly comfortable - middle back support doesn't quite work - sliding aspect pretty bad - hard to use and eliminates leg room - puts extra pressure on thighs at edge of seat - best improvement is adjustable headrest. | | 1 | | | |
| 2 | 2 | 27 | 5'1 1 3/4 | 180 | M | Head room welcome addition when decided to sleep: gave neccessary support to keep head from bobbing side to side. Could relax more. Reclining mechanics detrimental to leg and butt room. Ranks better because of head rest. | | 1 | | | |
| 3 | 1 | 22 | 5'2 | 120 | F | Lumbar support not too comfortable - tray table very difficult too open, but VERY comfortable & useful once deployed - prefer reclining seats to sliding seats - head rest made sleeping more comfortable (when reclined) because there was more support for turning your head. | | | 1 | | |
| 4 | 2 | 32 | 5'4 | 145 | M | Arm rest too small and too hard. Head rest not comfortable. | | | | 1 | |
| 5 | | | | | | | | | | | |
| 6 | 2 | 20 | 5'1 0 | 178 | M | Fs feature too complicated and effects on position not simple enough to be useful. Reduced total seat area. Lumbar support very nice, adjustability simple and specific enough to be effective. | | | 1 | | |
| 7 | 1 | 23 | 5'9 | 150 | F | Seat extremely comfortable - lumbar support made this chair stand out as the most comfortable airline seat I have ever sat in - did not really use the head rest (leaning position) - chair uncomfortable in reclined position - would be nice if (middle) armrest was wider to accomodate two arms - A normal reclining seat with lumbar support & adjustable head rest would be ideal. | | | | | |
| 8 | 3 | 24 | 6'1 | 190 | M | Seat seemed comfortable at beginning but less and less during flight (esp lumbar supp: maybe didn't find right position and lumping) - fs quite comfy but decreases too much leg room and cuts thighs - head rest comfortable but can be used only in resting position. Seat ranks a little better. | | 0.5 | 0.5 | | |
| 9 | 2 | 21 | 5'1 0 | 165 | M | Uncomfortable - head rest should be back more - sliding seat forward left me with less leg room - layout of seat did not support my back well | | | | 1 | |
| 10 | 1 | 21 | 5'7 | 145 | M | Pretty good - especially like the inflatable thing for the back - sliding part makes seat small. | | 1 | | | |
| 11 | 3 | 30 | 5'6 | 120 | F | Cumbersome: pumping of back and having to adjust. | | | 1 | | |
| 12 | 1 | 24 | 5'9 | 150 | M | Good points:tray, lumbar support. Bad points: bottom too narrow. | | 1 | | | |

# APPENDIX IX: EXPERIMENT RESULTS

## IX.B.1: Results for Baseline -- Questionnaire 1

| | | Biographical Data | | | | 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 |
| 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 familiar feel. Difficult 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 comfortable - 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 support not adequate - shoulder support 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 comfortable in this seat (attributing to early comfort familiarity with this type of seat). Immediately after sitting, felt as if was actually sitting in an aircraft. Nice leg/foot room. Noticeable difference in back support due to lack of lumbar 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 | 2.4 | 2.6 | 2.4 | 2.3 | 1.9 | 2.8 | 2.8 | 2.5 | 3.0 | 2.2 | 2.3 |

# APPENDIX IX: EXPERIMENT RESULTS

## IX.B.2: Results for Baseline -- 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 |
| 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 | 5'1 1 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 | 5'1 0 | 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 with thighs and legs. Tray uncomfortable: 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 | 5'1 0 | 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 | Overall comfort | arm | thigh | leg | foot | neck | shoulder | back | lumbar | hip | head | use of tray | comfort with tray |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Average | 2.7 | 2.5 | 2.6 | 2.3 | 2.3 | 2.8 | 2.4 | 2.9 | 3.3 | 2.5 | 2.7 | 2.7 | 3.8 |

# APPENDIX IX: EXPERIMENT RESULTS

## IX.B.3: Results for Baseline -- 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 |
| 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 for 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 because tray so low (like eating from your lap) - otherwise seat comfortable 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 seat. |
| 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 reclined was in the way significantly for any activity, esp eating - overall comfort 2 because tray is 1 but chair itself 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 forward 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 | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2.8 | 2.8 | 2.9 | 3.0 | 2.7 | 2.5 | 2.6 | 2.8 | 3.3 | 2.8 | 2.4 | 2.5 | 3.4 |

# APPENDIX IX: EXPERIMENT RESULTS
## IX.B.4.1: Results for Baseline -- Questionnaire 4

| | Biographical | | | | Questions | | | | | | | | | | | | | | Comments | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 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 |
| 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 especially at neck - no head support. |
| 3 | 27 | 5'11 3/4 | 180 | M | read, seat slightly rec, tray down. Front seat fully reclined | 3 | 3 | 1 | 1 | 1 | 4 | 2 | 2 | 3 | 2 | 3 | | | - | Choice of tasks made it difficult to be comfortable with front seat reclined. Very little room to read, tray too low. Arm tired having to hold paper at eye level. |
| 3 | 22 | 5'2 | 120 | F | rested, sat, talked (45mn) | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 1 | 2 | | | | |
| 3 | 32 | 5'4 | 145 | M | sleeping (30mn), relaxing (20mn) | 2 | 2 | 2 | 2 | 2 | 4 | 2 | 2 | 2 | 2 | 4 | | | fine | |
| 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. |
| 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. |
| 2 | 23 | 5'9 | 150 | F | homework | 3 | 2 | 4 | 3 | 3 | 2 | 2 | 4 | 4 | 2 | 2 | | | - | Space extremely restricted with front seat reclined. Difficult to have drink on table. Back sore, tray uncomfortable because it puts pressure on thighs. |
| 1 | 24 | 6'1 | 190 | M | working (1h30) | 5 | 3 | 5 | 4 | 4 | 5 | 5 | 4 | 5 | 3 | 4 | | | - | Tray too low. |
| 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. |
| 3 | 21 | 5'7 | 145 | M | chatting (1h) | 2 | 2 | 2 | 3 | 2 | 3 | 2 | 3 | 3 | 2 | 2 | | | | |
| 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. |
| 3 | 24 | 5'9 | 150 | M | rested | 3 | 3 | 4 | 3 | 3 | 3 | 4 | 3 | 4 | 4 | 3 | | | | Tray definitely too low. |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Average | 3.0 | 2.6 | 2.7 | 2.6 | 2.6 | 3.3 | 2.8 | 3.1 | 3.3 | 2.6 | 2.9 |

# APPENDIX IX: EXPERIMENT RESULTS

## IX.B.4.2: Results for Baseline -- Questionnaire 4 (continued)

| | | Biographical Data | | | | Comments | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Compare with... | | | | |
| Subject number | Exp number | Age | Height | Weight | Gender | General feeling | Much better | Better | Comparable | Worse | Much wor |
| 1 | 1 | 23 | 6'6 | 285 | M | Alright - uncomfortable - head support too low. | | | | | |
| 2 | 3 | 27 | 5'11 3/4 | 180 | M | Very average. Overall vey firm, making any position other than upright slightly uncomfortable. Head rest at very uncomfortable height. Very little side-to-side restraint for head, keeping from sleeping comfortably and deeply. Tray table should be higher. | | | | | |
| 3 | 3 | 22 | 5'2 | 120 | F | Fairly comfortable - only complaint; tray table very difficult to use and too low - headrest nice, standard but comfortable. | | | | | |
| 4 | 3 | 32 | 5'4 | 145 | M | Head support makes head uncomfortable when sitting reclined. | | | | | |
| 5 | 1 | 21 | 5'5 | 178 | M | Very average - neck support OK for short while but then quickly strains neck - arm rest: could use softer material - neck rest should be adjustable. | | | | | |
| 6 | 3 | 20 | 5'10 | 178 | M | Pain in back/butt region and strain in neck while writing - nice shoulder support, easiest to sleep/rest in - while other seats ratings were consistent, this one gets more uncomfortable with time, a large factor for longer flights. | | | | | |
| 7 | 2 | 23 | 5'9 | 150 | F | Started off fine. Lower back sore after eating. Tray too low, uncomfortable for thighs. Not enough room to operate tray table when front seat reclined. | | | | | |
| 8 | 1 | 24 | 6'1 | 190 | M | Not comfortable for lumbar, shoulders & back - really bad tray - here leg room not too bad - really tired at the end like always. | | | | | |
| 9 | 3 | 21 | 5'10 | 165 | M | Seat comfortable overall but not when sleeping. | | | | | |
| 10 | 3 | 21 | 5'7 | 145 | M | Pretty comfortable sitting upright, but when sleeping or slouching, lack support in back and head/neck. | | | | | |
| 11 | 1 | 30 | 5'6.5 | 120 | F | Leg space okay, considering time period. Bur for resting, head and neck uncomfortable. | | | | | |
| 12 | 3 | 24 | 5'9 | 150 | M | At beginning, seemed very comfortable but no lumbar support, tray too low and was lying on thighs. | | | | | |

# APPENDIX IX: EXPERIMENT RESULTS

## IX.C.1: Rating Differences between Forward-Sliding and Baseline -- Questionnaire 1

| Subject # | Overall comfort | arm | thigh | leg | foot | neck | shoulder | back | lumbar | hip | head |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | -1 | 1 | 0 | 0 | 1 | -2 | -3 | -1 | -1 | -1 | -1 |
| 2 | 0 | 0 | 0 | 0 | 0 | 0 | -1 | 0 | -1 | 1 | 0 |
| 3 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | -1 | -2 | 0 | 0 |
| 4 | 1 | 0 | 0 | 0 | 1 | 2 | 1 | 1 | 1 | 1 | 3 |
| 6 | 0 | 0 | -1 | 0 | 0 | -2 | 2 | -1 | -1 | 0 | 0 |
| 7 | -1 | 0 | 1 | 1 | 2 | 0 | -1 | -1 | -2 | 0 | 0 |
| 8 | -2 | -2 | 0 | -2 | -1 | -1 | -3 | -2 | -2 | 0 | -1 |
| 9 | 2 | 1 | -1 | 0 | 0 | 2 | 2 | 2 | -1 | 0 | 2 |
| 10 | 0 | 1 | 1 | 0 | -1 | 0 | 1 | -1 | -1 | 0 | -1 |
| 11 | 1 | 1 | 0 | 0 | 1 | -1 | -1 | 1 | 1 | 1 | -1 |
| 12 | 0 | -1 | 0 | 0 | -1 | 1 | 0 | -1 | -2 | -1 | -1 |
| | | | | | | | | | | | |
| Average | 0.000 | 0.091 | 0.000 | -0.091 | 0.182 | 0.000 | -0.182 | -0.364 | -1.000 | 0.091 | 0.000 |
| Standard Deviation | 1.205 | 1.038 | 0.696 | 0.771 | 1.080 | 1.556 | 1.957 | 1.327 | 1.205 | 0.771 | 1.476 |
| | | | | | | | | | | | |
| t-value | 0.000 | 0.290 | 0.000 | -0.391 | 0.558 | 0.000 | -0.308 | -0.909 | -2.752 | 0.391 | 0.000 |
| | | | | | | | | | | | |
| Number of positive differences | 3 | 4 | 2 | 1 | 4 | 4 | 5 | 3 | 2 | 3 | 2 |
| Number of negative differences | 3 | 2 | 2 | 1 | 3 | 4 | 5 | 7 | 9 | 2 | 5 |
| p-value | .113 | .033 | .033 | .006 | .113 | .274 | .5 | .113 | .033 | .033 | .033 |

## APPENDIX IX: EXPERIMENT RESULTS

### IX.C.2: Rating Differences between Forward-Sliding and Baseline -- Questionnaire 2

| Subject # | Overall comfort | arm | thigh | leg | foot | nsck | shoulder | back | lumbar | hip | head |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 1 | 1 | -1 | 0 | -3 | -1 | 0 | -1 | 0 | -2 |
| 2 | 0 | 0 | 0 | 0 | 0 | -1 | -1 | 0 | -1 | -1 | 1 |
| 3 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 |
| 4 | -1 | 0 | 0 | 0 | 0 | -1 | 0 | 1 | 1 | 1 | -1 |
| 6 | 0 | 0 | 0 | 1 | -1 | 0 | 1 | -1 | -2 | -1 | 0 |
| 7 | -2 | 0 | -1 | 0 | 1 | 0 | 1 | -1 | -2 | 0 | 0 |
| 8 | -1 | -2 | 0 | -1 | 0 | 0 | -1 | -3 | -3 | 0 | -1 |
| 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -1 | 0 | 0 |
| 10 | 0 | 1 | 1 | 1 | -1 | 1 | 0 | -2 | -1 | 0 | 0 |
| 11 | 0 | 0 | 0 | 0 | 0 | -1 | 0 | 1 | 1 | -0.5 | -1.5 |
| 12 | 0 | -1 | 0 | 0 | 0 | -1 | -1 | 0 | -1 | 0 | -1 |
| | | | | | | | | | | | |
| Average | -0.364 | -0.091 | 0.091 | 0.000 | -0.091 | -0.455 | -0.091 | -0.364 | -0.909 | -0.136 | -0.500 |
| Standard Deviation | 0.742 | 0.914 | 0.593 | 0.696 | 0.593 | 1.241 | 0.914 | 1.415 | 1.343 | 0.607 | 0.953 |
| | | | | | | | | | | | |
| t-value | -1.626 | -0.330 | 0.508 | 0.000 | -0.508 | -1.215 | -0.330 | -0.852 | -2.245 | -0.745 | -1.741 |
| | | | | | | | | | | | |
| Number of positive differences | 0 | 2 | 2 | 2 | 1 | 2 | 3 | 3 | 2 | 1 | 1 |
| Number of negative differences | 3 | 2 | 1 | 2 | 2 | 5 | 4 | 4 | 8 | 3 | 5 |
| p-value | 0 | .033 | .006 | .033 | .006 | .033 | .113 | .113 | .033 | .006 | .006 |

## APPENDIX IX: EXPERIMENT RESULTS

### IX.C.3: Rating Differences between Forward-Sliding and Baseline -- Questionnaire 3

| Subject # | Overall comfort | arm | thigh | leg | foot | neck | shoulder | back | lumbar | hip | head | tray |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | -1 | 0 | 0 | -1 | -2 | -1 | -1 | 1 | -2 | -1 | -1 | -2 |
| 2 | -1 | -1 | 0 | 0 | 0 | -1 | -1 | -1 | -2 | 0 | 0 | -2 |
| 3 | -1 | -2 | -3 | -3 | -2 | 0 | 0 | -1 | 1 | -1 | -2 | -4 |
| 4 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | -1 |
| 6 | 0 | -1 | 0 | -1 | 0 | 0 | 0 | -3 | -2 | -1 | 0 | 1 |
| 7 | -2 | 0 | -1 | -1 | -1 | -1 | -1 | -1 | -3 | -1 | -1 | -3 |
| 8 | -2 | -1 | -1 | -1 | -1 | -1 | -2 | -2 | -2 | -1 | 0 | -3 |
| 9 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 2 | 1 | 0 | 1 | -2 |
| 10 | 0 | 0 | 1 | -1 | 0 | 0 | 0 | -1 | -1 | 0 | 0 | -2 |
| 11 | 0 | 1 | -1 | -1 | 0 | 0 | 0 | 1 | 1 | -1 | 0 | -2 |
| 12 | -1 | -1 | 0 | -1 | -1 | -1 | -1 | -2 | -3 | -1 | -1 | -2 |
| | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| Average | -0.636 | -0.364 | -0.455 | -0.818 | -0.545 | -0.364 | -0.455 | -0.636 | -1.091 | -0.636 | -0.364 | -2.000 |
| Standard Deviation | 1.017 | 1.017 | 1.139 | 1.080 | 1.028 | 0.742 | 0.902 | 1.652 | 1.736 | 0.555 | 0.890 | 1.391 |
| | | | | | | | | | | | | |
| t-value | -2.076 | -1.186 | -1.323 | -2.513 | -1.760 | -1.626 | -1.671 | -1.278 | -2.084 | -3.803 | -1.355 | -4.767 |
| | | | | | | | | | | | | |
| Number of positive differences | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 3 | 3 | 0 | 1 | 1 |
| Number of negative differences | 6 | 5 | 4 | 8 | 5 | 5 | 5 | 7 | 7 | 7 | 4 | 10 |
| p-value | .006 | .033 | .006 | .006 | .006 | .006 | .006 | .113 | .113 | 0 | .006 | .006 |

## APPENDIX IX: EXPERIMENT RESULTS

### IX.C.4: Rating Differences between Forward-Sliding and Baseline -- Questionnaire 4

| **Subject #** | Overall comfort | arm | thigh | leg | foot | neck | shoulder | back | lumbar | hip | head |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | -1 | -1 | 1 | -1 | -1 | -2 | -1 | 0 | 0 | 0 | -1 |
| 2 | -2 | -1 | 0 | 0 | 0 | -2 | 0 | -1 | -1 | -1 | -2 |
| 3 | 1 | 0 | 0 | 0 | 0 | 2 | 2 | 2 | 2 | 1 | 1 |
| 4 | 0 | 1 | 0 | 0 | 0 | -2 | 0 | 1 | 1 | 0 | 0 |
| 6 | -1 | -1 | 0 | -2 | -3 | -1 | -1 | -2 | -2 | 0 | -2 |
| 7 | -1 | 0 | -2 | -1 | -1 | 0 | 0 | -3 | -3 | -1 | 0 |
| 8 | -2 | 0 | -2 | -1 | -1 | -3 | -2 | -1 | -2 | 0 | -2 |
| 9 | 1 | 0 | 0 | 0 | 0 | -1 | 0 | 1 | 0 | 0 | 0 |
| 10 | 0 | 0 | 1 | -1 | 0 | -1 | 0 | -2 | -2 | 0 | 0 |
| 11 | 0 | 0 | 0 | 0 | 1 | -1 | 0 | 0 | 0 | 0 | -1 |
| 12 | -1 | -1 | 0 | 0 | 0 | -1 | -2 | 0 | -2 | -2 | -1 |
| | | | | | | | | | | | |
| Average | -0.545 | -0.273 | -0.182 | -0.545 | -0.455 | -1.091 | -0.364 | -0.455 | -0.818 | -0.273 | -0.727 |
| Standard Deviation | 1.139 | 0.711 | 1.080 | 0.756 | 1.139 | 1.430 | 1.232 | 1.658 | 1.691 | 0.865 | 1.110 |
| | | | | | | | | | | | |
| t-value | -1.588 | -1.272 | -0.558 | -2.392 | -1.323 | -2.529 | -0.979 | -0.909 | -1.605 | -1.046 | -2.173 |
| | | | | | | | | | | | |
| Number of positive differences | 2 | 1 | 2 | 0 | 1 | 1 | 1 | 3 | 2 | 1 | 1 |
| Number of negative differences | 6 | 4 | 2 | 5 | 4 | 9 | 4 | 5 | 6 | 3 | 6 |
| p-value | .033 | .006 | .033 | 0 | .006 | .006 | .006 | .113 | .033 | .006 | .006 |

# APPENDIX X: STATISTICAL TESTS OF SIGNIFICANCE

Reference: Mosteller and Rourke, "Sturdy Statistics," Addison-Wesley, 1973.

### A. Paired T-Test

Assumes data is continuous and on interval scale (i.e., '3' is 3 times larger than '1'). Data is paired: same person responds in each category (baseline and forward-sliding).

x1bar : Mean Forward-Sliding rank

x2bar: Mean Baseline rank

dbar: Mean difference

n: Sample size – 11.

s: Variance

1) Calculate the variance.

2) Calculate the t-statistic:

$$t = (x1bar - x2bar) / (s / n^{1/2})$$

3) Determine significance from t-distribution table (Table X.I):

for n=11, we use t (n-1) = t (10). From the table, 95% confidence ($p < 0.05$) requires $|t| > 1.812$.

### B. Sign Test

1) List the signs of the differences:

(only list non-zero differences: if difference is zero, drop that set of data)

For example: +, -, +, -, -, +, -, +, +, -, +.

2) Record the number of the fewest type of sign, call this 'r.'

For above example, 5 of 11 differences are -'s so r=5.

3) Using a binomial distribution table (Table X.II), find the probability of getting 'r' or fewer 'hits' from 'n' trials where each trial has probability 0.5 of 'hitting.'

For this example, n=11, r=5, and from the table, p = 0.291.

Since $p > 0.05$, we cannot say Forward-Sliding was ranked significantly higher than Baseline.

**Table X.I: Critical Values of the T-Distribution**

| n-1 | Level of significance | | | | |
|---|---|---|---|---|---|
| | 0.1 | 0.05 | 0.025 | 0.01 | 0.005 |
| 1 | 3.078 | 6.314 | 12.706 | 31.821 | 63.657 |
| 2 | 1.886 | 2.920 | 4.303 | 6.965 | 9.925 |
| 3 | 1.638 | 2.353 | 3.182 | 4.541 | 5.841 |
| 4 | 1.533 | 2.132 | 2.776 | 3.747 | 4.604 |
| 5 | 1.476 | 2.015 | 2.571 | 3.365 | 4.032 |
| 6 | 1.440 | 1.943 | 2.447 | 3.143 | 3.707 |
| 7 | 1.415 | 1.895 | 2.365 | 2.998 | 3.499 |
| 8 | 1.397 | 1.860 | 2.306 | 2.896 | 3.355 |
| 9 | 1.383 | 1.833 | 2.262 | 2.821 | 3.250 |
| **10** | **1.372** | **1.812** | **2.228** | **2.764** | **3.169** |
| 11 | 1.363 | 1.796 | 2.201 | 2.718 | 3.106 |
| 12 | 1.356 | 1.782 | 2.179 | 2.681 | 3.055 |
| 13 | 1.350 | 1.771 | 2.160 | 2.650 | 3.012 |
| 14 | 1.345 | 1.761 | 2.145 | 2.624 | 2.977 |
| 15 | 1.341 | 1.753 | 2.131 | 2.602 | 2.947 |
| 16 | 1.337 | 1.746 | 2.120 | 2.583 | 2.921 |
| 17 | 1.333 | 1.740 | 2.110 | 2.567 | 2.898 |
| 18 | 1.330 | 1.734 | 2.101 | 2.552 | 2.878 |
| 19 | 1.328 | 1.729 | 2.093 | 2.539 | 2.861 |
| 20 | 1.325 | 1.725 | 2.086 | 2.528 | 2.845 |
| 21 | 1.323 | 1.721 | 2.080 | 2.518 | 2.831 |
| 22 | 1.321 | 1.717 | 2.074 | 2.508 | 2.819 |
| 23 | 1.319 | 1.714 | 2.069 | 2.500 | 2.807 |
| 24 | 1.318 | 1.711 | 2.064 | 2.492 | 2.797 |
| 25 | 1.316 | 1.708 | 2.060 | 2.485 | 2.787 |
| 26 | 1.315 | 1.706 | 2.056 | 2.479 | 2.779 |
| 27 | 1.314 | 1.703 | 2.052 | 2.473 | 2.771 |
| 28 | 1.313 | 1.701 | 2.048 | 2.467 | 2.763 |
| 29 | 1.311 | 1.699 | 2.045 | 2.462 | 2.756 |
| infinity | 1.282 | 1.645 | 1.960 | 2.326 | 2.576 |

Source: Fisher and Yates, 1974

**Table X.II: One-tail P-values (x 1000) for relatively extreme values in the sign test or binomial. (Binomial: p=0.5)**

| n | 0 | 1 | 2 | 3 | 4 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 500 | | | | | | | | | | | |
| 2 | 250 | | | | | | | | | | | |
| 3 | 125 | 500 | | | | | | | | | | |
| 4 | 062 | 312 | | | | | | | | | | |
| 5 | 031 | 188 | 500 | | | | | | | | | |
| 6 | 016 | 109 | 344 | | | | | | | | | |
| 7 | 008 | 062 | 227 | 500 | | | | | | | | |
| 8 | 004 | 035 | 145 | 363 | | | | | | | | |
| 9 | 002 | 020 | 090 | 254 | 500 | | | | | | | |
| 10 | 001 | 011 | 055 | 172 | 377 | | | | | | | |
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | | | |
| 11 | **006** | **033** | **113** | **274** | **500** | | | | | | | |
| 12 | 003 | 019 | 073 | 194 | 387 | | | | | | | |
| 13 | 002 | 011 | 046 | 133 | 291 | 500 | | | | | | |
| 14 | 001 | 006 | 029 | 090 | 212 | 395 | | | | | | |
| 15 | | 004 | 018 | 059 | 151 | 304 | 500 | | | | | |
| 16 | | 002 | 011 | 038 | 105 | 227 | 402 | | | | | |
| 17 | | 001 | 006 | 025 | 072 | 166 | 315 | 500 | | | | |
| 18 | | 001 | 004 | 015 | 048 | 119 | 240 | 407 | | | | |
| 19 | | | 002 | 010 | 032 | 084 | 180 | 324 | 500 | | | |
| 20 | | | 001 | 006 | 021 | 058 | 132 | 252 | 412 | | | |
| | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
| 21 | 001 | 004 | 013 | 039 | 095 | 192 | 332 | 500 | | | | |
| 22 | | 002 | 008 | 026 | 067 | 143 | 262 | 416 | | | | |
| 23 | | 001 | 005 | 017 | 047 | 105 | 202 | 339 | 500 | | | |
| 24 | | 001 | 003 | 011 | 032 | 076 | 154 | 271 | 419 | | | |
| 25 | | | 002 | 007 | 022 | 054 | 115 | 212 | 345 | 500 | | |
| 26 | | | 001 | 005 | 014 | 038 | 084 | 163 | 279 | 423 | | |
| 27 | | | 001 | 003 | 010 | 026 | 061 | 124 | 221 | 351 | 500 | |
| 28 | | | | 002 | 006 | 018 | 044 | 092 | 172 | 286 | 425 | |
| 29 | | | | 001 | 004 | 012 | 031 | 068 | 132 | 229 | 356 | 500 |
| 30 | | | | 001 | 003 | 008 | 021 | 049 | 100 | 181 | 292 | 428 |

Source: Mosteller & Rourke, 1973

# APPENDIX XI: COMPANY PROFILE AND CONTACT INFORMATION

## XI.I BE AEROSPACE

The world's #1 maker of commercial aircraft cabin products, B/E Aerospace sells its products to most major airlines and aviation equipment manufacturers. Its aircraft seating accounts for more than 50% of sales. Other products include passenger entertainment and service systems (in-seat video systems and audio distribution systems). It also makes cabin interiors and related products such as side walls, bathrooms, lighting, air valves, oxygen-delivery systems, galley structures, and inserts such as coffee and beverage makers, ovens, and refrigerators. B/E offers upgrade and refurbishment, maintenance, inspection, and repair of its own products and those of other manufacturers.

Address: 1400 Corporate Center Way
Wellington, FL 33414
Phone: 561-791-5000
Fax: 561-791-7900

(Source: www.hoover.com)

## XI.II OREGON AERO

This company designs and manufactures more than 300 products for aviation and other industries. These products, such as seat cushions, ejection seats, headrests and helmets, provide comfort, noise reduction, improved safety and better durability. Oregon Aero also manufactures products for motorcycles, fork lifts, trucks, race cars, humvees, bicycles, professional video cameras, computers, office chairs, and mountaineering and kayaking equipment.

Address: 4020 Skyway Drive,
Scappoose, Oregon 97056
Phone: 503-543-7399
1-800-888-6910

Fax: 503-543-7199

(Source: www.oregonaero.com)

### XI.III MILLIKEN & COMPANY

Milliken & Company's fabrics and chemicals are used in everything from crayons to spacesuits. One of the US's largest textile companies, it produces finished fabrics for uniforms, spacesuits, rugs, and carpets, as well as textiles for tennis balls, printer ribbons, and sails. The company also makes chemicals that are used in dyes, plastics, and petroleum products. Milliken owns more than 1,500 patents and operates almost 70 plants, including a large textile research center.

Address: 920 Milliken Road,
Spartanburg, SC 29304
Phone: 864-503-2020
Fax: 864-503-2100

(Source: www.hoover.com)

### XI.IV NORTHWEST AIRLINES

Northwest Airlines, the United States' fourth-largest airline, flies to 150 cities worldwide, with hubs in Detroit, Memphis, Minneapolis-St. Paul, Osaka, and Tokyo. Through code-sharing agreements with KLM and other carriers, the airline serves about 400 destinations in 80 countries. It also has an extensive alliance with Continental. With about 400 aircraft, Northwest is one of the world's top air cargo carriers (about 8% of revenues). Other interests include the WORLDSPAN computer reservation system (32%) and subsidiaries such as MLT (wholesale travel and tour programs) and Northwest Aerospace Training (pilot training).

Address: 5101 Northwest Drive
St. Paul, MN 55121-3034

Phone: 612-726-2111

Fax: 612-727-7617

(Source: www.hoover.com)

## XI.V TEKSCAN, INC.

Tekscan delivers the most advanced tactile pressure measurement systems in the world. Each sensor is a thin, flexible grid-based device utilizing conductive and semi-conductive inks. Tekscan systems are based on standard IBM-PC compatible platforms. Each system typically includes: system software, sensor connector (or scanning handle), and a custom data acquisition card. The software is menu-driven and is simple to use. Current applications of its system include automotive seating design and comfort studies, brake pad contact studies, circuit board fabrication, ergonomic tool design, high-speed impact studies, hospital and commercial matress design, tire tread pressure distribution and wheelchair cushion design.

Address: 307 West First Street,
South Boston, MA 02127-1342

Phone: 617-464-4500
1-800-248-3669

Fax: 617-464-4266

(Source: Tekscan, Inc.)

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