Anthropometric Study to Update Minimum Aircraft Seating Standards

Prepared for:

Joint Aviation Authorities

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Foreword

This study was initiated by the Joint Aviation Authorities (JAA) under UK Civil Aviation Authority funding. The study was undertaken against a background trend of generally increasing body dimensions within the European population. This trend, when combined with an increasing number of longer duration flights and high density seating, prompted the need for a wide-ranging review of published anthropometric data that would guide JAA when considering the need for any regulation in this area.

It should be noted that this report concentrates on the safety issues associated with seating arrangements. The specific aim is to ensure that seating standards are such that passengers would be able to quickly evacuate an aircraft in the event of an emergency. Thus, the study considers seating accommodation against expected population body dimensions. Software modelling has been used to make an initial assessment of the relationship between seating dimensions and evacuation difficulties. The health implications of aircraft seating are also considered. However, the comfort aspects of aircraft seating did not form part of the research study.

1.0 Executive summary

1.1. Objectives of the study

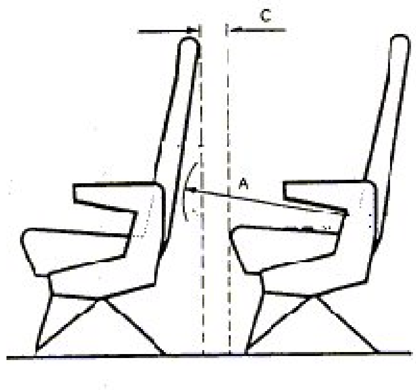
The Joint Aviation Authorities (JAA) requested ICE Ergonomics to undertake a review to advise on data for a possible JAA regulation. This review was to consider the *scope* of the requirements in addition to the actual *minimum values* contained therein.

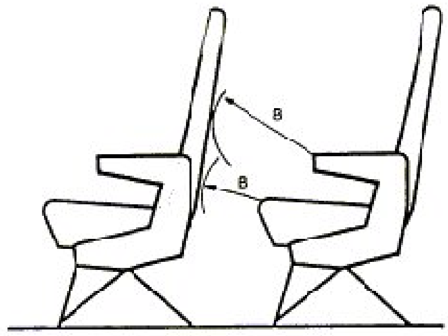
In addition to seated space and efficient passenger egress, the study was to review the health aspects of long term sitting in aircraft seats and the scope for addressing these through seat spacing or design.

The objective of the study was to provide information for JAA regulatory action, if required.

Member countries of the Joint Aviation Authorities (JAA) do not currently have regulations regarding aircraft seat spacing with the exception of the UK. The UK Civil Aviation Authority Airworthiness Notice 64 regulates the minimum seat space dimensions for all UK registered aircraft over 5700kg MTWA which carry 20 passengers or more. Minimum safety requirements were set out using anthropometric data for 5th percentile female and 95th percentile male values which aimed to minimise the effects of lower seat pitches upon the quality of seat occupancy and the ease of egress from the seats. The three main requirements described in AN64 are described below: -

Dimension	Description	Minimum
A	The minimum distance between the back support cushion of a seat and the back of the seat or other fixed structure in front	26 inches (660mm)
B	The minimum distance between a seat and the seat or other fixed structure in front.	7 inches (178mm)
C	The minimum vertically projected distance between seat rows or between a seat and any fixed structure forward of the seat.	3 inches (76mm)





These dimensions apply when the seat is in the upright position and do not take into account seat cushion compression.

1.2. Methodology

The work was based on a review of the most up-to-date anthropometric data taken from PeopleSize and Adultdata, which collate data from all available sources and weight this to take account of the increase in size of people over time. The most recent scientific knowledge on the causes and incidence of flight-related thromboembolic disease was also reviewed. A passenger questionnaire survey, expert appraisal and human-model Computer Aided Design (CAD) analysis were used to consider the potential requirements (using AN64 as a basis) and to review the need to amend its scope.

The anthropometric data was then used to review the adequacy of the dimensions in AN64 and to develop recommendations for revised dimensions by means of CAD modelling using the SAMMIE CAD system (an established tool which enables both equipment and human to be modelled and manipulated) and comparison with anthropometric data for both European and World populations.

AN64 is based on data for 5^{th}%ile to 95^{th} %ile range of passenger sizes, which means that at least 10% of passengers will not be accounted for. It is widely recognised that where safety is concerned the range should be increased to cover the 1st%ile to 99th%ile range. Using this range will also ensure that the gradual increase in people's sizes, which can be anticipated within the lifetime of any JAA regulation, is also accommodated. This study therefore developed both '**minimum'** recommendations (i.e. 5th and 95th percentile) and **'ideal'** recommendations (i.e. 1st and 99th%ile, to take account of safety and secular growth). However, it is strongly recommended that any revised minimum seat space requirements should be based on a wider range of user sizes, namely 1st %ile to 99th %ile.

The recommendations also accommodate the findings of the review of the health implications of long term sitting.

This stage of the study was not intended to include any validation testing and hence the recommendations are provisional at this time.

1.3. Findings

The dimensions of A, B and C are probably the most critical but the current minima need to be increased. The current requirement for dimension A, for example, will only accommodate up to 77th%ile of the European population (based on buttock-knee lengths). Dimensions B and C will accommodate even fewer passengers (based on whole-body depth measurements).

It is recommended that **dimension A** (seat back cushion to back of seat in front) be increased to at least 711mm (28.2") to accommodate up to the 95th%ile European seated passenger (minimum recommendation). This allows for an additional 25mm (1") of knee clearance to the back of the seat in front, which ideally should be afforded to ensure that the knees do not contact the seat in front (i.e. the passenger should not be jammed in) and to improve ease of access/egress, to allow for some postural flexibility. The ideal recommendation would be to increase dimension A to at least 747mm (29.4" – 99%ile world).

Furthermore AN64 currently only considers the seats when in the upright position. In order to ensure passengers have adequate space when seated, dimension A, and the proposed foot clearance envelopes, should be measured with the seat in front in the recline position.

The current requirement also does not provide enough space for taller passengers to adopt the ‘brace’ position, and, depending upon the outcome of any further work to specify an optimum safe brace position dimension A would need to increase to at least 885mm (35").

The current 635mm (25") vertical space requirement for dimension A also needs to be increased (ideally to 662mm (26")) to take account of passengers’ sitting knee heights.

Dimensions B (seat base to back of seat in front) was also found to be inadequate for both larger and smaller passengers.

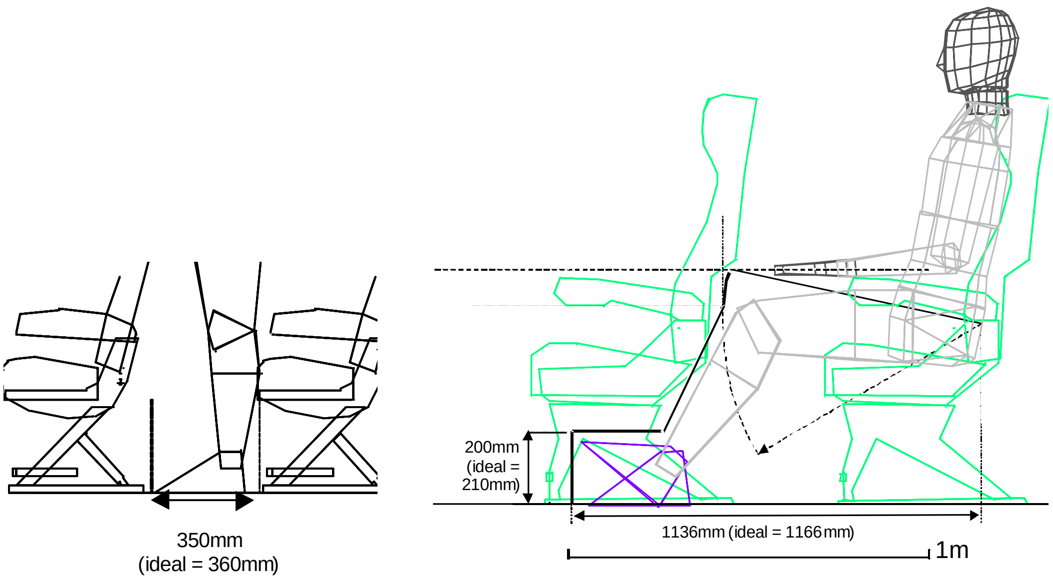
The depth of a 95%ile passenger’s thighs is greater than the 178mm (7") current minimum and the vertical clearance of 76mm (3") requires that passengers move in a semi-crouched, unbalanced, posture increasing the likelihood of tripping especially when trying to move from the seat quickly. The smaller passenger may be disadvantaged because Dimension B does not allow sufficient clearance for their lower buttocks.

Dimension B may be better expressed as two separate values. Between 230mm and 255mm (9 and 10 inches) would be an acceptable minimum for dimension B at armrest level and a minimum of 210mm (8.3") would be acceptable at cushion level.

Dimension C would need to be increased from the current 3" (75mm) to 12" (305mm) to permit a 95%ile passenger to stand upright. However, this is unlikely to be practical on economic grounds, as it would necessitate significant increases in seat pitches, therefore some degree of bending whilst leaving the seat is likely to be unavoidable.

However, further work, including egress trials, is needed to develop a final recommendation for dimensions B and C.

AN64 does not currently specify a **foot clearance envelope** (see following diagrams). Adequate foot clearance is desirable to avoid obstruction from seat structures when accessing/egressing the seat and to enable a healthy sitting posture and changes in posture. To allow sufficient seated space this envelope should extend to a minimum of 1136mm (45.7") forward of the seat back cushion surface and allow a vertical free space of at least 200mm (8") above the cabin floor. Ideally, these dimensions should be increased to 1166mm and 210mm respectively (99%ile – see diagrams). For seat access/egress, a foot clearance of at least 350mm (13.8") forward of the leading edge of the seat base is needed, the ideal being 360mm (14.2").



Foot clearance for both access/egress and when seated

Minimum and maximum dimensions for the designs of **seat base**, (specifically width and depth) and **armrests** should also be considered as these were found in the survey to be important for seat access and spacing issues. These dimensions are included in current and proposed seat spacing standards for other forms of public transport.

Seat base heights were found to be too high for smaller female passengers and this may lead to lack of adequate seat support and long term back problems for frequent fliers. Lowering the seat however may produce problems for taller passengers so a stowable foot/leg-rest is recommended. The upper surface of such a footrest would be about 350mm (14") below the front edge of the seat cushion. Importantly this device would have to fold away such that it could not intrude into the foot space and so cause and obstruction to movement during egress and access.

A suitably designed foot/leg-rest may also help reduce the risk of DVT (Deep Vein Thrombosis).

A similar problem was found with regard to **seat base** length. A maximum length of 423mm (16.7") is recommended (ideal = 379mm (14.9")). Overall, given that most of the body weight is supported by the seat bones, a short seat base is usually preferred so as to avoid causing smaller sitters to slump forward as described earlier. As this will also assist with access and egress, a short seat base length would appear optimal.

The randomly selected sample of economy class seats measured for this study did not provide adequate space between the **armrests**, which would result in larger passengers having great difficulty in getting in and out if their seats. A minimum width of 497mm (19.6") is recommended between armrests (ideal = 584mm (23")). Alternatively, if arm rests fold up, this figure would define minimum seat width. In addition, a minimum back width 536mm (21.1") is recommended (ideal = 608mm (23.9")).

Foldaway armrests (or even seats) could also assist with access/egress and are indeed specified in regulations for UK buses, coaches and rail vehicles.

A performance requirement for **seat back table** latching mechanisms should be considered, to ensure tables can not fall down when passengers brush against them during evacuation.

1.4. Health issues

Although there is almost no prospective, controlled data, anecdotal and retrospective reports would support a connection between prolonged immobility during travel and thromboembolic disease (TED). The incidence of travel related TED is, however, not known.

Thrombus formation has many causes of which immobility is one factor. Other factors include genetic predisposition, pre-existing cardio-vascular conditions, hypercoaguability and previous TED.

While travel has often been implicated as *the* cause of TED there appear to be a number of risk factors experienced during travel associated with immobility that are responsible.

Definitive data will only be acquired by carefully conducted prospective research with an adequate sample size and good clinical and basic scientific support. The research must involve adequate numbers and adequate time, taking into account delays in presentation. It is essential that any diagnostic tool used for both symptomatic and asymptomatic disease must have appropriate sensitivity and specificity.

The contribution of seat design and spacing to the development of TED is not known. The scope for reducing the risk of TED includes a review of aircraft seat design and spacing, as maintaining a seated position appears to be one of the risk factors in this condition. Aircraft seat redesign could theoretically reduce these risks and research should incorporate the testing of venous physiology in response to altered seat design.

1.5. Other considerations

Seat dimensions should include an allowance for older users as the proportion of older people in the population is growing significantly. Today there are almost a third fewer older people than there are younger adults. By 2020 their numbers will be equal, and by 2030 older people will outnumber younger adults by a fifth and this is likely to be represented within the flying population. Elderly and disabled passengers are likely to have greater difficulty in getting in and out of their seats at lower seat pitches, due to lack of manoeuvrability and difficulty in supporting their own body weight when in the unbalanced position required to access many seating configurations.

Any JAA regulation should include a specification for the procedure for testing for compliance. This should include allowance for cushion foam compression and the use of standardised equipment and procedures similar to the SAE H–point manikin, as used by the motor industry is recommended.

The relationship between duration of sitting in different seating configurations and possible reduction in mobility has not been quantified and requires further research.

1.6. Recommendations for future work

It is recommended that further research be undertaken including: -

- passenger trials to validate the recommendations,
- studies to investigate any specific relationships between seating parameters and TED.

Contents

2.0 Introduction

The Joint Aviation Authorities (JAA), requested ICE Ergonomics to advise on data for possible JAA regulation. This review was to consider the *scope* of the requirements in addition to the actual *minimum values* contained therein, together with future trends.

The only current seat spacing regulation within the JAA countries is CAA Airworthiness Notice No.64 which specifies minimum seat space dimensions in order to a) provide a minimum seated space and b) facilitate passengers leaving their seat and moving to the aisle in an emergency. This regulation was used as the starting basis for the study.

2.1. Objectives of the study

- To review the *minimum values* required by AN64 in light of any more recent anthropometric surveys, particularly taking into account secular trends in anthropometry (the increase in people's sizes over time). In addition to stature, consideration was to be given to changes in body mass, in view of the fact that in Western populations, especially the US, a larger percentage of the population are becoming increasingly overweight (54% of US population are 'overweight', 22% are 'obese' (CNN, 1998)).

- To review currently available anthropometric sources for the most reliable data so that aviation regulators would have the highest level of confidence in the findings.

- To review the *scope* of the parameters contained within AN64 and determine whether additional parameters affect seated space, health and emergency egress requirements.

- To consider the physiological and medical aspects of long term sitting and the scope for addressing this within the minimum seat space requirements.

- In assessing the requirements for egress space, to consider whether allowance should be made for reduced mobility due to prolonged sitting.

2.2. Who should be accommodated?

It is a design convention to ensure that the range of people sizes that should be allowed for covers the range 5th %ile (small) to 95th%ile (large)[1]. However, we would strongly recommend that any revised minimum seat space requirements should be based on a wider range of user sizes, namely 1st %ile to 99th %ile. There are two reasons for this:

- seat spacing is a safety issue, and a number of independent sources recommend this range for safety critical designs,

- the trend in the increase in people's sizes is likely to continue and some allowance for this should be included in any new requirements which may have a life of ten years.

These issues are dealt with in more detail within the report.

Clearly, the decision on percentile ranges accommodated must be based on a number of factors of which the findings of this study are only one. We have therefore provided data for both options wherever appropriate.

[1] %ile = percentile

2.3. The project team

Martin Freer, B.Sc., DPS - *Ergonomics Consultant, SAMMIE CAD Limited*
Martin has conducted some 200 ergonomics consultancy projects covering a wide range of application areas for SAMMIE CAD over the past 15 years. A significant proportion of his work has involved computer based human modelling and subjective user trial evaluations of vehicles and transport systems, with a specific focus on occupant packaging, seating design, vehicle access and egress and human movement, posture and comfort. He has completed a number of projects concerned with the development of both commercial and military aircraft seating systems, including several concepts involving novel approaches to the provision of additional seat space, alternative recline mechanisms, innovative entertainment packaging and for sleeping quarters for major world airline companies.

Professor Alan Moody BA (Oxon) Physiology, MA (Oxon), MB BS (London), MRCP, FRCR, *Professor and head of the department of Academic Radiology University of Nottingham Medical School*
Alan Moody's research interests are centred on the investigation of the process disease using magnetic resonance imaging with particular reference to vascular biology. The development of novel imaging techniques for the direct visualisation of intravascular thrombosis have lead to a programme of work investigating venous thromboembolic disease resulting in significant publications. Current studies include a Department of Health funded project researching the optimal diagnosis of pulmonary embolism and a recent British Heart Foundation funded project has confirmed the diagnostic accuracy of the new MRI techniques in the setting of deep vein thrombosis. He is a founder member of a new charity for research into thrombosis, Lifeblood, due to be launched later this year. He is a member of the haemostasis and thrombosis task force for the British Society of Haematologists preparing a guideline document on the diagnosis of deep vein thrombosis. He has lectured widely on the topic and further talks to the

International Society of Magnetic Resonance Technologists and the British Society of Haemostasis and Thrombosis have been invited.

Dean Southall, B.Sc., M.Sc., M.Erg.S. – *Principal Consultant, ICE Ergonomics*
Since joining ICE in 1984 Dean has worked primarily on transport related client projects. This has included projects on the ergonomics (human factors) aspects of seating, passenger evacuation and passenger movement space within vehicles. In addition he has undertaken a number of anthropometric studies and has advised clients on applied anthropometry related to vehicle layout, driver packaging, seat dimensions and seat space requirements. He has undertaken both research and consultancy for a number of airlines and aircraft seat manufacturers to assist in the development of economy, business and first class and pilot seats.

Claire Quigley, B.Sc. - *Project Officer, ICE Ergonomics*
Claire obtained her ergonomics degree from Loughborough University in July 1997 and joined ICE Ergonomics in March 1998. As part of her degree, Claire undertook a placement year working for the Institute of Naval Medicine in Gosport, working on projects which involved interviewing Naval personnel as well as recording technical information in order to evaluate the extent of any existing health or safety issues which may have arisen. Since joining ICE Ergonomics Claire has been involved in a number a major ergonomics studies for the Department of the Environment, Transport and the Regions. She has also been involved in a project for a major logistics operator looking into driver seating and cab space requirements for large vehicles.

Professor J Mark Porter, B.Sc., Ph.D., EurErg, FergS, *Professor of Design Ergonomics in the Department of Design & Technology at Loughborough University of Technology.*
Mark Porter is also the Head of the Vehicle Ergonomics Group and the Managing Director of SAMMIE CAD Ltd, an ergonomics design consultancy. Mark's considerable applied research encompasses both applied anthropometry (including the development of the SAMMIE-CAD system) and seating design. He has

undertaken many commercial client projects on the evaluation and design of car, office and aircraft seating, control design for emergency use by pilots, concept design of long haul aircraft seating and driver discomfort surveys, secular growth and body size differences for various nationalities. Recent research topics include: Anthropometry for 3D human models; CAD modelling of the human spine; Dynamic seating; Low back trouble and driving; Pressure distribution analysis for seat design and evaluation.

2.4. Airworthiness Notice 64

The purpose of Airworthiness Notice 64 is to regulate the minimum seat space dimensions for all UK registered aircraft over 5700kg MTWA which carry 20 passengers or more. Minimum requirements are set out using anthropometric data for the 5th %ile female and 95th %ile male and aim to minimise the effect of lower seat pitches and seat occupancy and ease of egress from the seats. The three main requirements of AN64 are described in Table 1 below and are shown in Figure 1.

Table 1 Descriptions of the minimum requirements outlined in AN64

Dimension	Description	Minimum
A	The minimum distance between the back support cushion of a seat and the back of the seat or other fixed structure in front	26 inches (660mm)
B	The minimum distance between a seat and the seat or other fixed structure in front.	7 inches (178mm)
C	The minimum vertically projected distance between seat rows or between a seat and any fixed structure forward of the seat.	3 inches (76mm)

These dimensions will be referred to as dimensions A, B and C.

These dimensions are displayed in the following illustration, taken from AN64 a full copy of which is included in Appendix 1.

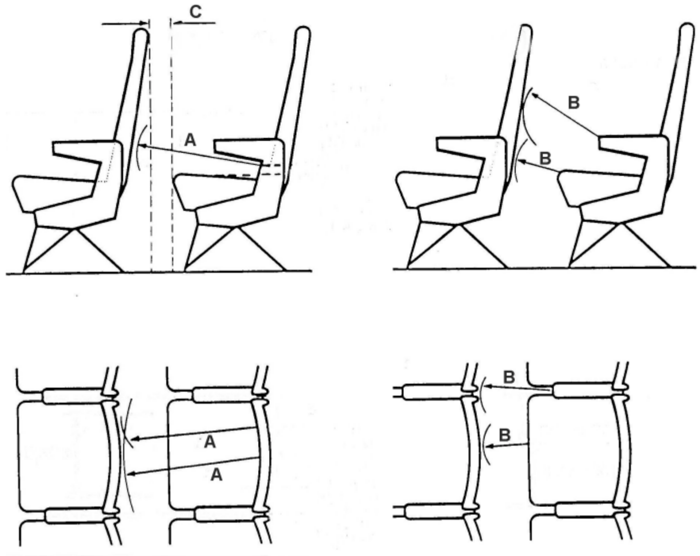


Figure 1 The three minimum dimensions described in AN64

3.0 Review of the scope of Airworthiness Notice 64

A review was made of seat design and installation features to identify any additional parameters (armrests, seat height, seat width, leg rests etc.) which should be included in the anthropometric review and/or AN64. Information for this review was obtained from:-

- the project team's previous experience,
- current practice in other transport modes,
- an expert appraisal of aircraft seats and,
- a passenger survey.

3.1. Review of current practice in other transport modes

An extensive international search did not reveal other relevant regulations for passenger aircraft seating. However, recently issued requirements for other forms of public transport were identified and this provided an opportunity of comparing the minimum requirements given in AN64 with those in other legislation and guidelines.

Part of the UK Disability Discrimination Act is the Public Service Vehicles (PSV) Accessibility Regulations for coaches and small and large buses (DETR, 1999). It provides proposed guidelines for passenger seat dimensions and their spacing, as do the Rail Vehicle Accessibility Regulations (RVAR) (DETR, 1998), set out by the Department of the Environment, Transport and Regions. Both sets of requirements are concerned with ensuring ease and safety of passengers whilst boarding and moving to and from seats. Table 2 shows the minimum requirements for passenger seat dimensions and their spacing which are set out in these two regulations along with the AN64 requirements as a comparison.

Table 2 Rail and PSV accessibility regulations compared with AN64

	The PSV Accessibility Regulations			RVAR	AN64
Dimension	Coaches	small buses	large buses		
Minimum distance between seat back and back of seat in front in upright position (A)	650mm	650mm	650mm	680mm	660mm (A)
Minimum clear space in front of seat (B)	-	230mm (300mm if bulkhead in front)		230mm	178mm (B)
Top of seat cushion height	400 - 500 mm	400–500 mm	400 – 500 mm	430 – 460 mm	-
Minimum seat cushion width		440	440	450	-
Minimum clear space/headroom above top of uncompressed seat cushion	1000mm	1000mm	1300mm	1250mm	-
Minimum gangway width to height of 900mm (1400mm) above floor	-	350 (550) mm	450 (550) mm	-	-
Minimum gangway height	-	1800mm	1800mm	-	-
Armrest between seating position & gangway	Must be capable of moving out of way easily to permit clear access to seat				-

It should be noted that the method of measurement for each dimension in the various regulations might not be identical.

In addition to this, a number of reports and publications have also included recommendations for minimum and maximum seat dimensions for passenger airlines (Table 3).

Table 3 Guidelines given for aircraft seat dimensions in previous research and publications

	Minimum dimensions (mm)			
Dimension (minimum unless otherwise stated)	*McClelland (1986)*	*Stearn (1988)*	*Edwards & Edwards (1990)*	*Cumberland & Bowey (1950)*
Seat cushion height (floor to front seat edge)*	410mm	410mm	380mm	305 – 356mm
Seat cushion width	-	460mm	400mm	483mm
Seat cushion width between armrests	460mm	460mm	-	457mm
Seat cushion width including armrests	-	-	565mm	-
Seat cushion length	400mm	410mm	432mm	470mm
Armrest height above compressed seat	230mm	-	-	-
Armrest height above uncompressed seat	-	165mm	200mm	190.5mm
Armrest width	60mm	50mm	-	-
Backrest height	-	710mm	-	-
Backrest width	-	520mm	-	-
Backrest length (seat pan to top edge)	600mm	-	-	-
Aisle width to height of 635mm	-	-	380 (508 +)mm	

**maximum*

The minimum dimensions stated in both McClelland (1986) and Stearn (1988) were ergonomic recommendations derived from international anthropometric data available at the time (using 95th %ile), and "a knowledge of the principles underlying good seat design" (Stearn, 1988). The measurements defined in Edwards & Edwards (1990) and Cumberland and Bowey (1950) are also based on anthropometric studies.

Seat cushion height and width are both dimensions which are regulated for passenger seats in PSVs and trains (DETR, 1999, 1998) and therefore could potentially be of importance to aircraft seats when trying to reduce access and health problems experienced by passengers. However, ergonomic considerations should also be given to seat cushion length and backrest armrest design.

Of the armrests provided on coaches and buses, it is regulated that the one nearest to the gangway must be capable of moving out of the way to permit clear access to the seat. This would particularly assist older, less agile passengers to get in and out of a seat by enabling them to slide along the seat, which is the method many use. This is an issue which should be seriously considered for passenger seating, particularly with the increase in the number of "Third Agers" (i.e. 55+ years of age). Today there are almost a third fewer older people than there are younger adults. By 2020 their numbers will be equal, and by 2030 older people will outnumber younger adults by a fifth (Foresight, 2000).

These public transport regulations and ergonomic recommendations provide us with some idea of which aspects of seat design should be considered in aircraft seating. However, another useful method would be to investigate passengers' experience on long-haul flights and this is dealt with in the next section.

4.0 Passenger survey

A brief airline passenger survey was conducted to aid in identifying whether the scope of AN64 was adequate and if not, what else should be included. The survey probed seat access/egress issues and the space available to passengers when seated. This latter issue prompts responses which may appear to relate to comfort but are in fact are intended to provide an indicator of potential health related issues.

The scale and design of the survey was adequate for its primary purpose of assisting in the identification of key items. It was not intended for detailed analysis of any issues raised as this would be undertaken by more reliable objective methods in the later CAD assessments.

4.1. Survey Method

A self-completion questionnaire was developed (see Appendix 2) and distributed to passengers travelling on long haul flights to or from the UK. A range of both charter and schedule flights were sampled (e.g. to/from U.S., Far and Middle East, Greece, Caribbean) from a number of different airlines (including European and US airlines) and on varying sizes and makes of aircraft. Flight duration ranged from 3.75 hours to 22 hours. A range of seating positions was sampled (aisle, centre and window seats).

4.2. Sample details

Questionnaires were completed and returned by 312 passengers (250 economy, 21 business, 15 first class and 26 'other' (e.g. premium upgrade)). Respondent ages ranged from 15 to 76 years with approximately the same number of males to females (ratio of 1:1.2). A wide range of body sizes were sampled, with heights ranging from 1.42 m (4'8") to 1.98 m (6'6") (0.5 to 99.99th %ile European) and weights from 44.5 kg to 158.8 kg (25stone) (0.5 to >99.99th %ile European). Personal mobility problems were reported by 14% of respondents.

4.3. Survey results

Data tables summarising the raw data from the 312 completed questionnaires are provided in Appendix 3.

4.3.1. Accessing and exiting the seat

Figure 2 shows how, for each class of seat, the respondents rated their seat for ease of access/egress.

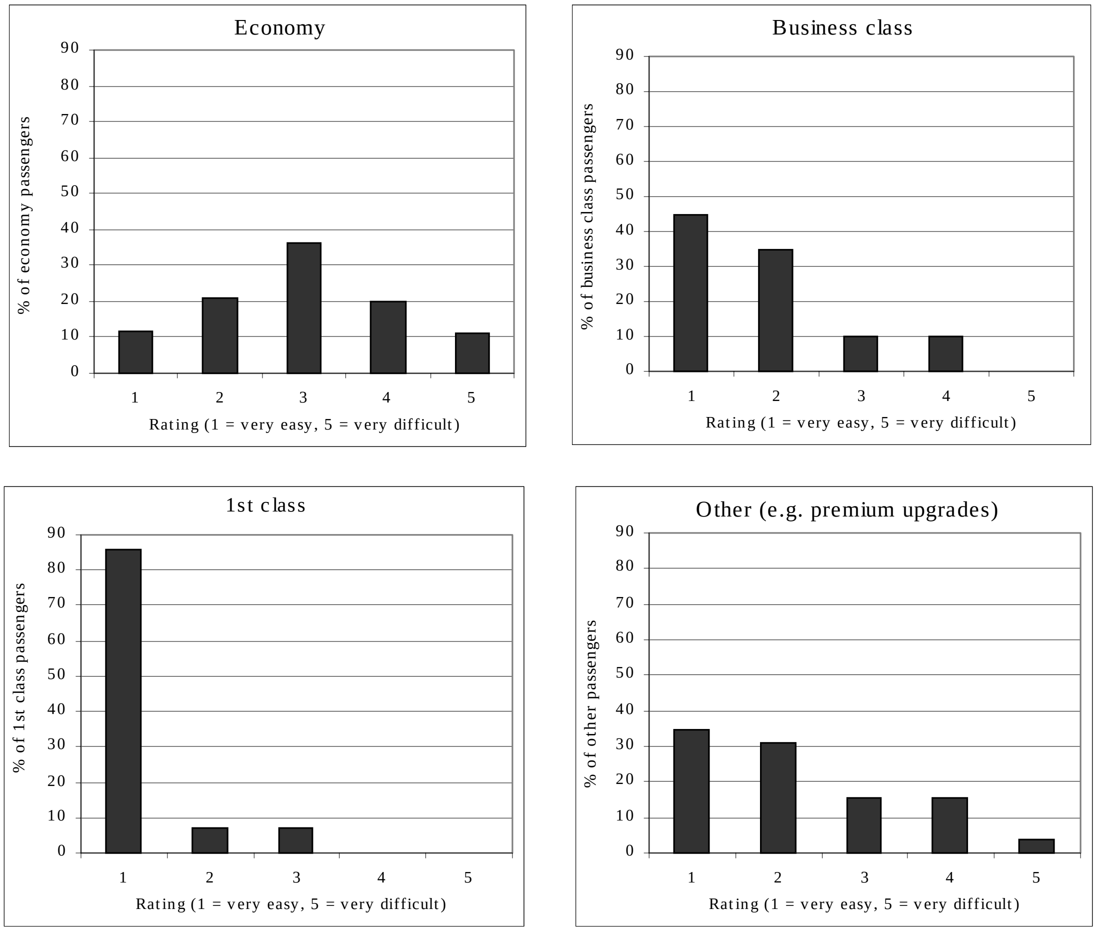
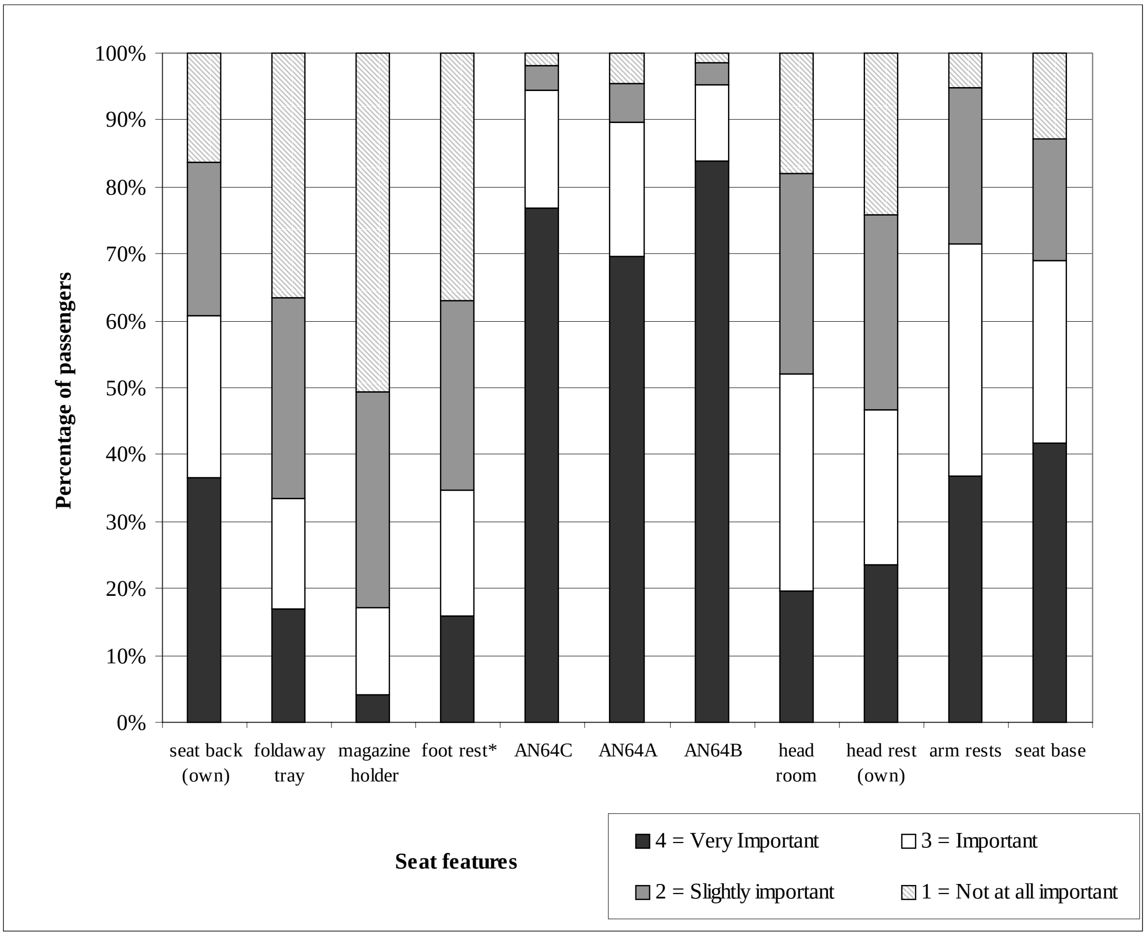


Figure 2 Passenger ratings of each class of seat for ease of access/egress

Overall, 27% of <u>all</u> surveyed passengers rated their seat at least difficult to get out of (i.e. a rating of 4 or more), of which 24% were economy class passengers.

At least 70% of the respondents considered the design of AN64 dimensions A, B and C to be “very important” when getting to and from their seat with ease (see Figure 3). Of the other seat features not covered in AN64, the designs of the armrests, seat base and the seat back were rated as being “very important” by the greatest number of respondents (between 37% and 42%).



** = approximately half of all respondents had a foot rest*

Figure 3 Ratings of importance of seat features for access to/from seat

Figure 4 shows the proportion of access/egress problems generated by each seat dimension or feature.

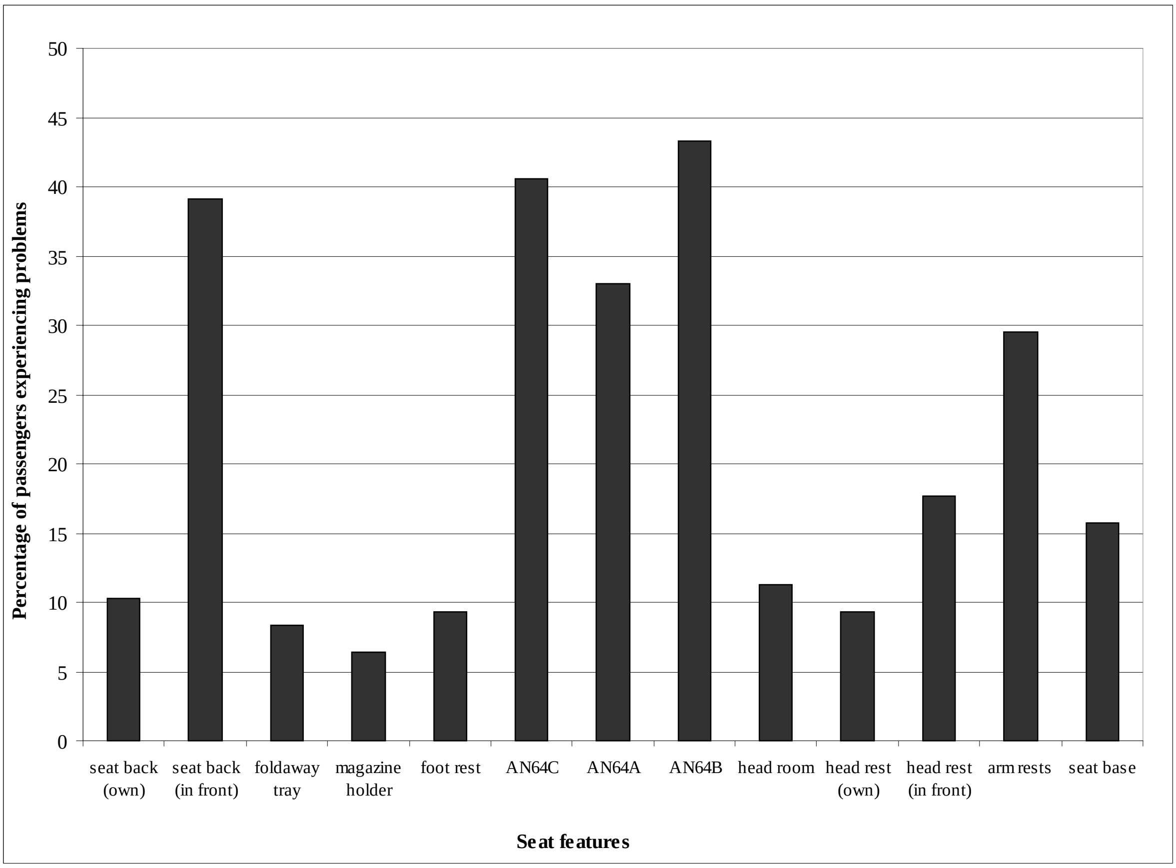


Figure 4 The percentage of passengers having problems with various seat/spacing features, when getting to and from their seat.

The seat dimensions generating the greatest number of access/egress problems were those relating to AN64 dimensions A, B, and C, the back of the seat in front and the arm rests. All of the comments from passengers highlighted the restricted space which these dimensions provided. In addition, 9% of all respondents commented specifically that the arm rests caused difficulty when getting to and from their seat because it was not possible to fold them away . (See Appendix 3 for full details of the specific problems experienced).

4.3.2. Seat spacing

Aches, pains, stiffness or numbness which passengers believed were caused by the flight were mentioned by 75% of the respondents. The main areas of complaint were the lower back, buttocks, neck and knees (see Figure 5).

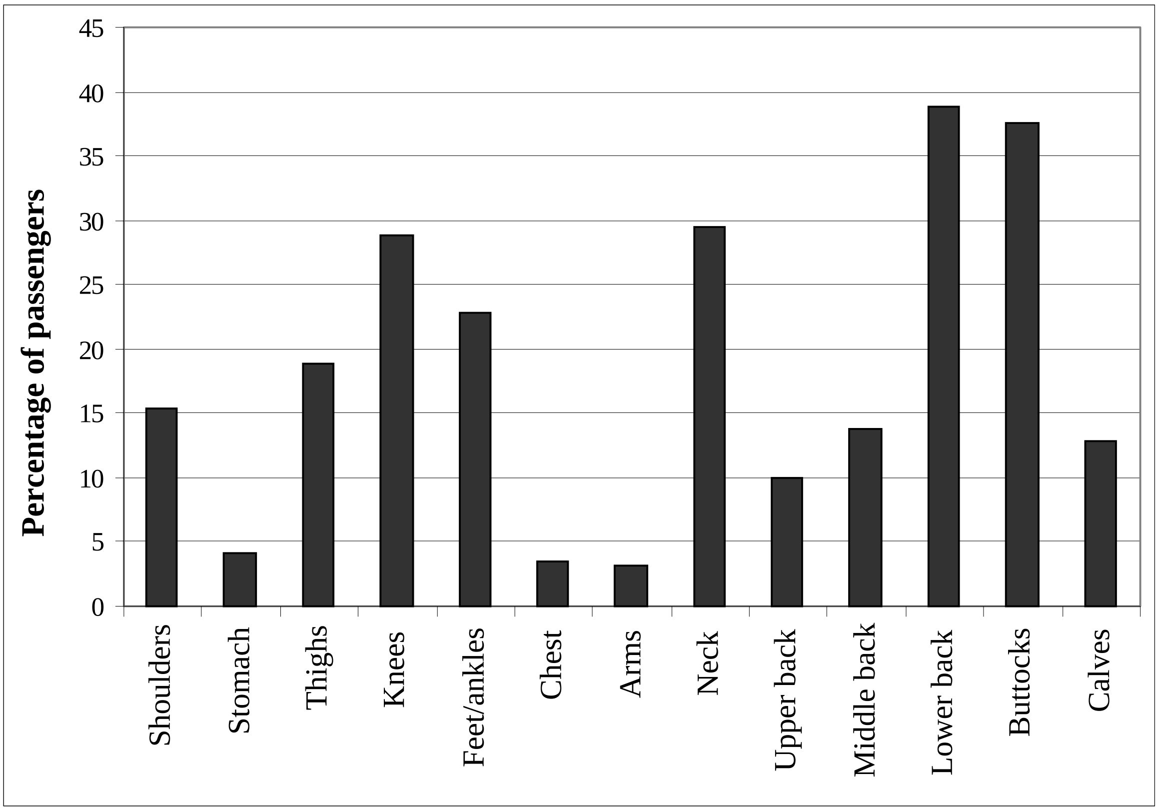
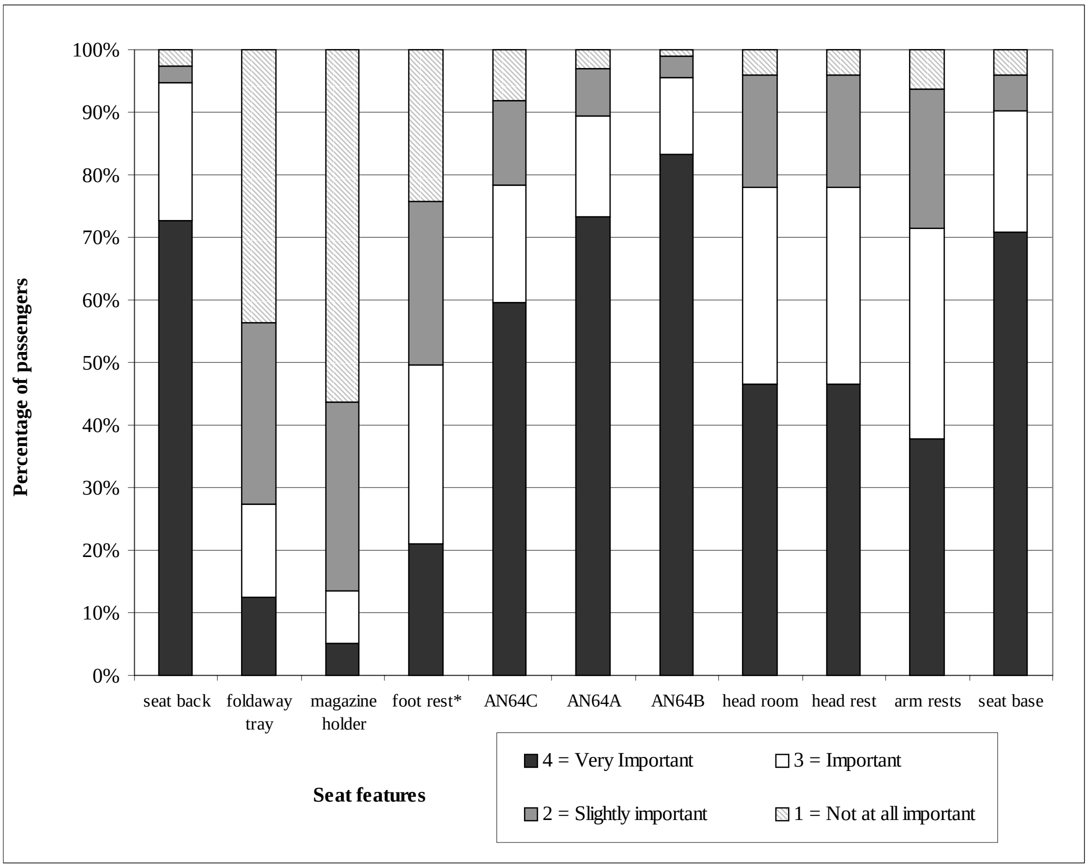


Figure 5 The types of aches and pains reported by passengers

Passengers were asked to suggest causes of the aches and pains. Most of the comments highlighted the lack of space to move about in the seat, the inability to move from the seat and the design/shape of the seat (e.g. inadequate lumbar support causing backache). Whilst the latter is a comfort issue and not of concern to this study, the comments regarding space reinforce the need to investigate this in the next stage of the work.

Passengers were asked to rate how important they found the design of various seat features for adopting a good posture and being able to change posture. At least 70% of the respondents found the design of the seat base and dimensions A and B from AN64 to be “very important” (i.e. gave a rating of ‘4’). See Figure 6 below



** = approximately half of all respondents had a foot rest*

Figure 6 Ratings given to each seat feature by all passengers (when seated)

Figure 7 shows the proportion of problems generated by each seat dimension or feature when seated.

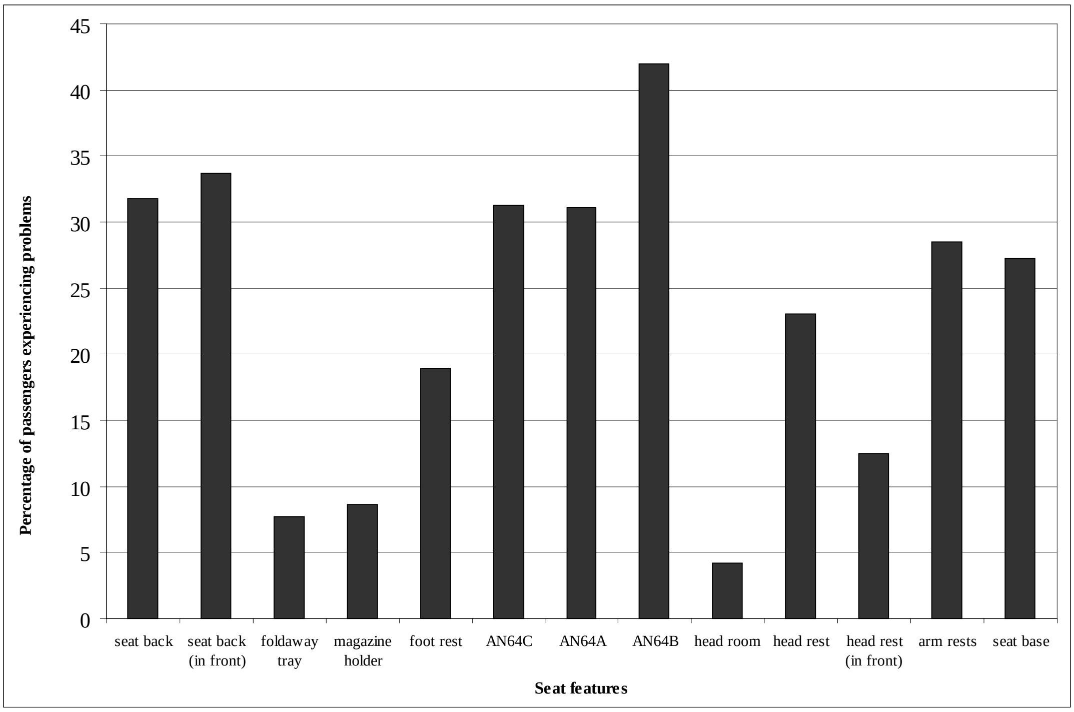


Figure 7 The proportion of passengers who experienced a problem when seated

The greatest number of reported passengers problems while seated related to AN64 dimensions A, B and C, the seat back (both their own seat and the seat in front) and the arm rests. However, an increased number of problems were experienced with the seat base, headrest and foot rest when seated compared to when getting to and from the seat. All of the comments from passengers highlighted the restricted space which all of these dimensions contributed towards.

4.4. Expert appraisal of the scope of AN64

Three ergonomists from the project team made a qualitative assessment of a representative economy class cabin mock-up, made available to us by a UK operator. The ergonomists represented larger male users (52, 87 and 96% males of average and above build).

The seat spacings as found exceeded the requirements of AN64 so the seats were repositioned to match AN64.

All three ergonomists found that the space available to exit was restrictive, with the calves rubbing against the seat base and the stomach rubbing against the seat back. This resulted in an unbalanced posture such that handholds were used to prevent falling over (see Figure 8).

The support legs of the seat in front intruded into the foot space and combined with the limited space to manoeuvre the legs resulted in an obstruction to passage into the aisle, thereby constituting a trip hazard

Figure 8

On a number of occasions the seat back table fell open when exiting because the stomach rubbed against the securing catch and released the table.

The location of the seat support legs was also found to intrude into the passenger's foot space and could contribute significantly to postural fixity (the inability to change posture at will) and which runs counter to good health advice. (see **Figure 9** below). This was particularly the case when the seat support leg was located in front of the occupant's seat but offset to one side.

An additional hazard of this seat support leg arrangement is that it can cause passengers to place their feet partially within the aisle, posing a tripping hazard to others.

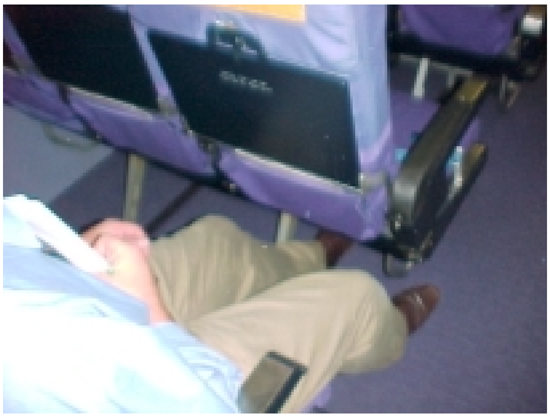


Figure 9

Figure 10

It was also evident that the seat widths would not accommodate adjacent passengers without body contact (see Figure 11). This restricts the opportunity for passengers to change posture, not only because of the limited space but also because of the disturbance it may cause the adjacent passenger.

Figure 11: showing restricted shoulder room

(sitters' shoulder widths are 97th and 89th %iles)

4.5. Summary findings from the review of the scope of AN64

The results of the passenger survey revealed the type of access problems passengers experienced while flying on a wide range of flights. The lack of available space, both around the seat and in the aisle, was one of the main issues highlighted. This resulted in many passengers (32%) not being able to get out their seat as many times as they would have liked.

AN64 dimensions A, B and C were considered to be very important in terms of both seat access and spacing and it was clear from the high frequency of passenger "problems" that the minimum requirements for these dimensions need to be reviewed with regard to both access/egress and potential health implications

Other aspects of seat design, which were found to be important to passengers for both seat access and spacing, were the seat base and seat back. Seat base design was considered "very important" both when seated and when accessing the seat (by 40% and 70% of respondents respectively). Although the armrests and seat back were other aspects considered to be at least "important" to a high proportion of respondents, it was clear from the specific problems they experienced during their flight that they were related to AN64 dimensions A, B and C (e.g. seat back in front too close, armrests restricted access to/from seat) and therefore these issues would be dealt with when evaluating AN64.

Drawing from the passenger survey and the expert appraisal, the scope of an AN64 successor regulation should include:-

- the current dimensions of A, B and C (but not their values), as their importance was highlighted in the survey.

- Additionally, adequate foot clearance to avoid obstruction by seat structures when getting to and from the seat.

- Additionally, adequate space in the foot/leg region to enable a healthy posture and changes in posture.

Consideration should also be given to: -

- **Minimum and maximum dimensions for the seat base, seat back (specifically width) and arm rests**. These were found in the survey to be important for seat access and passenger seated space. In particular, the width of the seat was mentioned by over a quarter of the 85 participants who reported having a problem with the seat base (8% of all 312 participants). A seat which is too narrow may result in some passengers having to lodge themselves into their seat in between the armrests, which could result in problems when trying to leave the seat. These dimensions are also included in current seat spacing standards for other forms of public transport.

- **Minimum and maximum dimensions for the seat base height.** This is included in other current regulations for other forms of transport (e.g. RVAR and PSVAR, DETR, 1998, 1999)). Seat height may have an influence on health issues as seats that are too high for some passengers may result in circulatory problems when seated over long periods (see section 6 for further details). This could particularly be a problem for smaller passengers if their feet are unable to reach floor leading to undesirable pressure on the back of the knees. However, if the seats are too low, this will cause problems for taller passengers. Stowable footrests may be a possible solution to overcome the problems smaller passengers may face with seat height. This is discussed further in section 5.9.

- **Seat cushion length** may also have an influence on health issues as seats that are too long for some passengers may result in circulatory problems when seated for long periods (see section 6). This could particularly be a problem for smaller passengers whose upper leg length is shorter than the length of the seat. This would result in undue pressure on the back of the knees caused by the passengers' feet being unable to reach floor. It may also cause passengers to slump on their seats leading to potential back problems.

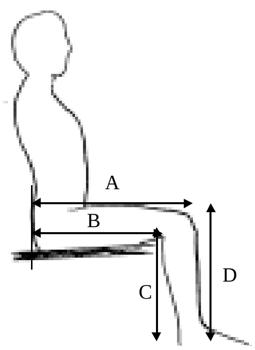
- **Seat back table latching** mechanisms to ensure these cannot fall down when passengers brush against them although it is noted that seating issues not related to minimum seating are included in JAR 25.

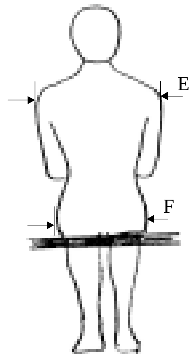
- Whilst it does expand the scope of AN64, the ability of passengers to adopt the ‘brace’ crash position should be considered as one of the criteria for determining acceptable seat space (note: the issue of the brace position is not covered in detail in this report as it falls outside the scope of the study.).

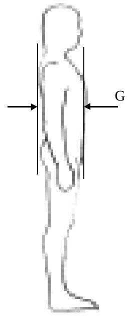
5.0 Evaluation of AN64

In this section the minimum dimensions in AN64 are assessed against the anthropometric data for UK, European and world populations. The suitability of these dimensions are then tested using a human-modelling CAD system (SAMMIE CAD) and recommendations for revisions to the current and newly identified items are developed. The results of the assessment were used to develop recommendations for both improving and extending AN64 in respect of fit, ease of access / egress, postural flexibility and movement, comfort and the potential for alleviating factors associated with Deep Vein Thrombosis (DVT).

The anthropometric dimensions referred to in this report are shown in the figures below:







A = buttock-knee length
B = buttock popliteal length
C = popliteal height
D = knee height

E = bideltoid shoulder width
F = hip breadth

G = whole body depth

5.1. The origins of AN64 requirements

Reference to data sources available at the time of the development of AN64 indicate the basis of the current minimum requirements.

Dimension A (26 inches (660mm)) relates to buttock-knee length. 95th %ile[2] values from Bodyspace (1988) show UK male 645 mm (25.4 inches), Dutch 665 mm (26.2 ins) and USA 650 mm (25.6 inches). MOD DEF STAN Part 2 Body Size (1985) shows buttock-knee length to be 641mm (25.2 ins) 95th %ile UK civilian males.

Dimension B (currently 7 inches) relates to thigh thickness. Bodyspace shows 95th %ile male thigh thickness for UK 185 mm (7.3"), Dutch 175 mm (6.9") and USA 185 mm (7.3"). MOD DEF STAN Part 2 Body Size (1985) shows thigh clearance (seated) to be 176 mm (6.9") for 95th %ile UK civilian males. However these values all relate to seated users’ thighs and, hence, compressed and thus underestimates the clearance required and results in considerable squeezing (i.e. compression of the thigh tissues).

[2] %ile = percentile

The origins of dimension C are unclear and clearly not based on simple anthropometric data for body depth as this would suggest a value nearer 12" rather than the 3" specified.

5.2. The anthropometric data used

5.2.1. Data sources and secular growth

Civilian anthropometric surveys are rarely conducted because of their cost. This presents a problem as people in most industrialised countries have grown larger throughout the last century (secular growth), as a result of improved nutrition and medical care. Eveleth and Tanner (1990) consider that the average secular increase in stature in Europe and North America has been of the order of 10 mm per decade. Peebles and Norris (1998) note that the mean UK male and female stature increased by 17 and 12 mm, respectively, from 1981 to 1995. In addition to stature, people in Western populations, are becoming broader. In the US for example, 54% are ‘overweight’ and 22% are ‘obese’ (CNN, 1998)).

Anthropometric databases are only updated when a new survey is conducted and, as this is a major and costly task, it is not done with great regularity. Consequently, ergonomists and designers have to extrapolate data for many body dimensions using the most recent data. The most recent data are often only available for stature and weight , such as the UK Department of Health survey of 24,403 adults (18–64 years) in 1994-5 and the US National Centre for Health Statistics NHANES3 sample of 6,665 adults (18–64 years) in 1991-4. Well known examples of estimated data include the book ‘Bodyspace’ (Pheasant 1988, 1996), the DTI publication ‘ADULTDATA’ (Peebles & Norris 1998) and the CD-ROM ‘PeopleSize 2000’ (Open Ergonomics Ltd).

PeopleSize 2000 is believed to be the most comprehensive collection of static anthropometric data currently available in the public domain. Data from a large number of surveys have been aggregated and corrections for secular growth up to the year 2000 have been applied using the method of ratio scaling[3] with respect to both stature and weight. The additional scaling by weight was considered necessary as weight has increased even more rapidly than stature in recent years in Western populations. Barkla (1961) and Pheasant (1982) describe the technique for scaling by stature and the latter paper presented a validation study which concluded that the data would be acceptable for most purposes. The additional scaling by weight developed for PeopleSize 2000 requires the calculation of correlation coefficients for each anthropometric dimension being estimated against stature and weight. The ratio between the squares of these correlations is then used to provide a weight coefficient (wt.coeff) which ranges from 0 to 1 and which expresses the relative strength of the relationship of the estimated dimension to weight (0 being unrelated). Because fatty dimensions (i.e. those body dimensions strongly correlate with weight) are not distributed normally, PeopleSize has developed a variant of the traditional z table[4] which they have named the W table. For each dimension, the extent to which it uses the z table and W table is determined by the wt.coeff so that if wt.coeff = 0 then only the z table is used, if wt.coeff =1 then only the w table is used, and if wt.coeff = 0.5 then a 50/50 average using both tables is calculated, and so on.

It was decided to use the most recently published sources of estimated data for this project, these being ADULTDATA and PeopleSize 2000. It should be noted that the PeopleSize 1998 software was used extensively in the preparation of the ADULTDATA book. Both publications present comparative data for a number of nationalities and are widely available. The 2nd edition of Bodyspace, although published in 1996, contains the same anthropometric estimates that were published in the 1st edition in 1988 and which are now somewhat out-of-date.

One potential anthropometry source is the SAE CAESAR survey, which is April 2002. The objective of this survey is to generate 3-D data that will revise current

[3] The known ratio of one body dimension to another is applied to new data to estimate dimensions for which there is no new data.

[4] The z table shows the proportion of the population (percentile) which will have any given value (e.g. stature) assuming that the population is normally distributed.

anthropometric databases of civilian males and females aged 18 to 65 of both light and heavy weights from US and European populations. However the data from this survey was not available at the time of this study.

5.2.2. Percentage accommodated

It is important to consider the percentage of people that should be safely accommodated by any JAA regulation. Traditionally, designers have aimed to include 95% of the adult population for a specific body dimension by using data ranging from 5th %ile female to 95th %ile male for this given dimension. However, where safety is important then it has been recognised that a wider range from 1st %ile female to 99th %ile male should be used wherever feasible (Pheasant 1996, Peebles and Norris 1998, MOD Def Stan, 1985). Even this wide range would not include everyone as it does not include children, people with disabilities and, statistically, it would be expected that 1 in 100 male passengers or 1 in a 100 female passengers would also be 'designed out' for a particular dimension. As body dimensions are fairly poorly correlated, the 1% of male passengers 'designed out' because, for example, their thighs were too long, would not necessarily be the same passengers designed out because their hips were too broad or their backs too long. Consequently, it may result that 5% or even more of male passengers are designed out in total, for different reasons related to different body dimensions. %iles are univariate and do not take into account multivariate issues. To be safely accommodated in an aircraft seat and to have easy access and egress involves the consideration of a large number of body dimensions and other variables such as strength and mobility. The use of 99th %ile values is strongly encouraged for the consideration of clearances, particularly where rapid evacuation is a possibility.

Use of data covering the 1st%ile to 99%thile will also ensure that some allowance is made for anticipated continued secular growth in European and world populations.

It has been considered inappropriate to create 'European' and 'World' databases (see Appendix 4). World data is included because, whilst any JAA requirements will only apply to European registered aircraft, we consider it important to recognise the global nature of airline operations and passenger base. The data for different populations has not been combined or averaged. The approach has been to identify the population with the smallest or largest sizes for the 1st and 5th%ile or 95th and 99th%ile respectively. For example, establishing a minimum clearance by the use of a 95th %ile value for a body dimension taken from a combined European male distribution would design out 5% of adult males in Europe. This may sound acceptable until one considers that aircraft fly from one country to another, and that the route flown determines to a large extent the nationalities of the passengers. A flight from London to Holland, for example, would contain a high proportion of British and Dutch passengers, and these nationalities are known to be the tallest in Europe. It would therefore be expected that many more than 5% would be designed out using a 5th %ile combined European value.

A distinction must therefore be made between designing for 95 or 99% of the European population and designing for 95 or 99% of passengers on any particular flight in Europe. The approach adopted has been to examine relevant data for all countries individually and then to use these to establish maximum and minimum dimensions for use in Europe or the world.

5.3. SAMMIE CAD

The SAMMIE Ergonomics Design System (System for Aiding Man-Machine Interaction Evaluation) (Porter et al. 1999, 1997, 1995), a computer based 3D human modelling tool, has been used for over twenty-five years in the evaluation and development of seating, including a number of aircraft passenger seating projects for manufacturers and airlines.

The body dimensions (anthropometry) of the passenger models were based upon the results of a detailed collation and review of existing data sources, and provide the most up-to-date representation possible of current and future passenger sizes for both European and world-wide populations. Appendix 4 shows the collated data tables with the relevant measurements used for the passenger models (European and world populations).

5.4. Sourcing seat models

Models of current 'standard' or 'economy' class seats were built using SAMMIE (see Figure 12 and Figure 13). These were used to help understand the level of variability in aircraft seat designs, to determine their compliance to AN64, to review AN64 with human models based upon data representative of current and future passengers and to help understand and evaluate ergonomics issues with current seats (such as whether seat heights are too high or low, whether comfortable seated postures can be attained or whether seat widths are suitable, and so on).

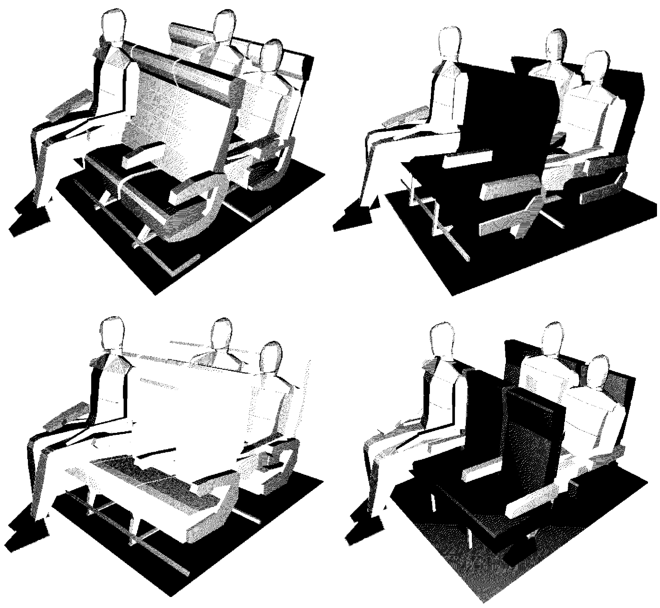


Figure 12 Four SAMMIE models of standard class aircraft seating.

Four different seats were modelled in order to cover the potential range of variability in design exhibited by current 'standard' class aircraft seating. The seats modelled were :-

- Standard Class Seat.
- Standard Class Seat used in B757 aircraft.
- Tourist Class Seat (Weber 5500).

- Economy Class Seat used in the cabin-crew training mock-up.

Seat design drawings were provided by four companies and are representative of typical seats in current service.

5.5. Seat model variability

In terms of size and shape and available space the four designs do not differ significantly for the purpose of this report. This can be seen in Figure 13 in which the seat designs are overlaid at a 762mm (30") pitch. The front edge of the cushion is at the same location in all four designs. The main differences are in the depth of the seat cushion, the depth of the back-rest, the shape and profile of the back-rest, the profile of the back of the seat and the form and shape of the legs and feet that support the seats. The length and height of the armrests also vary by 20 to 30mm (0.8" – 1.2"). Seat pitch varied between airline and aircraft type, but the minimum shown in the drawings provided was 711mm (28") and the maximum was 762mm (30"). The variation in basic seat dimensions is demonstrated in Table 4.

Table 4 Range of seat dimensions for four seat models

Model	Cushion front height	Cushion rear height	Cushion length
‘A’	465mm	430mm	360mm
‘B’	457mm	432mm	420mm
‘C’	445mm	395mm	405mm
‘D’	480mm	460mm	400mm

The effect of various seat dimensions on passenger accommodation and the consequences of the variations in seat feature dimensions are discussed in sections 5.9 and 5.10.

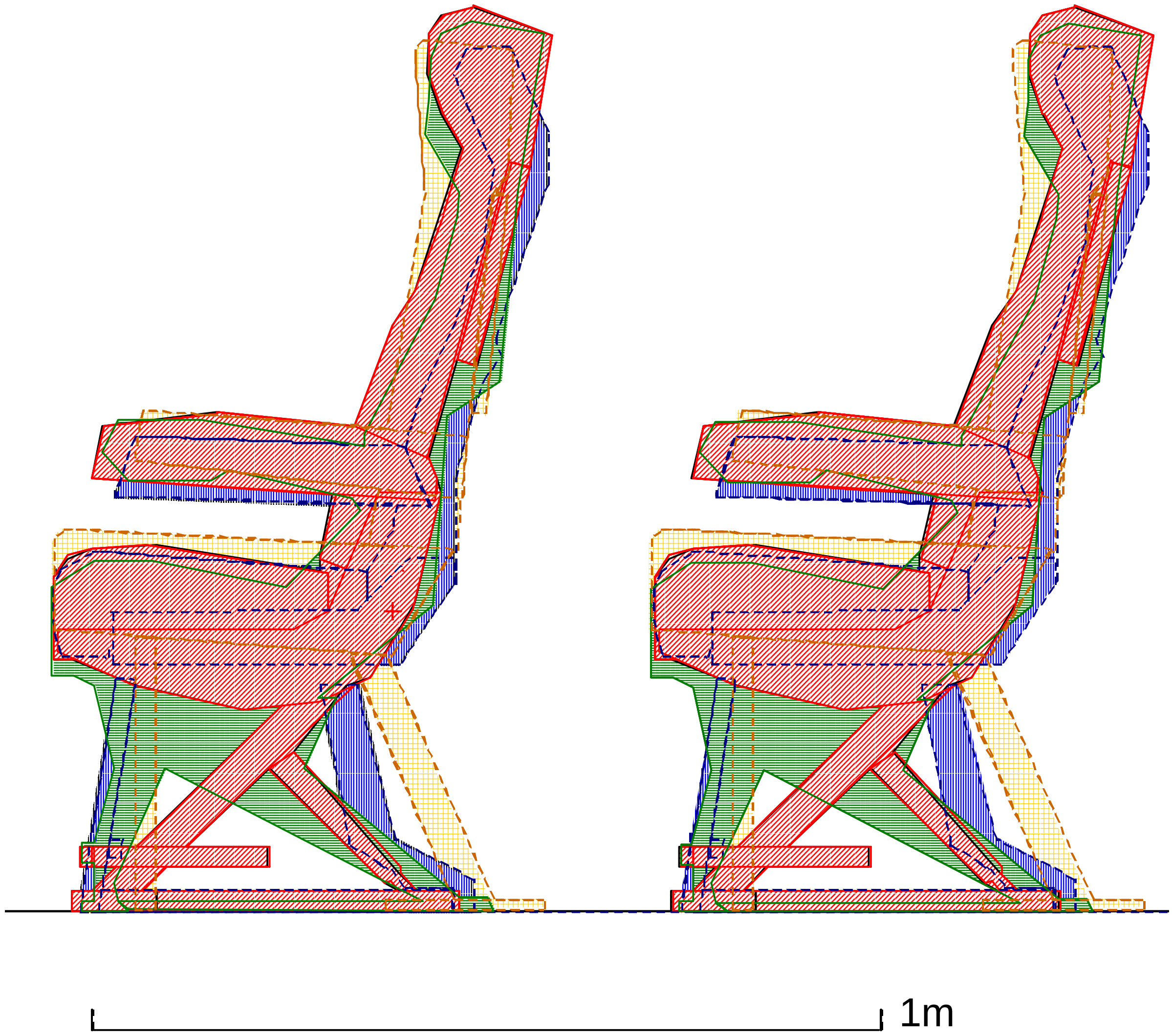


Figure 13 An overlay side view of the four seat designs at a 762mm (30") pitch, giving a general idea of their variability in terms of size and shape.

5.6. Compliance with AN64

All four seats comply with AN64 dimensions A, B and C when set at 711mm pitch (28") (see Figure 22).

5.7. Evaluation of AN64 dimension A

Table 5 displays the relevant 95th and 99th %ile data for evaluating dimension A (British, European and World populations), this being buttock to front of knee length.

Table 5 95th and 99th %ile male buttock-knee length data

	Population source	Data source	95th %ile	99th %ile
British	[redacted]	PeopleSize	677mm (26.7")	704mm (27.7")
European	Dutch	PeopleSize	690mm (27.2")	715mm (28.1")
World	U.S.	PeopleSize	692mm (27.2")	722mm (28.4")

The table shows that for British, European and World populations, both 95th and 99th %ile buttock-knee lengths are greater than the 26 inches (660mm) stated for AN64 dimension A. Table 6 displays what %ile dimension A currently equates to.

Table 6 The percentile AN64 dimension A currently equates to (using PeopleSize)

	Equivalent percentile (PeopleSize)
British	88
European	77
World	80

5.7.1. Knee room

The minimum space defined by dimension A should be at least equivalent to the buttock-knee length dimension of the largest passenger size that must be accommodated. Realistically some additional clearance allowance (of at least 25mm or 1" – preferably more) should be afforded to ensure that the knees do not contact the seat in front (i.e. the passenger should not be jammed in) and to improve ease of access/egress, to allow for some postural flexibility and to improve comfort. In preparation for and during egress from the seat a certain amount of repositioning of the legs and manoeuvring of the body's position is customary (to improve balance and mechanical advantage) and clearance space should be allowed for this to take place. Without such clearance the efficiency of egress is likely to be compromised. The 25mm (1") clearance space, suggested above, should be regarded as an absolute minimum. In reality more space is probably required, although this cannot be accurately determined using SAMMIE, since the system cannot model and evaluate the mechanical dynamics of human motion. Ideally the requirement for additional clearance might be determined more accurately by user trials.

The vertical limiting height for dimension A should be at least equivalent to the vertical knee-height dimension (including shoe heel height) of the largest passenger size that must be accommodated. Again some additional clearance should be provided to allow for small adjustments in posture, particularly during egress. It is also worth considering increasing the vertical limiting height further to enable passengers to lift their knees whilst taking off or loosening their shoes. Realistically this would require in the region of 178 – 203mm (7-8") of additional vertical space in the knee region .

The minimum space requirements for 95th and 99th %ile World / European passengers are shown in Table 7. The various dimensions referred to are shown in Figure 14.

Table 7 Values for dimension A.

Passenger size	Value of A2*	Value of A3**	H1†	H2‡
95% Euro male	690mm / 27.17"	715mm / 28.15"	620mm / 24.4"	645mm / 25.4"
95% World male	692mm / 27.20"	717mm / 28.23"	620mm / 24.4"	645mm / 25.4"
99% Euro male	715mm / 28.15"	740mm / 29.13"	637mm / 25.1"	662mm / 26.1"
99% World male	722mm / 28.43"	747mm / 29.41"	637mm / 25.1"	662mm / 26.1"

Notes:-

***** A2 is the absolute minimum space required, equivalent to buttock-knee length.

****** A3 is A2 plus 25mm (1") additional knee space clearance.

† H1 is equivalent to knee height plus 25mm addition for shoe heel height.

‡ H2 is H1 plus 25mm additional knee space clearance.

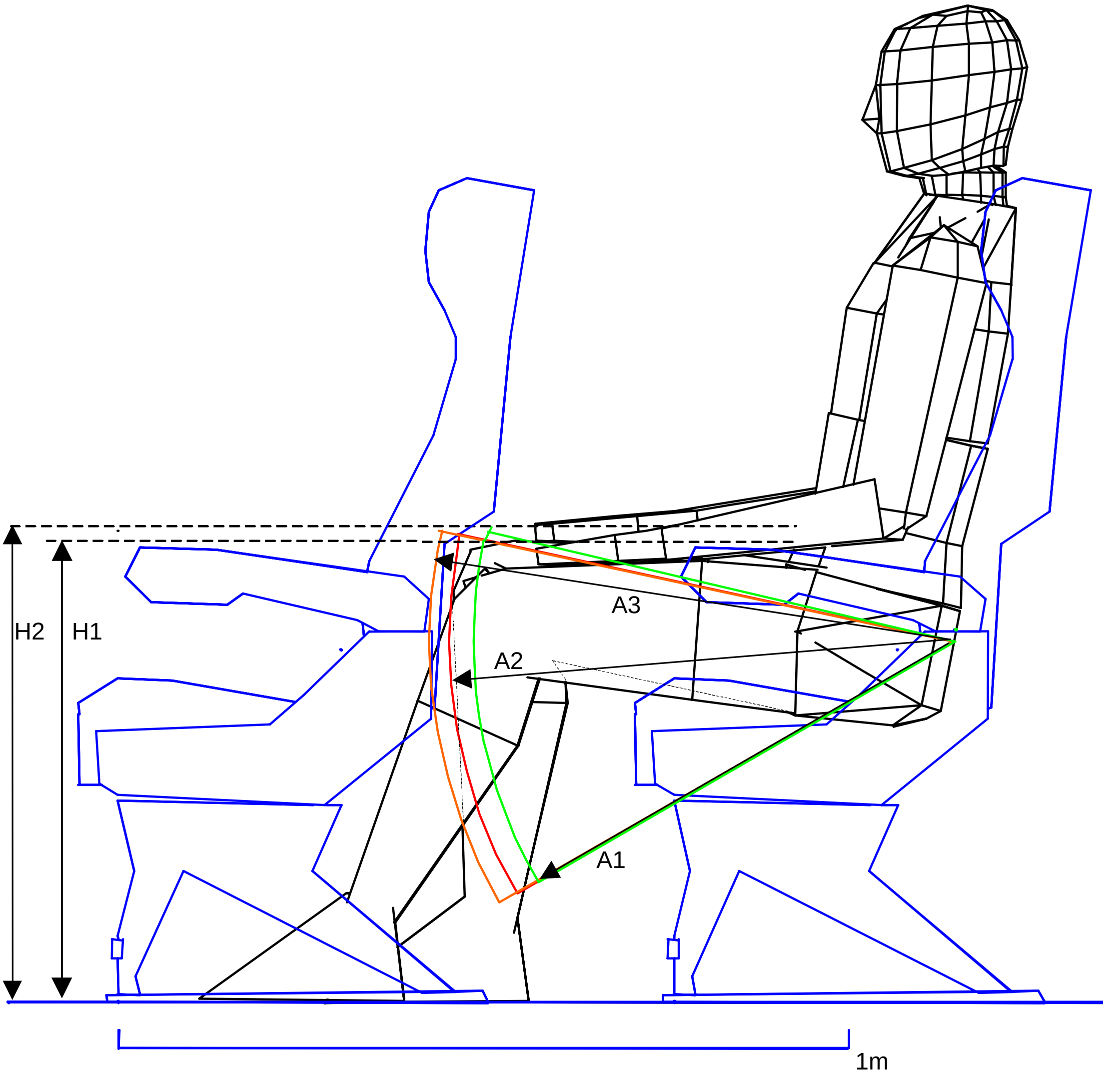


Figure 14 A World / European passenger with 95th %ile buttock-knee length and knee height.

A1 shows current 26" (660mm) minimum dimension.

A2 shows absolute minimum space (buttock-knee length).

A3 shows minimum space with 25mm (1") additional clearance.

H1 shows minimum vertical space (knee height).

The results in Table 7 above show that to ensure reasonable accommodation for the largest %ile passengers a sitting space of between 715mm and 747mm (28" and 29.4") is required (using values of A3 from the table).

1m

The vertical space requirement (currently 25" or 635mm) in AN64 is too small to reasonably accommodate the larger passenger sizes; 662mm (26") would be a more acceptable value (using values of H2 from the table).

Dimension A takes no account of the fact that the seat back compresses under the passenger’s weight. This compression effectively creates more space; i.e. the actual space experienced by a passenger is likely to be in excess of the measured dimension A. It has not been possible to quantify the amount of cushion compression that is currently, or likely in future, to be present in standard class seating; it is therefore not easy to determine how it might be accounted for in defining dimension A. In practice the selection of a new value for dimension A based directly on the buttock-knee length of large passengers (plus a clearance addition) is likely to provide more space than expected. From the passengers’ point of view this is a good thing, since they undoubtedly benefit from any additional space in terms of postural flexibility and comfort. However, since the use of any of the values determined here (see Table 7) will necessitate increases in seat pitch from 26 inches (660mm), with current seat designs, airlines might seek to mitigate against this by making seat backs, thinner, harder and firmer.

For example, Figure 15 shows two seats at the same pitch with different levels of seat back compressibility. Both seats actually provide a similar amount of space (under compression) to a seated person, yet the harder one complies with dimension A, but the softer one does not. To comply, the softer seat would have to be pitched further rearward.

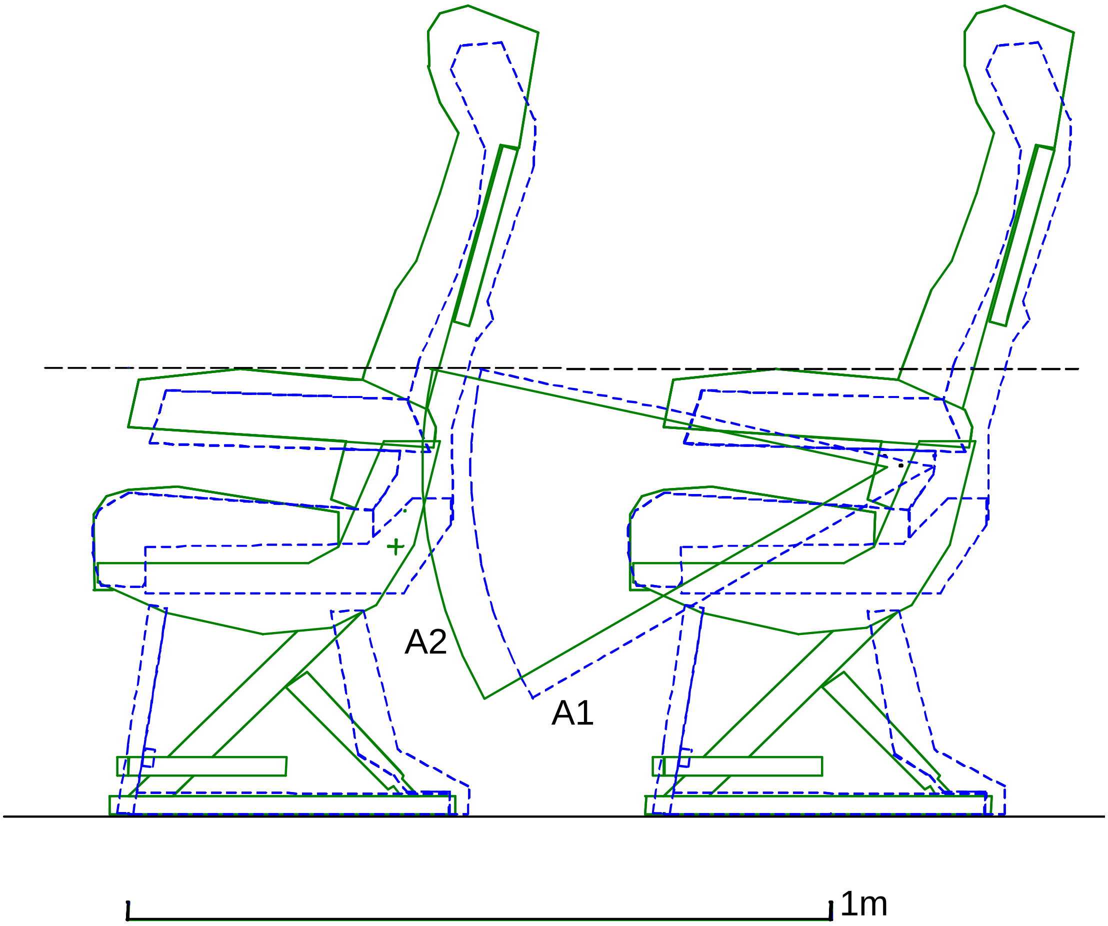


Figure 15 Two different seat designs overlaid.

The seat with the dashed profile has a thin and hard back support and complies with AN64 A (shown at A1). The seat with the solid line profile does not comply (shown at A2). However, this seat's cushion is softer and would comply if A were measured with a compressed seat back support cushion.

It would seem more appropriate to redefine the measurement of dimension A such that it relates more directly to the seated passenger and takes account of the nature of the seat being assessed. The space requirement envelope could be more easily defined and measured by using a modified version of the SAE H-point manikin. This is essentially a weighted plastic model of a human torso that includes adjustable lower legs and feet, enabling the simulation of a range of sizes of human bodies sitting in a seat (see Figure 16). Its use enables account to be taken of the compressive nature of the seat surfaces.

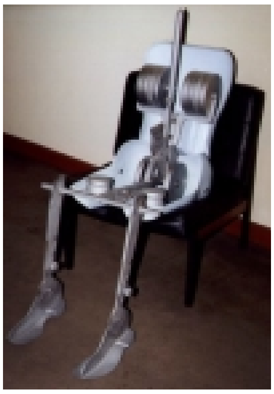


Figure 16 SAE H-point Manikin

The SAE H-point manikin is used in the automotive industry to define design points for compliance with regulations. Not only is the design of the manikin specified but so too is the procedure for its installation onto a seat and the measurement methods. Thus the posture of the occupant and the effects of seat foam compression are taken into account in a manner which is reproducible and minimises the effects of operator (measurer) error and the need for judgement as to the exact location of measurement points.

Importantly, the manikin would have to be modified to match the anthropometry data used in the evaluation. Additionally, the torso element would have to be sized to reflect larger passenger sizes and weighted accordingly (the existing SAE manikin is a 50th %ile torso and is 50th %ile weight).

However, with suitable modification a similar device (appropriately sized and weighted) could be placed into aircraft seats and used to directly determine compliance with regulations of compressed seats. It could also prove useful for testing lower-leg room, space for assuming a brace position, footrest position and seat width.

It should be noted that AN64 is applied with the seats in the upright position (section 5.5 of AN64). This makes sense as far as dimensions B and C are concerned (which relate to movement space), but not in relation to dimension A. Dimension A is concerned with providing a minimum seat space into which a large passenger can fit and as such should take account of the worst seating condition, i.e. when the seat in front is reclined. A reclined seat might take up between 15 and 50mm of space (or more), depending upon the form and profile of the seat back, the amount of rotation and the height from the floor at which one measures it.

If, when the seat in front is reclined, it hits the knees of the passenger (aside from the obvious potential for immediate discomfort and possibly pain) their posture will become extremely restricted which may in turn increase the potential for DVT; it certainly cannot help.

It is strongly recommended that any revision to the definition and / or measurement of dimension A be applied when the seat in front is reclined as well as when it is upright. The seats probably spend the majority of any long haul flight in a reclined position.

5.7.2. Leg room

Passengers who are forced to sit in a static posture for a considerable time on long haul flights may suffer from stiffness / cramps, "pins and needles" etc., in the legs. These temporary conditions may have an adverse effect upon passengers' ability to exit the seat in the event of an evacuation. If sufficient space is provided to allow passengers to stretch their legs out to some degree it is possible that the onset of stiffness / cramp can be avoided, or at least reduced. An investigation was therefore made to determine the amount of space required to allow various larger passengers to stretch their legs out. These are shown in Figure 17 and Figure 18. The basis for the derivation of the envelope was that the thighs were placed such that they are parallel to the cabin floor.

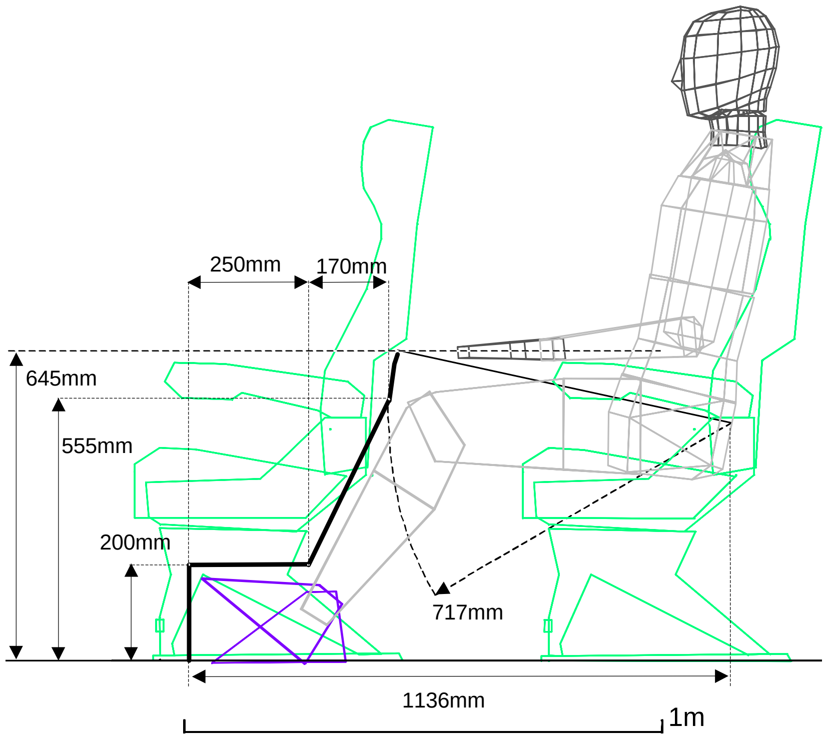


Figure 17 A leg movement space envelope for a 95th %ile Euro / World male (illustrative seats are at 813mm (32")pitch)

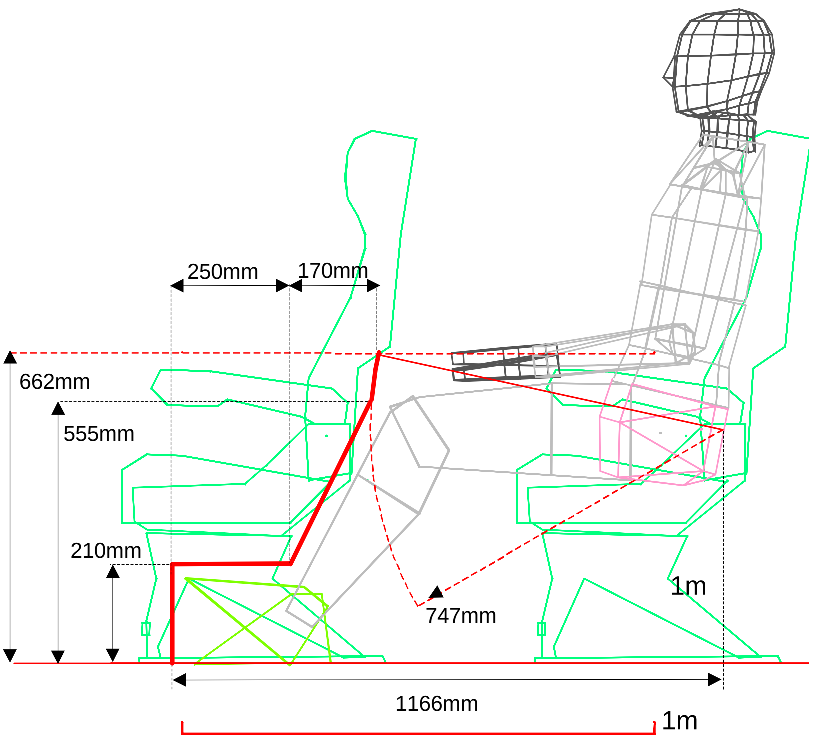


Figure 18 A leg movement space envelope for a 99th %ile World male (illustrative seats are at 838mm (33") pitch)

The leg room envelopes defined (see heavy line in Figure 17 and Figure 18) would provide a minimum of space to allow passengers to adopt a range of postures and to thereby stave off the onset of cramp and stiffness. It is presumed likely that the ability to make small but frequent changes to leg posture would also be beneficial in relation to the avoidance of DVT (see section 6).

Defining a clear method for testing seat compliance with the seat envelopes is complicated again by the fact that seat back support cushion compression needs to be accounted for. If testing were done with an H-point manikin like device compliance could be tested directly by moving the manikin's legs.

5.7.3. Armrest height

Many passengers will find that the level of fixed height arm rests is too low down to be used when they adopt a normal upright seated posture (see shaded image in Figure 19). This will encourage taller passengers wishing to make use of arm rests to slump down in the seat (by sliding forward on the seat cushion, tilting the pelvis and flexing the lower spine - see line-drawn image of the human in Figure 19) such that their elbows are brought lower. Importantly, the effect of slumping in the seat is for the passenger's knees to move forward thereby requiring more knee room.

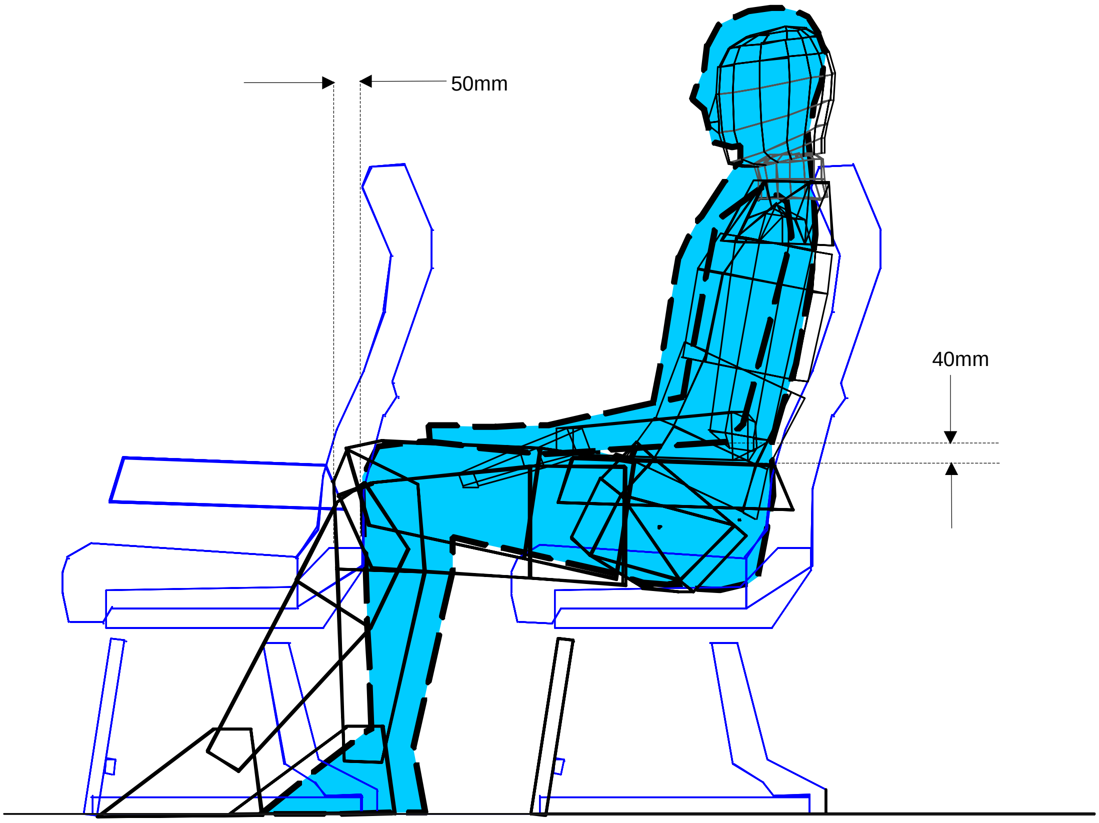


Figure 19 A 95th %ile European passenger slumping in order to make full use of the armrests (note that this seat had the lowest armrest height of the 4 models). The shaded underlay shows the outline of the same passenger in the normal upright posture, in which his arms do not reach the armrests.

In the figure above a 95th %ile European male passenger (human figure has 95th %ile knee-height, buttock-knee length, sitting height and arm length) sits in the seat (armrests are 146mm (5.7”) above seat height) and has to slump down by 40mm to rest his arms on the armrests. He requires an additional 50mm of knee room to be able to assume this posture. Ideally some additional clearance between the knee and the seat in front would be useful to avoid pressure points on the knee (e.g. 25mm). An overall horizontal space, from the compressed seat back support, of 765mm (30.1") is required (including 25mm clearance) to fit a 95th %ile European passenger (with a buttock-knee length of 690mm (27”)).

The 95th %ile World male passenger would require almost the same space. A 99th %ile European male would require a space of 795mm (31.3") and a 99th %ile World passenger would require a space of 800mm (31.5").

It should be noted that the 95th and 99th %ile European and World passengers modelled do not have the equivalent 95th or 99th %ile 'sitting elbow height'. This is because there is no available data to correlate the measures of sitting elbow height with other body dimensions, and so there is no way of knowing what the other body dimensions might be of a person who, for example, had 95th %ile sitting elbow height. It was felt therefore that the most realistic method of estimating elbow height for each %ile size was to give the model the equivalent %ile arm length. Thus for a human of 95th %ile knee height, buttock knee length and sitting height, arm length was made to be equivalent to the 95th %ile value.

It would be quite possible for taller passengers to have arms shorter than the equivalent %ile for sitting height or buttock-knee length, and hence shorter arms than modelled here (e.g. a man of 95th %ile sitting height might possibly have an upper arm length of only 70 %ile, or perhaps less). Such passengers would have to slump further to make use of the armrests than has been shown, and would consequently require even more knee room. However, accurate correlation data that would allow the determination of the variability of upper arm length against sitting height is just not available and hence it is not possible to quantify the potential additional knee room required by passengers who have to slump to make use of the armrests any further at this stage.

In the case of a fixed armrest (felt likely to remain the most practical solution) it is recommended that the regulations do not attempt to control their height in order to suit taller passengers. This is likely to make them too high for most people, with adverse effects on comfort and almost certainly on passenger movement along seat rows and probably access and egress to the seat (higher armrests may tend to act as barriers around which smaller passengers struggle to manoeuvre). It is recommended that an armrest height that effectively suits average (50th %ile) sitting elbow height will inconvenience the least number of people. The essential point is then that fixed armrest heights may be better left unchanged and provision for extra knee room should be made in order to allow passengers to use them, even though the posture required for their use for taller passengers may be slumped, and is not one to be recommended.

Ideally the armrests might be height adjustable in order to cope with the variation in passenger size. The problem with this is that it would require each passenger seat to have two dedicated armrests, otherwise two passengers of different sizes seated together would have to compete to set a shared armrest at their preferred height.

5.7.4. Space requirement for the 'brace' position

The recommended brace crash position (CAA 1995) is shown in Figure 20.

Figure 20: recommended crash brace position

The aspect of the recommended brace position that depends upon seat space is that “The upper body should be bent forward as far as possible with the chest close to the thighs and knees, with the head touching the seat in front. The hands should be placed on top of one another and on top of the head with the forearms tucked in against each side of the face”. However it was recognised that in seat/restraint configurations and seat pitches where the brace position could not be readily adopted, a brace position as close as possible to the recommended position should be used.

An evaluation of dimension A in terms of the ability to adopt a brace position was investigated using 95^{th} and 99^{th} %ile male sitting heights. Table 8 shows the data for British, European and World populations.

Table 8 95^{th} and 99^{th} %ile male sitting height data.

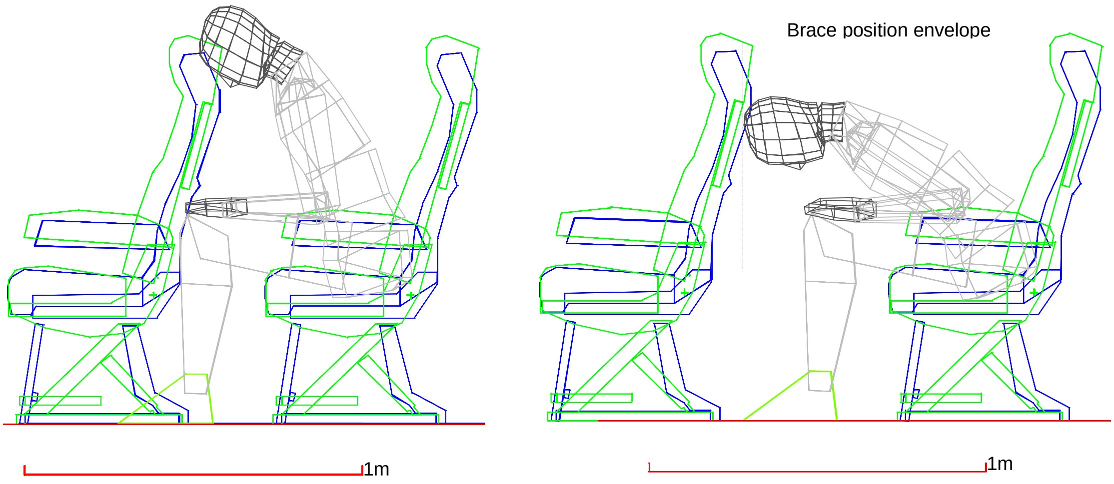
	Population source	Data source	95^{th} %ile	99^{th} %ile
British	[redacted]	Adultdata	979mm (38.5")	1004mm (39.5")
European & World	Dutch	PeopleSize	996mm (39.2")	1022mm (40.2")

95^{th} and 99^{th} %ile males were modelled in the brace position to see whether this would be possible for passengers with these dimensions.

The minimum space necessary for adoption of a braced position is determined by the length of the passenger's upper body, but is heavily dependant upon the actual posture and position required for passenger safety.

Figure 21(a) shows a passenger with 95th %ile World male sitting height (996mm (39.2")) leaning forward to adopt a brace position. The two seats illustrated are set at 762mm (30") pitch and represent the best and worst case seat profiles, in terms of space for 'bracing', of the four seats modelled. The figure demonstrates that larger passengers cannot adopt the recommended posture whereby the chest is close to the knees.

In order to adopt such a posture AN64 dimension A needs to be increased to around 885mm (35"). It would be sensible to include some additional clearance allowance to ensure that adoption of the posture is relatively easy, perhaps up to 25mm (1").



(a) **(b)**

Figure 21 (a) 95th %ile European male adopts a brace position in seats at 762mm (30")pitch and (b) 95th %ile European male adopts a more compact brace position in seats at 1041mm (41") pitch.

To accommodate passengers up to 99th %ile European male (sitting height of 1022mm (40.2")) in this posture, a space of at least 912mm (35.9") would be required (again additional clearance allowance of at least 25mm (1") should be allowed).

Note that the space envelopes are measured from the back of the passenger's pelvis to the furthest point on the head. Unless some allowance for seat compression is determined and included within the regulations it is difficult to suggest a suitable value that could used for compliance testing that might be measured in a manner similar to dimension A. As before, the use of an adapted H-point type manikin would allow more simple regulation definition and measurement since it essentially simulates the seated passenger and its size can be made to reflect the regulatory requirement directly.

Note that the more compact 'brace position' requires a seat pitch of approximately 1041mm (41") for 95th %ile users and 1067mm (42") to include up to 99th %ile European and World male passengers in any of the four seat types modelled for the evaluation (see 'brace position envelope in Figure 21(b)).

5.8. Evaluation of AN64 dimensions B and C

Table 9 provides the relevant data for evaluating dimensions B (distance from the seat back cushion to the back of the seat in front) and C (minimum vertical clearance between seat rows). The ability to move along rows of seats depends not only on body depth, but also requires the passenger to bend at the knee (see for example Figure 22). Hence knee height should be taken into account to determine whether any seat features restrict this posture. Hence 95th and 99th %ile whole body depth and 1st and 5th %ile knee height were used in the assessment (British, European and World populations). Standing leg depth (front to back thickness)would also have been a useful dimension for the evaluation; however no relevant data were found so this has been estimated as discussed later.

Table 9 1st and 5th %ile female knee height data and 95th and 99th %ile whole body depth data.

			Whole body depth		Knee height	
	Population source	Data source	95th %ile	99th %ile	1st %ile	5th %ile
British	[redacted]	PeopleSize	383mm (15.1")	409mm (16.1")	379mm (14.9")	397mm (15.6")
European	German, British	PeopleSize	390mm (15.4")	415mm (16.3")	379mm (14.9")	397mm (15.6")
World	U.S., Japanese	PeopleSize	405mm (15.9")	438mm (17.2")	318mm (12.5")	331mm (13")

The data shown in Table 9 shows that the minimum requirement for AN64 dimensions B and C is much smaller than both 95th and 99th %ile male body depth. In fact, both 7 and 3 inches (178 and 76mm respectively) would be equivalent to a %ile of <0.001 for British, European and World populations (male and female). In other words, most of the world population would not be able to stand upright when gaining access to or from an aircraft seat. Whilst it may be impractical to expect enough seat spacing on aircraft so that all passengers would be able to stand upright, this data demonstrates the inefficient posture passengers must adopt. As such it highlights the importance of ensuring that any further encumbrances to safe and efficient egress are minimised.

For efficient and easy access to and egress from seats, passengers require sufficient space between seats to maintain balanced and comfortable postures; and that neither seat material or body tissue compression are needed in order to make that space.

5.8.1. SAMMIE evaluation of dimensions B and C

The SAMMIE evaluations demonstrate that the AN64 requirements for minimum dimensions B and C are likely to prove insufficient to accommodate easy and efficient access and egress for both large and small sized passengers.

In Figure 22, a 95th %ile stature European male (of medium body build) is shown standing as upright as possible while exiting the seats. Note that all four seat models are overlaid and all are set such that dimension C is 3" (76mm) (equivalent to approximately 711mm (28") pitch).

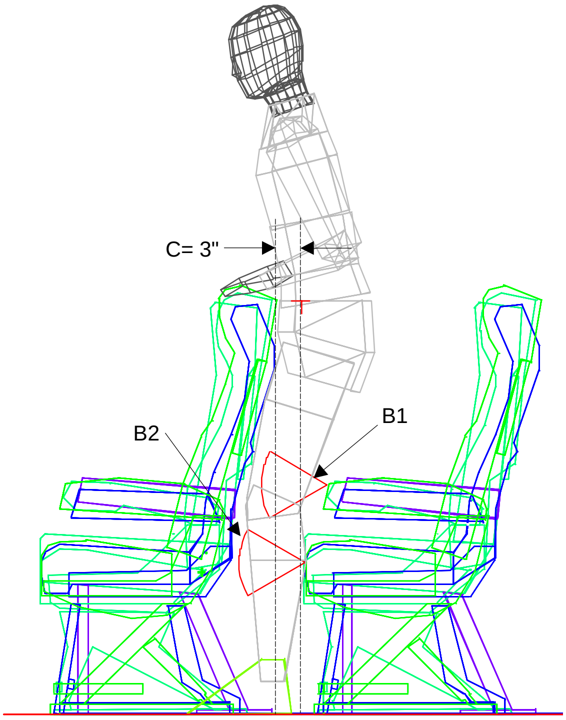


Figure 22 A 95th %ile passenger exiting his seat. The seats have been set at 711mm (28") pitch, where they all comply with dimension C. Arcs at B1 and B2 show dimension B (7" (178mm))

The passenger's thighs are pressed closely against the seat backs in front when he stands and during movement. The seat backs have irregular surfaces incorporating various hard protrusions that may impede movement and may cause some damage to clothing and / or superficial injury. The 3" (76mm) space allowance is not sufficient to allow the passenger to stand upright and leads to an unbalanced posture where the knees and ankles are forced forward by the position of the seat base cushion and the hips are forced rearward by the tops of the seat backs. Passengers will probably tend to lean forward over the front seats and to hold on to the seat backs in order to move their centre of gravity forward in order to gain some balance. A posture of this sort can rapidly lead to fatigue, particularly in the legs, if passengers have to stand and wait for any length of time. This could be a particular problem for elderly or disabled passengers.

Also note that passengers’ calves contact and compress the seat base cushion. This may also impede ease of movement, although such contact may well provide some support in maintaining balance while standing.

For passengers of a larger build the available space provided by both dimensions B & C are likely to prove inadequate. Figure 23shows a 95th %ile stature European male who has 95th %ile European male 'whole body depth' (this is 390mm (15.4"); note that 99th %ile World male at 438mm (17.2") is nearly 50mm (2") deeper).

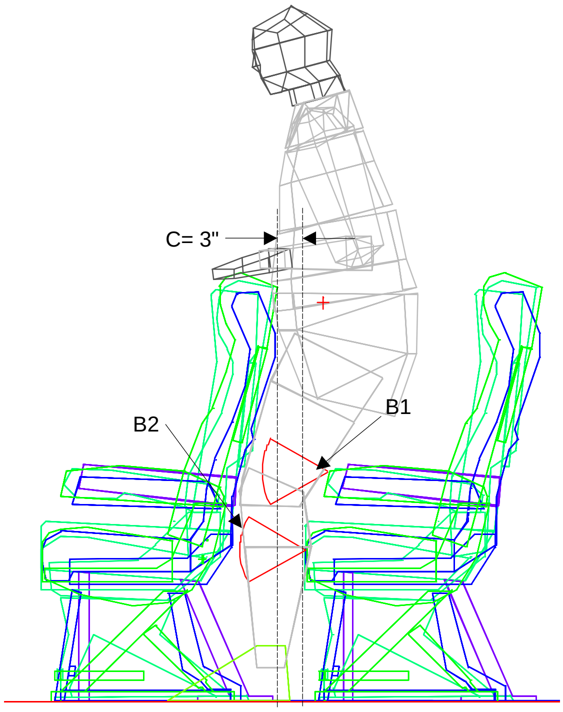


Figure 23 A large bodied 95th %ile male passenger exiting his seat. The seats are set to 711mm (28") pitch to comply with dimension C. Arc at B1 and B2 show dimension B (7" (178mm)).

The figure demonstrates that passengers with a larger build are forced into an even less balanced posture with their increased body depth forcing them to hold their hips further back over the seat cushion. Body contact with the seat back is likely to be quite extensive which will adversely affect the ease of movement. Note also that the backs of the thighs are quite likely to make contact with the arm rests of at least one of the seat designs (see area B1) which may cause the passenger to trip or slip. This is despite the fact that all the seats exceed dimension B, demonstrating the inadequacy of the 7" (178mm) value.

It should be noted that the depth of the large passenger's thighs and legs exceed the 7" value of dimension B (see B1 and B2 above). Taller heavily built passengers, as shown in the figure, may well find that their knees tend to wedge against the seat back as there is insufficient vertical space between it and the seat cushion to accommodate the bulk of their legs.

Anthropometric data for the depth of the thigh and calf in a standing posture is not available and so truly accurate assessment of the problem is difficult. However, 95th %ile values for seated thigh depths tend to be between 190mm (UK female - Adultdata 1998) to 223mm (US female - Adultdata 1998), which correspond to 7.5" to 8.8". Importantly it must be remembered that these dimensions reflect a compressed thigh (the tissues tend to spread out during seated measurement). Standing thigh depths, especially when muscles are under contraction, may be significantly greater than those quoted above.

The inadequacy of dimensions B and C is demonstrated further in Figure 24, which shows a heavily built UK female of average (50th %ile) stature.

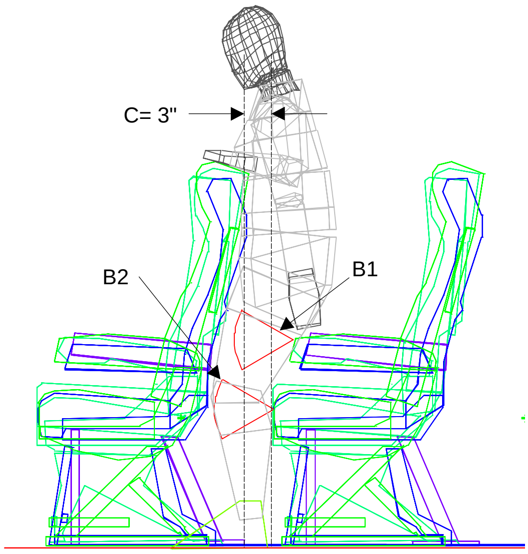
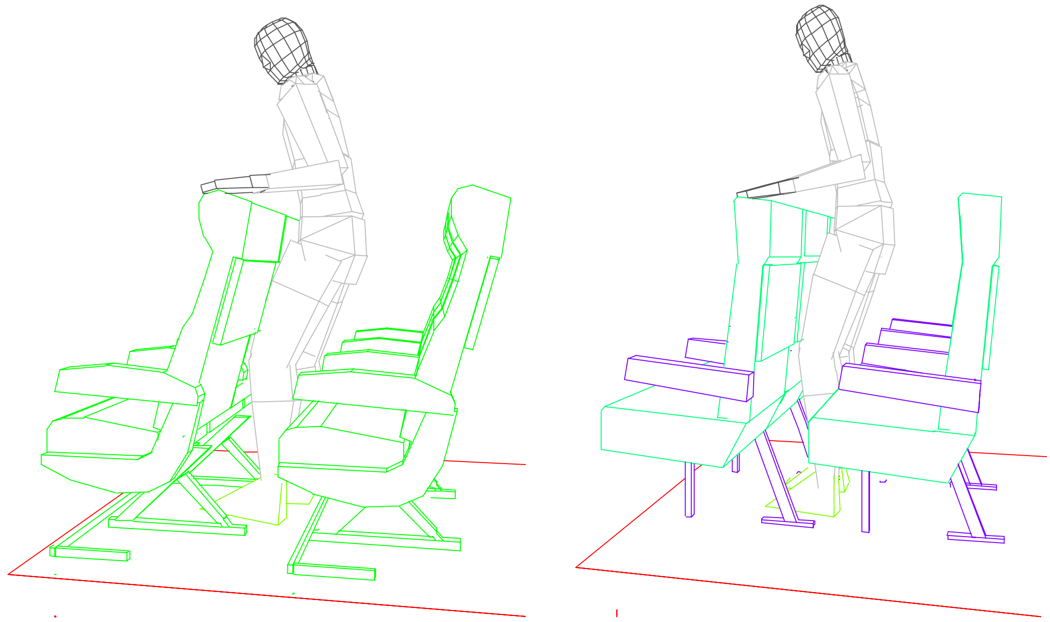


Figure 24 A heavily built UK female of average stature exiting her seat. The seats are set such that they meet the minimum vertical space requirement: dimension C (3" (76mm)).

Shorter passengers who are heavily built may find their ability to exit the seats compromised to an even greater extent since the larger volume of their upper thighs, buttocks and abdomen will tend to be lower down and therefore much closer to the narrowing of the space at the arm rest level. This suggests the need for shorter armrests or ones which lift up.

The ease of access and egress to aircraft seats can be adversely affected by the presence of obstructions to foot / leg movement, including placement of the seat's supporting structures. It is relatively easy for a passenger to catch their foot on the seat supports while moving along the row, which could cause them to stumble or fall (see Figure 25 (a) and (b)). During egress from the seat a fallen passenger may subsequently block the aisle and hold up evacuation (or get trampled). During access a falling passenger may land on another seat occupant resulting in injury to one or both of them.



(a) 'A' seating **(b) 'B' seating**

Figure 25 (a) and (b) A large passenger catches his left foot on the seat support structure as he moves along the seat row.

The likelihood of a trip or slip is greater in the situation shown in Figure 25 since the support structures protrude some considerable way into the seat row space. The situation is compounded for larger passengers by the fact that they are unlikely to be able to see their feet easily as they are bent forward over the seats in front to maintain balance. Trips might be avoided if the leading foot is manoeuvred around the structure by rotating the leg (assuming the passenger is aware of the potential obstruction) but the trailing foot remains liable to getting caught unless the passenger is able to turn the whole body in the direction of travel.

Some passengers may prefer to access the seats by facing the direction of travel (see Figure 26), which may help to avoid tripping over the seat supports. However, such a movement will require a certain amount of postural flexibility and sufficient arm strength to support a considerable proportion of the body weight. Such a posture would be unlikely to be attempted by anyone who is not either small or young and fit.

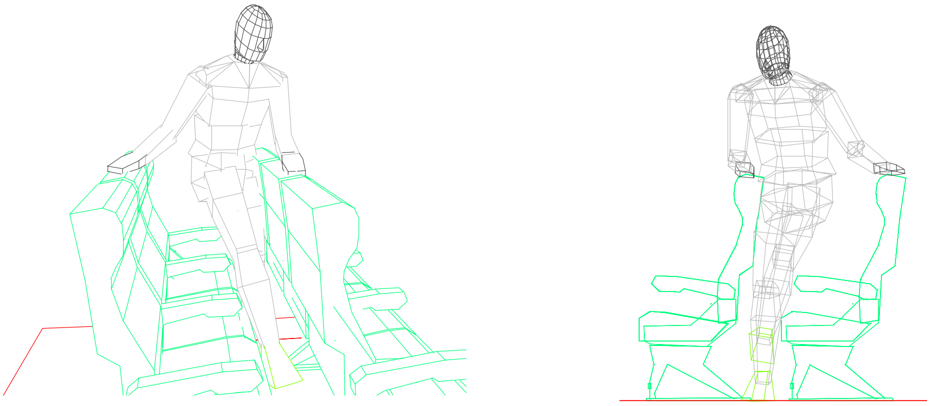


Figure 26 A perspective view (left) of a larger passenger accessing the seat row while facing the direction of travel. The view on the right demonstrates the complexity of the posture and its unbalanced nature.

While some younger and fitter passengers may avoid trips and slips and experience some measure of additional movement space, many passengers are unlikely to be capable of such actions.

In addition to larger passengers, dimensions B and C are inadequate for smaller passenger sizes. Figure 27 shows a 5th %ile European female (standing knee height 396mm (15.6")) exiting her seat. Note that her chest position is limited by the top of the seat back and that her thighs and bottom are very close to the arm rests. This situation would be aided if the armrests could be folded up (as is required for buses).

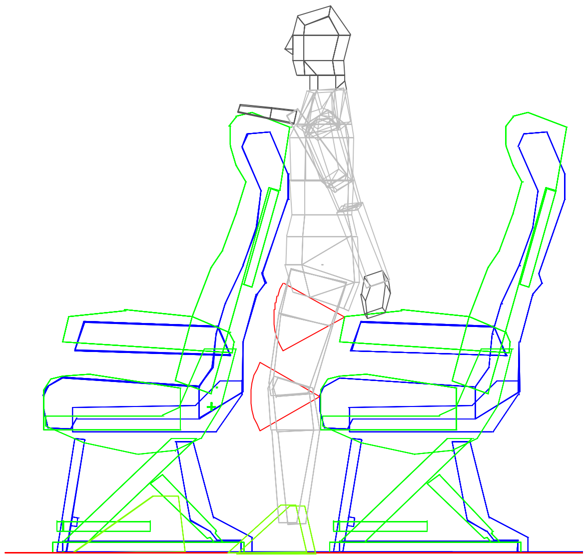


Figure 27 Female 5th %ile passenger

In Figure 28 a 1st %ile World female passenger is shown (348mm (13.7") standing knee height). This shorter passenger suffers even less adequate movement space since her buttocks are likely to come into contact with the arm rests and her chest is more compressed against the back of the seat in front.

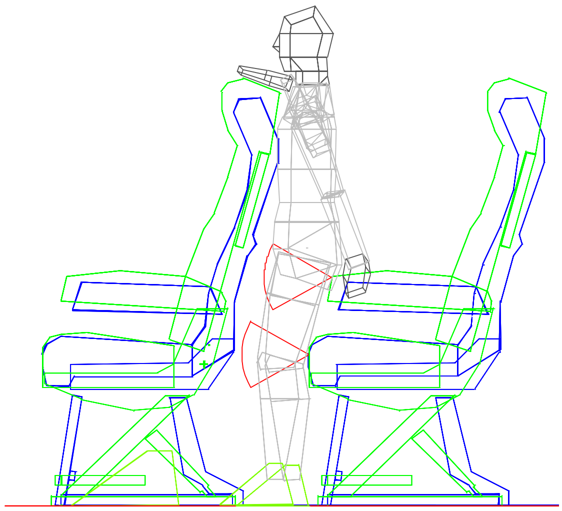


Figure 28 Female 1st %ile passenger

Smaller female passengers (especially those who have a larger bosom) are likely to be forced into a very unbalanced posture in order to keep their chest and buttocks clear from seat elements (see Figure 29). The passenger's hips are thrust forward and their balance is likely to be better maintained by either pulling on the seat back in front or using the arm rests to lean on.

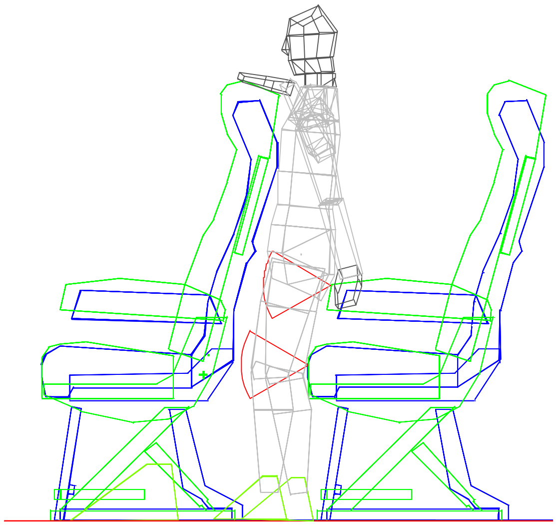


Figure 29 Female 1st %ile passenger staying clear of seat structures

5.8.2. Dimension B

The evaluation has shown that a value of 7" (178mm) for dimension B is very unlikely to be acceptable to allow easy access / egress for a wide range of passenger sizes (see Figure 23 and Figure 24). It is also clear is that more space is required between the armrests and the seat back in front than between the seat cushion and the seat back in front. That is, at the level of the armrests a space at least equal to the largest acceptable size of thigh thickness is required, while lower down at the level of the seat cushion a space equivalent to the depth of the knee and calf in a semi-crouched posture is required. This suggests that dimension B might better be expressed as two separate values, one related to space at the level of the arm rests and one to the space required at cushion level. Note that both will need to exceed 7" (178mm).

A space in excess of 7" is required between the armrests and the back of the front seat, particularly for large bodied but shorter passengers which would take account of thigh thickness and / or buttock depth. Unfortunately there is little in the way of anthropometric data for thigh depth / thickness in a standing posture, but a value of approximately 225mm (9") is given for the 95th %ile seated (compressed) thigh depth (Adultdata - US female), giving about 250mm (nearly 10") for 99th %ile value.

Standing trunk depth at the buttocks might be a more useful dimension to use than seated thigh depth, particularly for very short heavily built female users (1st to 3rd %ile stature but 95th %ile buttock depth), since it represents an uncompressed measurement (see Figure 28 and Figure 29). A value for this measure could be as great as 352mm or 13.8" (US 95%ile female - Adultdata). Realistically allowing for some bending of the legs and torso, a value of between 9" and 10" (230 and 255mm) would be a more acceptable minimum for dimension B at the level of the arm rests.

There is no available anthropometric data available that details leg thickness between the front of the knee and the back of the calves or thighs when the legs are bent. SAMMIE human models enable a provisional recommendation of 8" to be made. SAMMIE models indicate horizontal measures of around 210mm (8") for minimum knee room in front of the seat cushion for passengers of heavy build.

If whole body depth values were used to determine dimension C, then dimension B would possibly become superfluous, although its retention as part of the revised AN64 would ensure that seat back furniture and pockets do not intrude on the intended space provision.

5.8.3. Dimension C

A more realistic value for dimension C would take account of 'whole body depths'. To enable a tall passenger of large build (up to 95th %ile whole body depth) to have sufficient clearance within a seat row to stand upright, a dimension of at least 305mm (12") is required for the value of measurement C (see Figure 30). This would require a seat pitch of approximately 940mm (37").

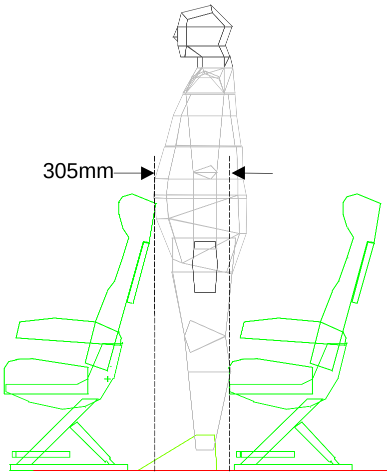


Figure 30 A large bodied 95th %ile European male passenger standing straight to exit his seat requires approximately 305mm (12") vertical space between seats.

This measure was determined by setting the SAMMIE human model's whole body depth to the relevant %ile value by scaling an appropriate body somatotype to determine where the back of the calf is most likely to be (note it falls inside the actual body depth). The passenger is then placed such that his calf rests against the seat squab and the clearance dimension is determined by moving the front seat forward until it clears the front of the human model. Note that there is no data available giving the actual difference in horizontal position between the back of the calf and the back of the buttocks in a standing posture; the scaled SAMMIE human model is the best estimate possible (except of course an anthropometric data survey).

It is worth noting that for a person of 'average' whole body depth (336mm (13.2") for UK males - from Adultdata 1998) a space of 255mm (10") is needed; requiring a seat pitch in the region of 889mm (35").

For a person of 99th European %ile body depth (415mm (16.3")) a space of approximately 330mm (12.9") is required, and for a World 99th %ile person (438mm (17.2") body depth) the space would need to be around 355mm (13.9").

A compromise would be to adopt a value for dimension C between the current 3" (76mm) and the more appropriate and larger values discussed above, but this depends upon the relative ease of adoption and acceptability of unbalanced postures to passengers. Further work, including access/egress trials would be required to determine this.

It is not possible to quantify the different levels of difficulty that may be experienced with different spatial allowances with SAMMIE in any greater detail than has been reported herein, since SAMMIE has no direct ability to model strength capabilities or to assess subjective 'ease of access' or perceived comfort levels. The only effective means of determining alternative values for the space requirements would be by subjective assessment (i.e. passenger user trials in a seating mock-up where passenger opinions are elicited) and / or objective testing by means of timed evacuation trials.

From a seat design point of view it would be worth considering the potential for having ‘flip up’ seat squabs, in a similar manner to cinema seating, which would serve to greatly increase the available space for moving along a row of seats during access and egress. The leading edge would also serve as a ‘perch’ on which to rest whilst standing waiting one’s moment to exit.

5.8.4. Foot space

Unsighted manoeuvre of the feet would be made considerably easier by requiring that seat support structure did not intrude into the movement space in the seating row.

Clear foot space equivalent to the horizontal distance between the back of the calf and the toe of a shod foot, up to the level of the seat cushion, (see Figure 31) should be provided. For a 95th %ile European passenger with a foot length of 295mm (11.6") (Adultdata), with a 30mm (1.2") correction for shoes (Pheasant 1986) and with 25mm (1") to account for fact that the calf overhangs the heel of the foot (measured from SAMMIE human model) a space of 350mm (13.8") is required. This might rise to 360mm (14.2") for a 99th %ile passenger.

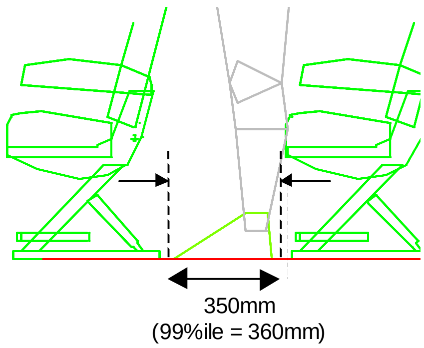


Figure 31 Clear foot space area

5.9. Evaluation of seat width

The current widths of typical economy class seats, and in particular the distances between the 2 armrests, are totally inadequate to accommodate large bodied passengers.

The minimum overall seat width should accommodate at least the ' bideltoid' shoulder width of the largest passenger required to provide each passenger with sufficient personal space. Importantly, the minimum space between armrests must accommodate the hip width of the largest passenger required in order to enable them to fit into the seat at all. Ranges of the relevant body dimensions are shown in Table 10, these being 95th and 99th %ile female sitting hip width and male bideltoid shoulder width.

Table 10 95th and 99th %ile female hip width data and 95th and 99th %ile shoulder width data.

			Sitting hip width		Bideltoid shoulder width	
	Population source	Data source	95th %ile	99th %ile	95th %ile	99th %ile
British	[redacted]	PeopleSize	485mm (19.1")	533mm (21.0")	536mm (21.1")	565mm (22.2")
European	German, European	PeopleSize	497mm (19.6")	546mm (21.5")	536mm (21.1")	565mm (22.2")
World	U.S.	Adultdata, PeopleSize	542mm (21.3")	584mm (23.0")	563mm (22.2")	608mm (23.9")

A comparison of a range of seat widths and the spaces between armrests, shown in Table 11 and the body size measures from Table 10 clearly shows that larger passengers cannot be readily accommodated. For example, a passenger with 95th %ile European female hip width (497mm (19.6")) will struggle to fit into the widest armrest space in any of the four seat designs (model ‘B’ at 439mm (17.3")). Indeed she is 58mm (or 2.25")wider than the space allows. This will lead to uncomfortable tissue compression between the armrest and the passenger's thighs and / or buttocks. Such compression, as well as being uncomfortable, may affect blood flow in the tissues of the leg and may contribute to DVTs (see section 6).

Table 11 Maximum seat width and armrest spacing for seat models.

Model	Maximum Seat width		Armrest width	
	Inches	Millimetres	Inches	Millimetres
‘A’	18.6"	472mm	17.07"	434mm
‘B’	18.3 - 19"	465-483mm	17.29"	439mm
‘D’	18"	457mm	16"	406mm
‘C’	19"	483mm	15.9 - 17.1"	404-434mm

The effective space between the armrests for this size passenger (and for a good number who are smaller) is so small as to effectively wedge her in (see Figure 32). This is likely to make egress more difficult and significantly slower than if there were sufficient free space between the armrests.

In the worst case: a passenger with 99th %ile world population hip width (584mm (23.0")) trying to sit in the narrowest version of the ‘C’ seat (404mm (15.9")); there is a space deficiency of 180mm (7"). It is not at all likely that such a person could actually get into such a seat (see how the armrests are virtually obscured from view on Figure 32).

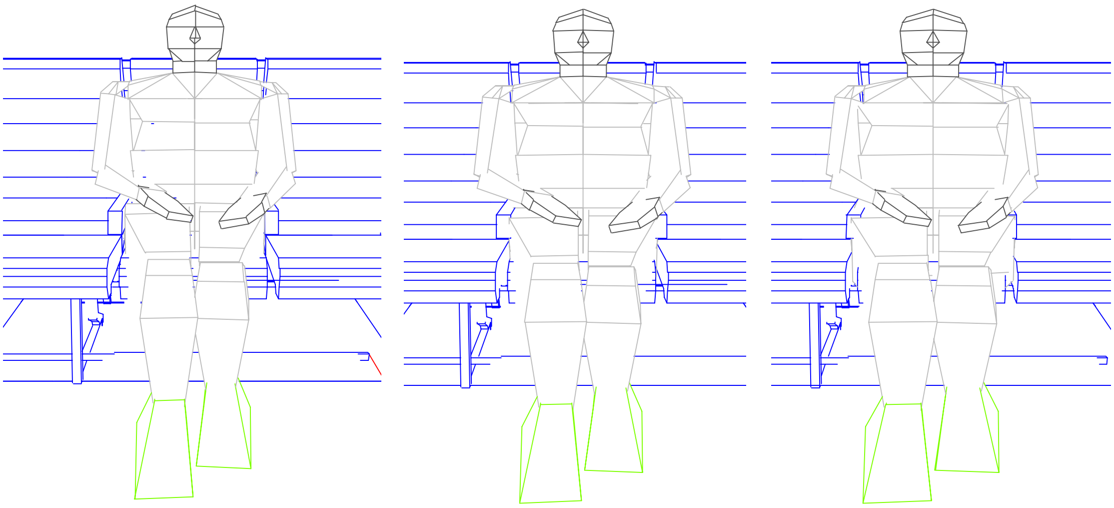


Figure 32 Three views of large bodied female passengers sitting in the widest armrest space ('B'). On the left is 95th %ile European female passenger, centre is 95th %ile World female and on the right is 99th%ile World female.

In terms of seat width, it is clear from Figure 32 that even the largest seat modelled is too narrow and that large bodied people will intrude by a considerable amount into the seat space of passengers to either side. Such large passengers may well be uncomfortable themselves, but will almost certainly affect the comfort of fellow travellers. It is also likely that such large people, and those beside them, will find that the lack of space severely limits any ability they might have to make even quite small postural changes to alleviate the onset of cramp / stiffness. Limiting the seating space of larger users in this manner may also have an adverse effect upon the ease and speed with which they, and those around them, can egress the seat in the event of an evacuation.

It is recommended that any regulation requires all seats to have a minimum acceptable space between armrests that is at least equivalent to the hip breadth of the largest acceptable %ile passenger. In view of the fact that in Western populations, especially the US, a larger percentage of the population are getting considerably more overweight (CNN, 1998), it would be sensible to regulate armrest width on the basis of the hip width of 99th %ile world population dimension (584mm or 23"). Additionally, it is recommended that any regulation requires overall seat width to provide sufficient space for the shoulder width of the largest acceptable percentile passengers. Again, as the numbers of heavily build people in Western populations appears to be growing it is worth considering using 99th percentile World population bideltoid shoulder width for the regulatory dimension (608mm or 24").

5.10. Evaluation of seat cushion height and length

The height of the seat cushion from the floor and the length of the seat cushion base has the greatest effect on the posture of smaller passengers, resulting in increased pressures under the thighs and back of knee.

5.10.1. Cushion height

An evaluation of seat cushion height was undertaken, by assessing the ability of passengers to place their feet fully on the floor while maintaining contact between seat back rest and their pelvis and spine. Table 12 shows 1st and 5th female and 95th and 99th %ile male sitting knee (popliteal) heights for British, European and World populations.

Table 12 1st and 5th female and 95th and 99th %ile male sitting knee height data

	Population source	Data source	1st %ile	5th %ile	95th %ile	99th %ile
British	[redacted]	PeopleSize & Adultdata	351mm (13.8")	356mm (14.0")	499mm (19.6")	518mm (20.4")
European	UK, Dutch	PeopleSize & Adultdata	351mm (13.8")	356mm (14.0")	518mm (20.4")	536mm (21.1")
World	Japanese, US	PeopleSize	318mm (12.5")	331mm (13.0")	501mm (19.7")	520mm (20.5")

Ideally the seat height would allow the maximum number of passengers to sit with their feet on the floor. However, when the anthropometric data above is compared with RVAR (DETR, 1998), PSV Accessibility Regulations (DETR, 1999) and previous aircraft seat recommendations, it can be seen that all the minimum recommended seat heights are between 30mm and 150mm (1.2" and 5.9") higher than the 1st %ile European female requires, increasing to between 60mm and 170mm (2.4" and 6.7") for the world population. If a minimum of 400mm (15.7") was used, this would mean, that 32% of British females would not be able to place their feet on the floor when seated. If a minimum of 500mm (19.7") was used, this would increase to 99.9%. The percentage would increase even more if world (i.e. Japanese) data were included. However, having a seat base height which is too low may disadvantage those passengers with larger popliteal heights (i.e. 95th to 99th %ile) when trying to leave the seat. Hence recommendations on seat height tend to be a compromise. However, the potential health risks to smaller passengers may mean that such a compromise may not be acceptable for long haul flights and, as the following shows, a footrest is therefore required.

If the cushion is too high, smaller passengers cannot rest their feet on the ground, and consequently will experience tissue compression on the back of the thigh at the front edge of the cushion. The cushion heights of all four models of seat used in the study proved to be too high for smaller users, indeed passengers of up to approximately 30th %ile female popliteal height will find the seats far too high (see also Figure 33, Figure 36, Figure 37 and Figure 38). In addition to being uncomfortable, such compression is known to adversely affect blood flow in the tissues of the leg and may restrict venous return of blood from the lower legs.

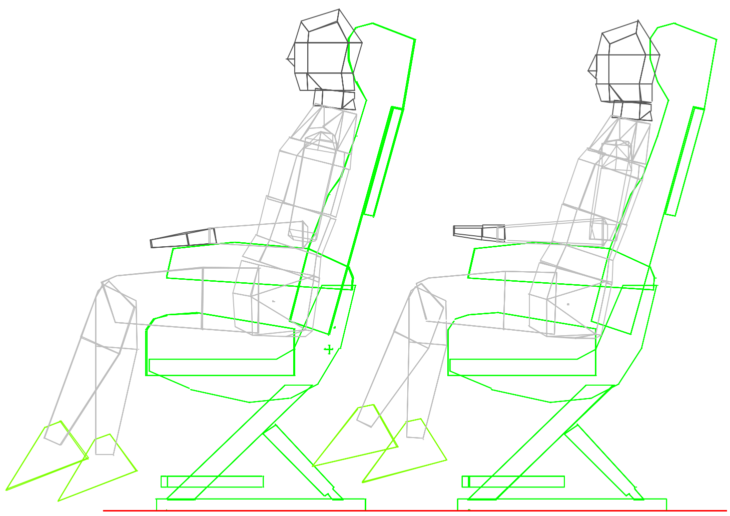


Figure 33 A 5th %ile World female (left) and a 1st %ile World female (right) sitting in seat A. Note that neither can reach the floor with their feet if they adopt a normal seating posture.

The preferred height of a compressed seat cushion would be some 10 to 20mm (0.4" to 0.8") less than the popliteal height of the passenger (usually including a shoe heel height factor). It is impossible to provide a fixed seat cushion height that would accommodate a wide range of passengers since the range of popliteal heights in a population is quite large, for example: 350mm to 471mm (13.8" to 18.5") for 5th to 95th %ile World male and female populations, or 318mm to 498mm (12.5" to 19.6") for 1st to 99th %ile male and female World population. So possible seat heights might be 323mm (popliteal height of 318mm -20 and + 25 for shoe heel height correction) for a 1st %ile World female up to as much as 503mm (popliteal height of 498mm -20 + 25mm for shoe height), as demonstrated in Figure 34 . The cushion heights for the modelled seats are displayed in Table 13.

Table 13 The cushion seat heights for the modelled seats

Model	Cushion front	Cushion rear
'A'	465mm (18.3")	430mm (16.9")
'B'	457mm (18.0")	432mm (17.0")
'C'	445mm (17.5")	395mm (15.6")
'D'	480mm (18.9")	460mm (18.1")

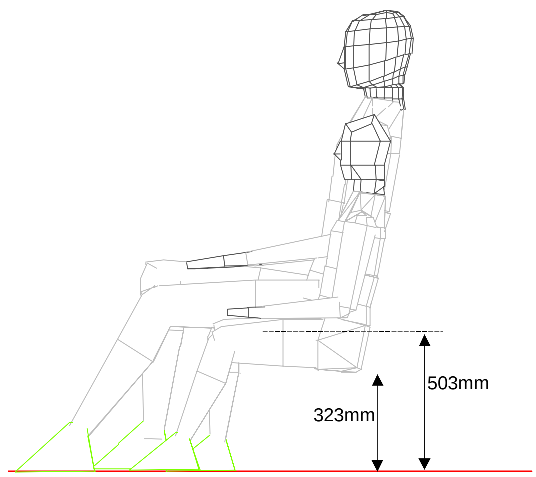


Figure 34 A 1st %ile World female and 99th %ile World male passenger overlaid to demonstrate the difference in possible cushion heights.

If the seat height were determined in order to allow the smallest acceptable size of passenger to rest their feet on the ground, the height would be far too low for larger users, forcing them to adopt uncomfortable leg and spinal postures. Sitting so low down may also increase the difficulty of exiting, especially for older or disabled persons (see posture in Figure 35).

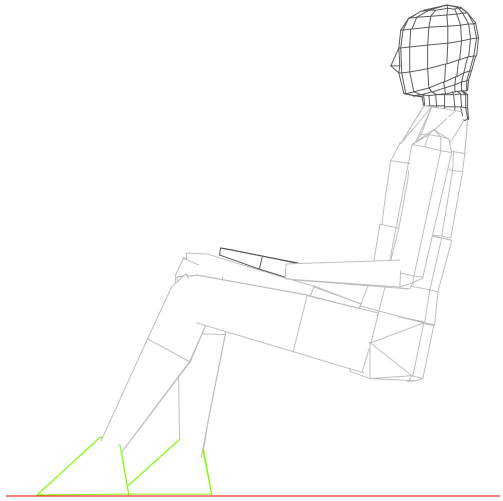


Figure 35 A 95th %ile World male sitting at the preferred seat height of a 1st %ile World female.

Ideally aircraft seating should be adjustable through a range of heights that accommodate the required range of passenger sizes. In the event that adjustability is unacceptable then a compromise solution would be to adopt a height closer to that most suitable for the 'average' size of passenger. This would compromise the posture and comfort of the least number of passengers, although, as currently, it would not suit most users.

Any fixed height seat should be accompanied by a footrest device enabling smaller passengers to rest their feet at a suitable / preferred height. The upper surface of such a footrest would be about 14" (350mm) below the front edge of the seat cushion. Importantly this device would have to fold away such that it could not intrude into the foot space and so cause and obstruction to movement during egress and access.

The design of any footrest device might usefully incorporate a capability for a rocking motion (as demonstrated in modern devices for office seating). This would allow the passenger to undertake optional and short periods of limited leg muscle 'exercise', which might improve circulation and help to minimise factors causing DVT's.

5.10.2. Cushion length

A cushion which is too deep will cause passengers to slump forward in their seat, rotating the pelvis and reducing lumbar support. In addition to comfort considerations, this may have long term back health implications for frequent long-haul fliers.

Seat cushion length was evaluated by checking for a minimum clearance behind the knee in the seated position while the passenger maintains pelvis and spinal contact with the back rest. For this purpose, 1st and 5th %ile female buttock-knee (popliteal) lengths were used. Table 14 shows the data for British, European and World populations.

Table 14 1st and 5th %ile female buttock-knee (popliteal) data

	Population source	Data source	1st %ile	5th %ile
British	[redacted]	Adultdata & PeopleSize	420mm (16.5")	435mm (17.1")
European	French	PeopleSize	408mm (16.1")	423mm (16.7")
World	Chinese	Adultdata & PeopleSize	379mm (14.9")	393mm (15.5")

McClelland (1986) and Stearn (1988) suggest minimum seat base lengths of 400 and 410mm respectively (15.7" and 16.1"). It appears from Table 14 that this is extremely close to 1st %ile buttock-popliteal length for European data but is 20-30mm (0.8-1.2") longer than 1st %ile world data. Overall, given that most of the body weight is supported by the seat bones, a short seat base is usually preferred so as to avoid causing smaller sitters to slump forward as described earlier. As this will also assist with access and egress a short seat base length would appear optimal.

The approximate uncompressed cushion lengths for the modelled seats are displayed in Table 15.

Table 15 Approximate measures of the uncompressed cushion lengths for the modelled seats

Model	Length
‘A’	360mm (14.2")
‘B’	420mm (16.5")
‘C’	405mm (15.9")
‘D’	400mm (15.7")

If the length of the seat cushion is too great for passengers they are likely to experience tissue compression in the popliteal area (back of the knee and upper calf) if they sit far enough back on the seat to use the backrest. The resulting pressure can be both uncomfortable and restrictive of blood flow (see Figure 36).

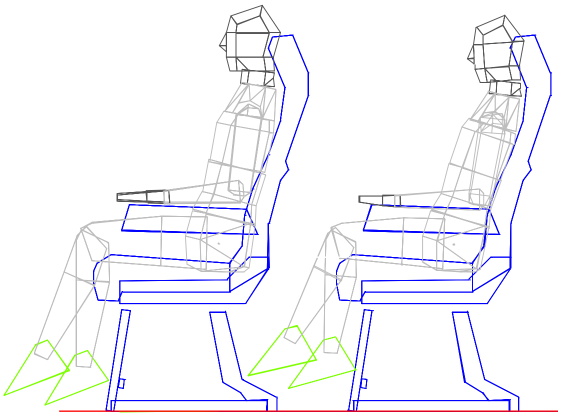


Figure 36 Small female passengers sitting against the seat back support in the ‘B’ seats. On the left is a 5th %ile World female, on the right a 1st %ile World female. Note that the cushion is too long and both will suffer pressure points behind the knee.

Passengers are likely to alleviate the pressure by sliding forward on the seat, tilting their pelvis backward and slumping the spine onto the backrest (see Figure 37). The resulting spinal posture is likely to quickly lead to discomfort and may well cause both pain and stiffness in the spine over longer periods, both of which may adversely affect a passenger's movement capabilities in the event of a sudden evacuation.

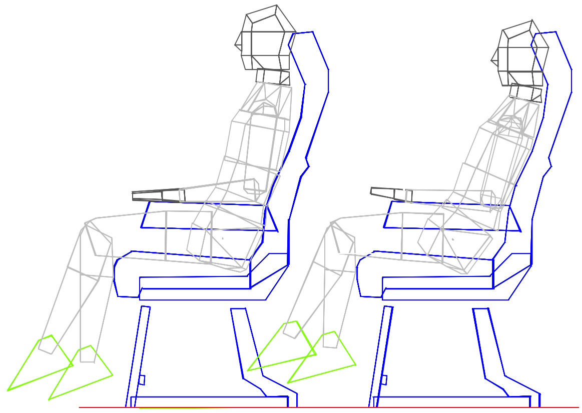


Figure 37 Small female passengers in the 'B' seats. On the left is a 5th %ile World female, on the right a 1st %ile World female.

Both passengers in Figure 37 have slid forward on the seat to alleviate any pressure at the back of the knees and both have poor spinal postures, particularly the 1st %ile passenger.

It is difficult to accurately assess the suitability of the modelled seat's cushion lengths for smaller passengers, since it was not possible to obtain data concerning the cushion's compressive qualities, nor their detailed surface profiles (except in the case of seats 'D'). However, assuming a minimum of seat compression reasonably realistic seating positions were established for the smaller SAMMIE human models.

The worst case seat is the 'B' (see Figure 36 and Figure 37), which has the longest uncompressed seat cushion length of 420mm. The 'C' and the 'D', are similar in length (400 to 405mm) and while they probably just about accommodate a 5th %ile World female passenger, they do not suit the smaller passengers down to 1st %ile size (see Figure 38 and Figure 39).

Of the modelled seats only the 'A' design has a seat cushion length short enough to allow a passenger of 1st %ile buttock popliteal length to use the back rest without experiencing pressure at the back of the knee and without slumping (see

Figure 33 above). This demonstrates that anthropometrically acceptable designs are achievable.

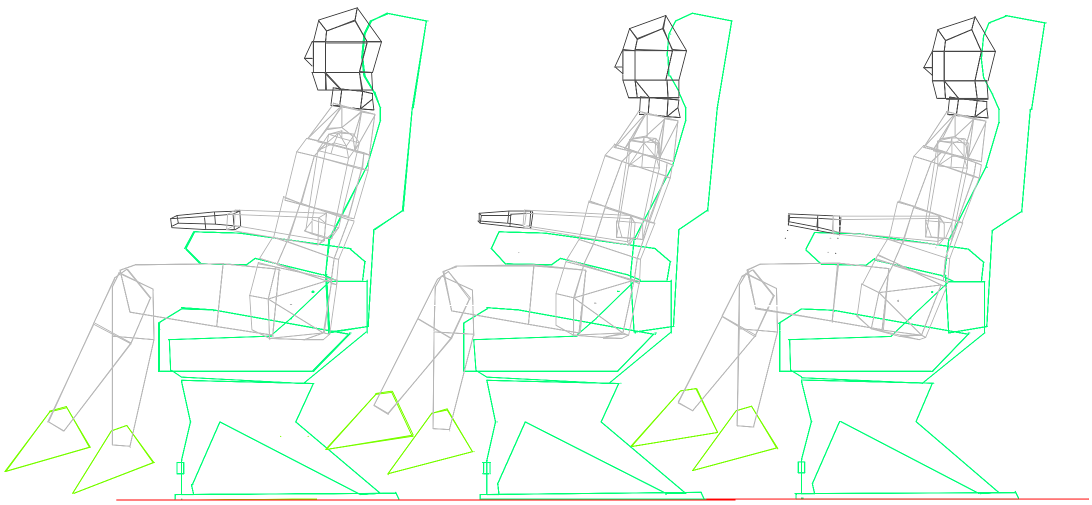


Figure 38 Small female passengers in seat 'C'.

On the far left of Figure 38 is a 5th %ile World female, for whom the seat length (405mm (15.9") uncompressed) is just about adequate. In the centre is a 1st %ile World female sitting against the back rest; in all likelihood she would suffer severe compression in the popliteal area. On the right, the 1st %ile female adopts a poor slumped posture to alleviate pressure on the back of her knees.

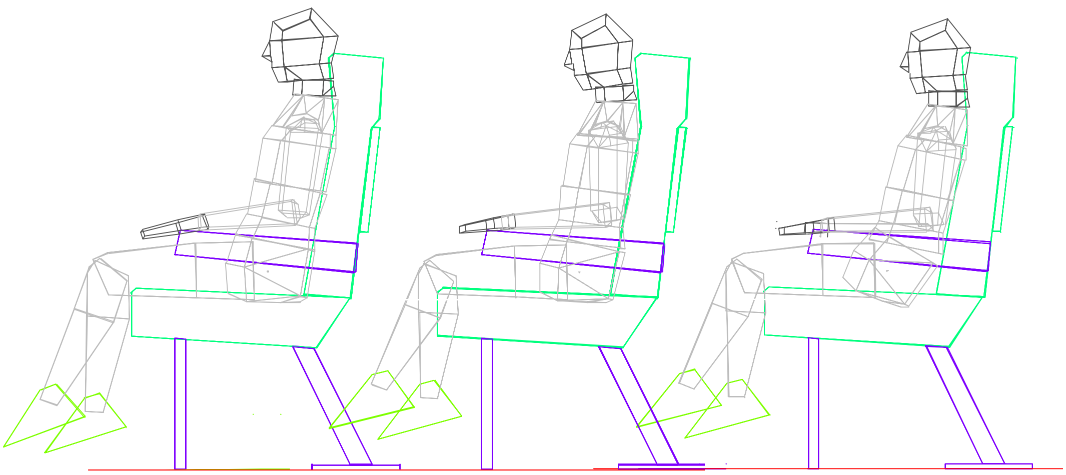


Figure 39 Small female passengers in seat 'D'.

On the left of Figure 39 is a 5th %ile World female, for whom the seat length (400mm (15.7") uncompressed) is just about adequate. In the centre is a 1st %ile World female sitting against the back rest; in all likelihood she would suffer severe compression in the popliteal area. On the right, the 1st %ile female adopts a poor slumped posture to alleviate pressure on the back of her knees.

In order to improve passenger comfort and health the compressed seat cushion length should not exceed buttock-popliteal length (1st %ile World female is 379mm (14.9"), 5th %ile World female is 393mm (15.5"), 5th %ile European female is 423mm(16.5")).

Ideally seat cushion lengths should be adjustable to accommodate the widest range of user sizes. In the event that this is not acceptable or possible, then the smallest acceptable buttock-popliteal length should be used to determine the required compressed cushion length.

Validation of both seat height and cushion length should take account of the compressed surfaces of the cushion and the seat back support. This will be difficult using a simple tape measure. It is recommended that should the regulations cover these seat dimensions they be measured using an adapted version of the 3D SAE H-point manikin as discussed in Section 5.7 .

6.0 Health issues - Venous thrombosis and other diseases associated with air travel

6.1. Introduction

During the second world war, Simpson (1940) made the observation of an excess of deaths (6 fold) due to pulmonary embolus (PE) in those people spending prolonged time (>12 hours) in underground shelters in the UK. It soon became evident that a recurring theme to these deaths was the enforced immobility endured during these period which were often repeated over successive nights. The victims had often been sitting in deck chairs or similar seats. Realisation of the connection between prolonged sitting, probably with additional pressure on the leg veins caused by the structure of the seat, and PE resulted in the advice that people exposed to such prolonged confinement should be provided with bunk beds so that they could lie flat. Having done so the incidence of this condition declined.

Since this early report repeated reference has been made to the harmful effects of prolonged sitting with regards the formation of deep vein thrombosis (DVT). Homans (1954) in 1954 presented 4 cases of travel/sitting thrombosis. Symington and Slack (1977) used the phrase ‘economy class’ syndrome alluding to the cramped conditions experienced by passengers in the economy section of aircraft but pointed out this syndrome was not restricted to this mode of transport alone. Cruickshank et al (1988) reported 6 cases emphasising the role of air travel and thrombotic disease.

Despite these reports the precise dangers and precipitating factors induced by air travel are incompletely understood. The aim of this review is to summarise the present knowledge on the subject with reference to possible improvements in aircraft seat design.

6.2. Anatomy

6.2.1. Superficial and deep venous systems.

The superficial and deep venous systems represent two separate compartments divided by the deep fascia. The deep system comprises of veins lying within (soleal and gastrocnemius) or between (tibial and peronneal) the muscles of the lower leg and act as the veins of the pump chamber. These join to form the popliteal vein and then continue superiorly to form the femoral and iliac systems, acting as the pump outflow tract.

The superficial system is a network of small veins draining the skin that empty both into the outflow tract and the pump chamber veins via communicating veins with valves causing the flow of blood into the pump compartment. The superficial system has two large vessels which themselves connect into the deep outflow tract. The short saphenous vein connects to the popliteal vein (sapheno-popliteal junction) and the long saphenous to the femoral vein at the sapheno-femoral junction. Valves within the deep and superficial systems direct blood towards the heart.

6.2.2. Muscle pumps.

During contraction of the calf muscles a pressure of 200-300 mmHg is generated which completely compresses and empties the deep veins. As little as 10 mmHg is required to overcome the resistance to flow in the outflow tract, such that the generated pressure is sufficient to overcome the gravitational hydrostatic pressure generated during standing or sitting. Flow into the superficial system is stopped by the valves located in the communicating veins. When the muscle contraction ceases pressure within the deep system is zero and there is therefore rapid filling from the superficial system under hydrostatic pressure and from inflow from arterial blood flow.

6.3. Venous physiology/pathology

The imposition of a prolonged period of immobility, usually in the sitting position has a number of effects on the venous system of the lower legs. The normal means of venous return i.e. the combination of muscle pumps and venous valves, will be significantly compromised by this imposed immobility and inactivity.

6.3.1. Decreased blood flow.

Normal venous return is maintained by the inherent tone within the venous system and the calf muscle pumps. The main drive for venous flow is the muscle pump with the venous tone controlling distribution and rate of return. The loss of the normal mechanisms for maintaining sufficient venous return will be manifest as a decrease in venous blood velocity. Ashby et al (1995) have shown that for legs that are immobile the blood flow within the lower leg veins is reliant on the position of the limb. The lowest blood velocity is in the sitting position, with the lower legs in a vertical position, only developing a velocity of 1.3 cms/sec. This is in comparison with the velocity in the standing position of 9.2 cms/sec and lying position of 27.6 cms/sec.

6.3.2. Blood pooling.

Lack of blood flow will result in pooling within the veins, which is maximal after approximately one hour in this position (Shvartz et al 1983). During this period the shape of the veins change from their normally collapsed, dumbbell cross-sectional shape to an ellipse, and then to a circular cross-section. Initially the pressure within the veins remains relatively static. However, once fully distended any additional increase in volume brought about by the further addition of blood results in an increase in intravenous pressure. This relationship becomes non-linear such that small increases in volume result in a disproportionate increase in pressure.

6.3.3. Interstitial oedema.

As a result of continued raised venous pressure increased flow of capillary transudate results in passage of fluid into the interstitial space. The degree of oedema, manifest as a change in leg volume, will be a result of the balance between fluid accumulation and fluid removal by the lymphatics. Landgraf et al (1994) have shown that an increase in leg volume is detected after 3-6 hours of simulated long distant flight and increases in the subsequent hours up to 12 hours.

6.3.4. Hydrostatic pressure.

In addition to the increased venous pressure caused by blood pooling, the situation is further compounded in the lower limbs because of the increased hydrostatic pressure resulting from being in an upright position. When standing, the ankle region is under approximately 100mmHg pressure when compared with the level at the heart. Above the ankle there is a proportional decrease in pressure as one ascends. In the sitting position there will be a slight overall reduction in ankle pressure compared with standing as the column of blood above this level is decreased.

6.3.5. Venoarteriolar reflex

An increase of hydrostatic pressure above 25 mmHg within the veins will generate a noradrenergic reflex causing local arteriolar vasoconstriction. The outcome of this reflex is therefore to reduce blood inflow to the leg and in turn reduce the amount of venous distension.

6.3.6. Endothelial function.

The endothelium, the lining of the blood vessels, can no longer be considered as a passive cellular lining of the blood vessels, as once thought. It is now known that these cells have an active role in maintaining vascular tone and also secrete a number of substances with anticoagulant, anti-inflammatory and anti-platelet properties. At the centre of many of these properties is nitric oxide (NO), formerly known as endothelially derived relaxing factor. As this name suggests this locally derived molecule has profound vasodilatory effects on the local vessel and has recently been shown to play a major role in the maintenance of vascular tone in capacitance veins (Blackman et al 2000). Its other main function is to inhibit platelet aggregation. The loss of NO will therefore have a profound effect on the local venous environment resulting in venoconstriction and promoting coagulation. The mechanism by which prolonged sitting can result in reduced NO is explained below.

6.4. Venous thrombosis

6.4.1. Virchow triad.

In 1856 Rudolph Virchow first proposed that a number of factors, either in isolation or combination, resulted in thrombosis. The triad of factors included alterations in:

1. the flow of blood
2. the lining of the vessel wall
3. the constituents of the blood

6.4.2. Flow

Stasis. From the preceding section it can be seen that prolonged immobility, especially in a sitting position, will already satisfy one component of this triad due to the resultant decrease in venous blood flow. Interestingly, however, the mere fact that blood is slow flowing or even static within a vessel does not necessarily result in thrombosis, as one might expect, with the blood remaining fluid for a number of hours (Wessler 1962). Using isolated vein segments Wessler demonstrated that macroscopic thrombi could not be visualised in less than twenty minutes and often not until 60 minutes after stasis. These thrombi were small, consisted mainly of fibrin, and increased only slowly with time, such that coagulation was still not complete eight to ten hours after stasis. This would therefore seem to suggest that while some degree of partial thrombosis can be generated by stasis alone this does not then lead to an accelerated process of large-scale vessel thrombosis. The existence of regions with prolonged blood stasis in vivo was demonstrated by the venographic studies of McLachlin et al (1960) which showed residual contrast medium could still be detected within thrombus-free calf valve sinuses 30-60 minutes following injection, provided the limb was immobile.

Interestingly, however, post-mortem studies have confirmed that it is these very same sites i.e. the valve sinuses, in which thrombus originated, confirming a contributory role for stasis in thrombogenesis. It has been proposed that turbulence within these valve pockets not only increase the risk of coagulation but also the preferential deposition of cellular components within the sinus i.e. red blood cells (Sevitt 1974). Once formed, the fate of these microthrombi will depend on the balance between thrombus progression and fibrinolysis, which will presumably be in part dependent on the continuing presence of leg immobility.

Hydrostatic pressure. Another mechanism by which stasis could have a thrombogenic effect is by the hydrostatic pressure resulting from blood pooling within the deep veins of the lower limbs. The increased pressure to which the legs are subjected has a direct and proportional effect on the function of the endothelium i.e. factor two of the triad. Using fibrinolysis, the breakdown of the end result of thrombosis, as a marker of endothelial activity, it has been shown that this is markedly reduced in those areas of the venous system subjected to the greatest hydrostatic pressure (Pandolfi et al 1967). Extrapolating this effect to the other endothelial functions, the result of prolonged hydrostatic pressure could lead to endothelial dysfunction and decreased protection from venous thrombosis. In support of this dysfunction, veins that are exposed to the continually increased pressure of the arterial system, as with arterio-venous shunts for renal dialysis or venous grafts for coronary bypassing, go on to exhibit the same endothelial damage exhibited by the arterial system i.e. atherothrombosis. This suggests that exposure of the endothelium to unusually high pressure will result in endothelial damage.

Shear stress. As seen above, one of the main mediators of endothelial function is NO. Local control of NO production is via a variety of mechanisms but one of the most important is stimulated by the shear stress detected at the blood/vessel interface. As the shear stress increases so does the production of NO resulting in a vasodilatory and increased anti-platelet response to cope with the increased blood flow. When flow is reduced, as with immobility, in a region where shear stress is already low, i.e. the venous system, the increase in vasoconstrictor response and decrease in anti-platelet activity increases the likelihood of thrombosis.

While stasis can therefore cause some degree of clotting directly via interaction of blood components, it seems likely that it is also acting via dysfunctional endothelium secondary to hydrostatic pressure and reduced shear stress.

Data from the passenger survey shown in (detailed in section 4) indicates the degree of enforced immobility experienced by many long-haul passengers.

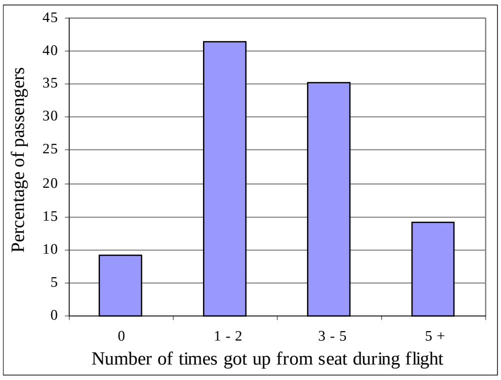


Figure 41: The number of times the 310 respondents got out of their seat during the flight

Just over 1/3 of passengers reported that they did not get out of their seat as many times as they would have liked during their flight. The main reason given was that the trolleys restricted any ability to move around the plane (i.e. to get to toilet) (9% of all respondents). In addition, 25% of those respondents who were sat in either window or centre seats were unable to get out of their seat as often as they would have liked. These respondents felt that the presence of passengers in the seats next to them made it difficult to get out and many felt uncomfortable disturbing other passengers, particularly those sleeping.

6.4.3. Vessel wall

Trauma. It is generally accepted that trauma to a vein will predispose that vessel to local thrombosis. This is commonly seen in association with local bony fractures (Bauer 1944). In the surgical setting of hip arthroplasty the high incidence of associated thrombosis is thought to be as a consequence of local vessel trauma during the operation. In keeping with this analysis of isolated popliteal vein thrombosis by Schmitt and Mihatsch (1992) revealed that the majority of patients gave a history of prolonged flexion during air travel. Thrombus appeared to have arisen on folds within the vessel wall formed when the vessel was flexed. On autopsy study, these folds were as a result of intimal fibrosis caused by microtrauma upon flexion and their occurrence appeared to be age related.

Hypoxia. Travelling within an aircraft at 43000 feet the cabin pressure is equivalent to an altitude of 8000 feet (Kesteven and Robinson 1999). Alveolar oxygen tension is normally 103mm Hg but at this effectively increased altitude is 65mmHg. While the alveolar oxygen may be 60-70% of normal the haemoglobin-oxygen dissociation curve in healthy adults results in haemoglobin that is still 80-90% saturated. At this level passengers with normal cardiovascular/respiratory reserve will be unaffected but those with impairment to the respiratory or cardiovascular systems may be distressed by this degree of hypoxia (Beighton and Richards 1968). The endothelium is vulnerable to hypoxia and reacts by venoconstriction; this may reflect a decrease in normal endothelial function including its antiplatelet action. Furthermore, focal areas of hypoxia may occur within the valve cusps increasing the risk of thrombosis at these sites (Hamer et al 1981). Simulated travel at reduced partial pressure has also shown that this has an adverse effect on the coagulation system with increase in the markers of activated coagulation by two to eight fold (Bjjorn Bendz, et al (2000)).

Nicotine. There is now no question as to the deleterious effect of cigarette smoking on the arterial system both acutely and chronically. Many of these effects are brought about by impairment of endothelial function. These same effects also occur within the veins and it has been shown that cigarettes in general and nicotine specifically causes venous endothelial dysfunction (Chalon et al 2000).

6.4.4. Blood constituents

Thrombophilia. A number of genetically acquired abnormalities of coagulation are now recognised, predisposing people to the risk of thrombosis, especially when combined with other additional risk factors. The most common of these is activated protein C resistance/factor V Leiden which is present in up to 7% of Caucasian populations. In one study this one defect alone has been found in up to 40% of patients suffering a DVT (Dahlbach et al 1995).

Hypercoaguability. There are now a number of well-recognised causes of hypercoaguability which will predispose to thrombosis; these include malignant disease, pregnancy, myocardial infarction and the oral contraceptive pill. As with thrombophilia, these become increasingly important when combined with other risk factors. Haemoconcentration may also lead to a hypercoaguable state and may be brought about by dehydration, secondary to a dry atmosphere, or following alcohol consumption, both of which may be encountered during prolonged air travel. Similarly the mere act of sitting for two hours has been shown to cause an elevation in blood viscosity in the lower limbs (Masahito Hitosugi et.al. (2000))

Combining all of the risk factors for thromboembolic disease and studying their effects over the time course of a long-haul journey it can be seen that there is a cumulative effect that in some patients might result in DVT. In the normal person with normal endothelial function the onset of thrombosis is not reached for a considerable time. At the other end of the spectrum passengers who are already hypercoaguable, due to an underlying condition, who further stress their endothelium will reach this level far quicker, perhaps sufficiently quickly that micro thrombi have the opportunity to form macrothrombi and become symptomatic. This is well illustrated in the case of two French workers, known to have activated protein C resistance/Factor V Leiden, who developed DVT when forced to undertake prolonged, repeated car journeys during a transportation strike. Five co-workers also known to suffer from the same condition did not, for various reasons, undertake prolonged travel and did not suffer DVT (Eschwege and Robert 1996).

6.5. Other diseases

6.5.1. Arterial thrombosis.

The pathophysiogical processes outlined above also apply to the arterial vasculature. Sporadic cases exist (Collins et al 1979) of arterial thrombosis occurring after long-haul flight, usually in patients with pre-existing arterial disease. The arterial system however is likely to be more protected than the venous when exposed to prolonged immobility as the alteration in intraluminal pressure is less dramatic and the endothelium is more adjusted to responding to a high pressure environment. However, secondary effects of venous hypertension and distension resulting in the venoarteriolar reflex could bring about arterial constriction that add to an already compromised system. The other risk factors secondary to alteration in blood constituents and the vessel wall will also apply and, in those patients already at risk, may predispose to thrombotic disease. This will be most evident in the coronary and cerebral circulations, with patients presenting with heart attack and stroke.

6.5.2. Collapse.

Besides the effects on the venous endothelium, prolonged sitting can have a number of other physiological effects. Schvartz et al (1982) have shown that following 5 hours of sitting the increase in heart rate and blood pressure normally seen on standing from the supine position is lost because the peripheral vasoconstrictor response is already initiated by prolonged blood pooling within the legs. This partially compensated system to the upright sitting position, inadequately responds to the demands of standing. Therefore the standing position will be poorly adjusted resulting in insufficient increase in peripheral resistance, lower limb blood pooling and a low cardiac output. This may be asymptomatic, result in dizziness or collapse, or worse, reduce tissue perfusion precipitating ischaemia (cardiac or cerebral). Thus prolonged sitting constitutes a liability for subsequent performance in the upright position.

6.6. Incidence of travel DVT

The cumulative data from numerous anecdotal reports regarding immobility and thromboembolic disease suggests that the two are related. While travel has often been implicated as the cause of DVT it appears to be a combination of stress factors experienced during certain modes of travel, associated with immobility, that are responsible. Milne (1992) has attempted to draw together a number of reviews on the subject, which suggest an association, though the lack of carefully controlled trials is highlighted. Ferarri et al (1999) by using questionnaires of patients attending hospital with DVT have shown that of these up to 25% gave a history of prolonged travel compared with a hospitalised control group of only 7.5%. However, a further recent case controlled study has concluded that the exposure to any form of prolonged travel does not increase the risk of developing DVT (Kraaijenhagen et al 2000). This study used patients presenting with clinically suspected DVT, subsequently shown to be negative, as the control group, and showed they had a similar rate of prolonged travel as those with DVT, thus demonstrating travel was not associated with an increased incidence of DVT. However, case controlled studies are reliant on the fact that the control group is appropriate. If travel should also bias the selection of patients with symptoms but without DVT then the control group will have a disproportionately high incidence of long distance travellers thus undermining the effect in the case group. It has long been recognised that significant discomfort and swelling can occur during prolonged travel, without the development of DVT (Johnson 1973) due to the same changes in physiology, namely alterations in hydrostatic pressure within the calf vessels, mentioned above. Clinical differentiation between those patients with and without DVT in a group of travellers with painful swollen legs will therefore be difficult and further testing will be required to exclude DVT. The possibility exists therefore that the control group will contain excess travellers as a direct result of the effects of prolonged immobilisation. Interestingly, this paper does provide information regarding the incidence of DVT in symptomatic travellers: 52 symptomatic patients gave a history of travel of whom 9 had a proven DVT i.e. 17.3%.

The precise incidence of travel-related symptomatic DVT is however not known. Prospective trials to calculate the incidence of thromboembolic disease (TED) among air travellers compared with suitable controls have yet to be performed.

6.6.1. Asymptomatic disease.

All of the above makes the assumption that thrombotic disease acquired during flight declares itself clinically. As seen above the pathophysiology is such that a balance may quickly be struck between thrombus formation and dissolution. Alternatively thrombus may be formed but is insufficient to cause overt symptoms. It could be argued that if the clot is symptomless then no harm is done. However a large proportion of the health care budget is spent on chronic venous disease, some of which has no apparent precipitating cause, which could therefore be due to asymptomatic thrombosis. Non-recognition of this disease will cause an underestimation of disease occurrence. Scurr has recently reported (2001) that up to 12% of long-haul passengers may develop asymptomatic DVT – obviously far greater than the reported symptomatic incidence in the general population of 1/1000 in the age range 40 – 70 (Rosendaal 1999).

6.6.2. Delay in presentation.

The rate of medically related claims following arrival (1/48) compared with those during flight (1/10,000) raises the possibility of conditions such as DVT presenting after some delay. Mercer et al (1998) looked at 33 patients with air travel related DVT. 24% presented soon after arrival whereas 82% had presented by the 15th days. Similar delays, on average 48 hours, were also documented by Milne (1992) and Cruickshank et al (1988). This delay in presentation may further reduce the accuracy of relating travel to DVT occurrence.

6.6.3. Long-haul

It would appear from the literature that prolonged immobility is a precipitating factor in producing DVT (Gibbs 1957). But what is prolonged immobility? From Simpson's report in 1940 sitting overnight, could induce thrombosis. More important however is the other end of the scale i.e. the minimum time required. Reviews suggest as little as four (Mercer and Brown 1998) or five (Milne 1992) hours immobilisation may be sufficient to cause DVT. The duration of travel becomes important as it will determine how long microthrombi have to enlarge and propagate, developing from non-symptomatic, non-obstructive microthrombi, to symptomatic, obstructive macrothrombi. It also raises the possibility that subjects who are exposed to repeated periods of prolonged immobility, i.e. a return journey, are more prone to develop significant thrombus. This would be particularly relevant in subjects who had already developed small valve cusp thrombi which have not been removed by fibrinolysis acting as a focus for rapid thrombus formation on repeat exposure. This was first alluded to by Simpson when he suggested that it may have been the successive nights spent in air-raid shelters that finally culminated in thromboembolic disease. This may have accounted for the recent tragic death of a young woman travelling from Australia. During her three week stay she was admitted to hospital with a chest infection which in retrospect may have been a pulmonary embolus arising from a DVT from the outward journey. Untreated this would then have acted as a nidus for further rapid thrombus formation which resulted in a fatal pulmonary embolus upon arrival in the UK (Times, p9, November 23, 2000).

6.7. Fact and fiction.

As a result of this review it has become evident that few hard facts are known about travel induced disease, specifically thromboembolic disease (TED). This is because of a number of factors.

6.7.1. Studies to date

1. Conflicting studies regarding the relevance of travel to TED.
2. Sporadic anecdotal reports of TED during travel.

3. Incidence of TED during travel compared with incidence in the general population is not known.

6.7.2. Diagnosis.

1. By definition passengers are travelling and therefore collation of data is difficult.
2. The disease is often difficult to diagnose clinically.
3. Diagnostic tests may miss small clots.
4. Presentation may be sometime after the travel episode.
5. Asymptomatic disease will go unnoticed.

6.7.3. Physiology

A number of intrinsic factors predisposing to thrombosis exist during prolonged seated air travel:

1. raised venous hydrostatic pressure
2. hypoxia
3. dehydration
4. decreased venous blood flow

To this may be added a number of extrinsic factors unrelated to air travel:

5. vein trauma
6. hypercoaguability
7. smoking
8. pre-existing cardiovascular problems
9. previous history of TED

It is known that a combination of these factors increases the likelihood of thrombosis.

6.8. Estimated Incidence

In the age group 40-75 the accepted incidence of DVT is 1/1000 (Rosendaal 1999). From the above data an estimate of the incidence of a history of air travel in this group would at a minimum be 10% and perhaps rising to 25%. For the UK with a population of 60 million the total number of DVT's per year would be 60,000 of which 6,000 are therefore air travel related. Assuming 20 million long-haul passengers leaving the UK per year, then 1 in 3000 will develop a symptomatic DVT. From the work by Scurr 300/3000 (10%) will have asymptomatic DVT and 4/3000 passengers will have symptoms and be investigated for DVT but none will be found (Kraaijenhagen 2000. Adopting the higher incidence of associated travel these figures may be multiplied by a factor of 2.5 so that almost 1/1000 travellers may experience symptomatic DVT, 100/1000 asymptomatic DVT and 4/1000 have symptoms but are negative when investigated.

6.9. General protective measures.

6.9.1. Hypercoaguability.

Measures to combat increased thrombosis due to the blood constituents can be helped by ensuring that dehydration is avoided taking regular non-alcoholic drinks; alcohol is to be avoided, as this in turn will cause dehydration.

Aspirin will decrease the stickiness of the blood platelet cells so reducing the opportunity for DVT. Its application in the setting of travel has, however, never been formally tested. Aspirin is not without side-effects and the risk-benefit for each passenger should be individually assessed. Those subjects known to have specific clotting disorders should seek medical advice and perhaps be formally anticoagulated prior to travel.

6.9.2. Vessel wall.

Support stockings are a means by which the transmural pressure can be reduced within the legs thus potentially overcoming some of the damaging hydrostatic pressure effects of prolonged sitting. Graduated support stockings can provide a pressure of 20–40 mmHg. The majority of studies into protection from DVT using stockings have been during surgery and the beneficial effects are generated usually when the patient is lying flat. The relevance of this to passengers is not known and no controlled trials in this population have been performed.

Smokers may be at increased risk of thrombosis due to chronic exposure with resultant endothelial damage.

6.10. Potential for aircraft seat design.

The intrinsic factors related to position while seated are:

- Stasis /Low flow
- Hydrostatic pressure

All of these are secondary to the dependent nature of the lower legs in the sitting position.

Stasis/low flow: this results from the lack of activity within the calf muscle pumps. During long flights movement and exercise of the legs while seated will reduce stasis. However, it would appear that the effects of exercise are only short-lived with the changes in flow existing only during the exercise period. Exercising every hour during enforced sitting for five hours does not appear to decrease abnormal haemodynamic responses (Shvartz et al1982). Similarly, the effects on leg oedema of intermittent exercise were effective but short-lived, the process of swelling being interrupted but not delayed with the leg showing a continuous swelling process (Shvartz et al 1983). Conditions conducive to prolonged low-level exercise while seated might provide improved protection from haemostasis. To achieve this, adequate room for leg/foot movement and exercise would be required.

Hydrostatic pressure: This results from the column of blood extending from the level of the calf up to the right heart. Reduction in the height of this column will reduce the resultant hydrostatic pressure experienced by the vein wall. Designs resulting in a degree of leg elevation should therefore be beneficial. Similarly, posterior support of the lower legs could have the potential to uniformly compress the deep veins, akin to support stockings, thus countering some of the effects of prolonged increased venous pressure. This could perhaps be provided by an adjustable leg /foot support. This would need to be stowable to allow egress, but could be employed in flight to provide support and elevation.

While seat height and venous compression by the seat edge have been suggested as causes of decreased venous flow no confirmatory scientific evidence is available. This should be the subject of further research as part of a general seat/physiology programme.

6.11. Future work on TED

Any attempt to advance our understanding of the effects of prolonged air travel on TED must be based on carefully constructed research rather than case reports and anecdotes that so far exist.

6.11.1. Incidence of symptomatic disease.

A means by which this information may be obtained includes postal survey of long haul passengers. This will obviously require co-operation between various travel related groups i.e. travel agents, airlines, aviation authorities etc. Considering the likely low incidence of symptomatic disease recruitment of large passenger numbers would be required. Attempts to use diagnostic tests (blood tests, imaging) on a large unselected population, is unlikely to provide accurate data. The tests used have to have sufficient sensitivity and specificity to allow accurate detection. Blood tests tend to be sensitive but lack specificity requiring additional diagnostic techniques. This is usually ultrasound scanning of the legs but this is time consuming and operator dependent.

6.11.2. Incidence of asymptomatic disease.

The recent report by Scurr is the first attempt to prospectively select and image passengers undertaking long-haul flights. This has produced some interesting data which needs reproducing. In addition the relevance of these small clots needs follow-up data. The use of compression ultrasound for the diagnosis of below knee asymptomatic disease is known to have reduced sensitivity – which would be the case for both pre- and post flight scans. Techniques with high sensitivity and specificity in all parts of the venous system should ideally be applied to this group. (e.g. magnetic resonance imaging is a relatively new potential technique) If the results are reproduced the asymptomatic DVT incidence may act as a useful surrogate marker of symptomatic DVT allowing study of this condition on far smaller numbers of passengers while maintaining statistical power.

6.11.3. Pathophysiology of prolonged sitting.

While symptomatic TED is the important, final presenting clinical condition, and asymptomatic TED may act as its surrogate marker, numerous physiological and pathophysiological processes occur during periods of prolonged immobility. Many of the parameters i.e. coaguability, endothelial function, blood flow, shear stress, venous volume etc, are accessible to non-invasive investigation in simulated travel studies. It may therefore be possible to use these tools to investigate the pathophysiological effects of immobility during simulated air travel in normal volunteers. These tests should therefore be more sensitive than the crude clinical outcome of thrombus formation and allow alterations in aircraft seat design to minimise any detrimental effects found. This could also be extended into testing the effect of frequent, repeated immobility; how long the effects of immobility last; the role of intermittent exercise; the effect of food and drink during immobility.

7.0 Conclusions

It is clear from the findings of the report, specifically the passenger survey and SAMMIE evaluation, that dimensions A, B and C are important for seat spacing and access/egress and should certainly be included in AN64. However, by using SAMMIE, it was evident that the current minimum requirements were in need of review, as the data was now outdated due to changes in secular growth, increases in the ageing population and increases in the proportion of overweight people in the Western world. It was also clear that a number of other minimum dimensions, which would help to improve seat spacing and ease of access/egress, should be considered, in particular seat width, height and length, and armrest position. When defining new minimum dimensions, consideration should be given to using 1st and 99th %ile data as opposed to 5th and 95th %iles, particularly where there are large differences between 1st & 5th or 95th & 99th and when regarding safety issues (e.g. clearances for evacuation).

7.1. Dimension A

As it presently stands, dimension A only accommodates up to 77th %ile European population and 80th %ile World population. Therefore, to ensure reasonable accommodation for the taller %ile passenger, the current minimum requirement of dimension A needs to be increased.

Further work is required to determine if the current minimum provides enough space for taller passengers to adopt the brace position.

The vertical space requirement in AN64 (currently 25" (635mm)) is too small to reasonably accommodate the larger passenger sizes.

The current definition and method of measuring dimension A is ambiguous and takes no account of the fact that the seat back compresses under the passenger's weight, the seat is very often in the recline position or that the height of the armrest may affect sitting posture (and therefore the amount of legroom).

A minimum foot clearance envelope would enable passengers to have enough space to adopt a range of postures.

7.2. Dimensions B and C

The space provided by the minimum dimensions B and C is too small for easy and efficient seat access and egress and causes unbalanced postures. Semi-crouched and unbalanced postures, which also include numerous body contact and friction points, any of which might cause trips and slips (clothing can get caught up, knees and feet might be banged), cannot be regarded as suitable for most people. Elderly and disabled passengers are likely to find the situation significantly less accommodating, especially since the unbalanced postures demonstrated may make strength and manoeuvrability demands upon them that are beyond their capabilities.

Smaller passengers may be disadvantaged because dimension B does not allow sufficient clearance for their lower buttocks. To overcome this, dimension B would be better expressed as two separate values; a minimum at armrest level and a minimum at cushion level.

A more realistic value for dimension C would take account of whole body depths. This may result in a minimum of 305mm (12") for dimension C (approximately 940mm (37") seat pitch). However, a pitch this large is unfeasible, therefore some bending would be acceptable. Further work, such as egress trials, would be of use in developing final recommendations for both dimensions B and C.

Ensuring that the seat support structure does not intrude into the movement space in the seating row would help to improve ease of access/egress.

The importance of seat height was highlighted by the fact that it is included in other current and proposed regulations for other forms of transport (RVAR and PSVAR (DETR, 1998, 1999)). Seat height may also have an influence on health issues as seats that are too high for some passengers may result in circulatory problems when seated over long periods. This could particularly be a problem for smaller passengers if their feet are unable to reach floor leading to undesirable pressure on the back of the knees. This may be overcome by the inclusion of a footrest.

Similar to seat cushion height, seat cushion length may have an influence on health issues as seats that are too long for some passengers may result in circulatory problems when seated for long periods. This could particularly be a problem for smaller passengers whose upper leg length is shorter than the length of the seat. This would result in undue pressure on the back of the knees caused by the passengers' feet being unable to reach floor. It may also cause passengers to slump on their seats leading to potential back problems.

The expert appraisal highlighted the importance of adequate seat back table latching mechanisms, to ensure these cannot fall down when passengers brush against them.

7.2.1. Seat cushion dimensions.

Minimum and maximum dimensions for the designs of seat base, seat back (specifically width) and arm rests should be considered for inclusion in any JAA regulation as these were found in the survey to be important for seat access and spacing issues.

The current widths of typical economy class seats, and in particular the distances between the two armrests, are totally inadequate to accommodate larger bodied passengers, e.g. 10% of European passengers would struggle even with the widest armrests encountered in this study. Therefore, seat access and the ability to change posture in the seat are restricted. In view of the fact that in Western populations, especially the US, a larger percentage of the population are becoming considerably overweight, it would be sensible to regulate armrest width on the basis of the hip width of 99th %ile world population dimension. Of course this also argues for increases in overall seat widths to accommodate larger passengers although folding arm rests may provide an alternative partial solution Additionally, any regulation should require overall seat width to provide sufficient space for the shoulder width of the largest acceptable %ile passengers. Again, as the numbers of larger build people in Western populations appears to be growing it is worth considering using 99th %ile world population shoulder width for the regulatory dimension.

The seat cushions sampled in this study were all found to be too high for smaller users (up to 30th %ile female popliteal height) and three of the four cushions were tool long. A seat height closer to that most suitable for the “average” passenger size would be most desirable, although this still wouldn’t suit most passengers. A footrest which can be stowed away easily should be provided for any fixed height seat which would enable smaller passengers to rest their feet at a suitable height. The smallest acceptable buttock-popliteal length should be used to determine the maximum length.

A definition and method of measuring cushion length and height are required if they are to be included in any JAA regulation.

7.3. Thromboembolic disease and other health issues.

Although there is almost no prospective, controlled data, anecdotal and retrospective reports would support a connection between prolonged immobility during travel and thromboembolic disease (TED). The incidence of travel related TED is not known.

Thrombus formation is multifactorial of which immobility is one factor. Other factors include genetic predisposition, pre-existing cardio-vascular conditions, hypercoaguability and previous TED.

While travel has often been implicated as <u>the</u> cause of TED there appear to be a number of risk factors experienced during travel associated with immobility that are responsible. Venous physiological responses to conditions experienced during air travel can predispose to thrombosis.

Definitive data will only be acquired by carefully conducted prospective research with an adequate sample size and good clinical and basic scientific support. The research must involve adequate numbers and adequate time, taking into account delays in presentation. It is essential that any diagnostic tool used for both symptomatic and asymptomatic disease must have appropriate sensitivity and specificity.

The contribution of seat design and spacing to the development of TED is not known. The scope for reducing the risk of TED includes a review of aircraft seat design and spacing, as maintaining a seated position appears to be one of the risk factors in this condition. Aircraft seat redesign could theoretically reduce these risks and research should incorporate the testing of venous physiology in response to altered seat design.

Dehydration should be avoided taking regular non-alcoholic drinks; alcohol is to be avoided, as this in turn will cause dehydration.

If at risk of clotting, aspirin will decrease the stickiness of the blood platelet cells so decreasing the opportunity for DVT though its application in the setting of travel has never been formally tested.

Those passengers known to have specific clotting disorders should seek medical advice and perhaps be formally anticoagulated prior to travel.

Support stockings are a means by which the transmural pressure can be reduced within the legs thus potentially overcoming some of the damaging hydrostatic pressure effects of prolonged sitting.

Smokers may be at increased risk of thrombosis due to chronic exposure with resultant endothelial damage.

During long flights movement and exercise of the legs while seated will overcome many of the detrimental effects of prolonged sitting i.e. stasis, increased pressure and low flow. It would appear however that these effects are only short-lived with the changes in flow existing only during the exercise period.

8.0 Recommendations

8.1. Provisional amendments to AN64 Successor Regulations

8.1.1. Seated Space

It is recommended that dimension A be increased from 660mm (26 inches) to at least 711mm (28.2 inches) to accommodate up to the 95^{th}%ile European seated passenger allowing 25mm (1 inch) of knee clearance to the back of the seat in front (ideally, this would increase to 747mm (29.4 inches) for the 99^{th}%ile world population).

It is also recommended that dimension A is measured with the forward seat in the reclined position to reflect minimum space provided.

The current 635mm (25 inch) vertical space requirement for dimension A also needs to be increased (ideally to 662mm (26 inches)) to take account of passengers' sitting knee heights.

In addition, to allow sufficient seated space, a minimum foot clearance envelope is recommended, which extends 1136mm (44.7") forward of the seat back cushion surface and allow a vertical free space of 200mm (8") above the cabin floor (see Figure 17, on page 37). Ideally, these dimensions should be increased to 1166mm and 210mm respectively (for 99%ile).

Further work is required to determine if the current minimum provides enough space for taller passengers to adopt the brace position.

8.1.2. Access/egress

Dimension B may be better expressed as two separate values. Between 230mm and 255mm (9 and 10 inches) would be an acceptable minimum for dimension B at armrest level and a minimum of 210mm (8.3") would be acceptable at cushion level. However, due to the paucity of anthropometric data on the standing thickness of the thighs it is difficult to make firm recommendations for both B and C.

Dimension C would, for example, need to increase to 305mm (12 inches) to accommodate a 95%ile passenger and permit them to stand upright. However, this is unlikely to be practical and some degree of bending whilst leaving the seat is likely to be acceptable. Further work, including egress trials, is needed to develop a final recommendation.

To improve ease of seat access/egress, a minimum foot clearance of 350mm (13.8") forward of the leading edge of the seat base is recommended (ideal = 360mm(14.2")) (see Figure 31, page 56).

From a seat design point of view it would be worth considering the potential for having ‘flip up’ seat squabs, in a similar manner to cinema seating, which would serve to greatly increase the available space for moving along a row of seats during access and egress. The leading edge would also serve as a ‘perch’ on which to rest whilst standing waiting one’s moment to exit.

8.1.3. Other recommendations

As the current width of typical economy class seats are too small to accommodate larger passengers, a minimum cushion width of 497mm (19.6") and back width of 536mm (21.1") are recommended (ideally 584mm (23") and 608mm (23.9") if using world data). As a minimum, armrests should be foldable to enable ready access/egress by larger passengers

The provision of an easy to use foot/leg-rest is recommended to aid smaller passengers who are unable to place their feet on the floor. The upper surface of such a footrest would be about 14" (350mm) below the front edge of the seat cushion. Importantly this device would have to fold away such that it could not intrude into the foot space and so cause and obstruction to movement during egress and access.

A maximum seat base length of 423mm (16.7") should also be considered (ideally 379mm (14.9") if using 99%ile world data). Overall, given that most of the body weight is supported by the seat bones, a short seat base is usually preferred so as to avoid causing smaller sitters to slump forward as described earlier. As this will also assist with access and egress a short seat base length would appear optimal.

A performance requirement for seat back table latching mechanisms should be considered, to ensure tables cannot fall down when passengers brush against them during evacuation.

The method for checking compliance with the minimum space requirements should be improved. Measurement equipment and procedures should be developed which provide a standardised and repeatable method for taking into account passenger seated position and cushion compression. The SAE H-point manikin and procedure provides a model for this.

8.2. Future work

In order to quantify the benefits that would be obtained from the recommendations in this report, further work would be required.

8.2.1. Access/egress trials

A series of access/egress trials should be undertaken to aid in developing final minimum recommendations for dimensions B and C. These could be in the form of timed evacuation trials. One method would be to time volunteers evacuating from rows of typical airline seats and investigating the effect of varying dimensions B and C on evacuation times. The added benefits vs practicality of 'flip-up' seat cushions could also be investigated.

Trials to investigate the effects of prolonged sitting and the amount of seat space on a person's ability to get out of a seat should also be undertaken. Both objective and subjective data would be collected. Objective emergency evacuation times measures should be supplemented with subjective data regarding passengers perceived ease of access/egress and ratings of the effects of seat features on ease of access/egress and seated space. Variables would include cushion width, height and length, foot clearance envelope and AN64 dimension A. Additionally, the ability to adopt a brace position could be investigated as part of these trials.

For both of these sets of trials, it should be ensured that the sample of participants includes a representative range of older volunteers to take account of the ageing population. The volunteer samples should also include appropriate representation of larger/heavier people to account for current and future changes in the composition of both European and World populations.

8.2.2. The role of seating in passenger health.

Further comprehensive research into the health issues (specifically DVT) associated with prolonged sitting in confined spaces is also required. Reliable data in this area will only be acquired by carefully conducted research at the population, clinical and basic science levels. Population / clinical related research must be long-term, taking into account the delays in presentation, difficulty in diagnosis, asymptomatic disease, and must therefore use diagnostic tests of the greatest accuracy.

8.2.3. Development of regulatory compliance testing

The current definition and method of measuring dimension A should be reviewed so that it takes into account the effect of seat compression and the seat being in a reclined position. This work could also incorporate defining a method of measuring seat cushion length and height if these dimensions were to be included in a successor to AN64. A standardised, objective procedure for identifying measurement landmarks and for taking measurements will overcome the need for judgement on the part of the measurer.

8.2.4. Review of the 'brace' position

It has been shown that to provide sufficient space for passengers to lean forward into the brace position can, depending upon the actual posture recommended, have considerable implications for seat spacing. As this in turn could affect passenger carrying capacities it is important to ensure that any recommended brace position is optimal. Thus further work is required and this should follow an international review of current recommended brace positions. An internationally agreed 'brace' position should then be developed based on a review of all pertinent accident biomechanics research. There is evidence that passengers currently have different interpretations of the brace position and it is therefore important that they receive sound and consistent advice.

The results of this review may have implications for minimum back-of-seat to seat in front distances (Dimension A).

Glossary of terms

***asymptomatic* –** exhibiting no outward symptoms

***alveoli* –** the gas exchange units of the lung

***anticoagulant* –** a drug to stop blood clotting

***arthroplasty* –** a joint replacement

DVT - deep vein thrombosis

***endothelium* –** the lining of blood vessels

***fascia* –**supporting sheet-like tissue between muscles

***fibrinolysis* –** breakdown of fibrin which is contained within clotted blood

***hypoxia* –** reduced oxygen content

***interstitial tissue* –** the supporting tissue between cells and vessels

***ischaemia* –** reduced tissue oxygen supply

***mmHg* –** millimetres of mercury as a measure of pressure

NO - nitric oxide

***oedema* –** fluid that collects in and around tissue

PE - pulmonary embolus

***Seat pitch* –** the fore-aft distance between rows of seats measured from the same point on each seat.

Somatotype – body shape or build

***popliteal* –** the area behind the knee

***TED* –** thromboembolic disease

***thrombosis* –** clotting of the blood

***sinus* –** blind ending pocket within vein valve

stasis - stationary

***transmural* –** across the vessel wall

***transudate* –** fluid exuded across vessel wall

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Appendix 1 : Airworthiness Notice 64

CIVIL AVIATION AUTHORITY CAA

AIRWORTHINESS NOTICE

	No. 64*
	Issue 1
	16 March 1989

THIS NOTICE GIVES DETAILS OF A MANDATORY ACTION

MINIMUM SPACE FOR SEATED PASSENGERS

1 Applicability This Airworthiness Notice is applicable to all UK registered aeroplanes over 5700 kg MTWA, certificated in the Transport Category (Passenger) and configured to carry 20 or more passengers.

2 Introduction

2.1 The CAA is required to approve the cabin interior layout of each aircraft on the UK register. As part of that approval each seat type shall be approved as required by JAR 25.785 or BCAR Section D, Chapter D4-4 paragraph 2.1.2. The approval procedure for such controlled items is defined in BCAR Section A, Chapter A3-3.

2.2 At the initial evaluation of a seat an assessment of the limiting conditions of use is made and, when agreed with the seat manufacturer, these are specified on the GA drawing, on the Declaration of Design and Performance (DDP) or specifically highlighted in a letter of approval. Included in these limitations is a minimum seat pitch at which approval for installation on an aeroplane has been granted. This minimum pitch is defined taking into account head, trunk and leg strike areas of the seat in front, the ability to occupy the seat and, if necessary, quickly vacate the seat and enter the aisle in an emergency.

2.3 The CAA has been asked to re-assess the use of seats at a pitch less than has generally been requested in the past, particularly with respect to the more modern, high technology seat designs, and yet still to be satisfied that the various general criteria above are being achieved. Of

*This number was previously used for a Notice concerning Dowty Rotol Propellers – No. 20 and No. 30 Size Blade Root Bearing which was cancelled in February 1982.

particular concern is the effect that such lower seat pitches can have on the seat occupancy and the ease of egress from these seats.

2.4 To formalise minimum acceptable seating standards the normal design extremes used for certification purposes for all occupied zones, namely the anthropometric data for the 5th percentile female to the 95th percentile male, have been taken into account. In this regard the critical dimension for the seated occupant is the buttock-knee length. Additionally, affecting the ease with which the occupant can stand up and move from the seat to the main cabin aisle, is the minimum distance and the vertically projected distance between the seat and any seat or fixed structure immediately ahead of the occupant.

2.5 Use of these three dimensions as the criteria for the determination of the acceptability of any seating configuration is considered to provide a realistic minimum standard which can be uniformly adopted whether the seating being considered is placed adjacent to seats of the same or different types, or other typical aeroplane interior structures. These Requirements are not intended to supersede or replace existing occupant protection Criteria prescribed in JAR 25.785 or BCAR D4-4.

3 Compliance

3.1 With effect from 1 April 1989, all aeroplanes defined in paragraph 1 above and which are being subject to the provision of a new (not previously CAA approved) or amended seating configuration, shall comply with the requirements of this Notice.

3.2 With effect from 1 January 1992 all aeroplanes defined in paragraph 1 above shall comply with the requirements of this Notice.

4 Requirements

4.1 The minimum distance between the back support cushion of a seat and the back of the seat or other fixed structure in front, shall be 26 inches. (Figure 1, Dimension A.)

4.2 The minimum distance between a seat and the seat or other fixed structure in front, shall be 7 inches. (Figure 1, Dimension B.)

4.3 The minimum vertically projected distance between seat rows or between a seat and any fixed structure forward of the seat, shall be 3 inches. (Figure 1, Dimension C.)

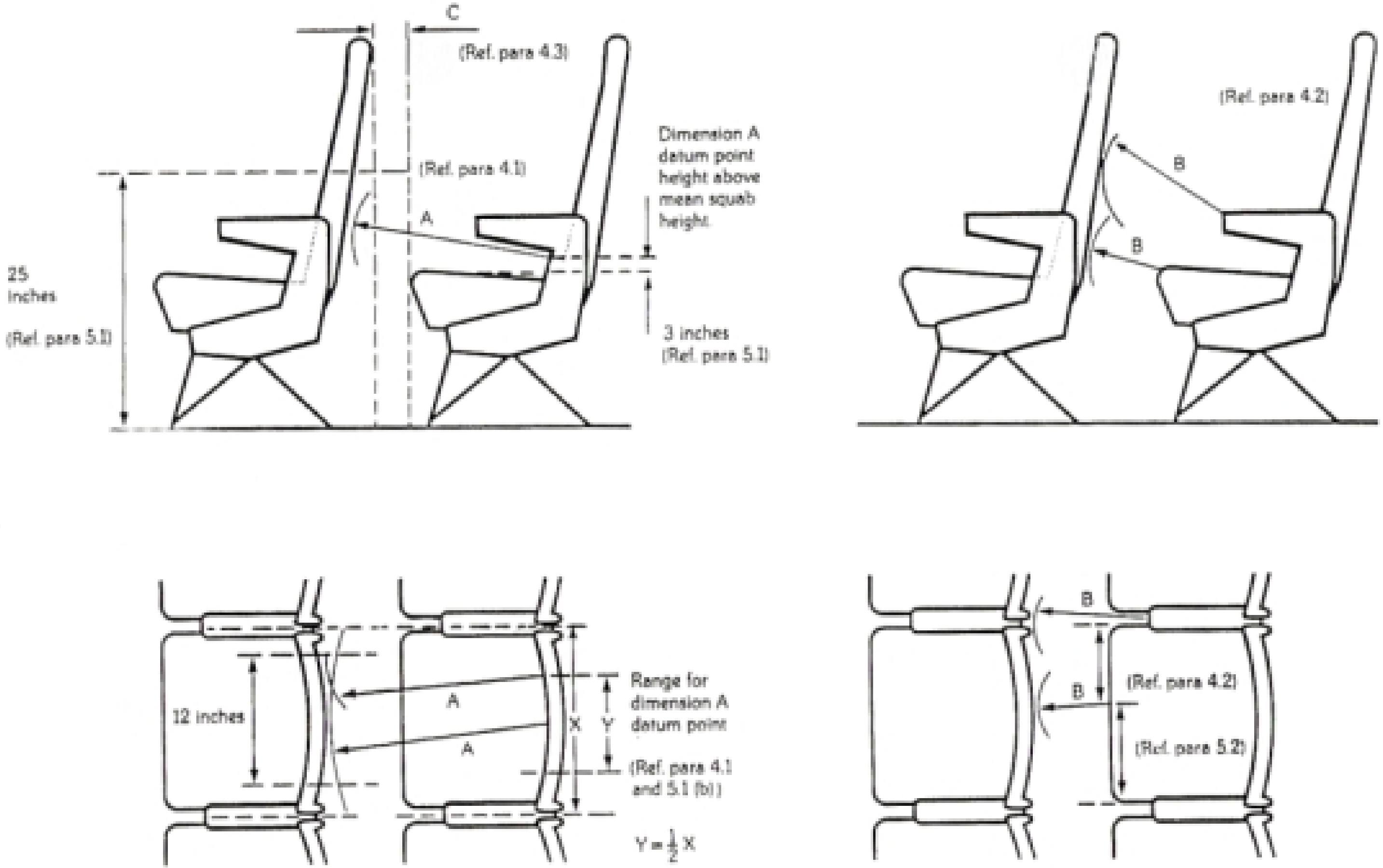

FIGURE 1 MINIMUM DIMENSION REQUIRED BY PARAGRAPHS 4.1, 4.2 AND 4.3

5 Additional Information

5.1 The measurements required for the demonstration compliance with the requirement given in paragraph 4.1 above are as follows:–

(a) from a datum point in the centre of the seat back at a height of 3 inches above the mean uncompressed seat squab height to the seat or other fixed structure in front made in both vertical and horizontal arcs up to a limiting height of 25 inches above the carpeted floor level, over the full seat place width 'X'. (See Figure 1.)

(b) from any point on the seat back within the centre one half 'Y' of the seat place width at a height of 3 inches above the mean uncompressed seat squab height to the seat or other fixed structure within the central 12 inch region in front made in vertical and horizontal arcs up to a limiting height of 25 inches above the carpeted floor level.

5.2 The full width of the forward edges of the seat squab cushion and the seat arm rests shall be used as the datum points for the measurements of the minimum distance required by paragraph 4.2 above. From these points the measurement of the distance shall be made in both horizontal and vertical unlimited arcs.

5.3 The vertically projected distance required by paragraph 4.3 above shall be measured between the forward edge of the seat squab cushion or the most forward extremity of the armrests and the most aft part of the seat or fixed structure in front.

5.4 Where a magazine rack is provided for the normal stowage of the cabin safety leaflet, sick bag and in-flight reading material provided by the operator, such normally provided material shall be in place during the measurements. Similarly, any fold down or other type of meal table attached to either seat or fixed structure should be in its normal stowed (take-off and landing) position for all measurements.

5.5 All measurements shall be made with the seats in the upright (take-off and landing) position, and the armrests shall be down.

5.6 No alleviation to these requirements will be granted on the basis of deformable soft furnishings.

5.7 All modifications to seats, their installation or any modification to adjacent fixed structures, necessary to achieve compliance with the requirements of this Notice shall be the subject of the appropriate BCAR Section A major modification procedure.

for the Civil Aviation Authority.

Safety Regulation Group,
Aviation House,
Gatwick Airport South,
West Sussex RH6 0YR.

Appendix 2 : Passenger survey questionnaire

Holywell Building
Holywell Way
Loughborough
Leicestershire
LE11 3UZ
UK

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+44 (0) 1509 283300

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+44 (0) 1509 283360

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LONG-HAUL PASSENGER SURVEY CONCERNING SEAT SPACE AND PASSENGER SEAT ACCESS/EGRESS.

Introduction

ICE Ergonomics at Loughborough University are currently undertaking a study, for the Civil Aviation Authority, to investigate any possible issues related to being seated on an aircraft for long periods of time, and when accessing and leaving the seat. As part of this research, we are carrying out a survey to find out the sort of experiences passengers actually have during their flights.

Therefore, as someone who is about to travel on an aircraft, would it possible for you to tell us of your experiences (whether good or bad) of the flight by completing this questionnaire at the end of your flight. There are no right or wrong answers. This is your opportunity to give us your views and experiences of travelling by air. Once completed, we would be very grateful if you could return your questionnaire in the pre-paid envelope as soon as you return to the UK. If you did not receive a pre-paid envelope, you can use the free-post address below (please note that the free-post address is only valid for questionnaires posted in the UK).

Please note that **ALL INFORMATION IS CONFIDENTIAL**. We will not reveal the results in any way in which you will be personally identifiable. Thank you for taking the time to complete this questionnaire.

FREEPOST ADDRESS:
ICE Ergonomics Ltd
FREEPOST MID22710
Loughborough
LE11 0BR

A. Regarding your flight……

A1 Flight details?

i. Departing airport & country		
ii. Destination airport & country		
iii. Airline Company		
iv. Flight duration		hrs

A2 Aircraft details?

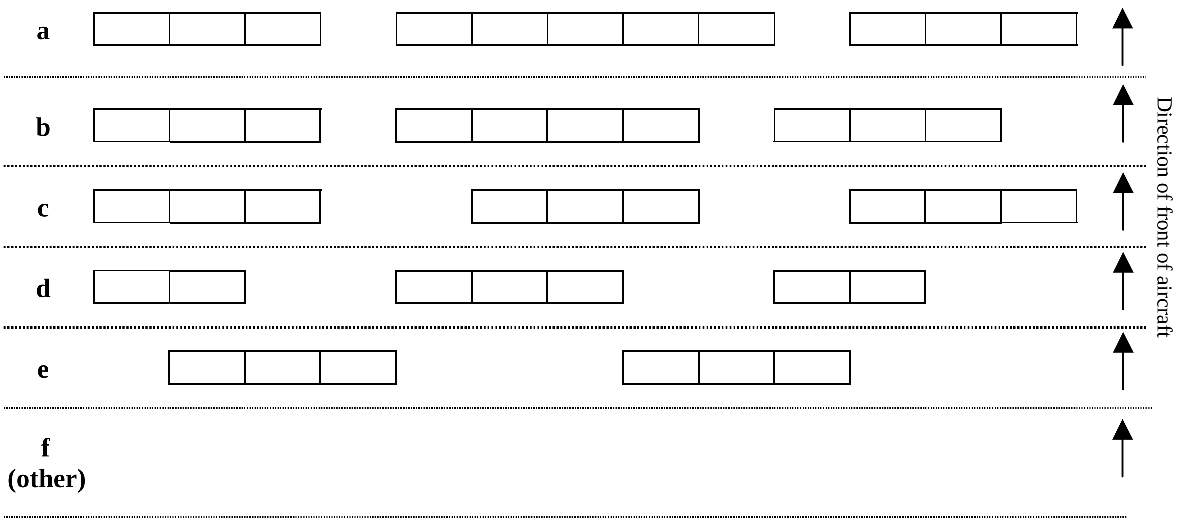
i. Make *e.g. Boeing*	
ii. Type *e.g. 757*	

A3 Did you travel:

a. Economy class		
b. Business class		
c. 1^{st} class		
d. Other (e.g. upgrade with "Premium" seats)		Please describe

A4 Shown below are the five most common row arrangements of aircraft seats. Please place a '✓' in __one__ of the boxes on __one__ of the rows (a to e) to show where along the row you were seated. If your seating arrangement is not shown, please sketch the arrangement in 'f' ('other').

FRONT OF AIRCRAFT



A5 Can you remember your seat number?

Row	
Seat	

A6 Did your seat have extra leg room? (e.g. it was located by the emergency exit or on the very front row)?

Yes ☐ No ☐

Reason for extra leg room

A7 During your flight, did you place any luggage or other objects on the floor in front of your seat?

Yes ☐ No ☐

Describe luggage/object

A8 How many times did you get up from your seat during your flight? (for whatever reason)

a. 0 ☐ b. 1 to 2 ☐ c. 3 to 5 ☐ d. more than 5 ☐

A9 Did you get up as many times as you would have liked?

Yes ☐ No ☐

Why not

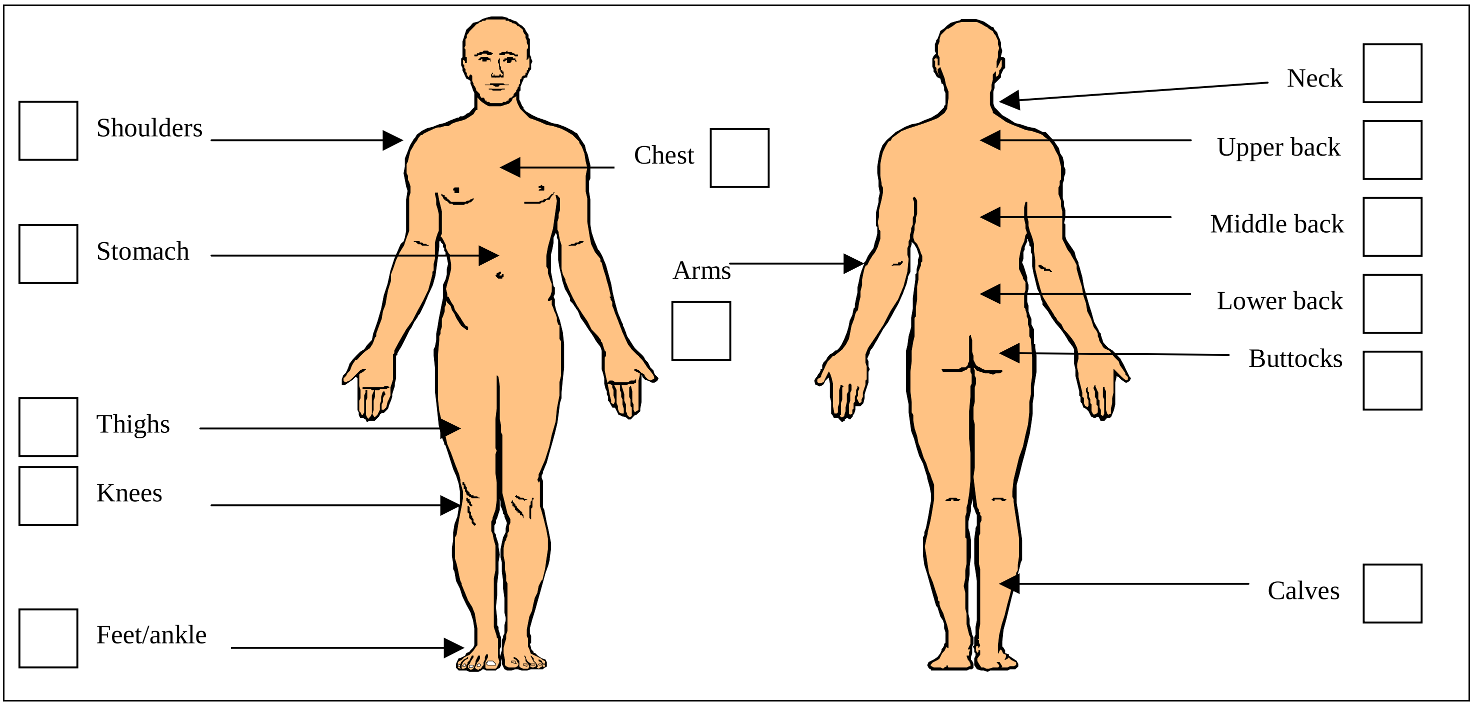
A10 During your flight, did you experience any aches/pains/stiffness/numbness which was due to the flight?

Yes ☐ ***go to question A11*** No ☐ ***go to question A16***

A11 Was this during or after the flight?

a. during ☐ b. after ☐ c. both ☐

A12 Where (on your body) were these aches/pains/stiffness/numbness?



A13 Can you describe the type of sensation and how severe it was?

A14 About how long into your flight did you begin to experience this ? ☐ *hours*

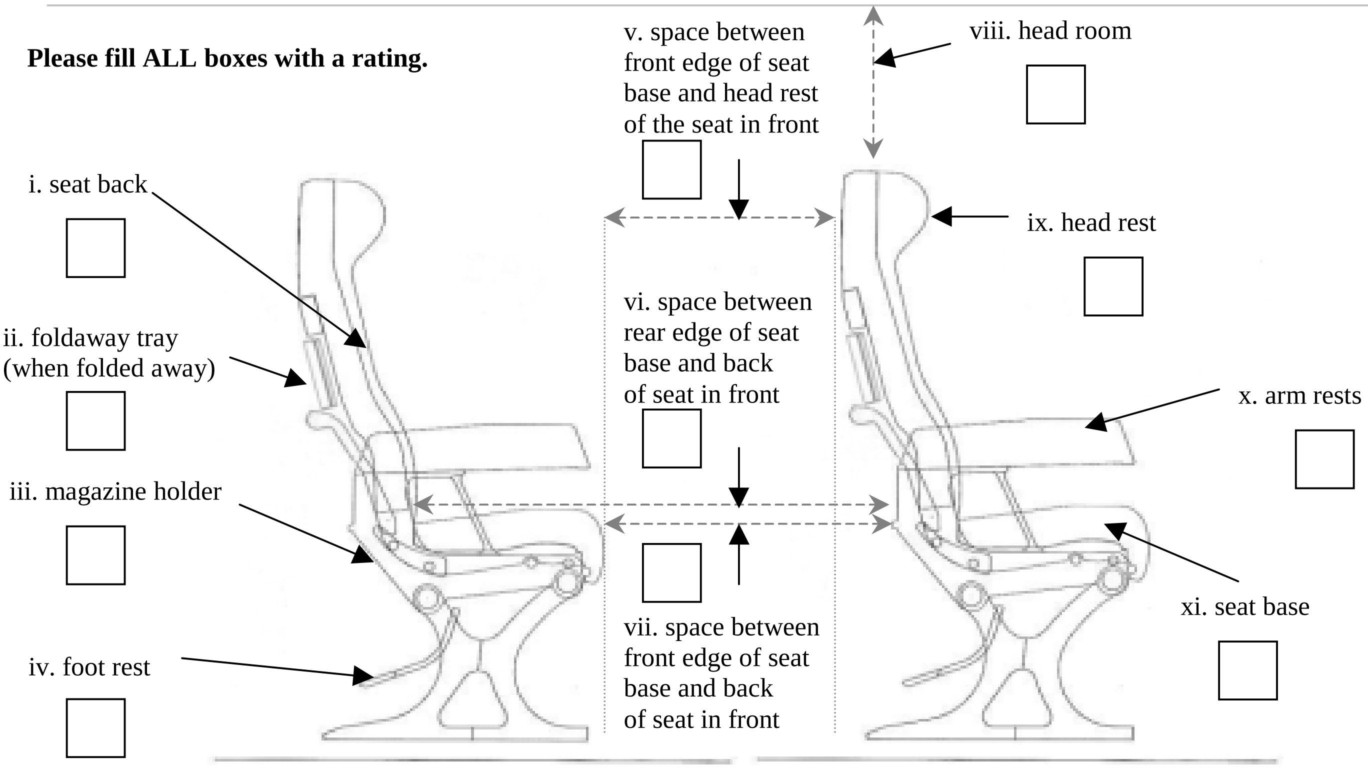
A15 What do you think the causes were?

A16 Thinking about getting ‘<u>to</u>’ and ‘<u>from</u>’ your seat easily, use the scale opposite to show how important you think the design of each of the seat features are.

For example, if you find the design of the arm rests ‘very important’ when it comes to getting ‘to and from’ your seat with ease, enter a ‘4’ into the appropriate box on the diagram.

1	Not at all important
2	Slightly important
3	Important
4	Very important

Please fill ALL boxes with a rating.



A17 How easy or difficult did you find it to get to and from your seat during your flight? Please rate by circling a number on the scale below:

Very easy				Very difficult
1	**2**	**3**	**4**	**5**

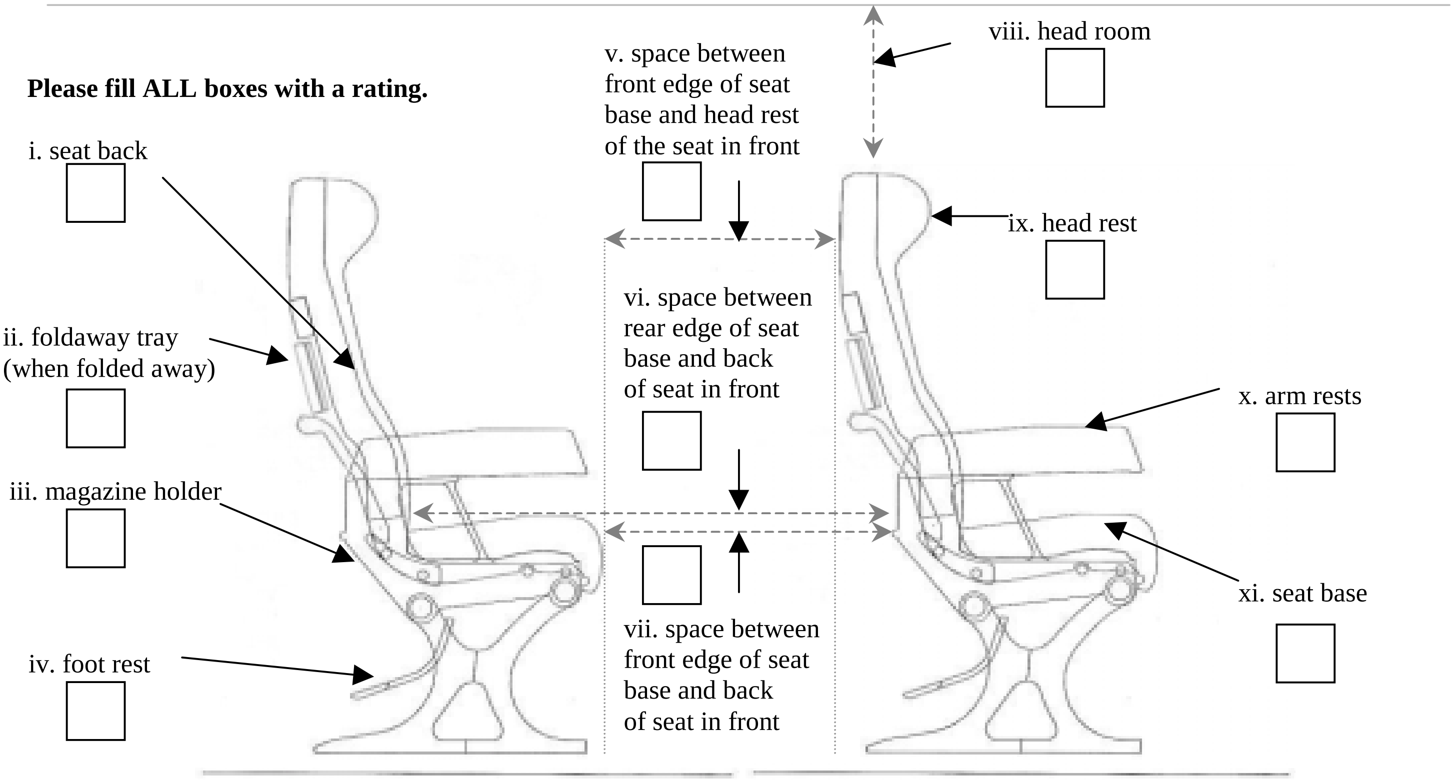
A18 Still thinking about getting to and from your seat during your flight, please state whether or not you experienced problems with the following seat features/dimensions by ticking the appropriate box, and where problems did occur, give details about the specific problems you experienced.

Seat feature/dimension	No problem *Please tick appropriate box*	Problem	If problem, give details (e.g. too short, high, narrow, little space etc.)	Was the problem when getting **to** the seat, **from** the seat or **both**?
seat back (your own)				
seat back (the seat in front)				
foldaway tray				
magazine holder				
foot rest				
space between front edge of seat base and head rest of seat in front				
space between rear edge of seat base and back of seat in front				
space between front edge of seat base and back of seat in front				
head room				
head rest (your own)				
head rest (the seat in front)				
arm rests				
seat base				
other ***(please give details)***				

A19 Thinking about being able to adopt a good sitting posture and change your posture, please rate how important you think the design of each of the different seat features are, using the scale opposite.
For example, if you find the design of the arm rests 'very important' when trying to adopt a good sitting posture, enter a'4' into the appropriate box on the diagram.

1	Not at all important
2	Slightly important
3	Important
4	Very important

Please fill ALL boxes with a rating.



A20 Thinking about your flight, please state whether or not you experienced problems with the following seat features/dimensions while seated, by ticking the appropriate box, and where problems did occur, give details about the specific problems you experienced when trying to adopt a good sitting posture or change posture.

Seat feature/dimension	No problem	Problem	If problem, give details (e.g. too short, high, narrow, little space etc..)
	Please tick appropriate box		
seat back (your own)			
seat back (the seat in front)			
foldaway tray			
magazine holder			
foot rest			
space between front edge of seat base and head rest of seat in front			
space between rear edge of seat base and back of seat in front			
space between front edge of seat base and back of seat in front			
head room			
head rest (your own)			
head rest (the seat in front)			
arm rests			
seat base			
other ***(please give details)***			

B. Personal details

Finally we need to ask for a few details about yourself. This is just to make sure that we have a good cross section of people in our survey.

B1 Date of birth ______

B2 Height (approximate) ______

B3 Weight (approximate) ______

B4 Gender
Please tick relevant box

Male ☐
Female ☐

B5 Do you have any personal mobility problems which cause restrictions to the movement of your back, legs, arms etc….? (e.g. rheumatism, arthritis, back problems...)?

Yes ☐ ***go to question B6*** No ☐ ***go to question B7***

B6 Please outline the mobility problems you experience (e.g. the type of problem, temporary or permanent, the part of body affected…)

______

B7 How often do you travel by air?

a. weekly (or more often) ☐
b. monthly ☐
c. more than once a year ☐
d. annually ☐
e. less often ☐

B8 How do you normally travel?

a. Economy class ☐
b. Business class ☐
c. 1st class ☐
d. Other ☐
(please state) ______

Optional

In case we need to clarify any of your answers can you please provide your name and daytime telephone number

Mr/Miss/Ms/other______________ First name____________________________ Surname ______________________________

Daytime telephone number _________________________________

That is all the questions.

If you have any other comments concerning seat spacing on this flight or on any other flight you have taken, please give details using the space provided on the next page.

Thank you for taking the time to help us with the survey.
Please return the questionnaire to us in the postage paid envelope provided.

C. Additional comments.

Please use this space if you have any other comments you would like to make regarding your experience of seat space, and getting to and from aircraft seats, either on this flight or any other flight.

Appendix 3: Summary results of passenger survey

A1 and A2: Passenger flight and aircraft details.

Flying from (country) (/312)

China	1
Dominican Republic	7
Israel	5
Kazakhstan	3
Canary Islands, Spain	3
Malaysia	1
Mauritius	1
South Africa	3
Thailand	1
Turkey	9
U.K.	254
U.S.A.	24

Flying from (airport/city)(/312)

Hong Kong	1
Puerto Plata	7
Ben Gurion	1
Tel Aviv	4
Almaty	3
Arecife, Lanzarote	3
Kuala Lumpur	1
Mauritius	1
Johannesburg	3
Bangkok	1
Dalaman	9
Birmingham	18
Gatwick	6
Glasgow	1
Heathrow	55
Luton	1
Manchester	173
Baltimore	1
Denver	1
JFK, New York	7
Sanford, Orlando	4
San Francisco	5
Seattle	6

Airline (/312)

Air Canada	2
Air New Zealand	2
Air 2000	1
Airtours	163
American Airlines	3
British Airways	67
Britannia	49
Cathay Pacific	2
EL AL	1
Eurocypria	1
EVA	2
Gulf Air	1
Icelandair	2
Malaysian Airlines	1
North West	1
Quantas	1
United Airlines	3
Varig	2
Virgin Atlantic	8

Flying to (country) (/312)

Australia	1
Brazil	2
Canada	2
Canary Islands, Spain	24
China	9
Crete, Greece	42
Cyprus	2
Dominican Republic	6
France	1
India	7
Israel	4
Jamaica	38
Mexico	1
South Africa	3
Singapore	1
Switzerland	1
Thailand	1
Turkey	8
UAE	1
UK	55
USA	103

Flying from (airport/city) (/312)

Sydney	1
Sao Paulo	2
Calgary	1
Vancouver	1
Arecife, Lanzarote	4
Tenerife	20
Hong Kong	9
Heraklion	42
Larnaca	2
Puerto Plata	6
CDG, Paris	1
Delhi	7
Tel Aviv	4
Montego Bay	38
Cancun	1
Johannasburg	3
Singapore	1
Geneva	1
Bangkok	1
Dalaman	8
Abu Dhabi	1
Gatwick	6
Heathrow	26
Manchester	23
Chicago	3
Honolulu	1
JFK, New York	12
Los Angeles	2
Sanford, Orlando	70
San Francisco	7
Seattle	7
Washington	1

Make: (/312 respondents)

Airbus	117
Boeing	167
McDonnell Douglas	21
Not specified	7

Type (/312 respondents)

A320	21
A330	94
A340	2
737	1
747	63
757	37
767	54
777	11
DC10	22
Not specified	7

Flight duration (hours)

Mean	7.60
Minimum	3.75
Maximum	22

Passenger flight details

A3. Did you travel…? (%)

a. Economy class	79
b. Business class	7
c. 1st class	5
d. Other	9

If other please state (%)

all upgrades to economy premium seating	9

A4. Seating arrangement (%)

a.	4
b.	15
c.	24
d.	20
e.	16
f.	21

Where sitting on plane? (%)

a. aisle seat	41
b. centre of row	24
c. window seat	28
not specified	7

Left, centre, right of plane? (%)

a. left	34
b. centre	28
c. right	31
not specified	7

A6. Extra leg room? (%)

Yes	20
No	80

(% of all respondents)

Reason for extra leg room (%)

1st class	3
Business class	1
At front/in front of bulkhead	3
Located by emergency exit	3
Premium/upgraded seats	5
Rear of aircraft	0
Not specified	5

A7 Luggage under seat (%)

Yes	48
No	52

A8. Times got up from seat?

0	8
1 - 2	39
3 - 5	37
5 +	15
not specified	1

(% of all respondents)

A9. As many times as liked?

Yes	65
No	32
not specified	3

If no, why not? (% of all respondents)

Restricted space between seats	7
Lack of aisle space - general	4
Cabin crew/passengers blocking aisles	6
Disturb other passengers	10
Turbulence	2
Didn't want to obstruct aisle	1
Personal disability	0
Nervous of walking in aisle - first time flying	0
Nowhere to go	2

A10. Aches, pains, stiffness, numbness?

Yes	71
No	29

(% of all respondents)

A11. During or after? (% of all respondents)

During	51
After	3
Both	12
not specified	34

A12. Where on body were the aches/pains? (%)

(% of all respondents)

Shoulders	15
Stomach	4
Thighs	19
Knees	29
Feet/ankles	23
Chest	4
Arms	3
Neck	29
Upper back	10
Middle back	14
Lower back	39
Buttocks	38
Calves	13

A13. Type of sensation (% of all respondents)

Aches	29
Stiffness	18
Pain	10
Numbness	19
Swelling	3
General discomfort	5
Cramp	4
Bloated	1

A14. After how long? (hours)

Mean	2.56
Minimum	0
Maximum	10.5

A15. Causes of aches, pains etc….(% of all respondents)

Length of time on flight	2
Cramped space in seat	29
Lack of movement/exercise (in and out of seat)	21
Specific seat design/shape	16
Cabin pressure	1
Personal problems (e.g. arthritis, back)	1
Banging limbs when exiting seat	0
Not known	1

See next page for A16.

A17. How easy to get to/from seat? (% of all respondents)

Rating	%
1 = very easy	18
2	19
3	27
4	15
5 = very difficult	8
Not specified	13
Mean rating	2.7

See next page for A18 to A20

Passengers personal details.

B1. Age (years)

Mean	43.30
Minimum	15
Maximum	76

B2. Height (cm)

Mean	1.73
Minimum	1.42
Maximum	1.98

B3. Weight (kg)

Mean	77.3
Minimum	44.5
Maximum	158.8

B4. Gender (%)

Male	53
Female	45
not specified	2

B5. Any mobility problems? (%)

Yes	14
No	86

B6. If yes, type of mobility problems (%)

Amputation	0.3
Rheumatism/arthritis	5.1
Asthma	0.3
Neck/back problems	6.1
Arms	0.3
Legs	1.6
Hip replacement	0.3

Passengers previous air travel experience.

B7. How often do you travel by air? (%)

a. weekly (or more often)	5
b. monthly	11
c. more than once a year	53
d. annually	25
e. less often	4
not specified	2

B8. What class do you normally travel? (%)

a. Economy class	85
b. Business class	8
c. 1st class	2
d. Other	2
not specified	3

If other, please state (%)

military aircraft	0.3
premier economy	0.7
Not specified	1

To/from the seat: A16 (rating importance of the design of seat features) and A18 (problems experienced on flight) (see previous page for A17).

	seat back		foldaway tray	magazine holder	foot rest	AN64C (space between front edge of seat base and head rest of seat in front)	AN64A (space between rear edge of seat base and back of seat in front)	AN64B (space between front edge of seat base and back of seat in front)	head room	head rest		arm rests	seat base
	own	in front								own	in front		
1 = Not at all important	49		110	150	102	5	13	4	54	72		16	38
2 = Slightly important	69		90	95	78	10	17	10	90	87		71	54
3 = Important	72		50	39	52	47	58	33	97	69		106	81
4 = Very Important	110		51	12	44	206	202	244	59	70		112	124
Mean rating	2.81		2.14	1.74	2.13	3.69	3.55	3.78	2.54	2.46		3.03	2.98
Number of problems	32	122	26	20	29	117	103	135	35	29	55	92	49
% of respondents	10	39	8	6	9	41	33	43	11	9	18	29	16
To?	2	1	0	0	1	2	0	0	0	0	0	2	1
From?	4	3	3	0	0	3	3	3	2	1	2	3	0
Both?	13	75	9	9	6	66	57	81	20	5	28	45	13

When seated: A19 (rating importance of the design of seat features) and A20 (problems experienced on flight).

	seat back		foldaway tray	magazine holder	foot rest	AN64C (space between front edge of seat base and head rest of seat in front)	AN64A (space between rear edge of seat base and back of seat in front)	AN64B (space between front edge of seat base and back of seat in front)	head room	head rest		arm rests	seat base
	own	in front								own	in front		
1 = Not at all important	8		129	167	68	22	9	3	12	12		19	12
2 = Slightly important	8		86	89	73	36	22	10	54	54		67	17
3 = Important	66		44	25	80	50	47	36	94	94		102	58
4 = Very Important	218		37	15	59	159	213	243	139	139		114	212
Mean rating	3.65		1.96	1.62	2.46	3.32	3.59	3.78	3.20	3.20		3.03	3.57
Number of problems	99	105	24	27	59	90	97	131	13	72	39	89	85
% of respondents	32	34	8	9	19	31	31	42	4	23	13	29	27

For specific problems experienced during flight, see following pages.

A18. Problems getting to/from seat.

Seat back (own)

didn't go back far enough
didn't stay upright
difficult when reclined
if seat is not brought up
little space
little space
little space
little space
little space
narrow
narrow
narrow
narrow
narrow
sliding back(faulty)
strain on back when rising
too hard and narrow
too high
Too high
too little padding
too little space
too long, slightly narrow
too narrow
too narrow
too narrow
too narrow
too short
too straight
would not tilt

Seat back (in front)

could not stand if it was reclined	too close
difficult to get into seat because in front reclined	too close
difficult when reclined	too close
Hitting back when moving	too close
if seat in front was reclined, made it difficult	too close
if seat in front was reclined, then awkward to get out	too close
limited working space	too close
little space	too close
little space	too close
little space	too close
little space	too close
little space	too close
little space	too close. Problem when two people get out
little space	too close - even upright
little space	too close when reclined
little space	too close when reclining
little space	too close, especially when reclined
little space	too close, little area to stand
little space	too close, little space to move
little space	too close, no space
little space	too close. Little space
little space	too close/little space
little space	too little room
little space	too little room
little space	too little room
little space	too little room when reclined
little space	too little space
little space	too little space
little space	too little space
little space	too little space
little space	too little space
little space	too little space when reclined
little space	too narrow
little space - difficult to manoeuvre	too narrow
little space when reclined	too near
little space when reclined	too near
moved when touched	too short
narrow	very little space
narrow	when reclined
narrow	when reclined
narrow space	when reclined
no one in front	when reclined
no room when reclined	when reclined
no room when seat not upright	when reclined
no seat in front	when reclined
no space	when reclined limited space overall
not enough space	when reclined, it's vertically above front edge of seat thus requiring you to lean backwards as you stand to get in/out of seat
not so easy to exit when reclined	
recline little space	
restricts forward movement	when reclined, little room to move
seat back space limited	when reclined, more difficult to get out
seat in front reclined too far	when reclined, too little space
seat was reclined	when reclined, difficult to get past
too close	when seat back, not much room
too close	when seat in front reclined unable to stand straight or turn
too close	
too close	when was reclined
too close	when was reclined
too close	when was reclined

Foldaway tray

bar from seat in front - split space for own feet
because no space, tray wouldn't fit
can't get out
cant put tray back in when seat in front is reclined
difficult to foldaway trays near emergency exits
kept falling down
little space
little space
little space
little space
little space
no room to fold down
not easy to move
slanted
slippery surface
To small
too close
too little space
tray constantly down
tucked into side of armrest, had to interrupt neighbour to move it so could get out
unable to pass when tray down

Magazine holder

Bent metal frame snagged
broken - metal bar jutted into knee
can be too full
didn’t have one-had to reach over to borrow
full of reading material
full, too little space
if using magazine holder, foldaway tray wouldn't shut, restricting the space
little space
metal bars dug into my knees
not arthritis friendly
not enough space
protruded
reduced limited space further, especially when loaded with magazines
too close
too full, restricts leg room
when I had two books in it
when stuffed full

Foot rest

could not reach it
did not extend enough
doesn't extend far enough
failed to stay in folded position
Had to remember to put away to allow access to and from seat
it got in the way
little space
Must be folded
needed to be retracted
never fits
no foot rest
no foot rest
no foot rest
no foot rest
no foot rest
no foot rest
no foot rest
no foot rest
no foot rest
no foot rest
no foot rest
no footrest
none
Not high enough
too far away
too little to access
too short
useless and got in the way

Space between front edge of seat base and head rest of seat in front (dimension C)

a joke. About 2" in vertical position.	too close
seat back, difficult to get out	too close
difficult to get out	too close
better than other economy but still not enough room for getting up easily	too close
	too close
difficult moving in & out of seat	too close
had to arch body to do so	too close
if seat in front was back made difficult	too close
Insufficient room	too close
little room to manoeuvre	too close
little room to stand	too close
little space	too close
little space	too close
little space	too close
little space	too close
little space	too close to stand up
little space	too close when reclined
little space	too close, no room
little space	too compact
little space	too cramped
little space	too little
little space	too little room
little space	too little space
little space	too little space
little space	too little space
little space	too little space
little space	too little space
little space	too little space when reclined
little space	too narrow
little space	too narrow
little space	too narrow
little space	too narrow
little space	too narrow
little space	too narrow
little space	too narrow
little space	too narrow
little space	too narrow
little space	too small
little space	too small
little space	too small gap
little space	too tight
little space	uncomfortable when forward when eating
little space when reclined	Very little space
narrow	when fully reclined difficult to get past
narrow	when reclined
narrow	when reclined
narrow	when reclined
narrow space	when was reclined
no one in front	with seat in front reclined, makes entry/exit a problem
no room	
no seat in front	
no space	
not enough room	
not enough room	
not enough room when reclined	
not enough space	
not wide enough	
numb knees	
only when seat in front reclined	
seat in front reclined, reducing space to move	
short space	
small amount of space	
space between the seats in the most important thing on long haul flights	

Space between rear edge of seat base and back of seat in front (dimension A)

could be bigger	too close
cramped	too close
difficult to get out when cramped	too close
difficult when reclined	too close
had to bend knees to move	too close
have to shuffle	too close
knees jammed against chair	too close
lack of space	too close
lack of space	too close
little room to stand	too close
little space	too close
little space	too close
little space	too close
little space	too close, difficult to stand
little space	too close, no room
little space	too cramped
little space	too cramped
little space	too little room
little space	too little space
little space	too little space
little space	too little space
little space	too little space
little space	too little space
little space	too little space
little space	too little space when reclined
little space	too narrow
little space	too narrow
little space	too narrow
little space	too narrow
little space	too narrow
little space	too narrow
narrow	too narrow
narrow	too narrow
narrow	too narrow
narrow	too narrow
no seat in front	too narrow
no space	too narrow
not enough leg room	too narrow
not enough legroom	too short
not enough room	too small
not enough room when reclined	too small
poor space	too small gap
short space	very little space
small amount of space	when reclined
space between the seats in the most important thing on long haul flights	when reclined, it's vertically above front edge of seat thus requiring you to lean backwards as you stand to get in/out of seat

Space between front edge of seat base and back of seat in front (dimension B)

absolutely minimal space	space between the seats in the most important thing on long haul flights
couldn't stand upright, had to hold top of seat in front	strain on hips/knees
difficult to get out when cramped	too close
difficult when reclined	too close
have to shuffle	too close
knocked knees	too close
lack of space	too close
lack of space	too close
little room to manoeuvre	too close
little room to stand	too close
little space	too close
little space	too close
little space	too close
little space	too close
little space	too close
little space	too close to stand up
little space	too close, awkward to move
little space	too close, no room
little space	too cramped
little space	too little room
little space	too little space
little space	too little space
little space	too little space
little space	too little space
little space	too little space
little space	too little space
little space	too little space
little space	too little space
little space	too little space
little space	too little space
little space	too little space
little space	too little space when reclined
little space	too little space, had to get people to move
little space	too narrow
little space	too narrow
little space	too narrow
little space	too narrow
little space	too narrow
little space	too narrow
little space, not able to stand	too narrow
narrow	too narrow
narrow	too narrow
narrow	too narrow
narrow	too narrow
narrow	too narrow
narrow	too narrow
narrow	too narrow
narrow space	too narrow when letting another passenger out
no seat in front	too near
no space	too restricted
not enough	too short
not enough	too short
not enough by a long shot!	too small
not enough leg room	too small
not enough leg room	too small gap
not enough leg room	too small, difficult to get in and out
not enough room	too tight
not enough room	very little space
not enough room when reclined	when reclined
not enough space	when reclined
poor space	when reclined, it's vertically above front edge of seat thus requiring you to lean backwards as you stand to get in/out of seat
quite narrow when seat in front is reclined	
small amount of space	

Head room

had to bend down slightly
had to duck because of overhead storage
having to crouch to get in and out
hit head
little room
little space
little space
little space due to light canopy
little space to stand up
luggage rack too low
not enough
not enough
not enough
not enough
Not enough
not high enough
only slight required bending
overhead lockers too close
restricted by overhead bins
too high
too little
too low
too low
too low
too low
too low
too low
too low
too low
too low down
too short
too tall for space

Head rest (own)

awkward when reclined.
Head not resting properly
lack of support
needs to be cushioned more and shapely
not enough room
not enough support
not high enough
not high enough
own head rest pushed head forwards
poor design
should be more bulky
too close when reclined
too far forwards
too high
too high
too high
too low
too low, angled back
too short
uncomfortable
uncomfortable
uncomfortable
uncomfortable
uncomfortable for sleep
uncomfortably designed

Head rest (in front)

aisle rest did not fold
as rest
had to strain neck
if reclined, awkward to get out
in your face
little space
little space
little space
little space
little space
narrow
narrow
narrow space
no one in front
not enough room
not enough room when reclined
overhangs arm rest when reclined
person next climbing out
problem when reclined
reclined too far
restricts head movement
restricts room to stand
short space
space in front too narrow
too close
too close
too close
too close
too close
too close
too close
too close especially when reclined
too close together
too close together
too close together
too close when back
too close when down
too close when inclined
too close when reclined
too close when seat reclined
too high
too little space when reclined
too low, too far back
too narrow
too narrow
too narrow between seats
unable to stand straight
when reclined
when reclined
when reclined
when reclined
when reclined no room

Arm rests

arm rest broken wouldn't lift
awkward to get in and out
Bruised myself several times to and from seat
bruised thighs - little space
caught thighs
couldn't work out how to lift up
did not lift up
did not lift up
didn't lift
didn't move so was an obstacle
difficult to get out
difficult to move upright
do not fold back
do not fold fully away
don't fully retract
end one wouldn't move
end ones do not fold away
get in the way
had to raise to get past
hard and slippery to the touch
heavy to push up
if arm rest in down position
impeded movement
in the way
in the way
inconvenient obstacle if can't be stowed away
little space
little space
little space
little space
little space
little space
little space
low, caught on clothes
made getting out and in difficult
more difficult if in static posture
narrow
narrow
narrow
narrow and tight
narrow space
no adjustment
not comfortable
not enough room
not enough space between seats
not padded and narrow
not wide enough
not wide enough
not wide enough
obstructive
obstructs access
often obstructive
out arm rest doesn't raise
outside one should be mobile
person next climbing out
poor design
rest didn't lift at end
restricting
restricts side step
seat too narrow
set off call button
should be adjustable
sitting right on edge of aisle, armrest is not comfy enough
some don't lift up - no space
too low
too close -narrow
too close to front seat
too close to front seat
too close together
too close together
too hard
too hard
too low
too narrow
too narrow
too narrow
too narrow and hard
too narrow between both
too short
were not moveable
when seat in front reclined, arm rests can restrict access/egress
would have been impossible to get out if they didn't fold up
would not move to get out
would not raise for easy access

Seat base

caused backache
could be softer
difficult getting out of seat
difficult to get out
hollow in base
if long, gets in way more
little hard
little space
little space
little space
little space
little space
narrow
narrow
no support
not enough room
not firm enough
not soft enough
not v comfortable
obstructs access
Other passengers in way
quite uncomfortable
too close
too close to front seat
too close to seat in front
too hard
too hard
too hard
too hard
too hard
too little space
too narrow
too narrow
too narrow
too narrow
too narrow
too narrow
too narrow
too narrow
too short
uncomfortable
very hard

Other comments/problems

entertainment console in arm rest reduces space
narrow gangways
passengers struggling with hand luggage into overhead bins
poor head rest, nowhere to rest head when sleeping
seat back, no lumbar support
TVs, when above seat, had to move around
other passengers luggage/objects on floor
seat too narrow width ways
adjacent foot rest to be retracted

Problems When Seated

Seat back (own seat)

a bit narrow	not same shape as back
back pain	not sufficient recline
bottom 6" plastic under thin material	not supportive enough
causes backache after long periods	not very comfortable
couldn’t push back, rests on person behind	own seat back had no shape/cushioning
did not prevent sore back	ridge in middle of backrest
did not recline	seat wouldn't recline far enough
did not recline far enough	support uncomfortable when fully upright
does not go back as it should	too flat, should be contoured
fault	too hard
front row	too hard and narrow
fuller recline would be nice	too high
greater variety of rake and other adjustments needed	too high
hard	too high
hard-could be better	too little manoeuvre
high	too little padding and non-adjustable
high	too little recline
high and narrow	too little space
I didn't have a problem, maybe passenger behind did	too long, slightly narrow
if recline, the person behind would be cramped	too low
inadequate lumbar support	too much lumbar
lack of lumbar support	too narrow
lack of lumbar support for a tall person	too narrow
lack of space to manoeuvre or change position	too narrow
lack of support in lower back	too narrow
lack of support in lower back	too rigid
little space	too short
little space	too short
little space, conscious passenger behind wouldn't have enough room	too short
Little space	too short
lumbar position in wrong place	too short
lumbar support inadequate	too short
makes you sit slouched	too soft, unsupportive of lower back
middle back support uncomfortable	too straight
narrow	too straight
narrow	too upright
narrow	too upright
narrow, no support for lower back	too upright even when reclined
narrow, not enough room to recline	too upright, poor lumbar support
need to recline more	uncomfortable
needed better lumbar support	uncomfortable , makes you slouch
no lower back support	understand space restrictions could be greater range of movement
no lumbar support	very hard
no lumbar support	very upright (reluctant to recline as inconvenient to passenger behind)
no lumbar support	wrong shape for back
no space	wrong shape, flat no contour
non supportive, too hard	
not a lot of movement	
not comfortable in lower back area	
not enough recline	
not horizontal	

Seat back (seat in front)

if recline, almost sat on your knee	too close
invaded my space	too close
lack of space	too close
little space	too close
little space	too close
little space	too close
little space	too close
little space	too close
little space	too close
little space	too close
little space	too close
little space	too close
little space	too close
little space	too close
little space	too close
little space	too close
little space	too close
little space	too close
little space - cramped knees	too close
little space to move	too close
little space to move in seat	too close - little space
little space when reclined	too close esc when reclined
narrow	too close especially when watching TV
narrow	too close even when upright
narrow	too close to adopt posture
narrow knee space	too close when inclined
no leg room	too close when reclined
no seat in front	too close when reclined
no space	too close when reclined
no space	too close when reclined
not enough padding	too close, felt cramped
not enough space when seat in front reclines	too close, jammed against knees
not when reclined	too close, knees jammed up into seat back
quite close	too close, even more when reclined
recline space limited	too little room
reclined too far	too little room
restricts legs rocked a lot. Less room when reclined	too little room
seat in front in recline position made very restricted for space	too little space
seat reclined by passenger in front, little space	too little space
too close	too little space
too close	too little space
too close	too narrow
too close	too narrow
too close	too near
too close	too near
too close	too near
too close	too short
too close	too short
too close	too tight when standing
too close	when reclined
too close	when reclined
too close	when seat in front reclined awkward to eat or move

Foldaway tray

broken
could not move when down
food slipped off, needs edging
lack of space
little space
little space
no room to fold down
no space - tray would not drop
not enough space to eat dinner
too close
too little space
too little space
too low
too low when stowed - should be higher
too narrow and lopsided - slanted
too short
Too small
too small - cramped up when trying to eat
too small restricting
unstable
unstable
useless
when down, rests on knees, so can't move

Magazine holder

1 between 3
broken, metal bar protruded
could not be used because knees against it
Couldn't reach it without removing seat belt
decrease knee space
full of magazines - reduced space
if full, knees even more restricted
if seat in front reclined, magazines touch knees
intruded into leg room and ability to straighten legs
lack of space
no leg room
not easy to access
not enough room
not enough space
protruded too far
put pressure on knees
too bulky
too close
too close
too close
too close to knees
too close to knees
too far away
too little space between seats
too many magazines
too small
took up valuable space

Foot rest

chin would rest on knees if tried to use it
could not reach it
couldn't find comfortable position
Couldn't get it to where I wanted
did not adjust to best position
didn't have one, would have liked one
doesn't fit height
failed to remain in folded position
intruded into leg room and ability to stretch
lack of space
little space
needs to be height adjustable
no foot rest
no foot rest
no foot rest
no foot rest
no foot rest
no foot rest
no foot rest
no foot rest
no foot rest
no foot rest
no foot rest
no foot rest
no foot rest
no foot rest
no foot rest
no foot rest
no foot rest
no foot rest
no foot rest
no foot rest
no foot rest
no foot rests
no footrest
none provided
none provided
none provided , but would have found it helpful, with there being little leg room because of presence of baggage
none provided so no support for lower leg if stretched forward
not available, used a bag instead
not big enough
not easy to operate
not enough leg room
not far enough away for effectiveness
not necessary
not one-didn’t miss it
not sufficient space to be of use
Should be balanced higher
too far
too far
too far away
too far back(under own seat)
too high
too little space
too low
too short, no leg room
Useless
what foot rest
would have liked a foot rest
would have liked one
wouldn’t stay up

Space between front edge of seat base and head rest of seat in front (Dimension C)

cannot stretch out	no space	too close - cramped
confined when reclined	no space	too close - not enough knee room
difficult to manoeuvre	not enough leg room	too close for comfortable sitting
head rest too near	not enough room	too close when inclined
if reclined was a problem	overhangs-space limited	too close when seat in upright position
lack of space	screen too near when front seat reclined to see TV	too close, no room
Limited working space	seats in front too near	too little
little space	too close	too little room
little space	too close	too little space
little space	too close	too little space
little space	too close	too little space
little space	too close	too little space
little space	too close	too little space
little space	too close	too little space for long journey
little space	too close	too little space when seat in front reclined
little space	too close	too narrow
little space	too close	too narrow
little space	too close	too narrow
little space	too close	too narrow
little space	too close	too narrow
little space	too close	too near
little space	too close	too near - had trouble getting into standing position
little space	too close	too short
little space	too close	too short
little space when reclined	too close	too short
more space needed especially for working, travelling with kids and eating	too close	too short
	too close	too tight
narrow	too close	unable to stand straight
no room	too close	when seat reclined causes problem

Space between rear edge of seat base and back of seat in front (Dimension A)

all seats need to be moulded so as to fit into the contours of your body	not enough leg room	too close, no room to adjust posture
	poor space	too little room
confined when reclined ore	restricted leg movement	too little room
could not stretch legs because of exit door, even though paid for extra room	short of space, had to splay legs	too little space
	too close	too little space
difficult to manoeuvre	too close	too little space
hip to knee length is 1" longer than space	too close	too little space
lack of space	too close	too little space
little space	too close	too little space for long journey
little space	too close	too little space,
little space	too close	too little thigh room
little space	too close	too narrow
little space	too close	too narrow
little space	too close	too narrow
little space	too close	too narrow
little space	too close	too narrow
little space	too close	too narrow
little space	too close	too narrow
little space	too close	too narrow
little space	too close	too narrow
little space	too close	too narrow
little space	too close	too narrow for next passenger to get in and out
little space	too close	too near
little space when reclined	too close	too near - had trouble getting into standing position
narrow	too close	too short
narrow	too close	too short
narrow	too close - cramped	too short
narrow	too close - wanted to stretch legs but couldn't	too short
no leg room	too close for comfort	too short a space
no space	too close for comfortable sitting	too tight
not enough leg room	too close when seat in upright position	when passenger in front reclined seat fully, I was unable to move
not enough leg room	too close, no room	

Space between front edge of seat base and back of seat in front (Appendix B)

knees touch seat in front	too close
a little lacking in space	too close
all seats need to be moulded so as to fit into the contours of your body	too close
	too close
better than some but not enough for sleeping	too close
confined when reclined	too close
could not get comfortable, too cramped	too close
could not stretch legs	too close
cramped - knees touched the back	too close
difficult to cross legs	too close
difficult to manoeuvre	too close
if reclined was a problem	too close
insufficient leg room, knee aches and pains	too close
lack of space	too close
little knee room if seat in front reclined	too close
little space	too close
little space	too close
little space	too close
little space	too close
little space	too close
little space	too close
little space	too close - cramped
little space	too close - wanted to stretch legs but couldn't
little space	too close for comfort
little space	too close for comfortable sitting
little space	too close unable to straighten legs
little space	too close when seat in upright position
little space	too close!
little space	too close, no room
little space	too close, unable to stretch legs
little space	too close difficult to get in and out
little space	too little
little space	too little room
little space when reclined	too little room
narrow	too little room
narrow	too little space
narrow	too little space
narrow	too little space
needs to be more space between seats, knees pressing against seat in front so had to stretch out legs in aisle	too little space
	too little space
no leg room	too little space
no leg room	too little thigh room
no room	too narrow
no space	too narrow
not able to stretch legs fully under seat	too narrow
not enough	too narrow
not enough for taller people	too narrow
not enough leg room	too narrow
not enough leg room	too narrow
not enough room	too narrow
not enough room	too narrow
not enough room	too narrow
not enough room to stretch legs	too narrow and I'm only 5'1"
not enough space	too near
only problem when picking up dropped item	too near
poor space	too short
restricted leg movement	too short
shortage of leg room	too short
slightly more room needed	too short
too close	too short for taller person
too close	too tight
too close	unable to get things off floor without disturbing fellow passengers
too close	
too close	when passenger in front reclined seat fully, I was unable to move
too close	

Head room

hit head when standing
lack of space
little space
little space
little space
not enough
not enough
not enough
not high enough
too low
too low down
too low for tall person
too short

Head rest (own seat)

too low
all seats need to be moulded so as to fit into the contours of your body
but perhaps more cushioning could be considered
Couldn't get it in right position to support neck
didn’t support neck - too high
forces head to look down
hard
incorrect height
insufficient support
lack of space
lack of support
lack of support
little neck and head support
needs to be bulky
no lateral support
no support for relaxing/sleeping
no support when trying to sleep
not adjustable for height
not curved enough
not high enough
not high enough
not on my flight
not supportive
not very comfortable
own head rest was wrong shape for short person
poor design
restricted movement prevents comfortable head/neck
slid too much up and down
too big and wrong position
too close
too far back
too far back
too far back
too far back
too far back in relation to body
too far forward
too far 'forward' could it be a a little further backwards
too hard
too hard
too high
too high
too high
too high
too high
too high
too high
too high - head didn't quite reach comfortable position
too high for my height, so didn't provide support
too high for my height, so didn't provide support
too high to give cervical support
too little padding and non adjustable
too low
too low
too low
too low
too low - just above my shoulder
too low - seat back not high enough
too low and no side support
too low down for small people
too low for tall person
too low, poor angle
too narrow
too protruding
too short
too short
too upright
uncomfortable
uncomfortable
wasn’t one
wrong height - should be adjustable

Head rest (seat in front)

general problem of reclined seats
difficult to watch TV when reclined
hard texture
lack of space
little space
little space
little space
little space
little space
little space
little space when reclined
little space when reclined
narrow
narrow
needs more space
quite oppressively close
too close
too close
too close
too close
too close
too close
too close
too close
too close
too close
too close
too close
too close
too close
too close
too close
too close
too close
too close - touched chin when reclined
too close when reclined
too close when reclined
too close when reclined
too close, especially when reclined
too close, especially when reclined
too low, poor angle
too near
too near
when reclined
when seat in front reclined, very close
when seat was reclined

Arm rests

adjacent passenger used the rests	narrow	too close to other passengers
arm rest on outside seat did not lift up	narrow	too close together
audio/video cables plugged into rest are nuisance when moving or exiting seats	narrow space between and hard so dug into arms	too close together
	need to move right back to be flush with seat	too hard
bit too low	needs more padding	too hard
cannot be used by two people at once	no adjustment, hard	too hard
control buttons kept being pressed when put arms on them	no padding	too hard
	no support/hard	too little space
couldn't move them	not adjustable	too long
cramped range when between two others	not big enough. Sitting between 2 men , both who were using arm rests which left to keep my arms on my lap	too low
did not move up		too low
did not raise	not enough elbow room between seats	too narrow
don't go back far enough when raised	not enough room	too narrow
ease of movement poor	not moveable	too narrow
got in the way when manoeuvring	not much room for two to share	too narrow
had to bend around arm rests	not wide enough	too narrow
hand and uncomfortable	not wide enough	too narrow
hard	obtrusive position	too narrow - not big enough for both passengers
hard on elbows	outer arm doesn't raise	
hard on elbows	overflow of adjacent passenger	too narrow and hard
inhibit movement during flight	seat very narrow	too narrow and only one available to use due to centre-seat passenger
kept accidentally hitting assist button	sharp edges, too narrow, don't foldaway	too narrow for two people
knocked neighbour's arms	should be able to fold back	too narrow, little space
lack of space	space	too small
lack of support	the built-in control for the TV interfered with comfort	unable to get out as need to swing legs round to stand
little space	they do need to go into upright position	
little space	tight restricting	uncomfortable
little space - uncomfortable	too big, don't push back into place	uncomfortable
little space, especially when eating	too close	uncomfortable
narrow	too close to each other	would not adjust

Seat base

back of thighs hurt a bit	not soft enough	too hard, caused numbness
could be less hard	not sure what causes the numbness	too horizontal and too flat
could be more comfy - wider	old and therefore had sagged	too little padding
curled back forwards	poor shape for buttocks	too narrow
cushion "bottomed" out	quite hard	too narrow
hard	seat not big enough	too narrow
hard	seat very narrow	too narrow
hard texture	slightly hard	too narrow
hollow in seat base	slightly high off the floor	too narrow
lack of space	too firm	too narrow
leg rest wouldn't come up far enough	too firm	too narrow
little space	too flat	too narrow
narrow	too hard	too narrow and hard
narrow	too hard	too short
narrow and hard	too hard	too short
narrow and uncomfortable	too hard	too short and narrow
need cushion	too hard	too short and too narrow
needed to be longer	too hard	too small (wide)
needs more padding	too hard	too soft, unsupportive, too narrow, aggravated by entertainment console/phone
no padding	too hard	
no support	too hard	too uncomfortable
not comfortable	too hard	too uncomfortable for resting
not comfortable - resulted in numbness	too hard	uncomfortable
not deep enough	too hard and narrow	uncomfortable
not long enough	too hard and no real shape	uncomfortable
not particularly comfortable	too hard at front ridge of seat	uncomfortable
not soft enough	too hard, uncomfortable	very little support

Other comments/problems

the seat back and foot rest don't let you lie back and relax as you could
box fitted to the floor which extended 1/3 the width of the space under the seat
difficulty getting past
get hit by trolley if in aisle seat
important when lying diagonal across seat to get comfy
leg room - pillar that seat in front was mounted on prevented me from stretching my legs - hence pain in legs and bottom
leg room appalling
most uncomfortable seats had misfortune to use on a par with most other plane seats
no lumbar support
no padding in lumber area of seat
not enough space to stretch out in front, beneath seat in front
on the whole very comfortable
passengers pull themselves up and down on the forward seat back so knocking the person sat in front
seat too narrow
too narrow for long haul
unable to extinguish therefore focused uncomfortable heat on passengers' heads
very awkward to bend down far enough to reach briefcase/holdall

Appendix 4: Anthropometric data tables

European

General European data

		People Size (European male & female, 18-64)					Adultdata (European male & female, 18-64)				
		bold,it=m	***bold,it=m***	***bold,it=f***	***bold,it=f***						
		1st (F)	5th (F)	95th (M)	99th (M)	AN64 Minimum	1st (F)	5th (F)	95th (M)	99th (M)	AN64 Minimum
1	Stature	1473	1513	1864	1919						
2	Weight	45	48	104	121						
3	Whole body depth					177.8					177.8
4	Sitting height	769	797	977	1006						
5	Shoulder breadth (deltoid)	371	386	536	565						
6	Hip breadth, maximum, sitting	***301***	***325***	***478***	***529***						
7	Buttock to front of knee, sitting					660					660
8	Buttock to back of knee (popliteal), sitting										
9	Top of knee height, sitting										
10	Back of knee height (popliteal), sitting										
11	Knee height (tibia), standing										
12	Knee height (popliteal), standing										
13	Elbow height (to seat, sitting)										

British data

		People Size (British male & female, 18-64)					Adultdata (British male & female, 18-64)				
		bold,it=m	***bold,it=m***	***bold,it=f***	***bold,it=f***						
		1st (F)	5th (F)	95th (M)	99th (M)	AN64 Minimum	1st (F)	5th (F)	95th (M)	99th (M)	AN64 Minimum
1	Stature	1471	1515	1870	1918			1514	1869		
2	Weight	44	49	103	117			45	101		
3	Whole body depth	217	230	383	409	177.8		220	380		177.8
4	Sitting height	777	800	979	1004			803	980		
5	Shoulder breadth (deltoid)	396	411	537	564			402	544		
6	Hip breadth, maximum, sitting	***326***	***343***	***485***	***533***			***342***	***480***		
7	Buttock to front of knee, sitting	520	541	677	704	660		521	673		660
8	Buttock to back of knee (popliteal), sitting	420	438	556	580			435	575		
9	Top of knee height, sitting	439	457	591	610			450	591		
10	Back of knee height (popliteal), sitting	351	369	499	518			356	494		
11	Knee height (tibia), standing	391	403	511	529			388	511		
12	Knee height (popliteal), standing	379	397	***479***	***496***			396	***479***		
13	Elbow height (to seat, sitting)	183	197	276	291			190	288		

Dutch data

		People Size (Dutch male & female, 18-64)					Adultdata (Dutch male & female, 20-60)				
		bold,it=m	***bold,it=m***	***bold,it=f***	***bold,it=f***		***bold,it=m***	***bold,it=m***	***bold,it=f***	***bold,it=f***	
		1st (F)	5th (F)	95th (M)	99th (M)	AN64 Minimum	1st (F)	5th (F)	95th (M)	99th (M)	AN64 Minimum
1	Stature	1517	1559	1913	1963			1545	1900		
2	Weight	51	55	103	115			49	92		
3	Whole body depth					177.8					177.8
4	Sitting height	794	817	996	1022			820	995		
5	Shoulder breadth (deltoid)	377	388	505	528			355	520		
6	Hip breadth, maximum, sitting	***340***	***355***	***469***	***506***			***340***	***450***		
7	Buttock to front of knee, sitting	550	567	690	715	660		550	665		660
8	Buttock to back of knee (popliteal), sitting (65 -74)	382	410	***567***	***609***			440	570		
9	Top of knee height, sitting							450	610		
10	Back of knee height (popliteal), sitting (65 -74)	339	366	518	536			370	495		
11	Knee height (tibia), standing										
12	Knee height (popliteal), standing										
13	Elbow height (to seat, sitting)	167	187	302	322			***195***	280		

French data

		People Size (French male & female, 18-64)					Adultdata French male & female, (18-55)				
		bold,it=m	***bold,it=m***	***bold,it=f***	***bold,it=f***		***bold,it=m***	***bold,it=m***	***bold,it=f***	***bold,it=f***	
		1st (F)	5th (F)	95th (M)	99th (M)	AN64 Minimum	1st (F)	5th (F)	95th (M)	99th (M)	AN64 Minimum
1	Stature	1476	1518	1846	1894			1507	1830		
2	Weight	42	46	93	104			47	95		
3	Whole body depth					177.8					177.8
4	Sitting height	797	818	977	1001			810	968		
5	Shoulder breadth (deltoid)	378	390	517	542			386	514		
6	Hip breadth, maximum, sitting	***317***	***331***	***437***	***473***			***333***	***432***		
7	Buttock to front of knee, sitting	510	527	646	668	660		521	642		660
8	Buttock to back of knee (popliteal), sitting	408	423	526	547			422	523		
9	Top of knee height, sitting	445	462	581	599			458	576		
10	Back of knee height (popliteal), sitting	366	382	471	488			354	464		
11	Knee height (tibia), standing										
12	Knee height (popliteal), standing										
13	Elbow height (to seat, sitting)							185	290		

German data

		People Size (German male & female, 18-64)					Adultdata (German male & female, 16-60)				
		bold,it=m	***bold,it=m***	***bold,it=f***	***bold,it=f***		***bold,it=m***	***bold,it=m***	***bold,it=f***	***bold,it=f***	
		1st (F)	5th (F)	95th (M)	99th (M)	AN64 Minimum	1st (F)	5th (F)	95th (M)	99th (M)	AN64 Minimum
1	Stature	1486	1529	1865	1910			1510	1841		
2	Weight	47	52	105	118						
3	Whole body depth	227	239	390	415	177.8		***233***	***357***		177.8
4	Sitting height	785	807	977	1000			805	962		
5	Shoulder breadth (deltoid)	410	425	547	***576***						
6	Hip breadth, maximum, sitting	***338***	***355***	***497***	***546***			***325***	***451***		
7	Buttock to front of knee, sitting	531	551	681	706	660		530	645		660
8	Buttock to back of knee (popliteal), sitting	428	446	559	582			426	552		
9	Top of knee height, sitting	444	462	588	606			462	574		
10	Back of knee height (popliteal), sitting	355	373	497	515						
11	Knee height (tibia), standing	395	407	509	526						
12	Knee height (popliteal), standing	384	401	***480***	***497***						
13	Elbow height (to seat, sitting)	186	200	275	289			191	280		

Italian data

		People Size (Italian male & female, 18-64)					Adultdata (Italian male & female, 18-64)				
		bold,it=m	***bold,it=m***	***bold,it=f***	***bold,it=f***		***bold,it=m***	***bold,it=m***	***bold,it=f***	***bold,it=f***	
		1st (F)	5th (F)	95th (M)	99th (M)	AN64 Minimum	1st (F)	5th (F)	95th (M)	99th (M)	AN64 Minimum
1	Stature	1457	1501	1847	1897			1500	1847		
2	Weight	44	47	92	102			46	92		
3	Whole body depth					177.8					177.8
4	Sitting height	772	795	956	981			794	595		
5	Shoulder breadth (deltoid)	357	368	497	519			***420***	496		
6	Hip breadth, maximum, sitting	***276***	***293***	***407***	***447***			***296***	***393***		
7	Buttock to front of knee, sitting					660					660
8	Buttock to back of knee (popliteal), sitting	***409***	***429***	534	560			425	531		
9	Top of knee height, sitting	425	446	589	610			450	590		
10	Back of knee height (popliteal), sitting							380	521		
11	Knee height (tibia), standing	364	381	517	540			389	521		
12	Knee height (popliteal), standing										
13	Elbow height (to seat, sitting)	160	180	300	323			***196***	301		

Polish data

		People Size (Polish male & female, ?)					Adultdata (Polish male & female, ?)				
		bold,it=m	*bold,it=m*	*bold,it=f*	*bold,it=f*		*bold,it=m*	*bold,it=m*	*bold,it=f*	*bold,it=f*	
		1st (F)	5th (F)	95th (M)	99th (M)	AN64 Minimum	1st (F)	5th (F)	95th (M)	99th (M)	AN64 Minimum
1	Stature							1502	1862		
2	Weight										
3	Whole body depth					177.8					177.8
4	Sitting height							778	955		
5	Shoulder breadth (deltoid)							350	475		
6	Hip breadth, maximum, sitting							***330***	***429***		
7	Buttock to front of knee, sitting					660		523	683		660
8	Buttock to back of knee (popliteal), sitting							454	610		
9	Top of knee height, sitting							461	596		
10	Back of knee height (popliteal), sitting							405	499		
11	Knee height (tibia), standing										
12	Knee height (popliteal), standing										
13	Elbow height (to seat, sitting)							***172***	***280***		

Swedish data

		People Size (Swedish male & female, 25-49)					Adultdata (Swedish male & female, 25-49)				
		bold,it=m	*bold,it=m*	*bold,it=f*	*bold,it=f*		*bold,it=m*	*bold,it=m*	*bold,it=f*	*bold,it=f*	
		1st (F)	5th (F)	95th (M)	99th (M)	AN64 Minimum	1st (F)	5th (F)	95th (M)	99th (M)	AN64 Minimum
1	Stature							1540	1850		
2	Weight							48	***70***		
3	Whole body depth					177.8					177.8
4	Sitting height							805	970		
5	Shoulder breadth (deltoid)							355	510		
6	Hip breadth, maximum, sitting										
7	Buttock to front of knee, sitting					660		550	665		660
8	Buttock to back of knee (popliteal), sitting							430	***540***		
9	Top of knee height, sitting							455	580		
10	Back of knee height (popliteal), sitting							350	475		
11	Knee height (tibia), standing										
12	Knee height (popliteal), standing										
13	Elbow height (to seat, sitting)							165	275		

World

Chinese data

		People Size (Chinese male & female, 18-45)					Adultdata (Chinese male & female, 18-45)				
		bold,it=m	***bold,it=m***	***bold,it=f***	***bold,it=f***		***bold,it=m***	***bold,it=m***	***bold,it=f***	***bold,it=f***	
		1st (F)	5th (F)	95th (M)	99th (M)	AN64 Minimum	1st (F)	5th (F)	95th (M)	99th (M)	AN64 Minimum
1	Stature	1421	1461	1792	1834			1461	1792		
2	Weight	37	40	74	82			37	73		
3	Whole body depth					177.8					177.8
4	Sitting height	758	782	965	990			782	965		
5	Shoulder breadth (deltoid)	348	358	483	508			351	480		
6	Hip breadth, maximum, sitting	***295***	***305***	***395***	***428***			***303***	***391***		
7	Buttock to front of knee, sitting	469	486	609	634	660		483	607		660
8	Buttock to back of knee (popliteal), sitting	379	396	500	523			393	499		
9	Top of knee height, sitting	397	415	548	567			415	548		
10	Back of knee height (popliteal), sitting	323	338	443	459			341	447		
11	Knee height (tibia), standing										
12	Knee height (popliteal), standing										
13	Elbow height (to seat, sitting)	184	197	272	287			197	272		

Japanese data

		People Size (Japanese male & female, 18-55)					Adultdata (Japanese male & female, 18-39)				
		bold,it=m	***bold,it=m***	***bold,it=f***	***bold,it=f***		***bold,it=m***	***bold,it=m***	***bold,it=f***	***bold,it=f***	
		1st (F)	5th (F)	95th (M)	99th (M)	AN64 Minimum	1st (F)	5th (F)	95th (M)	99th (M)	AN64 Minimum
1	Stature	1439	1474	1781	1820			1474	1781		
2	Weight	40	43	75	84			41	74		
3	Whole body depth					177.8					177.8
4	Sitting height	771	793	970	995			793	970		
5	Shoulder breadth (deltoid)	374	383	487	508			377	484		
6	Hip breadth, maximum, sitting	***317***	***325***	***404***	***429***			***323***	***398***		
7	Buttock to front of knee, sitting	485	499	609	632	660		496	608		660
8	Buttock to back of knee (popliteal), sitting	394	408	531	555			405	529		
9	Top of knee height, sitting	411	424	537	552			424	537		
10	Back of knee height (popliteal), sitting	318	331	447	463			***331***	447		
11	Knee height (tibia), standing	348	361	462	476			361	462		
12	Knee height (popliteal), standing										
13	Elbow height (to seat, sitting)	184	196	270	286			196	271		

U.S. data

		People Size (U.S. male & female, 18-64)					**Adultdata (U.S. male & female, 18-64)**				
		bold,it=m	***bold,it=m***	***bold,it=f***	***bold,it=f***		***bold,it=m***	***bold,it=m***	***bold,it=f***	***bold,it=f***	
		1st (F)	5th (F)	95th (M)	99th (M)	AN64 Minimum	1st (F)	5th (F)	95th (M)	99th (M)	AN64 Minimum
1	Stature	1470	1517	1877	1925		[redacted]	[redacted]	[redacted]	[redacted]	
2	Weight	41	47	113	130		[redacted]	31	110	[redacted]	
3	Whole body depth	213	229	405	438	177.8	[redacted]	190	401	[redacted]	177.8
4	Sitting height	777	801	983	1008		[redacted]	802	984	[redacted]	
5	Shoulder breadth (deltoid)	397	416	563	***608***		[redacted]	381	569	[redacted]	
6	Hip breadth, maximum, sitting	***320***	***342***	***522***	***584***		[redacted]	311	***542***	[redacted]	
7	Buttock to front of knee, sitting	520	543	692	722	660	[redacted]	506	***691***	[redacted]	660
8	Buttock to back of knee (popliteal), sitting	418	439	568	596		[redacted]	421	589	[redacted]	
9	Top of knee height, sitting	439	457	593	612		[redacted]	448	594	[redacted]	
10	Back of knee height (popliteal), sitting	350	369	501	520		[redacted]	354	496	[redacted]	
11	Knee height (tibia), standing	391	403	513	532		[redacted]	386	513	[redacted]	
12	Knee height (popliteal), standing	378	396	***482***	***500***		[redacted]	394	***484***	[redacted]	
13	Elbow height (to seat, sitting)	182	196	278	293		[redacted]	188	290	[redacted]	