DESIGN REQUIREMENTS FOR THE EXERCISE AREAS IN THE INTERNATIONAL SPACE STATION (ISS)

A THESIS

SUBMITTED TO THE DEPARTMENT OF

INTERIOR ARCITECTURE AND ENVIRONMENTAL DESIGN

AND THE INSTITUTE OF FINE ARTS

OF BİLKENT UNIVERSITY

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS

FOR THE DEGREE OF

MASTER OF FINE ARTS

By

Aslı Yılmaz

May, 2007

I certify that I have read this thesis and that in my opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Fine Arts.

Assoc. Prof. Dr. Halime Demirkan (Principal Advisor)

I certify that I have read this thesis and that in my opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Fine Arts.

Assoc. Prof. Dr. Çiğdem Erbuğ

I certify that I have read this thesis and that in my opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Fine Arts.

Assist. Prof. Dr. Nilgün Olguntürk

Approved by the Institute of Fine Arts

Prof. Dr. Bülent Özgüç, Director of the Institute of Fine Arts

ABSTRACT

DESIGN REQUIREMENTS FOR THE EXERCISE AREAS IN THE INTERNATIONAL SPACE STATION

Aslı Yılmaz

M.F.A. in Interior Architecture and Environmental Design

Supervisor: Assoc. Prof. Dr. Halime Demirkan

May, 2007

This study explores the design requirements of the exercise areas of the International Space Station (ISS) in terms of physical and behavioral requirements. The main focus of the study is to understand the interactions of the crew members with the exercise equipment. Besides, the interior and environmental conditions of the exercise areas in the station as well as interaction of the exercise activities with the other activities are considered. In this study, how well users' expectations fulfilled by the designers are discussed. It is found that some user needs are disregarded, because of the space, time and power constraints imposed by the station. However, in this study it is determined that design solutions can be generated both regarding the user needs and the constraints imposed by the station. Through out the study, some problems are figured out affecting both the physiological and psychological well being of the crew members. Some guidelines are suggested accordingly that can be useful for designers in designing exercise areas for space for further missions. In addition, this study indicates the lack of in-depth qualitative studies that explores users' physical and behavioral needs in the exercise areas in the ISS.

Keywords: Design requirements, exercise areas, exercise equipment, interior and environmental issues, International Space Station (ISS)

ÖZET

ULUSLARARASI UZAY İSTASYONU EGZERSİZ ALANLARI İÇİN TASARIM GEREKSİNİMLERİ

Aslı Yılmaz

İç Mimarlık ve Çevre Tasarımı Bölümü, Yüksek Lisans

Danışman: Doç. Dr. Halime Demirkan

Mayıs, 2007

Bu çalışma, Uluslararası Uzay İstasyonundaki egzersiz alanlarına yönelik tasarım gereksinimlerini fiziksel ve davranışsal açıdan ele alır. Bu çalışmadaki belirgin bakış açısı, mürettebat üyelerinin egzersiz alanlarındaki egzersiz aletleri ile ilişkisini anlamaktır. Ayrıca, istasyondaki egzersiz alanlarının iç mekan ve çevre koşulları ve yanısıra, egzersiz aktivitesiyle aynı mekanda bulunan diğer aktiviteler de göz önünde bulundurulmuştur. Bu çalışmada, tasarımcıların ne derecede kullanıcıların ihtiyaçlarını göz önünde bulundurdukları ve cevap verdikleri tartışılmaktadır. Yapılan analizler sonucunda bazı gereksinimlerin göz ardı edildiği ortaya çıkmıştır. Bunun başlıca sebebinin istasyonun mekan, zaman ve enerji anlamında getirdiği kısıtlamalar olduğu saptanmıştır. Fakat, bu çalışma, hem bu kısıtlamaları hem de kullanıcı isteklerini göz önünde bulunduracak tasarım önerilerilerinin olabileceğini ortaya çıkarmaktadır. Çalışma sırasında, mürettebat elemanlarının fiziksel ve davranışsal sağlığını etkileyen bazı problemler saptanmıştır. Bu problemleri çözmeye yönelik ve sonraki uzay misyonları için egzersiz alanlarının tasarımına da yararlı olabilmesi adına bazı tasarım önerileri yapılmıştır. Ayrıca, bu çalışma Uluslararası Uzay İstasyonundaki egzersiz alanlarındaki kullanıcıların fiziksel ve davranışsal gereksinimlerini irdelemeye dönük geniş kapsamlı nitel çalışmaların azlığını ortaya koymuştur.

Anahtar Kelimeler: Egzersiz alanları, egzersiz aletleri, iç mekan ve çevre koşulları, tasarım gereksinimleri, Uluslararası Uzay İstasyonu

ACKNOWLEDGEMENTS

I would like to thank my principal advisor Assoc. Prof. Dr. Halime Demirkan for her guidance, support and encouragement throughout the preparation of this thesis. It has been a privilege to work with her.

I express appreciation to the jury members, Assoc. Prof. Dr. Çiğdem Erbuğ and Assist. Prof. Dr. Nilgün Olguntürk for their invaluable support and interest. In addition, I express my gratitude to my instructors, Serpil Altay and Tijen Sonkan for their encouragement and generous support.

I owe special thanks to Özgür Gürtuna for his guidance, interest and encouragement while doing my research. Also, I would like to thank the Canadian astronauts Bob Thirsk and Marc Garneau for their support.

I would like to thank my best friend, Selime Gürol for her generous love, support and encouragement. Also, I would like to thank my roommates Elif Helvacıoğlu and Aslı Çebi for being with me in every moment of my master education; İpek Sancaktar, Güliz Mugan,Yasemin Afacan, Fatih Karakaya and Erhan Dikel for their guidance, help and support when I was lost or down, Sabriye Özbaldan, Nazlı Bakht, Ozan Dinçer, Erdem Akagündüz, Onur Akgün for their love and care; Gökçen Çağatay, Segah Sak, Fatma Tekdağ, Kıvanç Kitapçı, Kutay Güler, Seda Konyar for their moral support.

I am thankful to my aunts Özden Tutgun and Özay Akdoğan for their sweet care, love and support. I am grateful to my parents Ayşen Yılmaz and Kubilay Yılmaz and my lovely twin sisters, Pelin Yılmaz and Selin Yılmaz for their invaluable support, patience and encouragement throughout this thesis. Nothing could be done without them. I dedicate this thesis to my precious family.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATION

ACS	Atmosphere Control and Supply
AR	Atmosphere Revitalization
ARED	Advanced Resistance Exercise Device
ASI	Italian Space Agency
ATV	Automated Transfer Vehicle
CEVIS	Cycle Ergometer with Vibration Isolation System
CSA	Canadian Space Agency
ECLSS	Environmental Control and Life Support System
ECP	Exercise Countermeasure Project
ESA	European Space Agency
EVA	Extravehicular Activity
FDS	Fire Detection and Suppression
GRC	Glenn Research Center
HRF	Human Research Facility Rack
iRED	Interim Resistance Exercise Device
ISS	International Space Station
IVA	Intravehicular Activity
JAXA	Japan Aerospace Exploration Agency
JSC	Johnson Space Center
MELFI	Minus Eighty Degree Laboratory Freezer
MILT	Man-in-the-Loop Test
MLM	Multi-purpose Laboratory Module
MPLM	Multi-purpose Logistics Module
MSG	Microgravity Science Glovebox
NASA	National Aeronautics and Space Administration
NASDA	National Space Development Agency of Japan
NSBRI	National Space Biomedical Research Institute
PMA	Pressurized Mating Adapter
RSA	Russian Space Agency

SCHRED	Schwinn Resistive Exercise Device
SICSA	Sasakawa International Center for Space Architecture
SLD	Subject-loading Device
SM	Service Module
SPDM	Special Purpose Dexterous Manipulator
THC	Temperature and Humidity Control
TVIS	Treadmill Vibration Isolation System
USA	United Space Alliance
VS	Vacuum System
WM	Waste Management
WRM	Water Recovery and Management

1. INTRODUCTION

Space is a unique and unusual environment that presents a challenge for human being. As the number of missions of the International Space Station (ISS) increases and further concepts of missions to Mars stations and space hotels appear, more comfortable, efficient and functional way of living and working in extraordinary conditions of space environment stand out as an important issue to be explored. For this reason, the recent studies highlight designers as central figures as they have the responsibility to improve the quality of life, while figuring out human's problems in space and coming up with design solutions that will over come these problems.

Many factors interact with each other in intricate ways that influence the safety, comfort, health, performance and morale of the people living and working in space. Some factors are caused by extreme conditions in the environment such as gravitational influences, radiation, temperature and artificial light. Some factors are imposed by the space mission and transportation systems such as habitat dimension, launch transfer such as volume and mass constraints, characteristics of crew members or mission activities and duration. Therefore, designing for space is more inclusive and challenging, and requires more attention than designing for earth. As Dominoni (2002) stated, "designing for space means starting a new, applying a different logic for a different environment, conceiving new instruments for uses and activities that Earth dwellers have difficulty in envisaging, but which on the whole presuppose a different relationship between our bodies, and the surrounding space" (p.1).

In recent space design research studies, the importance of getting information from numerous disciplines and combining them for design applications are emphasized and suggested for better fulfilling the human needs in space. Most of the previous documentations prepared for ISS such as design requirements, guidelines or suggestions mainly focus on the physical interactions of the human with the interfaces of the station. They mainly focus on human-technology interface, human-human interface and human-environment interface are rarely touched (Dudley-Rowley and Bishop, 2002). The behavioral interactions are disregarded in these documentations; they should be integrated in to guidelines for further missions (Harrison, 2004; Musson; 2000). Stress caused by the factors such as isolation and confinement, monotony and boredom, adaptation to microgravity and lack of privacy and community are rarely touched. Moreover, they are generated in general means, covering standards and design requirements to guide designing ISS in the overall, not specifically focusing enough on each activity task or its context and content in the station.

1.1. Aim of the Study

The main purpose of this thesis is to underline the importance of both physical and behavioral needs of human beings in space while figuring out design requirements for space. Analyzing one specific activity area of ISS, which is the exercise area, this thesis aims to figure out the factors affecting both physiological and psychological well being of the crew members in these areas. Throughout the study, the approach is to understand the interactions of the crew member in the exercise areas in ISS, within a wide perspective, figuring out their interactions in the exercise areas while understanding their interactions with the other crew members. The interactions of the exercise activity areas with the other activity areas are also analyzed.

In this thesis, what users expect to be in an exercise area in space, and how the designers' approach to the users' expectations are discussed. This study points out the differences and similarities on the emphasis put forward by the designers and the users of the exercise areas in ISS. According to them, which priorities should be used in designing an exercise area for space is discussed. At the end of the discussion, problems in the exercise areas in the station are specified while the physical and behavioral bases of these problems are both explored. Taking into account all research in the field and the analysis of the conducted case studies as basis, some guidelines are given suggesting clues for designing equipment and planning the interior and environmental conditions of the exercise areas for ISS. Also, they may be helpful for further long duration missions to Mars or concepts of habitations in space hotels.

1.2. Structure of the Thesis

The thesis consists of five chapters. The first chapter is the introduction in which the challenging environment of space and importance of design for space is stated and how the design requirements for space are analyzed are explained. The aim of the study and the structure of the thesis are given. Also, there is a section that introduces ISS in this chapter by giving a brief history of ISS that explains the purpose, objectives and organizations of ISS and defines the ISS elements.

The second chapter explains the characteristics of the exercise areas in ISS. Firstly, the human characteristics are introduced under two main headings, which are the demographic and anthropometrical characteristics of the crew members. Secondly, the characteristics of the exercise modules are explained. Lastly, the characteristics of the exercises are examined and classified under three groups as the proposed exercises in ISS, their aim, and the specific exercise equipment located in ISS at the moment. Main aim of this chapter is to describe the exercise areas in ISS through explaining the users, place and the activities.

In the third chapter, the design requirements for the exercise areas in ISS are stated. They are mainly affected by two factors, which are the design requirements of physical and behavioral factors. In the first section, the physical factors affecting equipment, and interior and environmental factors are explored. In the second section, the behavioral factors affecting the design requirements of the exercise areas in ISS are introduced. The psychological and social stress in space environment is explained under two main headings as stress inducements and reactions. The design requirements against them are stated.

In the fourth chapter, design evaluations for the exercise areas in ISS are conducted. Firstly, the chapter is described and aim of the study is stated. The methodology of the study is introduced that used the case analysis and interview techniques. The information gathered form the analysis and interviews are discussed. Some guidelines are given according to the problems defined throughout the study. In the last chapter, major conclusions and limitations about the study are stated and suggestions for further research are generated.

1.3. Introduction to ISS

The International Space Station (ISS) is the most extensive and most complex international scientific project in history which started up in December 1998, still under construction and planned to be finished in 2010 (Boeing Company, National Aeronautics and Space Administration [NASA], United Space Alliance[USA], 1999; Wikipedia, 2007) (Figure 1.1).

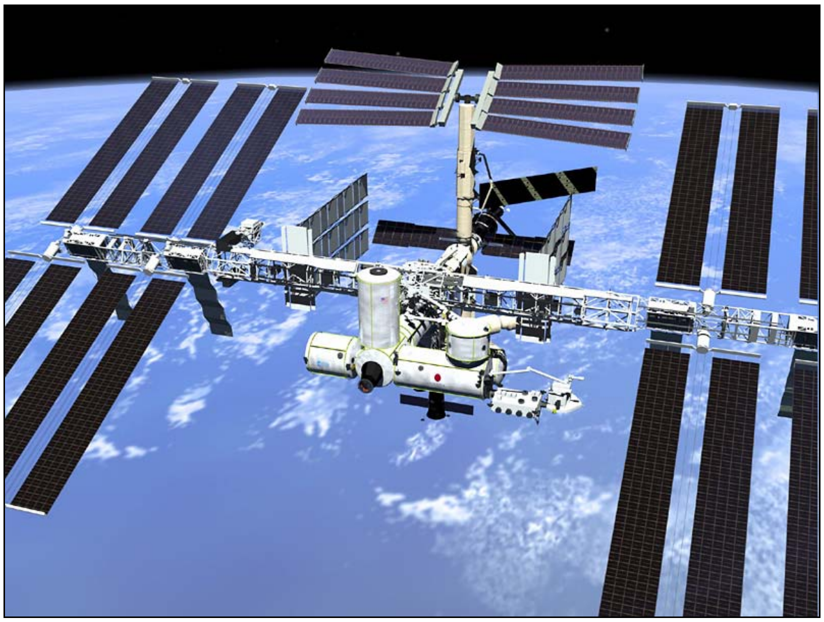


Figure 1.1. International Space Station
(http://nssdc.gsfc.nasa.gov/image/spacecraft/iss.jpg)

“The ISS orbits Earth at an altitude of about 400 km” (Oberg, 2005, #2). Launch vehicles of the international partners reach this orbit in order to accomplish delivery of crew and provide supplies and equipment during their missions. “When it is completed, the ISS will be more than four times as large as the Russian Mir Space Station” (Boeing Company et al., 1999, #2). It will have a mass of about 470000 kg, width of 108 m, length of 88 m and eight solar panels supplying more than 100 kW of electric power to the station (Boeing Company et al., 1999; Oberg, 2005). The station will include eight large modules each of which is being launched from Earth and connected to the station (Oberg, 2005).

Before introducing the exercise areas inside the ISS, this section presents a general overlook to the space station and explains important points related with its scientific, historical and structural background. In this section, the ISS is introduced under three main headings, which are the brief history of ISS, the purpose, objectives and organization of ISS and the ISS Elements.

1.3.1. Brief History of ISS

“The ISS is the ninth inhabited space station orbiting Earth” (Oberg, 2005, #8). The first one was Salyut 1 which was launched by Soviet Union in 1971 (NASA Human Space Flight, 2006; Wikipedia 2007). Two years later the United States’s first station Skylab was sent into orbit and it hosted three crew members (NASA Human Space Flight, 2006). It was the first space station hosting humans in the history.

“In 1986, the Soviet Union began operating Mir station as the first space station to be using a modular design” (Oberg, 2005, #9). The Soviets developed a reliable and economic transportation system which was called Soyuz that provided the delivery of supplies, equipment, and crew members to Mir Station (Oberg, 2005).

In the early 1980s, the Soviet Union were more advanced and experienced than the USA. While Soviet Union was operating Mir stations, NASA planned Space Station Freedom as a counterpart to the Soviet Salyut and Mir space stations (Japan Aerospace Exploration Agency [JAXA], 2003; Wikipedia, 2007). After the Cold War and following the collapse of the Soviet Union in 1991, Russians and USA came to an agreement and negotiated to build a combined station. Also space agencies in Europe, Canada and Japan joined to this partnership. It was in 1993 that the Freedom project was defined as the base of the ISS project (JAXA, 2003; Oberg, 2005; Wikipedia, 2007).

During the construction and design of the ISS, Mir station was taken as an experience and the problems in Mir station were figured out in order not to be repeated in the ISS. To prepare for the ISS project, shuttles flew to Mir station from 1995 to 1998. Astronauts from United States and Russia had been to Mir station as researchers and habitants for six months (Oberg, 2005).

The first piece of the ISS which is Zarya Functional Cargo Block was launched in 1998, by Russian Proton Rocket (Oberg, 2005; Wikipedia, 2007). At the moment "it serves as a backup and propellant storage tank for Zvezda Module" (NASA, 1998, p. 1-6). Afterwards, two further pieces which are Unity Module and Zvezda Service Module were added. In October 2000, the shuttle Discovery carried up several more pieces including the Truss systems and connecting unit called Pressurized Mating Adapter (PMA) (Oberg, 2005). In 2001, the Shuttle Atlantis carried the U.S. Destiny Laboratory Module to the station. It is the main laboratory unit at the moment. Also in 2001, two additional modules, U.S. airlock and Russian airlock and docking port were added (Oberg, 2005; Wikipedia, 2007).

In April 2001, the first space tourist, Dennis Tito, traveled as a passenger with Soyuz to the station. He was an investment manager from California, purchased the trip for a very high price (Oberg, 2005). He was trained in Moscow for six months before the flight and spent six days on the station (Oberg, 2005; Wikipedia, 2007). Until now, there have been five tourist visits to ISS.

In 2002, the station continued to be occupied by crew number of three. "Space shuttles replaced the crew members every four or five months. Russian cosmonauts also flew a new Soyuz spacecraft to the station every six months" (Oberg, 2005, #19). On February 1, 2003, the space shuttle Columbia broke apart on the reentry into Earth's atmosphere and all seven crew members died (Wikipedia, 2007). NASA postponed the shuttle flights until it could ensure the safety for the future flights. Then, Soyuz began carrying the crew. The station's crew was reduced to two people to conserve supplies normally carried to the station by shuttles (Wikipedia, 2007). From 2003 to 2006, Truss systems carrying solar panels and radiators were added.

1.3.2. Purpose, Objectives and Organization of ISS

The purpose of ISS is to conduct research to support human exploration of space and take advantage of the space environment as a laboratory for scientific, technological, and commercial developments (Boeing Company, 2006a; Looney, 2001; NASA, 1998). For this purpose, the stated specific objectives of the ISS are to develop an orbiting laboratory for conducting high-value scientific research, explore medical countermeasures for long term human space missions, access to microgravity resources, provide a long-duration habitable residence to live and work in space, act as a test bed for developing 21st Century technology and support effective international cooperation (Boeing Company, 2006b; Looney, 2001; NASA, 1998).

In order to actualize the ISS objectives, NASA has joined with four other space agencies and their major contractors (NASA, 1998). NASA's major contractor is the Boeing Company. The other four space agencies are Russian Space Agency (RSA), Canadian Space Agency (CSA), Japan Aerospace Exploration Agency (JAXA) and European Space Agency (ESA). Each of these agencies is composed of sub groups or teams which have specific responsibilities.

1.3.3. ISS Elements

The ISS is composed of various modules and elements constructed by different nations (Figure 1.2). At the moment, the United States and Russia are the main providers of the modules and the supplies to the station.

There are four pressurized modules currently in ISS. These are Zvezda Service Module, Zarya Module, Unity (Node 1) Module and US Destiny Module. The other elements of the station are scheduled for launch or launched periodically. These modules create a working and living environment for crew members for long duration missions. The exercise equipment are located seperately inside these modules. However, there are some projects proposed to unite all the exercise equipment in a specific exercise area located in one module (e.g. Transhab Project).

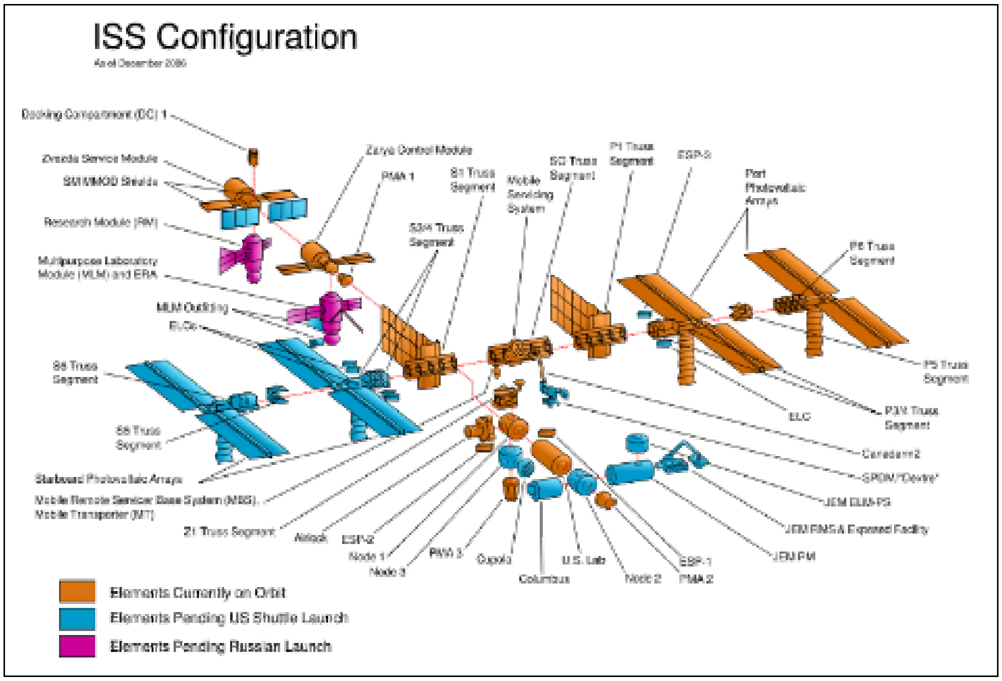


Figure 1.2. ISS configuration.
(http://www.nasa.gov/images/content/143942main_ISS_config.jpg)

Currently, the other main elements in ISS are Multi-purpose Logistics Module (MPLM), Joint (Quest) Airlock, Docking Compartment, subsystems including Integrated Truss Structure, Mobile Servicing System and ships including Space Shuttle, Soyuz, Progress, H-II Transfer Vehicle and Automated Transfer Vehicle (ATV) (Wikipedia, 2007). The elements scheduled to be launched are Node 2, Node 3, Columbus, Cupola, Special Purpose Dexterous Manipulator (SPDM), Kibo, Russian Research Module (RRM), Multi-purpose Laboratory Module (MLM) and European Robotic Arm (Wikipedia, 2007).

The Multi-purpose Logistics Module (MPLM) is a large pressurized container used to transfer cargo to and from the station; however, it is launched periodically (Wikipedia, 2007). The other module is the Joint (Quest) Airlock Module which is the primary airlock for the station, designed to host spacewalks (Wikipedia, 2007).

There are two Russian Docking Compartments used to “provide egress/ingress capability for Russian-based extravehicular activities (EVAs) and additional docking ports” (NASA, 1998, p.1-7). One of the subsystems is the Integrated Truss Structure. It is the backbone of the station and includes solar panels and radiators (Wikipedia, 2007). Finally, the ships are designed to carry crew members and supplies.

The ISS is still under construction and growing in space by the added elements. The next chapter explains the characteristics of the exercise areas in the station under the sub-headings of characteristics of human, exercise modules and exercises.

2. CHARACTERISTICS OF THE EXERCISE AREAS IN THE INTERNATIONAL SPACE STATION (ISS)

On Earth, human beings always move against the force of gravity. Their muscles and bones support their body against gravity. However, in space muscles and bones do not work against a force, as there is no gravity. Therefore, they become weaker. Exercise is the proposed activity by the experts in space that prevents muscle and bone loss and gives the needed strength to the body. In ISS, the astronauts use exercise equipment such as Treadmill, Cycle Ergometer and Interim Resistance Exercise Device (iRED) for cardiovascular conditioning and muscle and bone endurance.

The exercise equipment in ISS are located separately in different modules. The characteristics of the exercise areas in ISS are different than the ones on earth as there are constraints such as microgravity and the capacity limitations of the mission and the space station. In this section, the exercise areas are analyzed under three main headings as the characteristics of human, exercise modules and exercises.

2.1. Human Characteristics in ISS

In order to better understand the characteristics of the exercise areas in ISS, this section of the thesis introduces the user characteristics under two main topics. The first one is about the demographic characteristics of the crew members that explains ins size, nation, age and gender of the crew members. The second one is about the anthropometrical characteristics of the crew members that introduces body size, body volume and mass, body posture and body strength of the crew members in microgravity environment.

2.1.1. Demographic Characteristics of the Crew Members

The user population in ISS has not been well defined. It is difficult to define the user population in space programs because it changes as the programs expand and change. Also, the selection criteria of the astronauts change. In this chapter, the demographic characteristics of the crew members who have been to ISS so far are introduced. It is difficult to make generalizations about the demographic characteristics of the crew members on ISS for further missions since they differ according to the mission program and its requirements.

2.1.1.1. Size

As of April 21, 2007, the total number of astronauts and tourists who have been to ISS was 131, including the three people currently at the station. The ISS has however been visited by astronauts from 14 countries and was also the destination of the first five space tourists (four from United States and one from South Africa). "The first permanent crew entered the ISS on November 2, 2000" (Wikipedia, 2007, #4). Typically, there are 3 astronauts aboard the International Space Station at any one time. As the space station expands it will be possible to accommodate more inhabitants eventually. About 30% of the astronauts (38 astronauts) visited the space station for the second or third times.

2.1.1.2. Nation

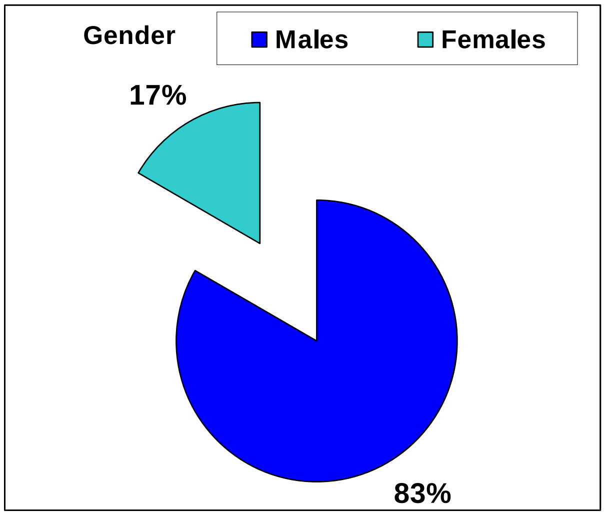
At the moment nations in ISS project are USA, Canada, Japan, Russia, Brazil and 11 nations of European Space Agency (ESA) which are Belgium, Denmark, France, Germany, Italy, Netherlands, Norway, Spain, Sweden, Switzerland and United Kingdom (Boeing Company et al., 1999; Wikipedia, 2007). The ISS visitors are from USA (four of them are space tourists), Canada, Japan, Russia, Brazil, Kazakhstan, South Africa (as space tourist), Belgium, France, Germany, Italy, Netherlands, Spain, and Sweden (Wikipedia, 2007).

The majority of the visitors (67.5%) were from USA, and the Russians followed the Americans (9%). The crew members from other countries contributed as 1-4% within the multinational space research work.

2.1.1.3. Gender

The majority of the crew members are males and represents 83% of the total. The participation of females is represented by 17%. Even though the distribution of males and females is almost 50% and 50% within the world's population, this percentage (17%) could be considered low, but being an astronaut requires being physically strong, therefore the participation by females is quite significant (Table 2.1). Most of the female crew members were from the United States. Twenty-two percent of the American astronauts are female. Therefore, the percentage of American female crew members was estimated high.

Table 2.1. Distribution of female crew members according to gender



2.1.1.4. Age

The age range of the crew members is 37 to 55 and the average age has been calculated as 45.7 ± 4.5 (n=46). These values have been estimated only using the crew members (n=46) who have visited the ISS for a long time for mission expeditions (Table 2.2). The others out of 131 astronauts have visited the station for short periods and they were taxi visitors or space tourists.

Table 2.2. Average age of the crew members

	Age			
	Mean	**St. Dev**	**Min**	**Max**
Total (Male+Female)	45.7	4.5	37	55

2.1.2. Anthropometrical Characteristics of the Crew Members

The anthropometrical characterstics of the crew members are defined and presented as standards by the united studies of the space agencies. The presented dimensions apply to a 1-g condition. Also, they are expected to change due to the change in the force of gravity (National Space Development Agency of Japan [NASDA], Canadian Space Agency [CSA], Italian Space Agency [ASI], European Space Agency [ESA] and NASA, 1999). In this section of the thesis, the changes on the human body are introduced under the headings of body size, body volume and mass, body posture and body strength. These data are necessary for designing exercise equipment and interiors of the exercise areas for space. Some of the important data that may help during the design of exercise areas for ISS are presented in Appendix A.

2.1.2.1. Body Size

According to NASDA et al. (1999), while designing crew interfaces in space, the body size of 40-year-old American male and the 40-year-old Japanese female projected to the year 2000 should be used.

"Body height increases approximately 3% over the first 3 to 4 days in weightlessness" (NASDA et al., 1999, p.3-2). Therefore, sitting and standing dimensions increase in weightlessness. Also, shoulder or acromial height increases. These are caused by the "removal of the gravitational pull on the arms and extension of the spinal column" (NASDA et al., 1999, p. 3-9). There is the effect of clothing while sizing. In IVA (Intravehicular Activity) environment there is little need for thick clothing. However, when the crew members wear EVA (Extravehicular Activity) spacesuits, body dimensions change significantly (NASA, 1995).

2.1.2.2. Body Volume and Mass

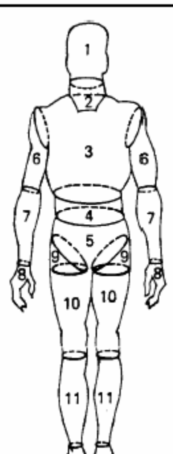
Body volume and mass data are useful for achieving the effective integration of the crew and space modules (NASA, 1995). The American male crew member body volume is specified in 1-g (Table 2.3) while the Japanese female crew member has not due to the insufficient data (NASA, 1995). Also, the body segments volume of American male crew member are specified in 1-g (Table 2.4)

Table 2.3. Body volume of American male crew member

American male crew member body volume	
5^{th} Percentile	68,640 cm^3 (4190 in^3)
50^{th} Percentile	85,310 cm^3 (5210 in^3)
95^{th} Percentile	101,840 cm^3 (6210 in^3)

(NASA, 1995, p.85).

Table 2.4. Body segments volume of American male crew member



Segment		Volume, cm^3 (in^3) 5th percentile	50th percentile	95th percentile
1	Head	4260 (260)	4400 (270)	4550 (280)
2	Neck	930 (60)	1100 (70)	1270 (80)
3	Thorax	20420 (1250)	26110 (1590)	31760 (1940)
4	Abdomen	2030 (120)	2500 (150)	2960 (180)
5	Pelvis	9420 (570)	12300 (750)	15150 (920)
6	Upper arm (1)	100 (100)	2050 (130)	2500 (150)
7	Forearm (1)	1180 (70)	1450 (90)	1720 (100)
8	Hand	460 (30)	530 (30)	610 (40)
9	Hip flap (1)	2890 (180)	3640 (220)	4380 (270)
10	Thigh minus flap (1)	5480 (330)	6700 (410)	7920 (480)
11	Calf (1)	3320 (200)	4040 (250)	4760 (290)
12	Foot (1)	840 (50)	1010 (60)	1180 (70)
5+4+3	Torso	31870 (1940)	40910 (2450)	49870 (3040)
9+10	Thigh (1)	8360 (510)	10340 (630)	12300 (750)
7+8	Forearm plus hand (1)	1640 (100)	1980 (120)	2320 (140)

Notes:
(1) Average of right and left sides.
(2) These data apply to 1–g conditions only.
(3) The American male crewmember population is defined in 3.2.1.

(NASDA et al., 1999, p. 3-44)

“The total mass of the body decreases by 3% to 4%. This is primarily due to loss of body fluids and, somewhat, to atrophy and loss of the mass of muscles that were used in 1-g (muscle mass loss is dependent on exercise regimes)” (NASA, 1995, p.27). Because of microgravity, fluids shift upward in the body and leave the legs. Therefore the center of body mass shifts upward and for the whole body there is a loss of mass in the leg segments. (NASA, 1995; NASDA et.al, 1999). Although body mass remains constant, body weight will depend on gravity conditions.

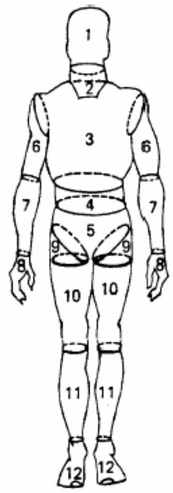
In Man-Systems Integration Standards and ISS Flight Crew Integration Standard, whole body mass and body-segment mass data are provided (Tables 2.5 and 2.6). In addition, center of mass and moment of inertia are presented. For the whole, data for both American male and Japanese female are specified. For the body segment mass data, only American male crew members’ are specified due to insufficient data.

Table 2.5. Body mass of year 2000 crew member population (Age: 40)

Male (American)			**Female (Japanese)**		
5th Percentile	50th Percentile	95th Percentile	5th Percentile	50th Percentile	95th Percentile
65.8 kg (145.1 lb)	82.2 kg (181.3 lb)	98.5 kg (217.2 lb)	41.0 kg (90.4 lb)	51.5 kg (113.5 lb)	61.7 kg (136.0 lb)

(NASA,1995, p.89)

Table 2.6. Mass of body segments for the American male crew member



Segment		Mass, gm (oz, weight)		
		5th percentile	50th percentile	95th percentile
1	Head	4260 (150)	4400 (160)	4550 (160)
2	Neck	930 (30)	1100 (40)	1270 (40)
3	Thorax	20420 (720)	26110 (920)	31760 (1120)
4	Abdomen	2030 (70)	2500 (90)	2960 (100)
5	Pelvis	9420 (330)	12300 (430)	15150 (530)
6	Upper arm (1)	100 (60)	2050 (70)	2500 (90)
7	Forearm (1)	1180 (40)	1450 (50)	1720 (60)
8	Hand	460 (20)	530 (20)	610 (20)
9	Hip flap (1)	2890 (100)	3640 (130)	4380 (150)
10	Thigh minus flap (1)	5480 (190)	6700 (240)	7920 (280)
11	Calf (1)	3320 (120)	4040 (140)	4760 (170)
12	Foot (1)	840 (30)	1010 (40)	1180 (40)
5+4+3	Torso	31870 (1120)	40910 (1440)	49870 (1760)
9+10	Thigh (1)	8360 (290)	10340 (360)	12300 (430)
7+8	Forearm plus hand (1)	1640 (60)	1980 (70)	2320 (80)

Notes:
(1) Average of right and left sides.
(2) These data apply to 1–g conditions only.
(3) The American male crewmember population is defined in 3.2.1.

(NASDA et al., 1999, p. 3-45)

2.1.2.3. Body Posture

The relaxed body immediately assumes the characteristic of the neutral body posture as can be described as an S- shape is seen in Figure 2.1. While maintaining 1-g postures in microgravity, astronauts may have back pains. Stooping and bending can cause fatigue in microgravity. According to NASA (1995, p.78), in order to prevent this, "the natural heights and angles of the neutral body posture must be accommodated". Some of the areas that should be considered are as follows:

> - Foot Angle - Since the feet are tilted at approximately 111 degrees to a line through the torso, sloping rather than flat shoes or restraint surfaces should be considered.
> - Feet and Leg Placement - foot restraints must be placed under the work surface. The neutral body posture is not vertical because hip/knee flexion displaces the torso backward, away from the footprint. The feet and legs are positioned somewhere between a location directly under the torso (as in standing) and a point well out in front of the torso (as in sitting).
> - Height - The height of the crew member in microgravity is between sitting and standing height. A microgravity work surface must be higher than one designed for 1-g or partial-gravity sitting tasks.
> - Arm and Shoulder Elevation - Elevation of the shoulder girdle and arm flexion in the neutral body posture also makes elevation of the work surface desirable.
> - Head Tilt - In microgravity the head is angled forward and down, a position that depresses the line of sight and requires that displays be lowered (p.178).

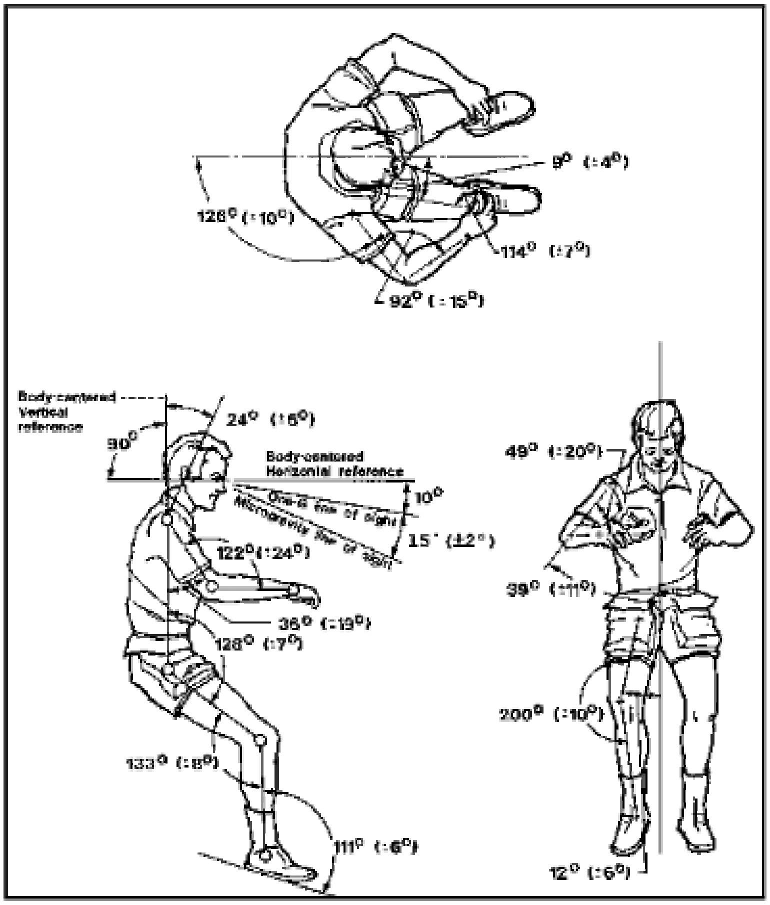


Figure 2.1. Neutral body position (NASA, 1995, p.82)

2.1.2.4. Body Strength

In design process, the following body strength data related to operation and control of space station hardware equipment should be used (NASDA et al., 1999):

> - Grip strength required to operate or control hardware or equipment shall be less than the 5th percentile female strength values
> - Linear Forces – Linear forces required to operate or control hardware or equipment shall be less than the strength values for the 5th percentile female, defined as 50.0 percent of the strength values and 60.0 percent of the strength values shown.
> - Torsional Forces – Torsional forces required to operate or control hardware or equipment shall be less than the strength values for the 5th percentile female, defined as 60.0 percent of the calculated 5th percentile male capability
> - Forces required for maintenance of Space Station hardware and equipment shall be less than the 5th percentile male strength values (p.4-2).

In ISS Flight Crew Integration Standard data for grip strengths for females, arm, hand and thumb/finger strength, maximal static push forces, leg strength and torque strength for 5th percentile male are presented (NASDA et al., 1999). Also data for joint motion of females and males in general and reach limits for American males and females in specific are presented in ISS Flight Crew Integration standard and Man-Systems Integration Standards that can be used for designing interfaces for space stations.

2.2. Characteristics of the Exercise Modules in ISS

The exercise equipment, namely Treadmill, Cycle Ergometer and iRED are located in Destiny, Unity and Zvezda modules. These are also the three of the four pressurized modules in the station (See Appendix B, for the technical drawings of the modules). In this section of the thesis, the characteristics of these modules are introduced.

2.2.1. Destiny Module (US Lab)

The Destiny Lab is a U.S. element that provides equipment for research and technology development. It also houses all the necessary systems and devices to support a laboratory environment and control the U.S.segment (Figure 2.2). It is launched on February 2001.

Figure 2.2. US Destiny laboratory
(http://spaceflight.nasa.gov/gallery/images/station/crew-3/hires/iss003e5218.jpg)

The module is made of aluminum and it is 8.5 m in length and 4.3 m in width (NASA, 2006a; Wikipedia, 2007). “The exterior of the module is covered by a debris shield blanket made of a material similar to that used in bulletproof vests on Earth. A thin aluminum debris shield has been placed over this blanket for additional protection” (NASA, 2006a, 11#).

The lab is compromised of three cylindrical sections and two end cones with hatches is attached to other parts of the station. Destiny’s aft hatch is attached to the Unity Module. The forward hatch provides access to Space Shuttle orbiters until Node 2 module arrives (Wikipedia, 2007). Destiny module also contains a 50 cm diameter window, which has an optical gem that provides high quality photos and videotapes (NASA, 2006a; Wikipedia, 2007). This window has a shutter that protects the window from potential micrometeoroids and orbital debris strikes (Wikipedia, 2007).

Inside the laboratory, there are sets of modular racks that could be added, removed and replaced easily (NASA, 2006a). These lab racks house the system hardware in these modular units. They can contain fluid and electrical connectors, videotape equipment, sensors, controllers and motion dampeners to support whatever experiments are housed in them (NASA, 2006a). Destiny contains the Minus Eighty Degree Laboratory Freezer (MELFI) for ISS, which is used both to store samples on the ISS and to transport them to and from the space station in a temperature controlled environment (Wikipedia, 2007). Also, there is the Microgravity Science Glovebox (MSG) which enables the crew members do experiments. One of the exercise equipment, Cycle Ergometer is located attached to the wall of the module facing the MSG.

2.2.2. Unity (Node 1)

The Unity is the first of the three connecting modules that will be part of the station when it is completed (Wikipedia, 2007) (Figure 2.3). It was also the first US built component of the station (NASA, 2000; Wikipedia 2007). It was built by the Boeing Company in a manufacturing facility at the Marshall Space Flight Center in Alabama (Wikipedia, 2007).

Figure 2.3. Unity module (http://spaceflight1.nasa.gov/gallery/images/station/crew-13/hires/iss013e40013.jpg)

Unity is cylindrical in shape, made of aluminum and measures 4.57 m in width and 5.47 m in length (NASA, 2006a; Wikipedia, 2007). It provides six docking ports (four radial and two axial) which are for attaching to other modules. It also provides external attachment points for the truss (NASA, 2000).

The main purpose of the Unity module is that it provides internal storage and it acts as a passageway while providing pressurized access to other modules (NASA, 2000; Wikipedia, 2007). Essential space station resources such as fluids and gases, environmental control and life support systems, electrical and data systems are installed in Unity to supply the working and living areas of the whole station (Wikipedia, 2007).

2.2.3. Zvezda Module

Zvezda also known as the Service Module (SM) is the third module launched to the International Space Station. It means star in Russian. It is the module where the main life support systems and living quarters for the crew members are located (Wikipedia, 2007) (Figure 2.4).

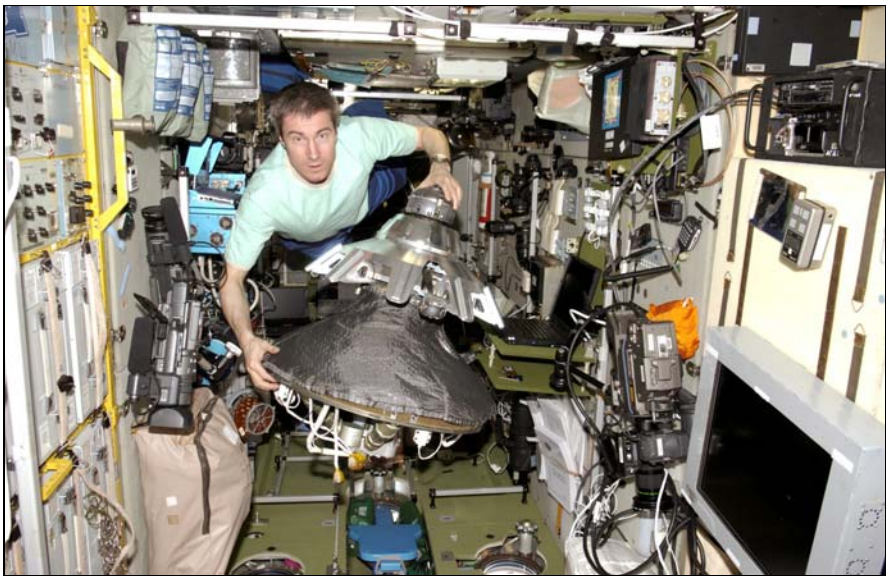


Figure 2.4. Zvezda module (http://spaceflight.nasa.gov/gallery/images/station/crew-11/hires/iss011e12809.jpg)

The module is cylindircal in shape, 13 m long and it spans 30 m accross its solar arrays which provide main power to the module (ESA, 2000; Wikipedia, 2007). It has three pressurised sections which begins with the Transfer Component at the forward end with 1.35 m diameter, followed by the Work Component with 4.15 m diameter and completed by Transfer Chamber at the aft with 2m diameter (ESA, 2000) (Figure 2.5).

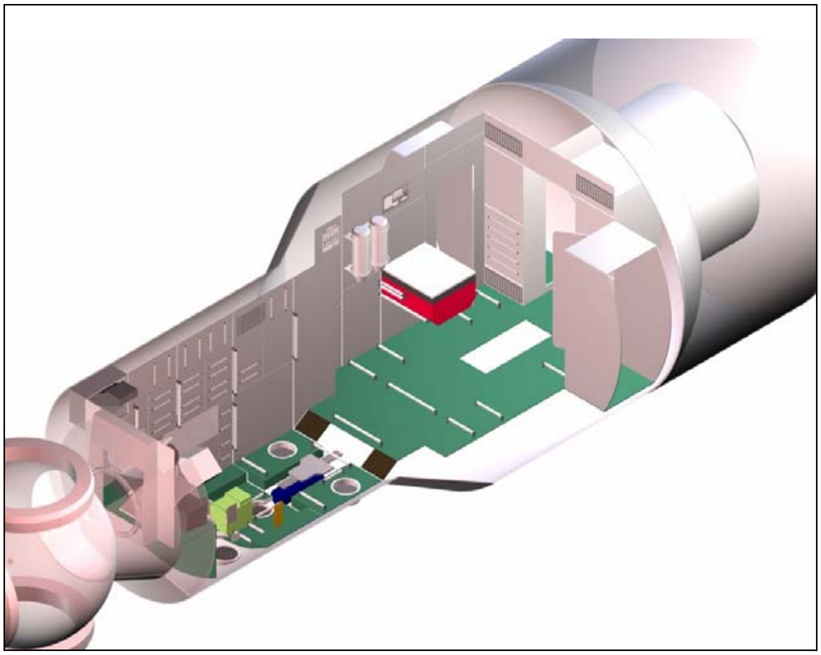


Figure 2.5. Zvezda module illustration (http://spaceflight.nasa.gov/gallery/images/station/servicemodule/hires/jsc2000e26926.jpg)

The layout of Zvezda Module's looks like to the layout of core module of Russian Mir Space Station (NASA, 2006a). Zvezda module is the first fully Russian contribution to the ISS (NASA, 2006a). The module is compromised of living quarters, life support system, communication system, electrical power distribution, data processing system, flight control system, and propulsion system (NASA, 2000).

Living accommodations on Zvezda Module include personal sleeping quarters for two people; a toilet and hygiene facilities; a galley with a refrigerator/freezer; and a table for securing meals while eating (ESA, 2000; NASA, 2000). There are 14 windows that view docking activities (ESA, 2000). Zvezda has four docking ports. One of them is in the aft and it functions as a connection to the ships such as Soyuz, Progress Ferry and Automated Transfer Vehicle (ATV). The other three docking ports all carry hybrid docking mechanisms for attachment to Zarya Module the later additions of Science and Power Platform and Universal Docking Module (ESA, 2000).

The crew members do spacewalks by wearing speacial space suits called Orlan-M from Zvezda Module by using the Transfer Component as an airlock (NASA, 2000). Furthermore, Zvezda is the primary source of Oxygen for the ISS. An elektron unit electrolyses water to generate up oxygen (ESA, 2000). The exercise equipment Treadmill is located in this module near the eating table.

2.3. Characteristics of the Exercises in ISS

Exercising in space is not just for fun; it is a necessary activity to keep astronauts healthy physically and mentally and make them productive. Also, the conditions in space are more restricted. Therefore the exercise activity is a carefully planned activity. This section introduces the characteristics of the exercises in ISS explaining proposed exercises in ISS and the aims of them.

2.3.1. Proposed Exercises in ISS

The exercises are proposed for each crew member by the health experts. The exercise activity is programmed and scheduled for each crew member for each mission. In this section, the programs and types of exercises related to programs are introduced.

2.3.1.1. Programs

The exercise programs are applied to space mission durations longer than 10 days (NASDA et al., 1999). Scheduling the exercise activities for each crew member is a difficult process as they do other tasks or activities and there are only three exercise equipment. It will be even harder when the crew member number will be six in the future.

According to NASDA et al. (1999), durations of the exercises and prescriptions should be defined and updated for each crew member. Before flight the astronauts are trained with the exercise equipment. Their exercise program is scheduled for a minimum of two hours a day and three days of the week (Ohshima, Mizuno and Kawashima, 2006). The exercise program for long space missions is scheduled for a minimum of 2.5 hours a day for the six days of a week (CSA, 2006; Ohshima et al., 2006).

Each astronaut's exercise routine is monitored and downloaded to the ground and can be adjusted by the experts if necessary based on his monthly fitness assessment (CSA, 2006). Sometimes astronauts perform a spacewalk; therefore it may cause to break in their exercise routines (CSA, 2006)

2.3.1.2. Types of the Exercises

There are two main types of exercises that are specified by the experts. They are resistive exercise and cardiovascular fitness exercise. The equipment are designed to function for these exercises. According to NASDA et al. (1999), a space station shall provide facilities for the following types of exercise:

> - Equipment for placing isokinetic, isotonic, and isometric force upon the major muscle groups of the body shall be provided in order to mitigate "disuse atrophy" used by microgravity.
> - Devices for exercising the cardiorespiratory system as a countermeasure to cardiovascular deconditioning shall be provided (p.7-6).

For training the muscle groups of the legs, hips, trunk, shoulders, arms, and wrists, resistive exercise is necessary. In ISS, iRED provides resistance training for the major muscle groups (NASA, 1998). For cardiovascular fitness conditioning Treadmill and Cycle Ergometer are used in ISS. The Treadmill is used primarily for postural and locomotor musculoskeletal maintenance, with cardiopulmonary benefits. The Cycle Ergometer can be used to perform upper and lower limb activites (NASA, 1998).

2.3.2. Aims of the Exercises

In order to prevent the harmful effects of microgravity on the human body, an exercise facility is necessary (Allen, Burnett, Charles, Cucinotta, Fullerton, Goodman, Griffith, Kosmo, Perchonok, Railsback, Rajulu, Stilwell, Thomas, Tri, Joshi, Wheeler, Rudisill, Wilson, Mueller and Simmons, 2003). The exercises in ISS are planned to strengthen the body. According to Allen et. al. (2003), exercise facilities should aim to provide muscle enhancement and increase cardiovascular strength and capacity. In this section, two aims of exercises as cardiovascular conditioning and bone and muscle endurance are explained.

2.3.2.1. Cardiovascular Conditioning

Cardiovascular fitness exercise is for cardiovascular conditioning. Because of the microgravity environment, serious cardiac dysthymias may occur. It may also impair cardiovascular response to orthostatic stress (Allen et al., 2003). "Orthostatic intolerance is characterized by a variety of symptoms that follow standing after landing: light-headedness, increase in heart rate, altered blood pressure, and pre-syncope or syncope" (Clément, 2005, p.188). According to Clément (2005), it is now well accepted that the orthostatic intolerance is caused by loss of fluid during spaceflight.

Aerobic exercise is useful for cardiovascular conditioning and maintaining overall function (NASA, 2006a). According to Rhatigan, Robinson and Sawin (2005), cardiovascular research is necessary to be determined in order to understand whether there is a significant loss in heart mass or function and if important irregular heart rhythms occurring during long duration missions.

2.3.2.2. Bone Mass and Muscle Endurance

Resistive exercise is for bone mass and muscle endurance. Because of microgravity muscles begin to weaken. The reduced activity of muscles against bone puts the natural processes of bone renewal out of balance and this causes bone losses as well (Rhatigan et al., 2005). Calcium is also lost and because of this kidney stones can occur (Whitson, Pietrzyk and Sams, 1999).

According to the first investigations of NASA on ISS, “bone mineral density loses at an average rate of about 0.9 % per month in the lumbar spine and 1.4% per month in the femoral neck” (Washam, 2004, p. 214-15). “In the hip, mass of loose in the cortical bone averaged around 0.5 % month whereas this averaged around 2.5% month in trabecular bone” (Lang, LeBlanc, Evans, Lu, Gennant and Yu, 2004, p. 1006-12). According to Watt and Lefebvre (2001), spinal cord excitability declines in weightlessness because of some muscle fiber units` not responding to the signals of the nervous system. Therefore, muscle mass declines. Watt (2003) further pointed out that the reduced excitability could be the result of partly nervous system response, not simply the issue of misusing the legs.

Currently, loss of muscle and bone mass during long-duration spaceflight is being researched both on the station and on the ground. In addition, new approaches and new countermeasures are being developed and tested. More quantifiable data is necessary to understand the actual on-orbit loads and for developing more efficient and focused countermeasures to bone and muscle loss (such as better exercise regimens or equipment) for exploration missions (Rhatigan et. al., 2005; Hagan and Schaffner, 2005). According to Hagan and Schaffner (2005) "much has been learned from ground based analogs, particularly bed rest, but these analogs are limited as it is difficult to compensate for the manner in which gravitational loading effects human body kinematics (motion) and kinetics (joint torques)" (p.2). Also limited number of crew members, voluntary participation in scientific studies, issues of crew compliance with exercise prescriptions and non-standardization of fitness training pre-flight and post-flight make it very difficult to achieve statistically significant results (Hagan and Schaffner, 2005).

2.3.3. The Exercise Equipment

According to Ohshima et al. (2006), in order to accomplish the exercise prescription precisely, there should be available in-flight exercise equipment that is designed to consider individual needs of the crew members. Currently, three exercise equipment are available on the ISS for exercise, including a "Treadmill to preserve aerobic power, a Cycle Ergometer to preserve aerobic capacity, a resistive exercise device to preserve muscle strength" (Clément, 2005, p.191). However, there are other exercise equipment design projects at development stage held by the design quarters at NASA, ESA and other agency groups. In this section, the general characteristics of equipment will be explained. In further chapters, they are introduced and analyzed specifically.

2.3.3.1. Treadmill

“The Treadmill used as an ambulating trainer, endurance exercise of postural musculature, high impact skeletal loading (bone maintenance), and aerobic exercise” (Clément 2005, p.192). It is also used for cardiopulmonary benefits (NASA, 1998). The Treadmill designed for space provides simulation of walking and running in 1-g (Figure 2.6). In other words, “Treadmill is used to stimulate bone mass, cardiovascular fitness, muscle endurance and the neurophysiologic pathways and reflexes required for walking and running on earth or other planetary surfaces” (NASA Human Research Program, 2006, #5).

Figure 2.6.Treadmill vibration isolation system (TVIS)
(http://stardate.org/images/radio/iss/iss013e08035.jpg)

Treadmill is located in the floor of the Russian Zvezda module close to the galley table. The crew member is restrained to the equipment by Subject-loading Device (SLD). This device consists of two spring-loaded cords that come from either side of the Treadmill, which attaches to a harness around the astronaut's waist (Reiter, 2006). Treadmill has vibration isolation system which prevents vibrations transfer to the rest of the station. Treadmill exercise can be performed in either a motorized (active) or non-motorized (passive) mode.

2.3.3.2. Cycle Ergometer

“The Cycle Ergometer is used as an aerobic and anaerobic exercise countermeasure, for the maintenance of lower body musculature endurance and for arm exercise training in preparation for extravehicular activity” (Clément, 2005, p.193). “Cycle Ergometer exercise is an important physical conditioning for doing ISS tasks such as space walks, and to exercise during pre-breathe period before a space walk” (NASA Human Research Program, 2006, #6).

The Cycle Ergometer is located in the American Destiny Module. It is similar to a stationary bicycle without wheels. The astronaut uses pedals and has the option of waist straps, back supports, and hand holds to secure them to the machine (Figure 2.7).

Figure 2.7.Cycle Ergometer with vibration isolation system (CEVIS) (http://www.nasa.gov/images/content/114308main_iss011e05137.jpg)

It can be controlled manually or the electronic controller can be used. Similar to the Treadmill's Cycle Ergometer has vibration isolation system which prevents the transfer of the vibrations to the rest of the station (Reiter, 2006). It has a control panel that picks up crew members heart rate during their exercise that allows the data to be downloaded to individual CEVIS memory cards designed for each crew member (NASA HQ, 2006).

2.3.3.3. Interim Resistance Exercise Device (iRED)

The iRED is used as training for muscle strength and provides resistance for major muscle groups, to maintain skeletal muscle mass and volume, and prevent bone loss (Clément, 2005; NASA, 1998; NASA Human Research Program, 2006). Resistive exercise or strength training is performed against weight (Figure 2.8).

Figure 2.8. Interim Resistance Exercise Device (iRED)
(http://spaceflight.nasa.gov/gallery/images/station/crew-10/hires/iss010e05343.jpg)

The iRED is located in the ceiling of Node 1. The exercise equipment is made up of resistance cords that allow crew members to exercise various muscles in the legs and in the upper body. According to NASA (1998), “ the squat, leg curl, military press, dead lift, knee lift, chest/butterfly, bent rows, leg abduction, biceps, calf raises, leg adduction, triceps, leg extension, lateral raises and side bends can be performed with the iRED” (p.14-4).

In space, exercise areas are one of the critical areas that designers and researchers have to consider. The next chapter is related with the design requirements put forward for the exercise areas in ISS. These requirements are also introduced to help further mission concepts.

3. DESIGN REQUIREMENTS FOR THE EXERCISE AREAS IN ISS

Design in space is fundamentally different than on Earth in many respects. Various factors such as the absence of gravity, total dependence on artificial systems, extreme radiation, temperature and operational conditions, stress and isolation strongly affect human's physiology and psychology. The crew members try to adapt to the new environment. During the adaptation, they inevitably change physically and psychologically. "Good design" helps this adaptation and "enhances their effectiveness, productivity, health and safety" (SICSA Lecture Series Report, 1988, p.1). According to the report of SICSA Lecture Series Report (1988), careful planning must be undertaken to optimize crew satisfaction and performance through calling attention to the special requirements in space habitats.

This thesis points out the exercise area as one of the critical areas to be carefully designed in a space habitat since it is directly related to the safety, health maintenance, productivity and effectiveness of the crew members. In this chapter, the design requirements for the exercise areas in the International Space Station (ISS) will be analyzed under two sub-headings, namely as the physical and behavioral factors that are basically affecting the design decisions.

3.1. Physical Factors

"Microgravity in space produces changes in body posture and consequently it influences the way most of the physical activities are accomplished" (SICSA Lecture Series Report, 1988, p.1). As the body size, strength, posture, volume, mass and movement of the human in space change, the design of the exercise equipment as well as the exercise area should be reconsidered. Besides, the whole environmental conditions are different than on earth. Also the characteristics of each equipment and the exercise areas are not similar with the ones on earth. In this part, the physical factors will be pointed out since they affect the equipment, interior and environmental design. Design requirements of the equipment are categorized under the anthropometrical and operational aspects. The interior design requirements are related to the interior volume utilization; layout and configuration in the station. Finally the environmental factors requirements of the exercise area are analyzed under thermal control system, air circulation and quality control, electric power, humidity control, fire detection and suppression and shock isolation system.

3.1.1. Equipment Design Requirements

"Future research on ISS is being targeted at the areas such as advanced environmental control and monitoring, human health and countermeasures, advanced life support systems, and development of better medical care and exercise equipment" (Rhatigan et al., 2005, p.17). In many studies, the benefits of using exercise equipment in space have been researched to maintain the health of the astronauts. According to SICSA Lecture Series Report (1988) "carefully designed equipment can prevent the errors associated with confusion, fatigue, and morale problems related to long-term isolation and boredom" (p.2).Therefore, the design of the exercise equipment plays an important role in exploration missions. It has to be considered in various aspects by the designers and engineers while testing the next generation of exercise equipment on ISS.

Similarly, NASA encourages their engineers and designers work on developing means for making exercises in space more effective, efficient, and pleasant in the future (NASA, 2006b). While designing exercise systems for the exploration missions, NASA engineers and scientists consider constraints on equipment size, equipment layout, exercise envelope and exercise power consumption that are imposed by the space station. They also consider unique engineering factors that allow astronauts adequately load their bodies during exercise while using restraint and harness systems, and comfortably completing their prescribed exercise regimens (NASA Human Research Program, 2006).

In the next 50 years, NASA plans to send astronauts to the Moon and Mars. These astronauts will need to perform a variety of mission tasks in longer durations (NASA Human Research Program, 2006). Therefore, the exercise will be more critical for preventing the risks of bone and muscle loss. NASA has the Exercise Countermeasures Project (ECP) that helps to “develop a new set of exercise countermeasures and also to determine the types and amounts of exercise needed for the long-duration space missions” (NASA Human Research Program, 2006, #2).

The ECP team works at the NASA’s Johnson Space Center (JSC) and Glenn Research Center (GRC), and involves experts in various scientific disciplines who are the members of National Space Biomedical Research Institute (NSBRI), colleges or universities (NASA Human Research Program, 2006). NASA Human Research Program (2006) goals are:

> - To develop prescriptions for exercise countermeasures those efficiently reduce the negative effects of zero and partial gravity and meet the medical needs of astronauts.
> - To establish the requirements for exercise equipment that will provide the prescribed exercise countermeasures within the constraints imposed by the space exploration vehicle and the astronauts' habitat on the Moon or Mars.
> - To develop a set of exercise devices for space flight that are effective, dependable, and lightweight, and require minimal maintenance (#3).

In this chapter, design requirements for the exercise areas are analyzed under two sub-headings as the anthropometrical and operational aspects. They are two major aspects of the process.

3.1.1.1. Anthropometrical Aspects

Because of the microgravity, human anthropometrical dimensions change significantly (Table 3.1). Therefore, while fitting the exercise equipment for human on space, this change must be analyzed carefully. In 1995, Man-Systems Integration Standards was prepared to be a guide for the designers since it covers the human standards in space. Having a section of Anthropometry and Biomechanics, it points out the design considerations of body size, joint motion, body reach, body posture, body surface area, body volume and mass of human in weightlessness. All of these design considerations are needed in designing exercise equipment. However, these data are based on 1-g conditions.

Table 3.1. Anthropometric changes in weightlessness

Parameter	Anthropometric Change		
	Short-term mission (1 to 14 days)	Long-term mission (more than 14 days)	
		Pre vs. during mission	Pre vs. post-mission
Height	Slight increase during first week (~1.3 cm or 0.5 in). Increases caused by spine lengthening. Height returns to normal *R+O	Increases during first 2 weeks then stabilizes at approximately 3% of pre-mission baseline. Increases caused by spine lengthening	Returns to normal on R+O
Circumferences	Circumference changes in chest, waist, and limbs.		
Mass	Post flight weight losses average 3.4%; about 2/3 of the loss is due to water loss, the remainder due to loss of lean body mass and fat. Center of mass shifts headword approximately 3-4 cm (1-2in.)	In-flight weight losses average 3-4% during first 5 days, thereafter, weight gradually declines for the remainder of the mission. Early in-flight losses are probably due to loss of fluids; later losses are metabolic. Center of mass shifts headword approximately 3-4 cm (1-2in).	Rapid weight gain during first 5 days post flight, mainly due to replenishment of fluids. Slower weight gain from R+5 to R+2 or 3 weeks.
Limb volume	In-flight leg volume decreases exponentially during first mission day; thereafter, rate of decrease declines until reaching a plateau within 3-5 days. Post flight decrements in leg volume up to 3%; rapid increase immediately post flight, followed by slower return to pre-mission baseline.	Early in-flight period same as short missions. Leg volume may continue to decrease slightly throughout mission. Arm volume decreases slightly.	Rapid increase in leg volume immediately post flight, followed by slower return to pre-mission baseline.
Posture	Immediate assumption of neutral body posture	Immediate assumption of neutral body posture	Rapid return to pre-mission posture.

*Recovery day plus post mission days

(NASA, 1995, p. 26)

It is stated in Man-Systems Integration standards that “current NASA standards provide data for both the 5th percentile Japanese female and the 95th percentile American male projected to the year 2000” although “this does not necessarily define the crew population” (Allen et al., 2003, p.33). One of the main lacks of this standards is that crew population is not defined yet. Body dimensions and mobility descriptions are limited to the range of people considered most likely to be the visiting personnel and crew members. It is assumed that these people are in good health, fully adult in physical development and at an average age of 40 years (NASA, 1995).

“There are three approaches for fitting a design to the user. Not all approaches may be suitable for all designs” (Allen et al., 2003, p.33), they are:

> **Single size fits all:** A single size may accommodate all members of the crew. For example, everyone can use a passage if it is designed for the largest person.
> **Adjustable:** It should be adjustable for all crew members.
> **Custom-build:** Individually fitted items may or may not be the right solution. Custom-built items are more expensive, however, and could increase overall mission costs (p.33).

As the crew members sharing the ISS are from different nations there are variations in body dimensions. Designers must be aware of these likely variations in body dimensions when they build equipment (Allen et al., 2003). According to NASA (1995), there are two major factors of inter-individual variations, which are sex and race. NASA applies general rules while considering the anthropometric variations due to sex and race. According to these rules:

> Sex Variations - Female measurements average about 92% of comparable male measurements (within race). Average female weight is about 75% of male weight.
> Racial Variations - Blacks and Whites are very similar in terms of height and weight measurements. The average torso measurement of Whites is longer than Blacks and limbs are shorter. Asians are generally shorter and lighter than Whites and Blacks. Most of this stature difference is in leg length. Asian facial dimensions may be larger in proportion to height (p.28)

Because of these variations, the extremes of the world population size range is represented in Man-Systems Integration Standards by the large (95^{th} percentile) White or Black American male and the small (5^{th} percentile) Asian Japanese female. According to NASA (1995), actual user population should be defined while using and applying anthropometric data. However, this is a difficult process because as the space program expands the user population will expand and change (NASA, 1995).

3.1.1.2. Operational Aspects

In order to develop efficient and user-friendly exercise equipment, besides its promise fitting the user comfortably, it should have durable and convenient mechanical system, comfortable and ergonomic restraints and uncomplex monitoring devices. In this part, the requirements of the equipment mechanical systems, restraints and monitoring devices will be analyzed.

3.1.1.2.1. Equipment Mechanical Systems

Weightlessness during space creates significant losses in bone density, muscle strength, and cardiovascular conditioning. ISS crew members use a Treadmill and a Cycle Ergometer for cardiovascular exercise, and Interim Resistance Exercise Device (iRED) for muscle strengthening. Each equipment requires special mechanical systems to compensate for the manner gravitational loading affects the human body on earth.

To begin with introducing the Treadmill's mechanical system, it requires a Subject-loading Device (SLD) to secure the astronaut to the Treadmill. The device consists of two spring-loaded cords that come from either side of the Treadmill, which attaches to a harness around the astronaut's waist (NASA, 2006c) (Figure 3.1). The cords can be loaded with 66 percent to 100 percent of the subject's body weight to determine the strength of the workout (NASA, 2006c, #6).

Figure 3.1. Astronauts exercising on Treadmill.
(http://spaceflight.nasa.gov/gallery/images/station/crew-3/hires/iss013e08032.jpg, http://spaceflight.nasa.gov/gallery/images/station/crew-12/hires/iss012e22729.jpg)

The Treadmill's base has teflon-coated aluminum sheet on a roller and it is locked to the floor (NASA, 2006d) (Figure 3.2). The SLD is attached to this base. There are also air fans nearby that are used to dry off the perspiration produced from exercising. Otherwise, the sweat would stick to the skin and get ticker (NASA, 2006d).

Figure 3.2. Astronauts working on Treadmill
(http://spaceflight.nasa.gov/gallery/images/station/crew-12/hires/iss012e18246.jpg
http://spaceflight.nasa.gov/gallery/images/station/crew-12/hires/iss012e18233.jpg)

Treadmill exercise is performed in either a motorized (active) or non-motorized (passive) mode. “The active mode provides the astronaut with speed control adjustable from 0 to 10 miles/ hour in increments of 0.1 miles/hour. Passive mode allows the astronaut to drive the tread belt variable mechanical resistance without the use of a motor” (NASA Human Research Program, 2006, #5). Because of the elasticized harness the process is so uncomfortable that astronauts need to take breaks every five or ten minutes (NASA, 2006b).

The Cycle Ergometer is similar to a stationary bicycle (Figure 3.3). The astronaut uses clip pedals and has the option of waist straps, back supports, and hand holds to secure himself to the machine. A seat belt is worn to attach the astronaut to the module wall behind the Cycle Ergometer and the incorporated suspension system prevents the transfer of the vibrations to the rest of the station (Reiter, 2006). This system is called Cycle Ergometer Vibration Isolation System (CEVIS).

Figure 3.3. Astronaut Leroy Chiao cycling on Cycle Ergometer
(http://spaceflight.nasa.gov/gallery/images/station/crew-0/hires/iss010e05608.jpg)

Cycle Ergometer can be controlled either in a manual mode, where the astronaut controls manually, or an electronic mode, where there is an electronic controller (Reiter, 2006). “The workload on the device being used in the ISS can be set at a maximum of 350 watts for pedal speeds up to 120 rpm” (NASA Human Research Program, 2006, #6).

While Treadmills and Cycle Ergometers were being used in space since Skylab in 1970s, they caused a good deal of vibration (NASA, 2006b). However, vibration can disrupt sensitive experiments elsewhere in the space station, making sophisticated shock absorption systems necessary (NASA, 2006b). Interim resistive exercise device, a relative newcomer to the ISS, solved the vibration issue. Its principle is working against a resistive force, usually by pulling against strong bungee cords. “There is less motion; therefore there is very little vibration” (NASA, 2006b, #10). The iRED mechanism is primarily composed of two canisters, each of which contains a number of “flex packs” stacked on each other in series (Moore et al., 2004) (Figure 3.4).

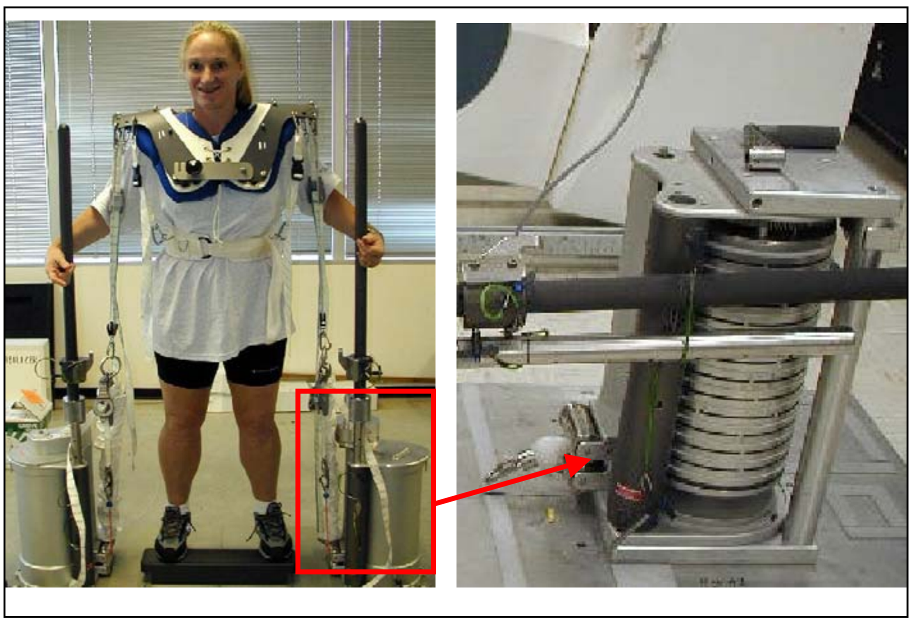


Figure 3.4. The iRED canister (Moore, Amonette, Bentley, Rapley, Blazine, Loehr, Collier, Boettcher, Skrocki, Hohmann and Korth, 2004, p.2, 3)

Each of the flex packs consists of an outer aluminum rim to which elastic polymer spokes are attached (Figure 3.5). A metal shaft in the center of the flex packs is fastened to a spiral pulley. A nylon cord one end of which is wrapped around this spiral pulley passes through a stopper device on the exterior of the iRED canister.

The cord termination point is this stopper device where the cord bends around it and stitch back upon itself (Moore et al., 2004).

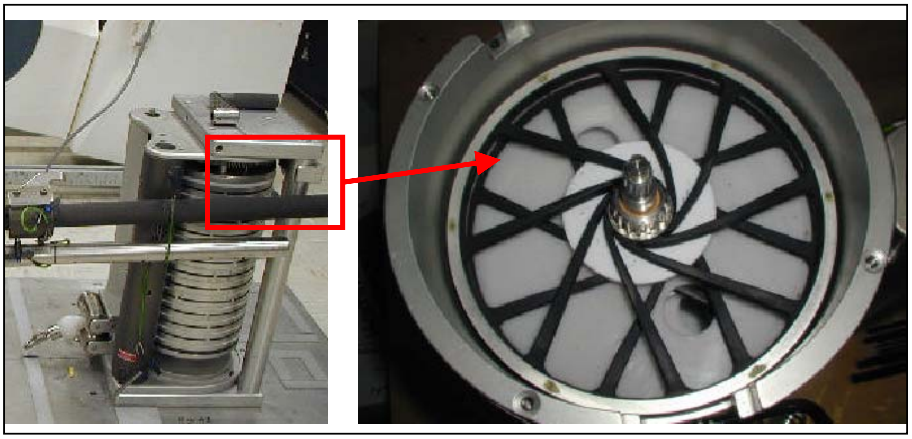


Figure 3.5. Top view of a flex pack in the iRED (Moore et. al, 2004, p.3)

The iRED in ISS is a prototype and small. It doesn't create enough loading. However, in the next two years the upgraded SCHRED (Schwinn Resistive Exercise Device) will be determined (Rhatigan et al., 2005). Also, another device evaluated in the laboratories is the ARED (Advanced Resistance Exercise Device) which is based upon a different force system. "The challenge for the ARED is to provide much greater loading capability while constraining volume and mass to an acceptable level for flight hardware" (Rhatigan et al., 2005, p.18).

3.1.1.2.2. Equipment Restraint Systems

Restraint systems are for stabilizing the crew members in microgravity and preventing them from a thrust or push. Foot plate, foot loop, toe loops, bungee cords, bungee plates, padded socks and handrails are some of the restraint design solutions.

"Equipment restraint systems allow crew members to restrain loose equipment at a worksite within the ISS interior" (NASA, 2000, p. 117). In addition, while using the exercise equipment, crew members need to use these systems to stabilize themselves and control the exercise activity. According to NASDA et al. (1999), equipment restraints should be designed according to the following requirements:

> - Equipment restraints shall be designed such that tools are not required to attach or detach the restraint.
> - Equipment restraints shall be designed such that they can be attached/detached by either the left or right hand.
> - The equipment restraints shall be designed such that they can be attached/detached without having to look at them.
> - Both adjustable and fixed–length tethers shall be provided.
> - The equipment restraint shall be designed such that it cannot damage the item to be restrained or the spacecraft interfacing surfaces and adjacent hardware.
> - Adhesive equipment restraints shall not leave an adhesive residue on the item or on the spacecraft surface when the adhesive restraint is detached.
> - All equipment tethers shall use a common attachment method.
> - All equipment items, which will require tethering shall provide a tether, attach point, which is an integral part of the item. This attach point shall also be provided on the interfacing surface to which the item is to be secured.
> - The tether hook shall be designed in such a way that it will provide a positive indication that it is locked/unlocked in both day and night lighting conditions.
> - Equipment restraints shall be of a standardized color to make them distinguishable from other types of loose equipment and the items that will be restrained.
> - Group restraints shall provide a system, which allows the removal of one item at a time (p.11-17 – 11-18).

In order to do cycling activity, astronauts use clip pedals and there are the options of restraint systems; waist straps, back supports, and hand holds to secure themselves to the Cycle Ergometer (Figure 3.6). Astronauts generally prefer waist straps and back supports to stabilize themselves.

Figure 3.6. Astronaut Williams S. McArthur exercising on CEVIS
(http://spaceflight.nasa.gov/gallery/images/station/crew-12/hires/iss012e14206.jpg)

While using iRED, astronauts wear a harness system on their shoulders, which is attached to the main system by resistant bungee cords (Figure 3.7). This system not only stabilizes the astronaut but also serves as weight lifting as they perform heel lifts, squats and dead lifts.

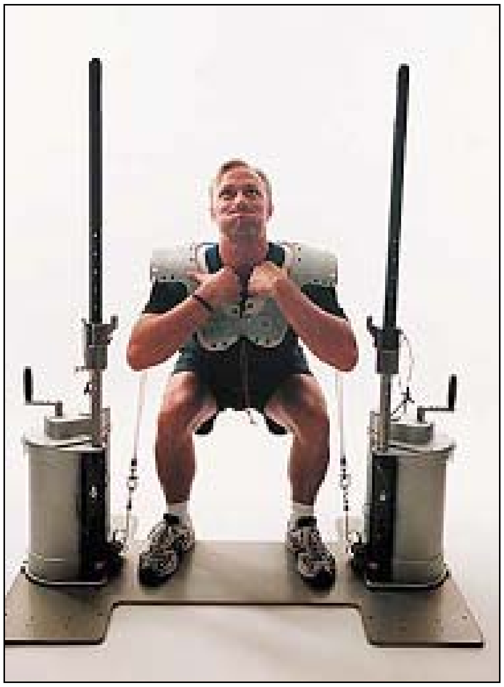


Figure 3.7. iRED shoulder harness system
(http://quest.arc.nasa.gov/people/journals/space/sugar/ired.jpg)

Similarly, astronauts are attached to Treadmill equipment from their waist with two spring-loaded cords that come from either side of the equipment (Figure 3.8). These cords used in iRED and Treadmill serve as resistant systems at the same time stabilizing the crew member. Other restraint systems; handrails and foot plates are located near the equipment for the crew members to leave the equipment safely when they finish up with their activity.

Figure 3.8. Cosmonaut Sergei K. Krikalev exercising on TVIS
(http://spaceflight.nasa.gov/gallery/images/station/crew-11/hires/iss011e05155.jpg)

3.1.1.2.3. Equipment Monitoring Devices

Monitoring devices on the equipment are important as the crew members follow and control their exercise program with the support of them. Also the data is downloaded to the ground for the experts to follow the crew members' exercise activities.

According to NASDA et al. (1999), the physiological parameters shall be monitored in the interface of the equipment in two categories as "routine monitoring" and "periodic monitoring" (p.10-11). In routine monitoring, the parameters shall be monitored on a "routine basis" as "heart rate, duration of microgravity countermeasure regimen and data output from instrumented exercise device". In periodic monitoring, the parameters shall be monitored on a "periodic basis" as "blood pressure and electrocardiograph, metabolic gas monitor, muscle performance and body mass measurement" (NASDA et al., 1999, p.10-11).

"The blood pressure/electrocardiograph device shall measure and record blood pressure (mm Hg), heart rate, and waveform during periodic fitness evaluations and Lower Body Negative Pressure" (NASDA et al.,1999, p.10-11). "The metabolic gas monitor shall provide respiratory quotient, minute ventilation (VE), ventilatory threshold, VO_2, VCO_2, identify maximum VO_2, vital capacity, forced expiratory volume in 1.0 second (FEV 1.0), Ti: Ttot, PET CO_2, respiratory rate, and respiratory quotient" (NASDA et al.,1999, p.311). "The electromyograph and accelerometers shall record movements (force and direction) and measure neuromuscular efficiency and function" (NASDA et al., 1999, p.10-11)

In International Space Station Flight Crew Integration Standard requirements for the digital displays for the equipment are stated in detail. However, according to Dudley-Rowley and Bishop (2002), this information related with displays and controls do not adequately address the use of current color graphic systems and needs to be updated.

3.1.2. Interior Design Requirements

"Unique to the design of interior environments for survival in space is the problem of how humans interact with the built environment in micro-gravity conditions" (Dunn, 1995, p.A4). Unlike Earth gravity environments, every surface of the micro-gravity environment must be aesthetic as well as functional since people living or working in such an environment are more likely to come in frequent contact with all surfaces (Lindsey, 1998). According to SICSA Lecture Series Report (2006b), "good "habitability" design will be essential to influence how effectively/ safely tasks are accomplished, how thoroughly/ rapidly crews adapt, how they feel about their surroundings and peers and how healthy they remain over time" (p.262). In addition, SICSA Lecture Series Report (2006b) stated that "design must respond to requirements imposed by space environment and the space station and transportation systems" (p.265). The requirements of the space environment are basically figured out as "gravitational influences, special radiation and debris exposures requiring special safeguards". The requirements of the space station are pointed out as "habitat dimension, volume and mass, power constraints, crew size, activities and mission duration" (SICSA Lecture Series Report 2006b, p.265). These factors can limit design decisions and usage.

3.1.2.1. Interior Volume Utilization

In ISS, the modules are very crowded. The devices are located very close to each other. The exercise equipment in ISS, are not located in a separate area; they are located in the modules where other tasks and activities are done. The activity envelopes intersect with each other. However, according to Nikon (1986), a separate and dedicated exercise function is required for physical exercise and health maintenance.

The equipment in ISS, Treadmill, Cycle Ergometer and iRED are defined as large exercise equipment. They are mountable and demountable, but their storage is not easy since they are big in size and heavy. Their special operation systems, like vibration isolation system, resistant bungee cord system, cause them to be bulky. To prevent crowded conditions demountable and stowable exercise equipment should be used (Nixon, 1986). Design on element and equipment compactness/ miniaturization should be emphasized in order to minimize associated volumetric size specifications and maximize habitable volume available for crew use (Nixon, 1986). Innovative industrial design solutions on the equipments and assembly of them help maximizing optimum operational efficiency and space.

Similarly, SICSA Lecture Series Report (2006b) suggested using modular exercise equipment. The equipment can be foldable or storable after the end of the exercise activity (Figure 3.9). Flexible, versatile use of equipment through adaptability and modularity is important for utilizing the space efficiently SICSA Lecture Series Report (2006b).

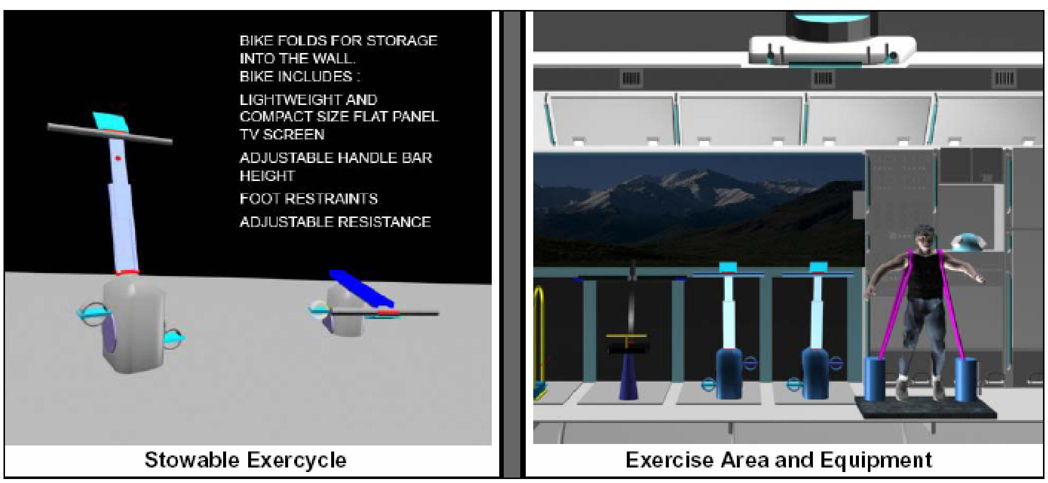


Figure 3.9. Stowable exercise equipment concept. (SICSA Lecture Series Report, 2006b, p.329)

"Until better data are available, designers should plan on allocating a minimum of 16.99 m^3 of usable space per crew member" (Allen et al., 2003, p.47). For optimizing habitat capacity, ceiling areas can be easily used for workplaces, stowage, outside viewing or other functions (SICSA Lecture Series Report, 2006b). Floor areas must be large enough to accommodate necessary activities and equipment and avoid claustrophobic psychological conditions (SICSA Lecture Series Report, 2006b).

According to SICSA Lecture Series Report (2006b), overall volumetric configurations should provide efficient integration of functional areas. “There should be appropriate functional relationships between activities, tasks and equipment” (SICSA Lecture Series Report, 2006b, p.267).

Also, the structure and shape of the module influence the interior volume. There is a conducted review of 6 different module concepts in SICSA Lecture Series Report in terms their volumetric characteristics (SICSA Lecture Series Report, 2006b) (Table 3.2). The module concepts are conventional, telescopic, inflatable cylinder, inflatable horizontal, inflatable vertical and vertically stacked. It is seen that newer inflatable concepts are advantageous in creating more interior volume for the crew members.

Table 3.2. Volumetric characteristics of different modules

Conventional	All equipment can be integrated prior to launch. No expansion is possible.	Inflatable Horizontal	Area of the inflatable section expands rapidly with increased diameter (a function of r^2).
Telescopic	Floor area can expand at approx 1:1 ratio, but telescoping section has smaller diameter.	Inflatable vertical	Area of the inflatable section expands rapidly with increased diameter (a function of r^2).
Inflatable Cylinder	Floor area expands as a direct function of inflatable section length.	Vertically Stacked	Expansion is only possible by adding modules. Vertical circulation will reduce useful space.

(SICSA Lecture Series Report, 2006b, p.140)

3.1.2.2. Layout and Configuration in the Station

According to Nixon (1986), exercise area can not be combined together with other activities in a space station in a single or shared function. However, it is spatially compatible with group game activity area (Figures 3.10 and 3.11). It is disconnected or not related with handovers, planning, on-board training (doing on-board experiments), meeting, teleconference, hygiene and maintenance areas. It is spatially incompatible and should be physically, although not necessarily acoustically or visually separated with food preparation, eating (group meals), entertainment and relaxation activities. However, it is spatially incompatible and should be physically, acoustically and visually separated from eating (individual meals), library (study) and station control operations (Nixon, 1986) (Figure 3.10).

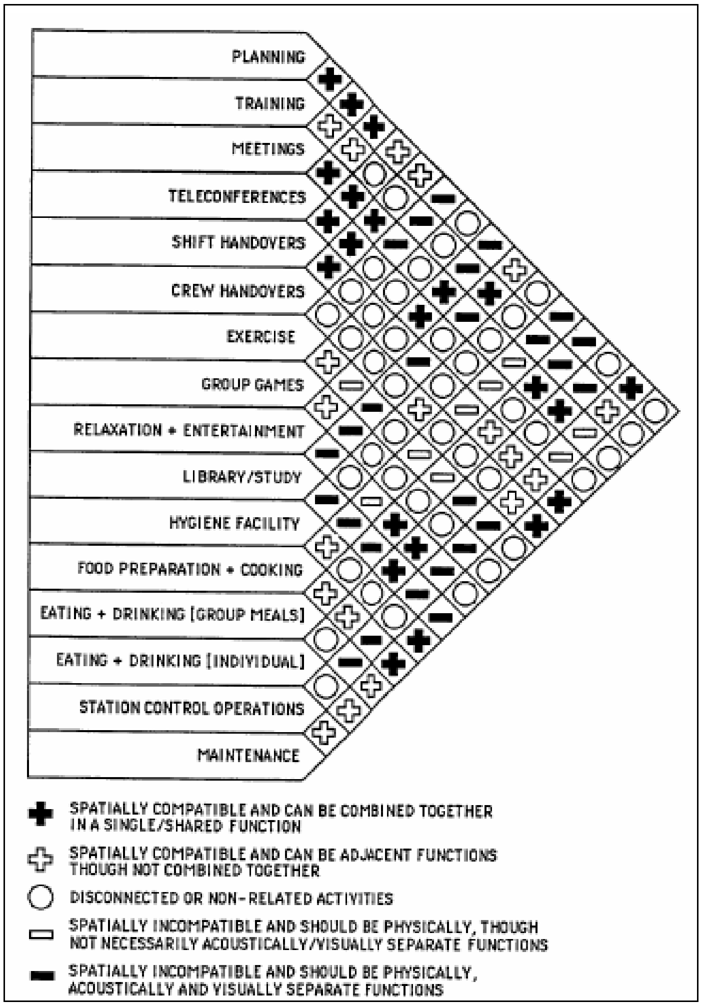


Figure 3.10. Activity adjacency compatibility matrix (Nixon, 1986, p.21)

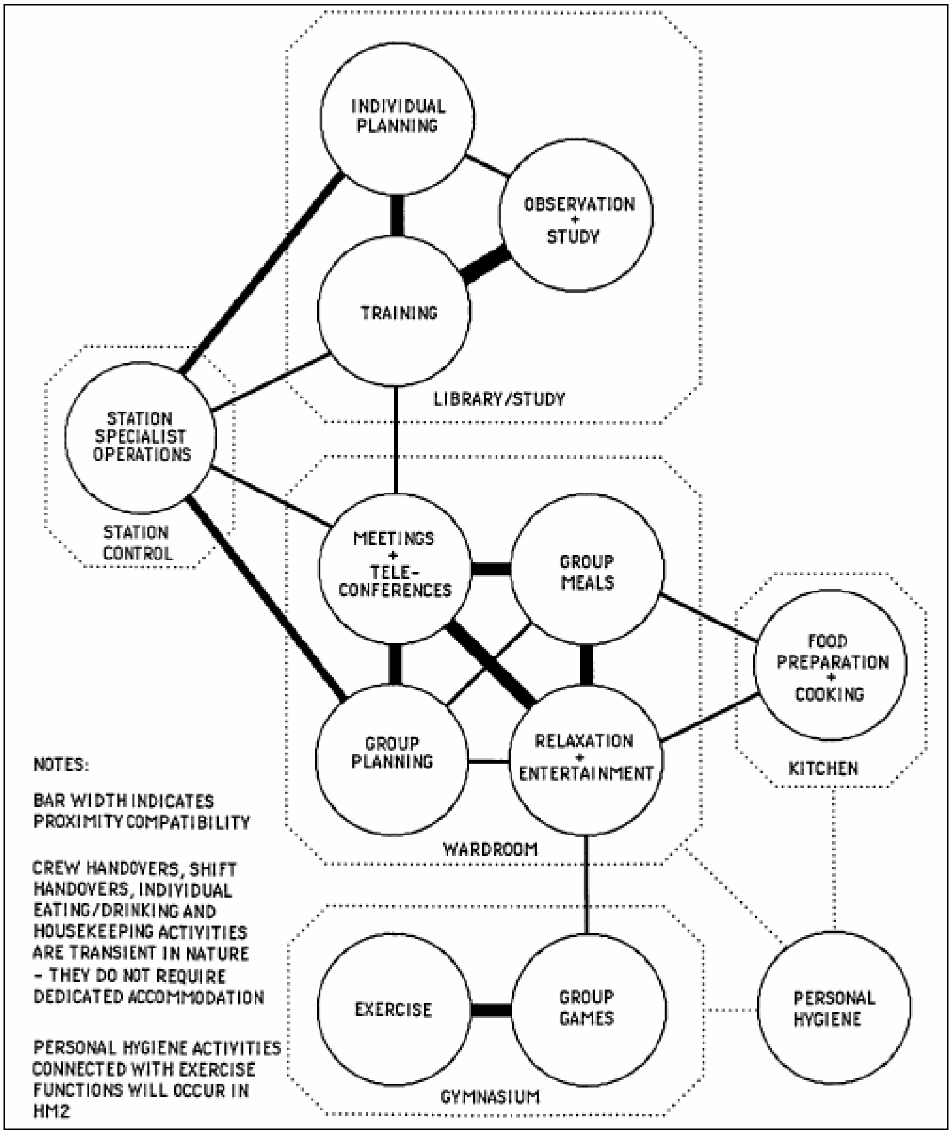


Figure 3.11. Activity proximity bubble diagram (Nixon, 1986, p.22)

The exercise equipment might be located close to a window for crew observation while in use. Also, an entertainment system can be associated during exercise activity (Nikon, 1986). This might show "simulated terrestrial routes synchronized with equipment operation" (Nikon, 1986, p.8).

Unlike from Nikon, it is stated in the SICSA Lecture Series Report (2006) that the exercise area can be combined with recreation spaces in order to strengthen crew morale and interpersonal relationships. “In these areas there should be possible inclusion in wardroom area, possible connection with health maintenance area, fixed and/or stowage equipment, towel and clothing stowage” (SICSA Lecture Series Report 2006a, p.140).

This exercise layout design is up-to-date. More entertainment elements are integrated. “Videotape screens/ projections can add to satisfaction, pairs of exercises can enable competitive races, special games can be designed for low-g conditions and wardroom areas can afford recreation spaces” (SICSA Lecture Series Report, 2006, p.286). Also, providing conditions for two or more people to exercise at one time can prevent boredom and facilitate work schedules and conversations (SICSA Lecture Series Report, 2006) (Figure 3.12).

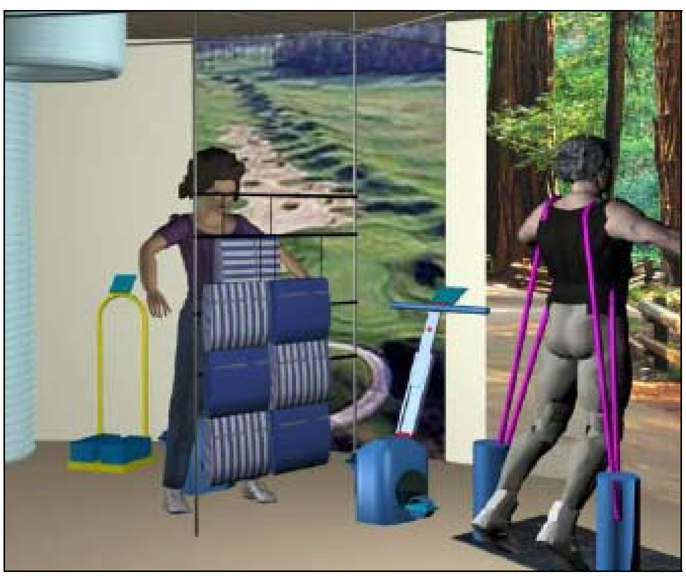


Figure 3.12. SICSA exercise area concept (SICSA Lecture Series Report, 2006b, p.286)

This exercise and recreation area is located on the first floor of an inflatable module where the lab facilities are located on the second floor and sleeping accommodations are actualized on the third floor. On the first floor besides exercise area galley, medical area and wardroom area is located (Figure 3.13).

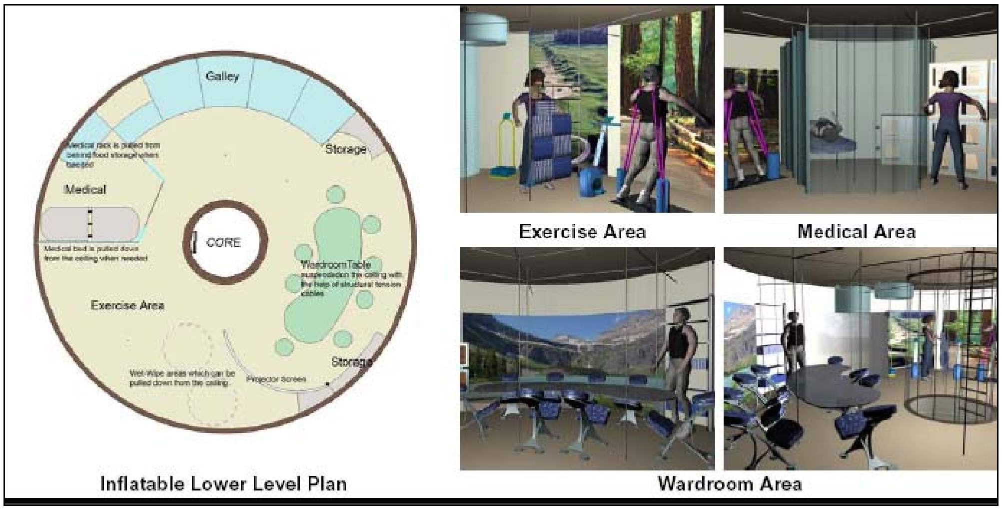


Figure 3.13. SICSA exercise area location in an inflatable module (SICSA Lecture Series Report, 2006b, p.320)

Another approach related with the layout of the exercise area in the station is combining the stowage with the exercise area. This layout is actualized in Transhab Project in 2003. “In this project the habitat is composed of four main levels that are pressurized tunnel area (Level 4), stowage and crew health care (Level 3), mechanical room and crew quarters (Level 2) and wardroom and galley area (Level 1)” (Figure 3.14) (NASA Human Space Flight, 2003, #6).

Figure 3.14. Levels of Transhab
(http://spaceflight.nasa.gov/history/station/transhab/index.html)

The Level Three houses an exercise area which is a complete health care area including a space bath area and a soft stowage area (NASA Human Space Flight, 2003) (Figure 3.15). Also, in this area there are two ISS Crew Health Care System racks, a full body cleansing compartment, changing area for private medical exams and conferencing, and an Earth-viewing window. Furthermore, in the stowage area soft-sided cabinets are placed for spare parts, supplies, clothing and other equipment (NASA, Human Space Flight, 2003).

Figure 3.15. Third level of Transhab/ Stowage and Health Care
(http://spaceflight.nasa.gov/history/station/transhab/index.html)

It is pointed in SICSA Lecture Series Report (2006) that for the safety of the crew members, horizontal and vertical internal circulation layouts and orientation references should be planned. In the station, the equipment are located very close to each other and they are very fragile equipment. Sharp corners should be avoided in design of the equipment that they can cause injuries (SICSA Lecture Series Report, 2006a). Moreover, fragile fixtures and control surfaces should be protected (SICSA Lecture Series Report, 2006a). "Lastly, configuration and layout design must be appropriate for mission applications, considering g-levels/ orientations, emergency egress, outside viewing and other factors" (SICSA Lecture Series Report, 2006a, p.39).

3.1.3. Environmental Factors Requirements

In ISS, Environmental Control and Life Support System (ECLSS) provides safe habitat environment that crew members can live. ECLSS` subsystems are Atmosphere Control and Supply (ACS), Atmosphere Revitalization (AR), Temperature and Humidity Control (THC), Fire Detection and Suppression (FDS), Vacuum System (VS), and Water Recovery and Management (WRM) and finally Waste Management (WM) (NASA, 2000). These functions are shown in Figure 3.16.

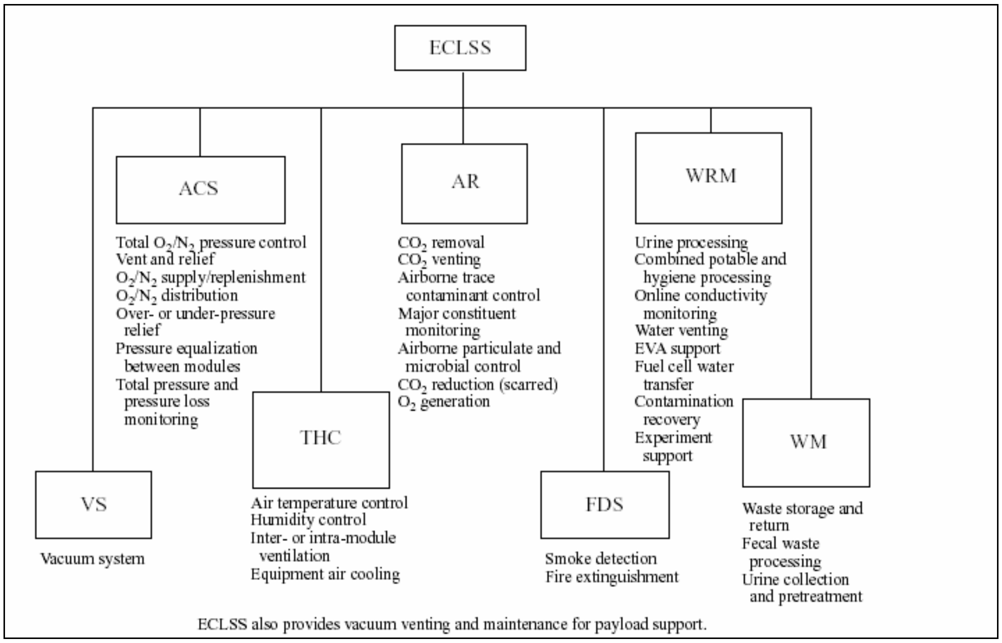


Figure 3.16. ECLSS functional overview (NASA, 2000, p.82, 3-44)

In this part of the thesis, the environmental systems that are needed for the exercise area are analyzed. Thermal control system, air circulation and quality control, humidity control, fire detection and suppression which are controlled by ECLSS, electric power controlled by solar panels and shock isolation system that is also necessary for the exercise area are introduced.

3.1.3.1. Thermal Control System

Thermal control system is necessary to maintain the temperature of the exercise area for the comfort of the crew members. Experiments and equipment inside the modules generate heat that must be removed (NASA, 2000). According to Collins, Kuwahara, Fukuoka and Nishimura`s future gymnasium concept (1997) temperature control involves “both passive design using multi-layer insulation and heaters attached to the external surface, and active systems using cooling water, cold-plates, air-conditioning equipment and temperature sensors" (p.2). In ISS the temperature in exercise areas is constant and it is 72 degree Fahrenheit (22.2 degree Celsius) (Yahoo, 2001).

3.1.3.1. Air Circulation and Quality Control

In ISS, the "Atmosphere Control and Supply (ACS) subsystem provides oxygen/nitrogen pressure control, pressure vent and relief, oxygen/nitrogen storage and distribution, pressure equalization between modules, and total pressure control as well as pressure loss monitoring" (NASA, 2000, p.82, 3-44). In the exercise areas in ISS, the air quality lowers because of the increased carbondioxide levels. According to future gymnasium concept of Collins et al. (1997), "the atmosphere in the gymnasium area is monitored and maintained primarily through atmosphere exchange with the central system that will remove carbon dioxide to the appropriate extent, replenish the oxygen through partial recycling, and remove odors" (p.95). They added that "in order to be used as an emergency shelter, an autonomous carbon dioxide absorption system and reserve supplies of oxygen and nitrogen also may also be provided" (Collins et al., 1997, p.95).

3.1.3.3. Electric Power

In the exercise area, electric power for equipment, lighting, environmental sensors and control, emergency systems should be supplied. It can be supplied from the station's power system, generated from solar panels (Collins et al., 1997). Integrated Truss Systems are designed to generate electric power.

3.1.3.4. Humidity Control

In ISS, the Temperature and Humidity Control (THC) subsystem provides cabin air temperature, humidity control and air ventilation in each pressurized element (NASA, 2000). Inter module ventilation is provided between adjoining pressurized elements to circulate air for the crew and to transport contaminants in the cabin air to the purification equipment. In addition, the “THC provides equipment air cooling in each powered rack” (NASA, 2000, p.83). According to Collins et al. (1997), "the exercise area designed for the long duration missions should have humidity control system” (p.96). Water should be recovered from the air and recycled as in the rest of the station’s water supply system, to which the exercise area is connected. This area should have adjustable airflow controls and added ventilation to relieve sweating during exercise. “The direction of the airflow should not blow sweat into other station areas, particularly eating or sleeping stations, and should blow over the entire body, not just one part of the body” (Allen et al., 2003, p.57).

3.1.3.5. Fire Detection and Suppression

In ISS, the Fire Detection and Suppression (FDS) subsystem provides smoke detection sensors for station modules and consist of a system of alarms and automatic responses to a fire event (NASA, 2000). In addition to this system, fire sensors and fire extinguishing equipment should be designed to suit the special characteristics of fires that can occur in zero-gravity. Non-inflammable materials should be used in the exercise area fittings (Collins et al., 1997).

3.1.3.6. Shock Isolation System

Most exercise equipment is noisy and causes vibration. Therefore they should be isolated from the crew quarters, science and spacecraft systems and equipment, which can be harmed by vibration (Allen et al., 2003). The Treadmill and Cycle Ergometer in ISS have shock isolation systems. Collins et al. (1997) suggested using shock-absorbing pistons to be connected between the main area and the exercise area in their future gymnasium concept. Also, the new exercise equipment are designed to have vibration isolation system.

3.2. Behavioral Factors

Human behavior on long-term planetary missions is an area well studied in ground analog situations (e.g., Antarctic research posts) (Rhatigan et al., 2005). In space, long duration missions create too much pressure on groups and individuals that can affect mission success. According to Rhatigan et al. (2005), more studies on behavioral health and performance are necessary to determine how to support long duration missions' crews and maintain their well being where studies of analog environments are insufficient. They added that many of the behavioral factors studied will be important in planning system decisions and relationships between crew members and ground personnel for Lunar and Mars missions.

3.2.1. Psychological and Social Stress

In recent years, psychological and social factors have been emphasized in studies for long duration space missions. Many factors create stress upon crew members. In this section of the thesis, stress inducements and stress reactions which are caused by the inducements will be analyzed.

3.2.1.1. Stress Inducements

The stress inducements, which cause severe psychological and social stress in prolonged space exploration missions can be classified as microgravity, isolation and confinement, monotony and boredom, privacy and community needs. They are caused by the unusual environment in the station.

3.2.1.1.1. Microgravity

The absence of gravity in orbiting habitats strongly affects human activities. For example, in ISS because of the microgravity, the directions are established by the interior layout of the facilities, not by the orientation with respect to Earth (SICSA Lecture Series Report, 1988).

The human body must physically adapt to microgravity environment and during this adaptation, changes occur in cardiovascular, muscular, and skeletal deconditioning as well as in immune and nervous systems (Morphew, 2001). As Morphew (2001) stated during their first few days of adapting microgravity, about half of the crew members experience a condition called Space Adaptation Sickness (SAS), which causes symptoms such as nausea, disorientation, headache, and a sea-sick or flu-like feeling. He added that these can be prevented by exercise and pharmacological interventions, but muscle and bone loss remains as a significant obstacle.

3.2.1.1.2. Isolation and Confinement

"Living in a confined environment as a space habitat is a strain on normal human life" (Vogler and Jorgensen, 2004, p.1). The environment is unusual to the astronauts as there is the lack of key points in normal human life such as seasons, weather change, smell of nature, visual, audible and other normal sensory inputs which can give a fixation for time and place (Vogler and Jorgensen, 2004). Therefore, this confined environment with minimal external stimuli available, gives a strong pressure on group and individuals, leading to commonly experienced symptoms: "tendency to depression, irritability and social tension" (Vogler and Jorgensen, 2004, p.1). According to Allen et al. (2003), psychological disturbances increase during long- term missions as the crew feel confined and isolated.

According to SICSA Lecture Series Report (2006a), the factors that cause isolation and confinement are "separation from loved ones, friends and community, lack of access to enjoyed places and activities, restricted volume, amenities and entertainment and interactions limited to a small group living and working in close quarters"(p.113). In adequate volume and living in close quarters are mainly driven by the capacity of the space station. Therefore as Vogler and Jorgensen (2004) stated:

> As much professional care and detail is given into the engineering problem of having the spacecraft in orbit and keeping the humans alive, as much neglect is given to basic architectural and psychological issues, which, if known at the beginning of the design process, would even reduce costs and could contribute to the development of space habitats which are more than inhabited machines (p.1).

3.2.1.1.3. Monotony and Boredom

According to SICSA Lecture Series Report (2006a), the factors that cause monotony and boredom are "routine schedules dictated by mission requirements, altered day-night cycles without seasonal changes, tiresome tasks without access to "outside services" and limited menu, clothing and environmental variety" (p.113). Unsafe physical conditions in the layout and design of the equipment may also lead boredom and stress (SICSA, 2006b).

3.2.1.1.4. Privacy and Community Needs

"The human being is living in a balance of privacy and community, which is always pushed, and counteracted" (Vogler and Jorgensen, 2004, p.2). In other words, the need for privacy is counter-balanced by the need for community. The interaction with people is an important factor for emotional reassurance (Vogler and Jorgensen, 2004). Sharing emotions can boost morale.

On the other hand as missions become longer, the need for privacy is also necessary. Therefore the need for the space required for each crew member increases. The ability of crew members to personalize certain portions of their environment can boost morale (Allen et al., 2003). The need for privacy is determined by individual and cultural factors. The level of privacy is an individual trait and the size and construction of the intra-personal space, is both a mental and physical factor, and is a variant from individual to individual (Allen et al., 2003; Vogler and Jorgensen, 2004). Besides, cultural factors determine the way of privacy that human need.

3.2.1.2. Stress Reactions

Psychological and social stress can affect crew morale, performance and interpersonal relationships. Stress on long-duration missions has influence on individual behaviors as well as on group behaviors (SICSA Lecture Series Report, 2006a). "Mission success and safety depend upon the mental health and stability of each individual" (SICSA Lecture Series Report, 2006a, p.114).

3.2.1.2.1. Influences upon Individual Behaviors

According to SICSA Lecture Series Report (2006a), anxiety and depression lead motivational impairments upon work. Also, sleep patterns can change causing fatigue and reduced alertness and antisocial actions that harm relationships and safety of the individuals. Moreover if these actions become uncontrollable, they can risk the entire crew (SICSA Lecture Series Report, 2006a).

The isolation, confinement, and distances of long-duration missions require unique communications issues. Unlike life on Earth, one cannot leave his problem by getting out of the environment (SICSA Lecture Series Report, 2006a). Therefore the crew members need to communicate with their family and friends. Distance will prevent real-time communications, so computer-to-computer transmissions should be scheduled for crew members (Allen et al., 2003).

3.2.1.2.2. Influences upon Group Behaviors

According to SICSA Lecture Series Report (2006a), because of the unusual environment of space, "crew member and ground personnel conflicts, difficulties in working as a cooperative team, intolerances to small personality and action irritants, depression/paranoia impairing mission performance appear upon group behaviors"(p. 113).

As the crew members live and work together in a small and confined environment they need strong interpersonal skills. Small interpersonal disagreements can lead to serious conflicts among crew members (SICSA Lecture Series Report, 2006a). In order to minimize these conflicts astronauts' interpersonal skills and personality characteristics should also be emphasized (Allen et al., 2003). According to Allen et.al (2003), important considerations for mission designers include built-in training approaches. Among these are to train:

> - All crew members to identify and manage conflicts and stress during the mission.
> - The crew to protect against "groupthink", a situation in which maintaining group harmony prevents critical thinking (group think may lead to poor or unsafe decisions, which are of particular concern because outside communications are so restricted.
> - Crew members in cockpit resource management (CRM) methods (i.e., individual crew members must behave assertively for the protection of the entire team, including questioning a leader's decision) (p.29).

3.2.2. Design Requirements against Stress

Design of interior areas and the equipment are very essential for more comfortable, flexible and convenient environment in space. In order to avoid stress caused by microgravity, lack of private and communal areas, isolation and confinement, monotony and boredom, there is need for good applied design.

According to SICSA Lecture Series Report (2006a), "crew adaptation to microgravity can be facilitated by responsive human factors design" (p.34). Related with interior design spatial references, landmarks and maps are essential to prevent confusion (SICSA Lecture Series Report, 2006a; Marquez, Oman and Liu, 2004). In addition, indicators (e.g. navigation signs and directional indicators) and good designed interfaces are necessary for minimizing stress and disorientation (Morphew, 2001). Color and graphic information should be designed (NASDA et al., 1999; SICSA Lecture Series Report, 2006a). Wall and ceilings, windows can be used as vertical and horizontal references (Allen et al., 2003; SICSA Lecture Series Report, 2006a).

Because of microgravity, restraint and anchorage, devices are needed to hold people when they are doing stationary tasks and secure equipment to prevent it float away.

Storage systems can be solution to keep contents from escaping when opened (SICSA Lecture Series Report, 1988).

In the unconventional environment of space crew members need both private and communal areas (SICSA Lecture Series Report, 2006b; Harrison, Caldwell, Struthers, 1988). Individual and group needs are very critical considering the design requirements for the exercise areas. According to SICSA Lecture Series Report (2006a), living environments should be similar to the environments where people enjoy on earth, including private and social areas with clean and healthy conditions.

Some certain places can be allowed for personalization (Allen et al., 2003). More private places should be arranged and the impression of crowding should be reduced (Harrison et al., 1988). On the other hand, there is a need for social areas against stress. Group activity areas should be arranged to create conversations between crew members (SICSA Lecture Series Report, 2006b). According to SICSA Lecture Series Report (2006a), exercise area is defined as a communal area where "accommodations for two or more people to exercise at one time can facilitate work schedules and conversations" (p.37).

Against isolation and confinement, adequate volume should be planned for each crew member (Allen et al., 2003). For this manner selecting materials and modular design systems to minimize volume should be suggested (SICSA Lecture Series Report, 1988). Modules increasing social interaction among crew members will prevent isolation and confinement (SICSA Lecture Series Report, 2006a). Furthermore, communication with outside world (e.g. through windows, electronics) should be arranged (SICSA Lecture Series Report, 2006b; Vogler and Jorgensen, 2004).

Against monotony and boredom, appropriate design of lighting and décor, materials, textures and color needs to be selected (SICSA Lecture Series Report, 2006b). Intrusions like noise, odor and light should be prevented (SICSA Lecture Series Report, 2006b; Allen et al., 2003). In addition, TV displays and videotapes can add to satisfaction, and prevent the boredom. Crew selected entertainments can be provided and special games can be designed for low-g conditions in order to prevent monotony (Dudley-Rowley, Cohen and Flores, 2004; SICSA Lecture Series Report, 2006a and 2006b). Variety is important to prevent boredom and depression. "Means to change and personalize the appearance of interior areas and incorporate color and interest into the surroundings will be helpful" (SICSA Lecture Series Report, 1988, p.4). Environmental conditions (e.g. air quality, temperature, humidity level) should be appropriate and comfortable (SICSA Lecture Series Report, 2006b).

Work overload can also cause boredom. Therefore, it should be scheduled carefully (SICSA Lecture Series Report, 2006b). There should be "ease of maintenance and repair operations" (SICSA Lecture Series Report, 2006b, p.266). Design structures and equipment should be cleaned and easily repaired in order not to cause stress (SICSA Lecture Series Report, 2006b).

Design requirements are put forward by the researchers for ISS and further concepts in space. Besides physical factors, behavioral factors are also emphasized in new design requirement documentations. However, they are limited in number. Behavioral factors should be more integrated in the documentations prepared to help designers for the design process of ISS (Harrison, 2004; Musson, 2000). In the next chapter design of the exercise areas in ISS are evaluated both examining the physical and behavioral interactions in the exercise areas of ISS and analyze the current situations while figuring out the needs of the crew members.

4. DESIGN EVALUATIONS FOR THE EXERCISE AREAS IN ISS

4.1. Description and Aim of the Study

"International space station (ISS) program has been a motivator of further requirement documentations" (Dudley-Rowley and Bishop, 2002. p.3). In literature it is found that numerous standard documentations including requirements, guidelines and suggestions for design solutions had the main focus in interactions of human with the equipment and technology (Dudley-Rowley and Bishop, 2002). Man-Systems Integration Standard Documentation, with the latest version released in July 1995, has mostly focused on anthropometric data and design guidelines for machine and equipment technology. Similarly, taking Man-Systems Integration Standard Documentation as basis, ISS Flight Crew Integration Standard Documentation, has been useful and referenced by many studies, but it is also technology-specific and out of date (Dudley-Rowley and Bishop, 2002). The data related to the issues of architecture and interior design are stated in general. Except from workstation areas not enough information is put related with the other activity areas.

This study, emphasizing not only physical but also behavioral interactions, examines a specific area in ISS, which is the exercise area, needed for crew health maintenance. Based on the information from numerous disciplines, this study aims to figure out the physical needs in the exercise areas of ISS, in terms of equipment design, interior and environmental design issues as well as the behavioral needs of human beings that guide design decisions for extended missions.

In this study, the current situations in the exercise areas in ISS are analyzed. The photographs of the crew members and the modules and videotapes of exercising crew members are analyzed. In addition, interviews were done by one crew member of the station and three members of the design teams of the space agencies NASA and ESA. Based on these, findings, the study suggested some guidelines to fulfill the needs of the crew members for the specifically analyzed exercise areas in ISS.

4.2. Methodology of the Study

The methodology of the study is based on the use case analysis of the exercise areas in ISS and the interviewing with the designers and a user. In the use case analysis technique, the aim is to figure out the problems and needs of the crew members while using the exercise areas in the modules of ISS. In order to accomplish this, texture documentations, photographs and videotapes are used (See Appendix C for videotape observation sheets). The next method is the interview method in which the aim is to understand how the user and designer approach to the exercise areas in the station.

The purpose of using two analysis techniques is to figure out the problems in the exercise areas within a framework. The aim is both to understand users` physical and behavioral needs during their interaction with the exercise areas in ISS and the way designers` contribute to the design of these areas. This study also aims to figure out the constraints and limitations affecting design decisions of the exercise areas in ISS.

4.2.1. Analysis of the Use Cases in the Exercise Areas in ISS

The analysis of the use cases is made under two main headings which are the analysis of the exercise equipment and interior and environmental factors. Both past and current situations in the ISS are analyzed.

4.2.1.1. Analysis of the Exercise Equipment

At the moment, in ISS, there are three exercise equipment, which are the Treadmill, Cycle Ergometer and Interim Resistance Exercise Device (iRED). In this part, the use cases of each of the equipment are analyzed pointing to durability and maintainability, reliability and comfort.

It is found that all three equipment were not durable while two of them (Treadmill and iRED) were severely broken and had to be repaired with hardware packages sent from earth (Moore et.al, 2004; Parma, 2002). Also, it is understood from ISS crew reports that the maintenance time of each equipment requires too much energy and time and causes stress upon crew members.

It was on 24 June 2002 that, the Treadmill was making a ticking noise as the crew members were running on it (Parma, 2002). A detailed analysis showed that the chasis, the structural bone of the Treadmill was damaged (Parma, 2002) (Figure 4.1). The damaged part was replaced by the Treadmill repair hardware brought on the next flight as there was no spare hardware in the station at that time. Therefore, crew members have had to use the other exercise equipment. Also on 25 February 2001, the Treadmill slats and foot plate had been broken and replaced by the crew members (ISS Program Office, 2001).

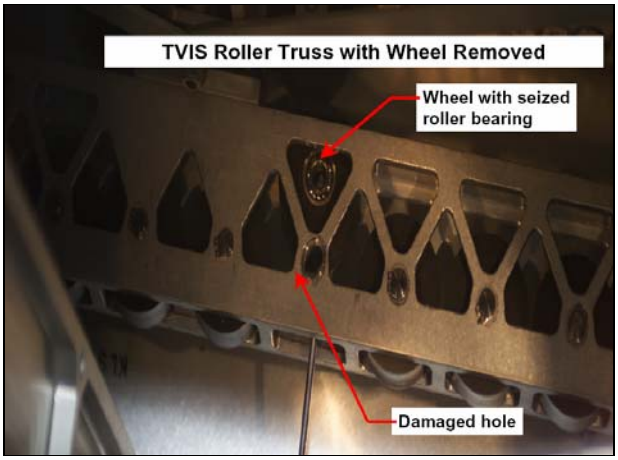


Figure 4.1. Treadmill failure (Parma, 2002, B-21).

Similar event happened with iRED, on 3 March 2001, which the fore canister on the iRED was severely broken. “It is assumed that the side- to- side movement of the flexpacks caused them to scrape against the canister housing, caused the flexpack spokes to break rendering the entire fore canister unusable” (ISS Program Office, 2001, #23). There was no spare fleck packs on board to do repair, so no change out of the canisters occurred and crew waited until the re-supply of new canisters to the board (ISS Program Office, 2001). The canister failure repeated in 2004, when iRED was evaluated with Man-in-the-Loop Test (MILT) (Moore et.al, 2004) (Figure 4.2)

Figure 4.2. Flex pack failure (Moore et. al, 2004, p. 15)

Secondly, apart from mechanical failures and poor quality hardware, the equipment in ISS have been unreliable due to poor instrumentation for the quantification of the exercise sessions (Hagan and Schaffner, 2002; Rhatigan et al., 2005). Hagan and Schaffner (2002) stated that the exercise equipment in ISS are insufficient in measuring loads, displacements and power output. Because of this, exercise evaluations can not be evaluated critically which restricts the improvements for the next exercise equipment. Many studies were conducted to improve the equipment reliability in ISS; however, there are not meaningful quantitative evaluations because of the limited number of crew subjects.

Before their send to ISS, exercise equipment are tested on Earth. However, "it is particularly difficult to compensate for the manner in which gravitational loading effects human body kinematics and kinetics" (Hagan and Schaffner, 2002, p.2). For the exercise equipment in ISS, the loading available on the equipment do not correspond to the body mass loading in 1-g (Rhatigan et al., 2005). Both three equipment in ISS have not been able to produce post flight values equal to the ones seen at preflight (Hagan and Schaffner, 2002). This was figured out first in Foot experiment data where forces experienced during Treadmill exercise were nearly 63% of the forces that would have been experienced running on a Treadmill on Earth (Cavanagh, Maender, Rice, Gene, Ochia and Snedeker, 2004).

Currently in ISS, the interim resistive exercise device (iRED) also has been very unreliable. “Total available force is limited to 136 kg (300Ibs) compared to the required 272 kg (600Ibs)” (Rhatigan et. al, 2005, p.18). “This device has limited efficacy at maintaining muscle strength and little effect on bone” (Hagan and Schaffner, 2002, p.2). However, Hagan and Schaffner (2002) added that a new generation resistance exercise device is being designed to simulate weight training on earth better.

For the long duration missions, Treadmill also needs improvement. “During Treadmill exercise session, the crew member is loaded from 1/3 to 3/4 of body weight to approximate the magnitude of musculoskeletal loading experienced in 1-g” (Hagan and Schaffner, 2002, p.1). According to Rhatigan et al. (2005), Subject-loading Device (SLD) should provide measurements equivalent to what would be experienced on earth and a virtual reality display should show them so that the exercise effectiveness can be monitored during the mission. These enhancements are necessary for better exercise capability (Rhatigan et al., 2005).

To compare with other exercise equipment Cycle Ergometer is the most reliable one. “It is compact and suitable for exploration class missions” (Rhatigan et al., 2005, p.18). However, it is still obvious that crew members experience loss of muscle strength and bone density. “New exercise countermeasures need to be evaluated to determine if they offer additional capabilities beyond current approaches” (Hagan and Schaffner, 2002, p.1)

Lastly, because of these loading systems, exercising is very uncomfortable for the crew members. It can be understood both from the photographs and videotapes that crew members put too much effort and because of the unconventional usage of the equipment, they are very uncomfortable. Many of them inform the exercise session as difficult. Exercise activity is a must activity rather than a leisure activity for them.

The restraint systems designed for securing the crew members to the equipment make the exercise difficult. They are restrained with bungee and elastic cords and this cause subject boredom. Besides, they are loaded to imitate the gravity force that is experienced on earth that makes the exercise difficult (See Appendix C for video observations)

It can be understood from the videotapes and photographs that there is the wrong placement of the monitoring device of the Cycle Ergometer (See Appendix C3 and C4). This points out that the reach limits of crew members was not considered. Sometimes the back structure of it is used as handrails by the crew members, however, it is box profile and cause uncomfortable grasping (Figure 4.3).

Figure 4.3. Astronaut John L. Phillips exercising on CEVIS (http://spaceflight.nasa.gov/gallery/images/station/crew-11/hires/iss011e09822.jpg)

The Treadmill has no monitoring or control display. It is analyzed from a videotape that a crew member looks to a watch to follow his exercise (See Appendix C1).Also as the body is loaded, running is very difficult, the crew members take breaks every five or ten minutes (See Appendix C1). There is no monitoring or control display for iRED as well. Also, the length of the bar is short and that makes the exercise uncomfortable (Figure 4.4).

Figure 4.4. Bar of the iRED device
(http://spaceflight.nasa.gov/gallery/images/station/crew-13/hires/iss013e08046.jpg)

Both three exercise equipment look very primitive in aesthetics. Their surfaces are unfinished, their mechanisms are unhidden. Similar to other equipment exercise equipment have sharp corners. Their usage is unconventional that may affect crew adaptation.

To summarize, from the use case analysis of exercise equipment in ISS, it is found that both three equipment are undurable and their spare parts are not maintained. Treadmill and iRED is unreliable. Both three equipment are uncomfortable (Table 4.1).

Table 4.1. The summary of use case analysis of the exercise equipment in ISS

	Durability and Maintainability	Reliability	Comfort
Cycle Ergometer	X	√	X
Treadmill	X	X	X
iRED	X	X	X

According to Rhatigan et al. (2005), the current exercise equipment used in space are not sufficient to support crew health and morale. They added that for long missions to Mars, new generation devices need to be tested. In terms of preparing for long duration settings, ISS gives the opportunity for testing and exploring better countermeasures for crew health and morale. More quantifiable data gathered from both ground and on-flight studies are necessary in order to design better exercise equipment.

4.2.1.2. Analysis of the Interior and Environmental Factors

In ISS, each exercise equipment is located in different modules. The Treadmill is located in Russian Module Zvezda, the Cycle Ergometer is located in Destiny Laboratory and the Interim Resistance Exercise Device is located in Unity. Because of the limited volume in modules of ISS, many activities areas are located very close to each other often intersecting. There is no specifically or deliberately decided area for exercising in the modules. These crowded conditions cause stress and confinement. In this part, use cases in each of the modules will be analyzed pointing interior volume utilization, layout and configuration in the station and environmental conditions as well.

To begin with, the interior volume utilization of each module will be analyzed. The Destiny, which is also called U.S. Laboratory Module, is a very crowded module consisting of many equipment placed linearly and closely to each other. The Cycle Ergometer is located facing the Microgravity Science Glovebox (MSG) (Figure 4.5). Inside the Destiny, there are other equipment such as Human Research Facility Rack (HRF), which includes lung function equipment, ultrasound equipment, medical equipment and computers, MSG, Express Racks, Minus Eighty Degree Laboratory Freezer (MELFI), for ISS videotapes and communication devices (Figure 4.6).

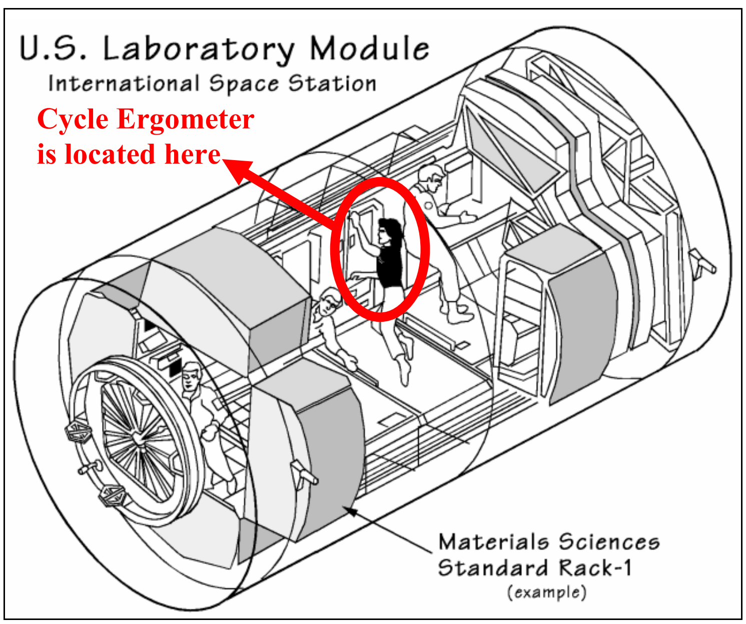


Figure 4.5. Location of Cycle Ergometer in Destiny module
(http://images.google.com.tr...) (See References)

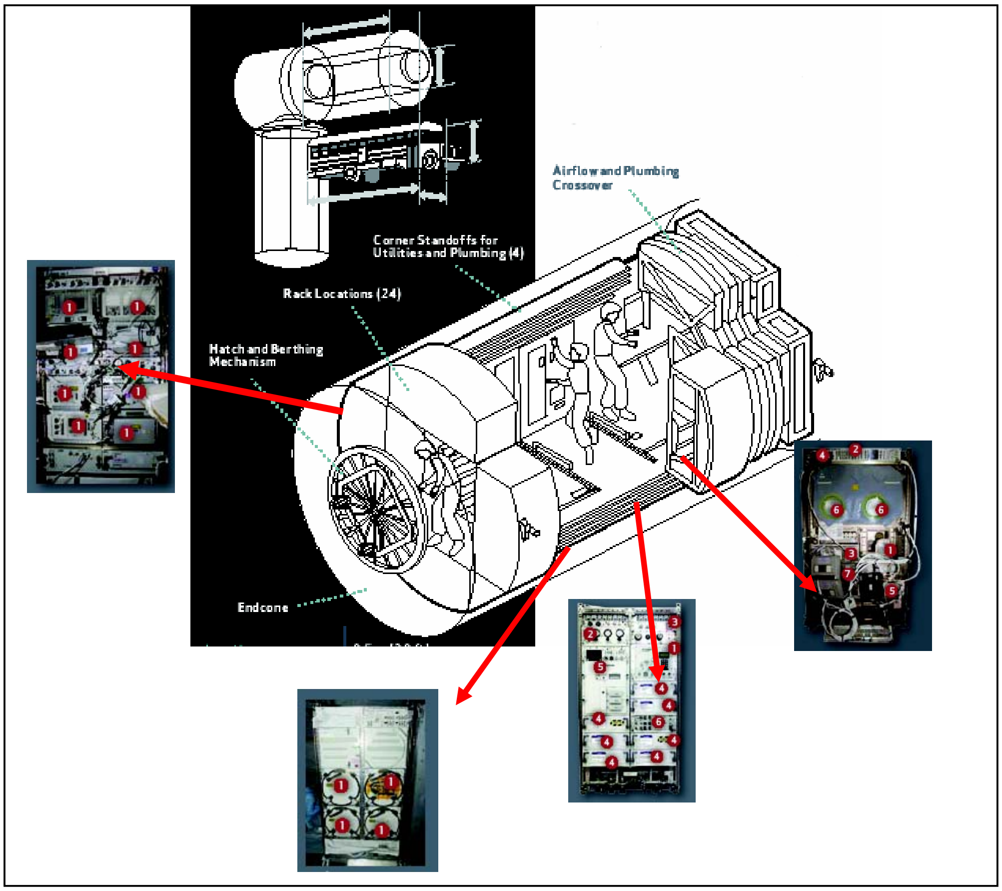


Figure 4.6. Equipment in Destiny module (NASA HQ, 2007, p.8)

It is understood from videotapes and photographs there are very fragile equipment in this laboratory and they are left open and not stored. Their cables are not hidden and they take too much space. As the activity envelopes intersect with each other, the equipment can be damaged or the users may be injured in case of an accident (See Appendix C5)

Similar volume utilization can be seen in the interior of the Russian Zvezda module. The equipment of different activities are located linearly and very close to each other. Only the floor areas and walls are used in activity areas. The Treadmill is located very close to the dining table (Figure 4.7). The crew members do not have a chance to eat while somebody is exercising. The module is messed up with equipment of different activity areas intersecting as it is in Destiny and this causes stress (Figures 4.8 and 4.9).

Figure 4.7. Cosmonaut Valery I. Tokarev exercising on Treadmill (http://spaceflight.nasa.gov/gallery/images/station/crew-12/hires/iss012e22728.jpg)

Figure 4.8. Interior of Zvezda module (http://spaceflight.nasa.gov/gallery/images/station/crew-11/hires/iss010e24914.jpg)

Figure 4.9. Activities in Zvezda module
(http://spaceflight.nasa.gov/gallery/images/station/crew-1/hires/iss01e5083.jpg,
http://spaceflight.nasa.gov/gallery/images/station/crew-12/hires/iss012e23142.jpg,
http://spaceflight.nasa.gov/gallery/images/station/crew-12/hires/iss012e22732.jpg
http://spaceflight.nasa.gov/gallery/images/station/crew-13/hires/iss013e08185.jpg)

In the Unity module, unlike from the other modules the ceiling areas are used for activity areas. Also, it is less crowded than the other modules as it only provides internal storage and pressurized access between modules. Interim Resistance Exercise Device (iRED) is located in the ceiling of Unity (Figure 4.10). However, it is placed right near the passage way. According to Fitss (2002), the iRED operational volume should not conflict with the other operational volumes. He defined the dimensions of the needed volume for the operation of iRED (Figure 4.11). However, in ISS, the situation is obviously wrong. The crew member’s safety is disregarded. This volumetric utilization is an invitation to injuries ad accidents (Figure 4.12).

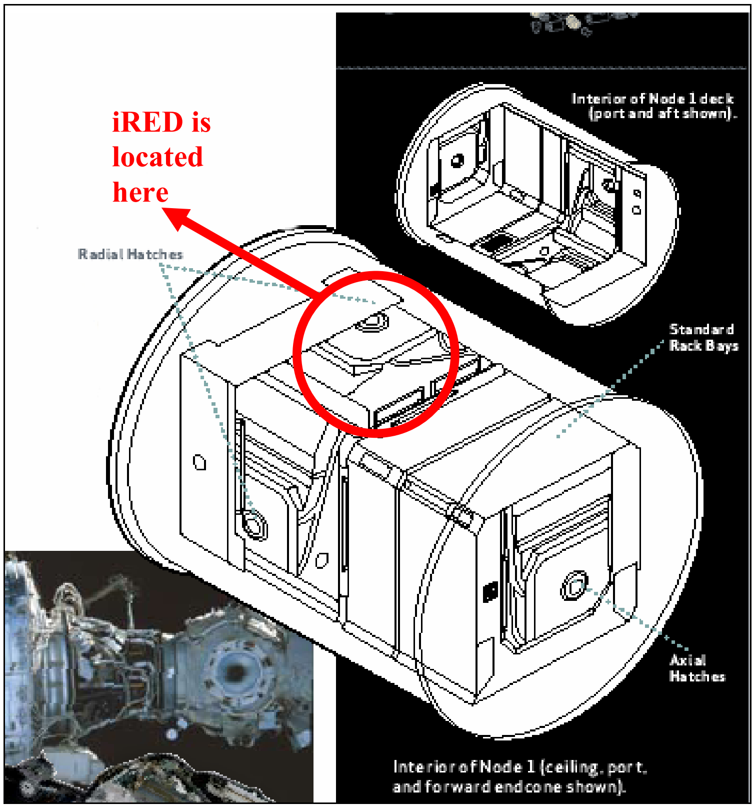
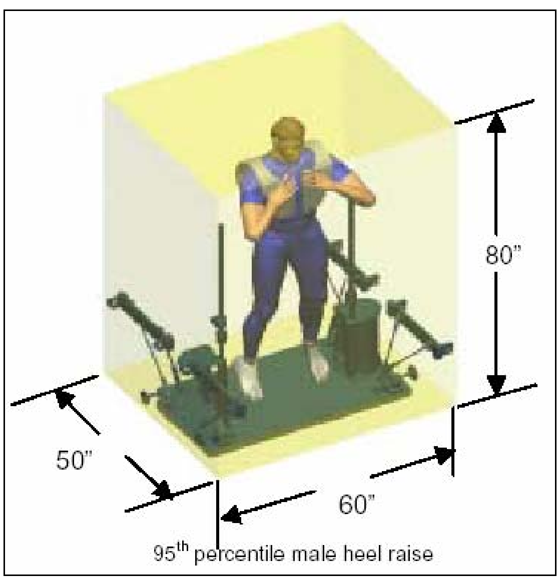


Figure 4.10. Location of iRED in Unity module. (NASA HQ, 2007, p.5)



(80”=2.03m, 60”=1.52m, 50”=1.27m)

Figure 4.11. Operational envelope of iRED (Fitss, 2002, p.11)

Figure 4.12. Astronauts sharing Unity module
(http://spaceflight.nasa.gov/gallery/images/station/crew-9/hires/iss008e21996.jpg)

Secondly, the layout and configuration of the exercise areas in the station will be analyzed. As it is understood from the name of the module, the main experiments and research is conducted in U.S. Laboratory Module. Moreover it is the module where the crew members communicate with the ground through the communication devices located in the module. According to Nixon (1986), exercise activity must be spatially, visually and functionally separated from the work area. Also, according to the habitat concepts stated by NASA Human Space Flight (2003) and SICSA Lecture Series Report (2006b), exercise area should be located on a different layer and separated from laboratories or work areas. However, in Destiny Laboratory module, Cycle Ergometer exercise activity and working activities are done at the same time (Figures 4.13, 4.14 and 4.15). This situation is not healthy and affects the psychology of the crew members. It can cause conflict and stress between the crew members. To avoid these situations, one or other crew member may have to quit or postpone the activity he is supposed to be doing.

Figure 4.13. Astronaut Jeffrey Williams exercising on CEVIS in Destiny module (http://spaceflight.nasa.gov/gallery/images/station/crew-13/hires/iss013e17268.jpg)

Figure 4.14. Astronaut Susan J. Helms working in Destiny module (http://spaceflight.nasa.gov/gallery/images/station/crew-2/hires/iss002e5478.jpg)

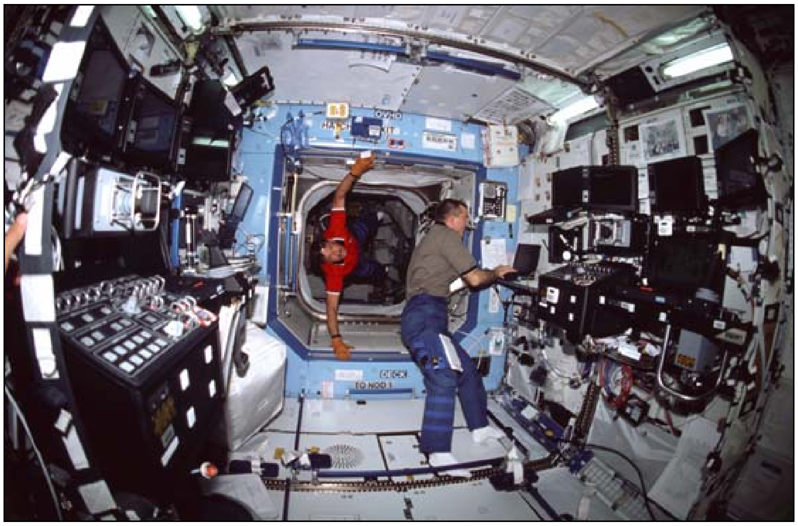


Figure 4.15. Astronauts sharing Destiny module
(http://spaceflight.nasa.gov/gallery/images/shuttle/sts-105/hires/sts105-304-025.jpg)

Russian Module called Zvezda, which is the main living module, hosts the Treadmill (Figure 4.16). Living accommodations on Zvezda Module include personal sleeping quarters for the crew; a toilet and hygiene facilities; a galley with a refrigerator/freezer; and a table for securing meals while eating. Spacewalks using Russian Orlan-M spacesuits can be performed from Zvezda Module by using the Transfer Compartment as an airlock. However, Treadmill exercise area located near the eating and sleeping area is very unhealthy as the sweat of the astronauts may flow and to that areas.

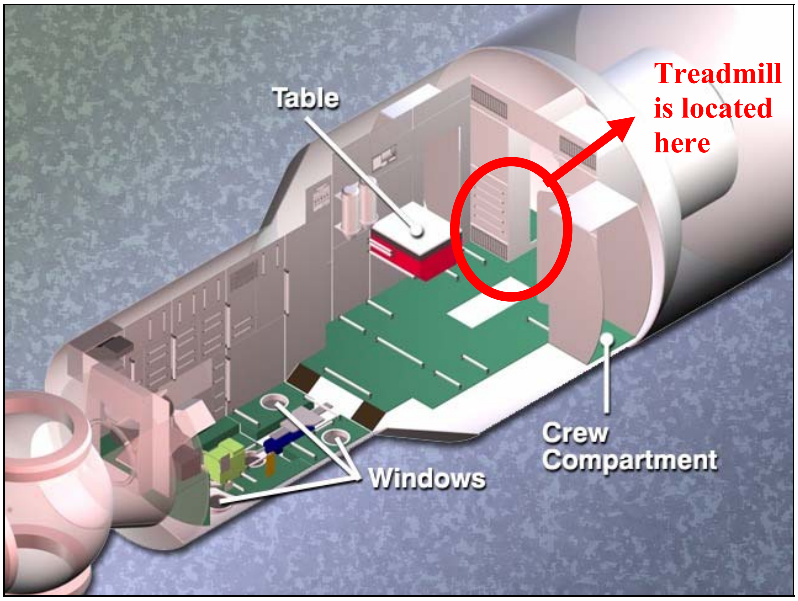


Figure 4.16. Treadmill location in Zvezda module
(http://spaceflight.nasa.gov/gallery/images/station/servicemodule/hires/jsc2000e26922.jpg)

According to NASA Human Space Flight (2003), exercise area is compatible with stowage area. The iRED is located near the internal storage area. In Unity, the layout and configuration of iRED exercise area is more meaningful as the low quality air caused by the exercise area does not combine with the other activity areas by this way.

Apart from the interior volume utilization and layout and configuration of the exercise areas, environmental conditions are also very important for crew morale and health. It can be understood from videotapes and photographs that the modules are dark normally, and they are lit by artificial lighting which may be disturbing for long durations. Also the astronauts sweat and the humidity increases in the environment. But, there are special fans located near the equipment in order to flow the air and prevent sweat sticking to astronauts. Nevertheless, the air quality decreases in the exercise areas.

To summarize, from the use case analysis of the interior and environmental factors in the exercise areas of ISS, it is found that both three exercise areas in the modules, Destiny, Zvezda and Unity are inefficient in terms of interior volume utilization. The exercise areas' layout in the station is not compatible with the other activity areas in the modules Destiny and Zvezda. The environmental conditions are disturbing as the modules are lit by artificial light. Moreover, the air quality decreases in the exercise areas (Table 4.2).

Table 4.2. The summary of the use case analysis of the interior and environmental factors in the exercise areas in ISS

	Interior Volume Utilization	Layout and Configuration in the Station	Environmental Conditions
Destiny Module	X	X	X
Zvezda Module	X	X	X
Unity Module	X	√	X

4.2.2. Interview

In this study, in-depth, semi-structured interview technique is used. The reason for using this form is that it is a way of obtaining a wide range of information that is hard to obtain through regular interview techniques. According to Merriam (1998), most commonly used interview form is a semi-structured interview including a set of questions and issues to be explored, but neither the exact wording nor the order of questions is predetermined.

Participants for the interview are Dr. Donald Hagan, manager of Exercise Lead Human Adaptation and Countermeasures Office at NASA Johnson Space Center, Dr.

Stuart Gill, biomedical engineer at ESA Medical Operations, Dr. Nora Petersen, exercise specialist at ESA and an ISS crew member that did not prefer to give his name. Dr. Donald Hagan is American. Dr. Stuart Gill is Canadian and 29 years old. Dr. Nora Petersen is German and 29 years old. The ISS crew member is male and was one of the expedition mission members of ISS. The interview with Dr. Donald Hagan is a phone interview that took approximately 40 minutes. The other interviews are email-interviews. The interview with the ISS crew member was done after his return to earth.

In this study, the first three participants are categorized as 'designers' since they are the manager or members of design teams who actively work in space agencies for designing the exercise areas for ISS. They are the people who have the knowledge about the technologies and conditions in the ISS exercise areas. Also, they do not make plans only for the current purposes, but also for the near future when crew members have to live longer in space during the missions to Mars. Second category is the 'user' category. The ISS crew member is defined as the user of the ISS exercise areas. Therefore, the questions are also in two categories, one for the designers and the other for the user of the exercise areas in ISS (See Appendix D for the interview questions).

4.3. Discussion

The interview questions for designers were planned mainly for understanding their approach to how the exercise areas for ISS should be according to their priorities and concerns. Similarly, the interview questions for the user were planned to understand his opinions related with the exercise equipment, interior and environmental conditions in ISS that also define how the exercise areas for ISS should be according to his needs. Although there is only one user interview, the use case analyses support the answers of the user. The approaches of designers` and users` point of views are introduced under two main headings which are equipment analysis and interior and environmental analysis of the exercise areas for ISS. In this part of the thesis, the main purpose is to discuss how well designers' intentions for the exercise areas in ISS match user's needs in the exercise areas in ISS.

4.3.1. Discussion on the Exercise Equipment

In the content of exercise equipment analysis of the exercise areas for ISS, user and designers have common points but the priorities of them are different (Table 4.3). According to designers, the most important considerations while designing exercise equipment for ISS is reliability and efficiency. Both three equipment are stated as unreliable by the designers. What is aimed is that enough workload should be created and well distributed in the exercise equipment and what bones and muscles experience on earth should be stimulated while designing the exercise equipment according to their approaches. Dr. Hagan stated that different exercise equipment such as Advanced Resistance Exercise Device (ARED) and Fly Wheel are now being designed for ISS in order to increase workload and reliability. He added that more quantifiable studies should be made on earth and on board in order to better stimulate the forces experienced on the ground. However, there is limited number of crew members to actualize this.

Table 4.3. Analysis of exercise equipment in the exercise areas for ISS

Main Points	
Designer Approach	**User Approach**
1) Reliability	1) Simplicity
2) Efficiency (3 main constraints: time space and power)	2) Comfort
	3) Reliability
3) Suitability to NASA design requirements	4) Efficiency
4) Comfort	
5) Simplicity	

The efficiency of the equipment is also emphasized by the designers. According to them, in order to design efficient equipment, it should respect to the constraints of time, space and power driven by the station and mission scope. As time is very valuable on board, according to Dr. Hagan and Dr. Gill and Dr. Petersen, the equipment should require minimum maintenance time when it is broken. Dr. Petersen added that the exercise equipment should be time saving during set-up, usage, cleaning and stowing. In order to accomplish this, the equipment should be durable and constantly be up dated. The amount of power that equipment requires is the other main constraint that is emphasized by the designers. According to them, the equipment should require minimum power of the station and human-powered exercising is also offered. Lastly, space is another main constraint as it is very limited in the station. According to Dr. Hagan, the exercise equipment should be small in size and require minimum space. However, he added that NASA requirements are to build exercise equipment that will accommodate 95% North-American Male and 5% Japanese Female which is a very wide range of human size that cause the equipment to be big. According to Dr. Gill, space station is a very tight place, therefore this should be taken into account while designing exercise equipment so that they can be easily hidden/relocated and removed when necessary. The amount of power that equipment requires is the other main constraint that is emphasized by the designers. According to them, the equipment should require minimum power of the station and exercising using no power should also be offered. It is analyzed that apart from the constraints of time, space and power driven by the station and mission scope, the design requirements of NASA also affect the design decisions of the exercise equipment.

On the other side, the user put the emphasis on comfort and simplicity more than the equipment's reliability and efficiency. Simple and conventional equipment is what he needed while exercising in the station. He preferred iRED in Unity as it is simple, comfortable and effective. However, he found Treadmill very uncomfortable because of its harness system. He described Treadmill exercise as very difficult because of being loaded both on the hips and shoulders while running or walking. The durability of the exercise equipment is also important for him because broken and unworking equipment or part of the equipment caused stress. Broken equipment's causing stress is also determined by the use cases analysis. In addition, uncomfortable usage of some parts of equipment such as iRED bar, Cycle Ergometer monitoring display is figured out by the use case analysis.

Comfort and simplicity of the equipment was emphasized by some of the designers as well. According to Dr. Gill, the biggest problem of the ISS restraint devices is that they have inadequate padding on the shoulders. Also they should be adjusted for each crew member to increase the comfort. Similarly, Dr. Petersen put the emphasis on the user-friendliness and simplicity of the equipment. According to her, the harness system should be uncomplex and require low adjustment time. For extra comfort she added that the harness should include sweat remainders and avoid heat accumulation.

It is analyzed from the approaches that, user needs related with exercise equipment can be fulfilled with simple solutions in the hand with respecting the limitations of space, time and power and requirements of NASA. However, in ISS exercise areas, it is determined that comfort and simplicity of the equipment is disregarded while planning reliable and efficient equipment.

Because of microgravity, workload is created with resistant systems and loading devices that are only designed for space exercise equipment. Therefore, the equipment are unconventional, and can be difficult and time requiring to be adapted by the crew members even after long trainings on earth, in microgravity stimulated environments. However, this unconventional usage of exercise equipment can also be fun, encouraging and interesting as long as it is designed to be simple and comfortable.

Although durability of equipment is emphasized by the designers, there are still situations of broken and not operating equipment parts in the exercise areas in ISS that arouse stress among the crew members. Sometimes, the spare parts for replacing broken parts are not provided at the stations that affect the whole exercise schedules for each crew member and cause stress. In addition, although the designers emphasize the exercise equipment fitting to anthropometrical requirements, there are uncomfortable usage of some parts of the equipment in the exercise areas in ISS because of their size and form. It brings out the question of why designers disregarded them or put in to later plans or was that because of the insufficiency of the current anthropometric requirements.

In this section, the results of use case analysis and user interview related with durability and maintainability, reliability and comfort of the exercise equipment in ISS are also compared. The results are matching. However, the user stated that iRED device is reliable (See Table 4.4).

Table 4.4. User approach to the exercise equipment in ISS

	Durability and Maintainability	Reliability	Comfort
Cycle Ergometer	X	no comment	no comment
Treadmill	no comment	X	X
iRED	no comment	√	X

4.3.2. Discussion on the Interior and Environmental Issues

In terms of Interior and Environmental Analysis of the Exercise Areas for ISS, some of the designers points are common with the user point, but some of them are totally in contrast (Table 4.5).

Table 4.5. Analysis of interior and environmental factors in the exercise areas for ISS

Main Points	
Designer Approach	**User Approach**
1) Efficiency (main constraint: space)	1) Privacy
2) Location of exercise areas together with other activity areas in different modules	2) Location of exercise area separated from other activity areas in one module
3) Comfort- Appropriate environmental conditions	3) Comfort-Silent and uncrowded environment
4) Integration of leisure elements	

According to designers, space in ISS is limited, therefore it is very precious. However, until new modules are added to the station, the volume utilization becomes a very important issue. According to Dr. Gill, volumetric conflicts will occur when the station increases to a team of 6 crew members. According to the designers equipment should be designed in an efficient way to obtain more space.

According to Dr. Hagan, ISS is more than just a living place, a lot of work and experiment go at the same time. Therefore, although exercise activity is very critical, it should share the space with other activities. This is the only configuration that space is used efficiently in ISS. He added that there was the idea of locating the exercise equipment together in to one module, but it was rejected because it would not be feasible and would cause too much waste of space. Similarly, Dr. Gill and Dr. Petersen stated that the exercise equipment separated in different modules is more beneficial since volumetric conflict would occur because of astronauts` exercising parallel at the same time in the same module. They added that exercise activity is an individual and private activity and separated exercise activity in different modules supports the idea. Moreover, according to Dr. Petersen air quality will decrease in accumulated training.

On the other hand, the user needed all exercise equipment located in a common area. The reason for that is, by this way, the exercise activity would not interfere with other on going activities in the station, loads and vibrations imparted to the station structure from exercising could be isolated to one area of the station and lower air quality associated with exercising crew members could be confined to one area of the station. The user gives a suggestion of using Node modules (Node 1 and planned Nodes 2, 3) for putting exercise equipment in as they are more spacious and there is not too much ongoing activity in these modules.

As it is understood from the user answers to the questions 1, 3 and 4 (See Appendix D) that he was more comfortable and unstressed doing exercise activity in spacious, uncrowded and silent areas. For instance he stated that Zvezda module is a very crowded and noisy place to do Treadmill activity comfortably. He would prefer the Treadmill located in an area of station where there is less traffic and where it would not interfere with access to other onboard facilities. The user is uncomfortable as there is not enough space for exercising in Zvezda module.

It is ironic that designers put forward comfort issues mainly focusing on the environmental conditions that would also require power and money. In the exercise areas of ISS, air fans work in order to create healthy atmosphere. Enough temperature, humidity, oxygen and carbondioxide levels are created in the exercise areas. Dr. Gill stated that although it might be uncomfortable while exercising in areas with fans directing air flow towards the exercise equipment, they are necessary to prevent carbondioxide building up around the exercise area. Dr. Hagan stated that in ISS, appropriate conditions are supplied in the exercise areas in ISS for the health and comfort of the crew members. On the other hand, the user did not put emphasis on any environmental conditions. Rather than the air quality of the exercise areas, he is focused on the layout and density of the area. What he put the emphasis on is the preference of a silent and spacious environment where neither the activities nor the people are disturbing each other. For his exercise activity, he even preferred a module including all the exercise equipment, disregarding or not caring much about the low air quality that would occur in a single module.

As it is determined with the use cases analysis in ISS, all the activity areas in the modules are spatially and visually combined with each other. Some modules are more spacious while some have more traffic. According to Dr. Gill, although the exercise areas should be located with the other activity areas, the exercise equipment should not be located in a high traffic area. It was also analyzed from the use cases that some unsafe conditions may occur when the equipment is placed on a passageway, in a high traffic area or in the middle of a module. All the designers stated that although ISS is a tight, confined environment, it is an unusual place where the astronauts arrange themselves and manage not to bump in to each others activity while they are sharing the same module. According to Dr. Hagan, this is the only way at the moment because every meter of the ISS is being used and needed for some activity.

From the approaches of the designers it is understood that leisure elements should be integrated to the exercise areas in ISS. As Dr. Hagan stated crew members can watch movies and videotapes while exercising on the Treadmill, and read books while exercising on the Cycle Ergometer. According to Dr. Petersen, exercising should be motivating and entertainment factors should be integrated. Similarly, Dr. Gill stated that individual entertainment systems can be attached to the exercise equipment. As the user stated, he can watch movies on a laptop while exercising on the Cycle Ergometer, listen to the music or audio books while exercising on iRED, but can not do any activity while exercising on Treadmill because Zvezda module is too noisy.

The question 15 (See Appendix D) is a specific and open ended question to understand the possibility of doing other activities while exercising. As the activity areas intersect with each other causing a confined environment, doing activities at the same time may turn this negative situation in to more advantageous one. However, it is determined that the activities suggested were limited with reading books, watching movies and listening to the music. According to Dr. Petersen, these activities should be done according to individual preferences and it is better for crew members to concentrate on the exercise activity.

To sum up interior and environmental analysis of the exercise areas for ISS, it is determined from the approaches that the user needs related with the exercise area layout in the station is disregarded in ISS. This is also because of the constraint of space as the biggest limitation of designers while planning the layout and volumetric configuration of the exercise areas. The designers mainly stated the environmental conditions such as air quality, temperature quality etc. in order to create a healthy environment. However, the psychological well being of crew member should also be discussed. Behavioral needs of crew members are tried to be fulfilled by adding extra entertainment factors. Nevertheless, the confined environment causes stress to crew members and this should also be discussed as a limitation of doing comfortable, healthy and enjoyable exercise activity.

In this section, the results of use case analysis and user interview related with the interior volume utilization, layout and configuration and environmental conditions of the exercise areas in ISS are also compared. The results are matching. However, the user stated that the volume of Unity module well utilized as it is spacious (See Table 4.6).

Table 4.6. User approach to the exercise areas in ISS

	Interior Volume Utilization	Layout and Configuration in the Station	Environmental Conditions
Destiny Module	no comment	no comment	no comment
Zvezda Module	X	X	X
Unity Module	√	√	no comment

While figuring out the problems, user needs are highlighted however limitations such as space, power and time is also taken into consideration. While determining the problems, both physical and behavioral needs of the crew members are indicated. From the interviews and use case analysis, there are 7 problems introduced as related with the equipment and 5 problems introduced related with the interior and environmental conditions of the exercise areas for ISS (Tables 4.7 and 4.8). Each problem has physical and behavioral bases.

Table 4.7. Physical bases of the problems in the exercise areas in ISS

PHYSICAL BASES OF THE PROBLEMS	
Exercise equipment	**Interior and environmental conditions**
1) Undurable and broken exercise equipment cause too much maintenance time (Both three had been broken on board). 2) The exercise equipment are not modular and take too much space. 3) Harness system of the Treadmill is not robustly designed. 4) Treadmill and iRED is unreliable 5) The exercise equipment are primitive in design quality, mechanisms are not hidden, include sharp corners and are unsafe. 6) Some parts of the equipment (display of Cycle Ergometer, bar of iRED) are uncomfortable to use because of their sizes or placements. 7) The exercise equipment are unconventional and complex that their set-ups require too much time.	1) The equipment are located in the middle of the module, near the passage way or in the high traffic area of the module which is unsafe. 2) The exercise area in Zvezda has unhygienic conditions. Low quality of the exercise area may affect the eating and sleeping areas located in the same module. 3) Noise in Zvezda Module may decrease the efficiency of the exercise activity. 4) Activity areas located very close to the exercise areas cause volumetric conflicts. 5) Sharp corners near the exercise areas create unsafe conditions.

Table 4.8. Behavioral bases of the problems in the exercise areas in ISS

BEHAVIORAL BASES OF THE PROBLEMS	
Exercise equipment	**Interior and environmental conditions**
1) Broken equipment cause subject stress. 2) Confined and crowded environment of exercise areas cause subject boredom. 3) Uncomfortable loading of Treadmill harness system cause subject to be demoralized and stressed. 4) Unreliable equipment such as Treadmill and iRED cause subject disappointment. 5) The exercise equipment are unappealing because of their primitive structure that can decrease motivation of the subject. 6) Not-fitting equipment cause subject disappointment. 7) The exercise equipment are unconventional and complex, that cause subject stress.	1) Unsafe location of exercise equipment causes subject stress. 2) Unhygienic conditions of Zvezda can be demoralizing. 3) Noise in Zvezda Module affects the concentration and motivation of the exercise activity 4) Disturbance between subjects occurs as the activity areas located very close to each other, causing crowded conditions. In addition, this cause subject confinement. No private exercising causes subject stress. 5) Unsafe conditions such as sharp corners near the exercise areas can decrease motivation of the subject

4.4. Guidelines

In this part of the thesis, guidelines are prepared according to the problems defined. Previous guidelines mainly focused on human equipment interface and they are technology specific (Dudley-Rowley and Bishop, 2002). The main aim of the prepared guidelines is to understand both physical and behavioral needs of the crew members in the exercise areas in ISS. They are presented under two headings as guidelines for the exercise equipment and for the interior and environmental conditions of the exercise areas for ISS. They are prepared for designers to be helpful in designing exercise areas for space.

Guidelines for the Exercise Equipment of the Exercise Areas for ISS:

1) The exercise equipment should be durable, repaired easily and should not require too much maintanence time when it is broken. Also, spare hardware of the exercise equipment should be constantly maintained in the station.

2) The exercise equipment should be modular and stowable. They should not require too much space when they are not in use. Foldable concepts can be used.

3) The harness systems of the exercise equipment should be comfortable and easily attachable/detachable. The load on the harness systems should be well distributed to the body. More padding can be integrated to the harness systems.

4) The exercise equipment should be reliable that should stimulate the forces that body experiences in 1-g environment. They should be designed to provide collecting meaningful data to the ground during the exercise on board.

5) Sharp corners should be avoided in the form of the exercise equipment. They should be ergonomically designed and aesthetic in form.

6) The exercise equipment should be designed according to anthropometric characteristics of human in microgravity. They should be adjustable to different sizes of crew members.

7) The exercise equipment should be simple and usage of it should be easily understood. They should not require too much set up time. The usage of the equipment can be presented graphically on it.

Guidelines for Interior and Environmental Conditions of the Exercise Areas for ISS:

1) The exercise areas should not be located in the middle of the module, near passage way nor in high traffic areas.

2) The exercise areas should have systems to relieve sweating and increase in carbondioxide. The exercise areas should not be located close to eating and sleeping areas. Low quality air caused by the exercise activities should not flow into eating and sleeping areas. Air fans can be integrated near the exercise equipment.

3) The exercise areas should be silent and should not be located close to sleeping and working areas not to cause noise disturbance. The systems absorbing noise can be integrated in the exercise areas.

4) Enough space should be created for each exercise activity. The exercise areas should not be tight and confined. More privacy of the crew members should be provided during exercises.

5) Sharp corners should be avoided near the exercise areas.

5. CONCLUSION

According to the findings of the study, some user needs in the exercise areas in ISS are disregarded. The main reason for this is the constraints of space, time and power imposed by the station. The designers put the main emphasis on these constraints. Therefore, the design requirements that block these constraints are cancelled. However, it is determined that design solutions can be offered both regarding the constraints imposed by the station and the user needs in this study.

In the study, some problems are figured out affecting both the physiological and psychological well being of the crew members. While determining these problems for the equipment, the interior and environmental factors of the exercise areas of the station, the relationships among the crew members and other activities besides the exercise activities are taken into consideration. Each problem has to be analyzed according both to the physical and behavioral bases.

Some guidelines are suggested for preventing these problems in further design process of the exercise areas in ISS. These guidelines can be helpful in foreseeing new ways of planning exercise areas in new modules scheduled to fly to ISS or for other space vehicles or habitats. They can also be helpful in designing for further missions to Mars where crew members have to stay in space for longer durations. However, there are concepts like artificial gravity or partial gravity that are studied by the engineers that the future conditions of space may look more domestic and exercising in space may not be that much critical compared to today's conditions in space.

For this study, there is the limitation of the lack of user input to the analysis of exercise areas in ISS since internal regulations of the agencies forbid the crew members to be questioned without formal approval. Moreover, it is understood from the study that research related to the exercise areas of the station mostly focus on the equipment reliability, efficiency and technology. For further studies, more in-depth qualitative studies that aim to understand user needs in exercise areas of the station are necessary. By this way, the physical and behavioral needs of the users can be determined in order to increase the efficiency, productivity, health and morale of the crew members. Alternative ways of satisfying them and respecting the regulations of the station can be provided.

REFERENCES

Allen, C. S., Burnett, R., Charles, J., Cucinotta, F., Fullerton, R., Goodman, F. R., Griffith, A. D., Kosmo, J., Perchonok, M., Railsback, J., Rajulu, S., Stilwell, D., Thomas, G., Tri, T., Joshi, J., Wheeler, R., Rudisill, M., Wilson, J., Mueller, A., Simmons, A. (2003). *Guideliness and Capabilities for Designing Human Missions*. NASA/TM-2003-210785. Johnson Space Center, Texas.

Boeing Company, NASA and USA. (1999). *The International Space Station*. Retrieved November 21, 2006, from http://www.shuttlepresskit.com/ISS_OVR/

Boeing Company. (2006a). *The International Space Station (ISS)*. Retrieved November 21, 2006, from http://www.boeing.com/defense-space/space/spacestation/

Boeing Company. (2006b). *Space Exploration /International Space Station Backgrounder*. Retrieved November 21, 2006, from http://www.boeing.com/defense-space/space/spacestation/docs/ISS_overview.pdf

Cavanagh P. R., Maender, C., Rice, A. J., Gene, K. O., Ochia, R.S. and Snedeker J. G. (2004). Lower-extremity loading during exercise on the International Space Station. *Transactions of the Annual Meeting of the Orthopedic Research Society*. No.0395.

Clément, G. (2005). The maintenance of physiological function in humans during spaceflight. *International SportMed Journal*, 6 (4), 185-198.

Collins, P., Kuwahara, S., Fukuoka, T., Nishimura, T. (1997). Design and Construction of Zero-Gravity Gymnasium. Journal of Aerospace Engineering. 10(2), 94-98. Also available: http://www.spacefuture.com/archive/design_and_construction_of_zero_gravity_gymnasium.shtml

CSA. (2006). *Exercising in Space*. Retrieved March 15, 2007, from http://www.space.gc.ca/asc/eng/astronauts/living_exercising.asp

Dominoni, A. (2002). Designing for Space. *AIAA Space Architecture Symposium, 10 October 2002*. AIAA 2002-6108. (1p). Also available: http://pdf.aiaa.org/preview/CDReadyMSAS02_698/PV2002_6108.pdf

Dudley-Rowley, M. and Bishop S.L. (2002). Extended Mission Systems Integration standards for the Human-Environment and Human-Human Interfaces. *53rd International Astronautical Congress (IAC) of the International Astronautical Federation (IAF), International Academy of Astronautics (IAA), and International Institute of Space Law (IISL), Human Factors for Long Duration Spaceflight, World Space Congress*, *1 October 2002*.(p.1-11). AIAA 2002-6110. Houston, Texas.

Dudley-Rowley, M., Cohen M. M. and Flores, P. (2004). 1985 NASA- Rockwell Space Station Crew Safety Study: Results from MIR. *Aviakosm Ekology Med*, 38 (1), 15-28.

Dunn, M. (1995). NASA's long-running pipe dream becoming reality. Greenville, NC: *The Daily Reflector*, A4.

ESA. (2000). *Technical Description of the Zvezda Module*. Retrieved March 20, 2007, from http://www.spaceflight.esa.int/file.cfm?filename=mopzvezdamod

Fitss D.J. (2002). International Space Station (ISS) Internal Volume Configuration (IVC). *AIAA Space Architecture Symposium*. Houston, Texas.

Hagan, R.D. and Schaffner G. (2002). Exercise Countermeasures Used During Space Flight. *EMBS/BMES Conference, Proceedings of the Second Joint.* Houston, Texas.

Harrison, A. A., Caldwell, B. and Struthers, N.J. (1988). Incorporation of privacy elements in space station design. *Unpublished final report*. N88-21242. NASA-Ames Research Center, Moffett Field, California.

Harrison, A. A. (2004). New Directions in the behavioral health: A workshop integrating research and application. NASA NAG 9-1572.

International Space Station. Photo. National Space Science Data Center. Retrieved November 24, 2006, from http://nssdc.gsfc.nasa.gov/image/spacecraft/iss.jpg

ISS Configuration. Photo. National Space Science Data Center. Retrieved November 24, 2006, from http://www.nasa.gov/images/content/143942main_ISS_config.jpg

ISS Program Office (2001). *ISS MER Status Report 9 March 2001*. Johnson Space Center. Retrieved March 15, 2007 from, http://www.spaceref.com/news/viewsr.html?pid=2385

ISS01-E-5083. Photo. NASA Space Station Gallery. Retrieved November 24, 2006, from http://spaceflight.nasa.gov/gallery/images/station/crew-1/hires/iss01e5083.jpg

ISS002-E-5478. Photo. NASA Space Station Gallery. Retrieved November 24, 2006, from http://spaceflight.nasa.gov/gallery/images/station/crew-2/hires/iss002e5478.jpg

ISS003-E-5218. Photo. NASA Space Station Gallery. Retrieved November 24, 2006, from http://spaceflight.nasa.gov/gallery/images/station/crew-3/hires/iss003e5218.jpg

ISS008-E-21996. Photo. NASA Space Station Gallery. Retrieved November 24, 2006, from http://spaceflight.nasa.gov/gallery/images/station/crew-9/hires/iss008e21996.jpg

ISS010-E-05343. Photo. NASA Space Station Gallery. Retrieved November 24, 2006, from http://spaceflight.nasa.gov/gallery/images/station/crew-10/hires/iss010e05343.jpg

ISS010-E-24914. Photo. NASA Space Station Gallery. Retrieved November 24, 2006, from http://spaceflight.nasa.gov/gallery/images/station/crew-11/hires/iss010e24914.jpg

ISS011-E-1280. Photo. NASA Space Station Gallery. Retrieved November 24, 2006, from http://spaceflight.nasa.gov/gallery/images/station/crew-11/hires/iss011e12809.jpg

ISS011-E-05137. Photo. NASA Space Station Gallery. Retrieved November 24, 2006, from http://www.nasa.gov/images/content/114308main_iss011e05137.jpg

ISS011-E-09822. Photo. NASA Space Station Gallery. Retrieved November 24, 2006, from http://spaceflight.nasa.gov/gallery/images/station/crew-11/hires/iss011e09822.jpg

ISS012-E-14206. Photo. NASA Space Station Gallery. Retrieved November 24, 2006, from http://spaceflight.nasa.gov/gallery/images/station/crew-12/hires/iss012e14206.jpg

ISS012-E-18233. Photo. NASA Space Station Gallery. Retrieved November 24, 2006, from http://spaceflight.nasa.gov/gallery/images/station/crew-12/hires/iss012e18233.jpg

ISS012-E-18246. Photo. NASA Space Station Gallery. Retrieved November 24, 2006, from http://spaceflight.nasa.gov/gallery/images/station/crew-12/hires/iss012e18246.jpg

ISS012-E-22728. Photo. NASA Space Station Gallery. Retrieved November 24, 2006, from http://spaceflight.nasa.gov/gallery/images/station/crew-12/hires/iss012e22728.jpg)

ISS012-E-22729. Photo. NASA Space Station Gallery. Retrieved November 24, 2006, from http://spaceflight.nasa.gov/gallery/images/station/crew-12/hires/iss012e22729.jpg

ISS012-E-22732. Photo. NASA Space Station Gallery. Retrieved November 24, 2006, from http://spaceflight.nasa.gov/gallery/images/station/crew-12/hires/iss012e22732.jpg

ISS012-E-23142. Photo. NASA Space Station Gallery. Retrieved November 24, 2006, from http://spaceflight.nasa.gov/gallery/images/station/crew-12/hires/iss012e23142.jpg

ISS013-E-08032. Photo. NASA Space Station Gallery. Retrieved November 24, 2006, from http://spaceflight.nasa.gov/gallery/images/station/crew-3/hires/iss013e08032.jpg

ISS013-E-08035. Photo. NASA Space Station Gallery. Retrieved November 24, 2006, from http://stardate.org/images/radio/iss/iss013e08035.jpg

ISS013-E-08046. Photo. NASA Space Station Gallery. Retrieved November 24, 2006, from http://spaceflight.nasa.gov/gallery/images/station/crew-13/hires/iss013e08046.jpg

ISS013-E-08185. Photo. NASA Space Station Gallery. Retrieved November 24, 2006, from http://spaceflight.nasa.gov/gallery/images/station/crew-13/hires/iss013e08185.jpg

ISS013-E-17268. Photo. NASA Space Station Gallery. Retrieved November 24, 2006, from http://spaceflight.nasa.gov/gallery/images/station/crew-13/hires/iss013e17268.jpg

ISS013-E-40013. Photo. NASA Space Station Gallery. Retrieved November 24, 2006, from http://spaceflight.nasa.gov/gallery/images/station/crew-3/hires/iss003e5218.jpg

Japan Aerospace Exploration Agency (JAXA). (2003). *History of the ISS Project*. Retrieved February 15, 2007, from http://iss.sfo.jaxa.jp/iss/history/index_e.html

JSC2000-E-26922. Illustration. NASA Space Station Gallery. Retrieved November 24, 2006, from http://spaceflight.nasa.gov/gallery/images/station/servicemodule/hires/jsc2000e26922.jpg

JSC2000-E-26926. Illustration. NASA Space Station Gallery. Retrieved November 24, 2006, from http://spaceflight.nasa.gov/gallery/images/station/servicemodule/hires/jsc2000e26926.jpg

Lang, T., LeBlanc, A., Evans, H., Lu, Y., Gennant, H., Yu, A. (2004). Cortical and trabecular bone mineral loss from the spine and hip in long-duration spaceflight, *Journal of Bone and Mineral Research*, 19(6), 1006-12.

Lindsey, P. F. (1998). *Computer Simulation and the Design of the Interior of NASA's Habitation Module for the International Space Station*. Retrieved March 22, 2007, from http://scholar.lib.vt.edu/ejournals/JDC/Fall-1998/lindsey/module2.html

Looney, P. (2001). NASA R&D in the FY 2001 Budget. *American Association for the Advancement of Science (AAAS) Report*, 25, 123-130. Also available: http://www.aaas.org/spp/rd/contents.htm

Marquez, J. J., Oman, C. M., Liu, A.M. (2004). You-Are Here Maps for International Space Station: Approach and Guidelines. *Porc. of the 34th International Conference on Environmental Systems*. Colorado Springs, CO.

Merriam, S.B. (1998). *Case study research education: A qualitative approach*. San Francisco: Jossey-Bass.

Moore, A. D., Amonette, W. E., Bentley J. R., Rapley, M. G., Blazine, K. L., Loehr J. A., Collier K. R., Boettcher C. R., Skrocki J. S., Hohmann R. J. and Korth, D. W. (2004). *Results of the International Space Station Interim Resistance Exercise Device Man-in-the-Loop Test*. Houston, Texas. Retrieved April 24, 2007, from http://ston.jsc.nasa.gov/collections/TRS/_techrep/TP-2004-212062.pdf

Morphew, M. E. (2001). Psychological and Human Factors in Long Duration Spaceflight. *McGill Journal of Medicine* (*MJM)*, 6, 74-80.

Musson, D. M. (2000). A proposal for the integration of behavioral research in to International Space Station Operations. *Proceedings of the Space Technology and Applications International Forum.* Also available: http://homepage.psy.utexas.edu/Homepage/Group/HelmreichLAB/Publications/pubfiles/pub251.pdf

NASA. (1995). *Man-Systems Integration Standards*. NASA-STD-3000/VOL1. Also available: http://standards/msfc.nasa.gov/default.htm

NASA. (1998). *International Space Station Familiarization*. Mission Operations Directorate Space Flight Training Division, Johnson Space Center, Texas.

NASA. (2000). *International Space Station Evolution Data Book*. NASA/SP-2000-6109/VOL1. Hampton, Virginia.

NASA. (2006a). *Space Station Assembly*. Retrieved March 20, 2007, from http://www.nasa.gov/mission_pages/station/structure/index.html

NASA. (2006b). *The Role of Exercise in Space*. Retrieved November 21, 2006, from http://weboflife.nasa.gov/currentResearch/currentResearchGeneralArchives/workout.htm

NASA. (2006c). *Exercising in Space*. Retrieved November 21, 2006, from http://www.space.gc.ca/asc/eng/astronauts/living_exercising.asp

NASA. (2006d). *Exercising Astronauts*. Retrieved December 22, 2006, from http://liftoff.msfc.nasa.gov/academy/astronauts/exercise.html

NASA HQ (2006). *NASA Space Station On-Orbit Status 13 July 2006*. Retrieved March 15, 2007, from http://www.spaceref.com/news/viewsr.html?pid=21341

NASA HQ (2007). *NASA Reference Guide to the International Space Station* Retrieved March 15, 2007, from http://www.spaceref.com/news/viewsr.html?pid=23098

NASA Human Research Program (2006). *Exercise Countermeasures*. Retrieved November 21, 2006, from http://exploration.grc.nasa.gov/Exploration/Advanced/Human/Exercise/

NASA Human Space Flight. (2003). Transhab Concept. Retrieved February 01, 2007, from http://spaceflight.nasa.gov/history/station/transhab/index.html

NASA Human Space Flight. (2006). *History of ISS*. Retrieved February 01, 2007, from http://spaceflight.nasa.gov/history/station/index.html

National Space Development Agency of Japan (NASDA), Canadian Space Agency (CSA), Italian Space Agency (ASI), European Space Agency (ESA) and NASA. (1999). *International Space Station Flight Crew Integration Standard*. NASA-STD-3000/T. REV C. Houston, Texas.

Nikon, D. (1986). Space Station Group Activities Habitability Module Study. *NASA Contractor Report 4010*.

Oberg, J. (2005). *International Space Station*. World Book Online Reference Center. World Book, Inc. Retrieved December 12, 2006, from http://www.nasa.gov/worldbook/intspacestation_worldbook.html

Ohshima, H., Mizuno, K. and Kawashima, S. (2006). Effects of Space Flight on Bone and Muscle, and Astronaut Exercise Program. *Japanese Journal of Rehabilitation Medicine*, 43(3), 186-194.

Parma, G. (2002). Treadmill with Vibration Isolation System (TVIS) Repair Hardware. *9AFRR. Special Topic International Space Station Program,*19-23

Reiter, T. (2006). *ESA ISS Activities Look Ahead Report No. 20.* Retrieved February, 2007, from http://esamultimedia.esa.int/docs/astrolab/report-8-week-18-Sep-06.doc

Rhatigan, J., Robinson, J. A. and Sawin, C.F. (2005). *Exploration-Related Research on ISS: Connecting Science Results to Future Missions*. NASA/TP.2005–213166. Houston, Texas. Also available: http://techreports.larc.nasa.gov/cgi-bin/TRS

SICSA (Sasakawa International Center for Space Architecture) Lecture Series Report. (1988). Living in Space: Considerations for Planning Human Habitats beyond Earth. *Outreach*, 1(9). Also available: http://www.sicsa.uh.edu/index.php?option=com_docman&task=doc_details&gid=27

SICSA (Sasakawa International Center for Space Architecture) Lecture Series Report. (2006a). Part II: Human Adaptation and Safety in Space. Retrieved January 6, 2007, from http://www.sicsa.uh.edu/index.php?option=com_docman&task=doc_details&gid=2

SICSA (Sasakawa International Center for Space Architecture) Lecture Series Report. (2006b). Part IV: Space Mission and Facility Architectures. Retrieved January 6, 2007, from http://www.sicsa.uh.edu/index.php?option=com_docman&task=doc_details&gid=4&Itemid=59

STS105-304-025. Photo. NASA Space Station Gallery. Retrieved November 24, 2006, from http://spaceflight.nasa.gov/gallery/images/shuttle/sts-105/hires/sts105-304-025.jpg

US Laboratory Module. Illustration. Google. Retrieved 6 January, 2007, from http://images.google.com.tr/imgres?imgurl=http://mek.kosmo.cz/pil_lety/mezinar/iss/moduly/destiny/labcut.gif&imgrefurl=http://mek.kosmo.cz/pil_lety/mezinar/iss/moduly/destiny/index.htm&h=514&w=640&sz=50&hl=tr&start=5&um=1&tbnid=60nPHFMuhXbxDM:&tbnh=110&tbnw=137&prev=/images%3Fq%3Ddestiny%2Bin%2BISS%26svnum%3D10%26um%3D1%26hl%3Dtr

Vogler, A. and Jorgensen J. (2004). Windows to the world- Doors to space- A reflection on the psychology and anthropology of space architecture. *Space: Science, Technology and the Arts (7th Workshop on Space and the Arts)*. ESA/ ESTEC, Noordwijk, The Netherlands.

Washam, C. (2004). New technology sheds light on bone loss in space. *Space Research*, 25, 214-15. Also available: http://spaceresearch.nasa.gov/general_info/spaceresearchnews.html

Watt, D., Lefebvre, L. (2001). Effects of altered gravity on spinal cord excitability, first research on the International Space Station. *AIAA Conference on International Space Station Utilization*, *October 15-18*. AIAA 2001-4939.

Watt, D. (2003). Effects of altered gravity on spinal cord excitability. *Proceedings, Bioastronautics Investigators' Workshop*. (1p). Also available: http://www.dsls.usra.edu/meetings/bio2003/pdf/Neurovestibular/2054Watt.pdf

Whitson, P.A., Pietrzyk, R.A., Sams, C.F. (1999). Space flight and the risk of renal stones. *Journal of Gravitational Physiology*, 6(1), 87-88.

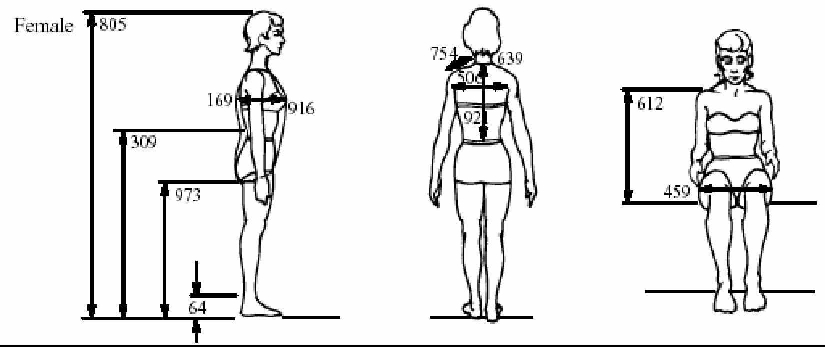
Wikipedia. (2007). *International Space Station*. Retrieved November 21, 2006, from http://en.wikipedia.org/wiki/International_Space_Station

Yahoo. (2001). *How do astronauts sleep in the International Space Station? Do they use beds?* Retrieved May 05, 2007, from http://ask.yahoo.com/20010830.html

APPENDIX A

The tables in Appendix A are taken from International Space Station Flight Crew Standard that is prepared by National Space Development Agency of Japan (NASDA), Canadian Space Agency (CSA), Italian Space Agency (ASI), European Space Agency (ESA) and NASA in 1999.

Table A.1. Body size of the 40-year-old Japanese female for year 2000 in 1-g conditions (1of 12)

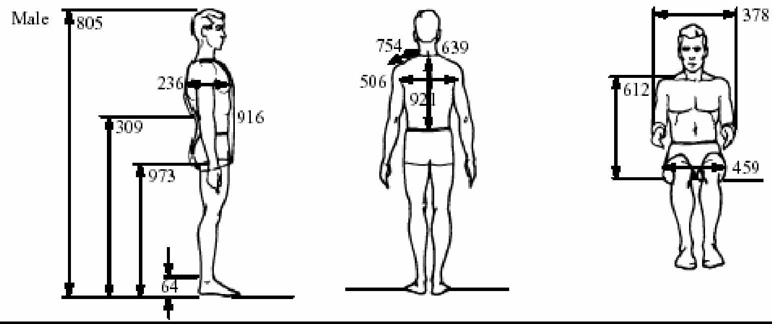


Notes	No.	Dimension	5th Percentile cm (inches)	50th Percentile cm (inches)	95th Percentile cm (inches)
1	805	Stature	148.9 (58.6)	157.0 (61.8)	165.1 (65.0)
1	973	Wrist height	70.8 (27.9)	76.6 (30.2)	82.4 (32.4)
	64	Ankle height	5.2 (2.0)	6.1 (2.4)	7.0 (2.8)
1	309	Elbow height	92.8 (36.5)	98.4 (38.8)	104.1 (41.0)
	169	Bust depth	17.4 (6.8)	20.5 (8.1)	23.6 (9.3)
1	916	Vertical trunk circumfrence	136.9 (53.9)	146.0 (57.5)	155.2 (61.1)
1, 2	612	Midshoulder height, sitting			
	459	Hip breadth, sitting	30.4 (12.0)	33.7 (13.3)	37.0 (14.6)
1	921	Waist back	35.2 (13.9)	38.1 (15.0)	41.0 (16.1)
	506	Interscye	32.4 (12.8)	35.7 (14.1)	39.0 (15.4)
	639	Neck circumfrence	34.5 (13.6)	37.1 (14.6)	39.7 (15.6)
	754	Shoulder length	11.3 (4.4)	13.1 (5.1)	14.8 (5.8)

General Notes:
(a) Gravity conditions – the dimensions apply to a 1–G condition only. Dimension expected to change significantly due to microgravity are marked.
(b) Measurement data – the number adjacent to each of the dimension are reference codes. The same codes are in NASA RP 1024, Volume 2. NASA RP 1024, Volume 2 provides additional data for these measurements plus an explanation of the measurement technique.

Notes for application of dimensions to microgravity conditions:
(1) Stature increases approximately 3 percent over the first 3 to 4 days in weightlessness (See NASA–STD–3000, Volume I, Figure 3.2.3.1–2, for information). Almost all of this change appears in the spinal column and thus affects (increases) other related dimensions, such as sitting height (buttock–vertex), shoulder height –sitting, eye height, sitting, and all dimensions that include the spine.
(2) Sitting height would be better named as buttock–vertex in microgravity conditions, unless the crewmember were measured with a firm pressure on shoulders pressing him or her against a fixed, flat "sitting" support surface. All sitting dimensions (vertex, eye, shoulder, and elbow) increase in weightlessness by two changes:
(a) Relief of pressure on the buttock surfaces (estimated increase of 1.3 to 2.0 cm (0.5 to 0.8 inches).
(b) Extension of the spinal column as explained in note (1) above (3 percent of stature on ground).

Table A.2. Body size of the 40-year-old American male for year 2000 in 1-g conditions (2 of 12)



Notes	No.	Dimension	5th Percentile cm (inches)	50th Percentile cm (inches)	95th Percentile cm (inches)
1	805	Stature	169.7 (68.8)	179.9 (70.8)	190.1 (74.8)
1	973	Wrist height			
	64	Ankle height	12.0 (4.7)	13.9 (5.5)	15.8 (6.2)
1	309	Elbow height			
	169	Bust depth	21.8 (8.6)	25.0 (9.8)	28.2 (11.1)
1	916	Vertical trunk circumfrence	158.7 (62.5)	170.7 (67.2)	182.6 (71.9)
1, 2	612	Midshoulder height, sitting	60.8 (23.9)	65.4 (25.7)	70.0 (27.5)
	459	Hip breadth, sitting	34.6 (13.6)	38.4 (15.1)	42.3 (16.6)
1	921	Waist back	43.7 (17.2)	47.6 (18.8)	51.6 (20.3)
	506	Interscye	32.9 (13.0)	39.2 (15.4)	45.4 (17.9)
	639	Neck circumfrence	35.5 (14.0)	38.7 (15.2)	41.9 (16.5)
	754	Shoulder length	14.8 (5.8)	16.9 (6.7)	19.0 (7.5)
	378	Forearm–forearm breadth	48.8 (19.2)	55.1 (21.7)	61.5 (24.2)

General Notes:

(a) Gravity conditions – the dimensions apply to a 1–G condition only. Dimension expected to change significantly due to microgravity are marked.

(b) Measurement data – the number adjacent to each of the dimension are reference codes. The same codes are in NASA RP 1024, Volume 2. NASA RP 1024, Volume 2 provides additional data for these measurements plus an explanation of the measurement technique.

Notes for application of dimensions to microgravity conditions:

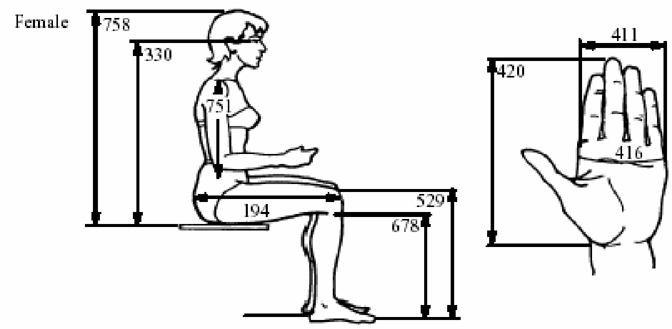
(1) Stature increases approximately 3 percent over the first 3 to 4 days in weightlessness (See NASA–STD–3000, Volume I, Figure 3.2.3.1–2, for information). Almost all of this change appears in the spinal column and thus affects (increases) other related dimensions, such as sitting height (buttock–vertex), shoulder height –sitting, eye height, sitting, and all dimensions that include the spine.

(2) Sitting height would be better named as buttock–vertex in microgravity conditions, unless the crewmember were measured with a firm pressure on shoulders pressing him or her against a fixed, flat "sitting" support surface. All sitting dimensions (vertex, eye, shoulder, and elbow) increase in weightlessness by two changes:

(a) Relief of pressure on the buttock surfaces (estimated increase of 1.3 to 2.0 cm (0.5 to 0.8 inches).

(b) Extension of the spinal column as explained in note (1) above (3 percent of stature on ground).

Table A.3. Body size of the 40-year-old Japanese female for year 2000 in 1-g conditions (3 of 12)



Notes	No.	Dimension	5th Percentile cm (inches)	50th Percentile cm (inches)	95th Percentile cm (inches)
1, 2	758	Sitting height	78.3 (30.8)	84.8 (33.4)	91.2 (35.9)
1, 2	330	Eye height, sitting	68.1 (26.8)	73.8 (29.1)	79.8 (31.4)
4	529	Knee height, sitting	41.6 (16.4)	45.8 (16.4)	49.5 (19.5)
	678	Popliteal height	34.7 (13.6)	38.3 (15.1)	41.9 (16.5)
	751	Shoulder–elbow length	27.2 (10.7)	29.8 (11.7)	32.4 (12.8)
	184	Buttock–knee length	48.9 (19.2)	53.3 (21.0)	57.8 (22.7)
	420	Hand length	15.8 (6.2)	17.2 (6.8)	18.7 (7.3)
	411	Hand breadth	6.9 (2.7)	7.8 (3.1)	8.6 (3.4)
	416	Hand circumference	17.9 (6.5)	17.9 (7.0)	19.3 (7.6)

General Notes:

(a) Gravity conditions – the dimensions apply to a 1–G condition only. Dimension expected to change significantly due to microgravity are marked.

(b) Measurement data – the number adjacent to each of the dimension are reference codes. The same codes are in NASA RP 1024, Volume 2. NASA RP 1024, Volume 2 provides additional data for these measurements plus an explanation of the measurement technique.

Notes for application of dimensions to microgravity conditions:

(1) Stature increases approximately 3 percent over the first 3 to 4 days in weightlessness (See NASA–STD–3000, Volume I, Figure 3.2.3.1–2, for information). Almost all of this change appears in the spinal column and thus affects (increases) other related dimensions, such as sitting height (buttock–vertex), shoulder height –sitting, eye height, sitting, and all dimensions that include the spine.

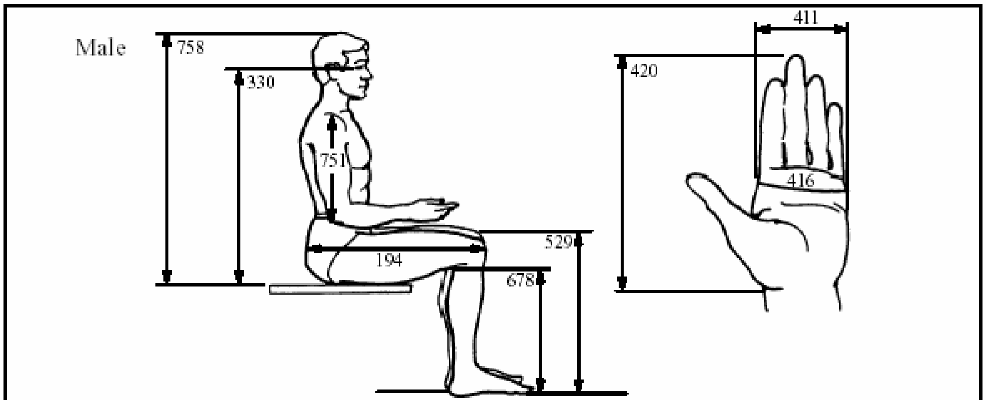
(2) Sitting height would be better named as buttock–vertex in microgravity conditions, unless the crewmember were measured with a firm pressure on shoulders pressing him or her against a fixed, flat "sitting" support surface. All sitting dimensions (vertex, eye, shoulder, and elbow) increase in weightlessness by two changes:

(a) Relief of pressure on the buttock surfaces (estimated increase of 1.3 to 2.0 cm (0.5 to 0.8 inches).

(b) Extension of the spinal column as explained in note (1) above (3 percent of stature on ground).

(4) Knee height–sitting may increase slightly in microgravity due to relief of the pressure on the heel which it occurs when it is measured on the ground. The increase is probably not more than 2 to 3 mm (0.1 inch).

Table A.4. Body size of the 40-year-old American male for year 2000 in 1-g conditions (4 of 12)



Notes	No.	Dimension	5th Percentile cm (inches)	50th Percentile cm (inches)	95th Percentile cm (inches)
1, 2	758	Sitting height	88.9 (35.0)	94.2 (37.1)	99.5 (39.2)
1, 2	330	Eye height, sitting	76.8 (30.3)	81.9 (32.2)	86.9 (34.2)
4	529	Knee height, sitting	52.6 (20.7)	56.7 (22.3)	60.9 (24.0)
	678	Popliteal height	40.6 (16.0)	44.4 (17.5)	48.1 (19.0)
	751	Shoulder–elbow length	33.7 (13.3)	36.6 (14.4)	39.4 (15.5)
	184	Buttock–knee length	56.8 (22.4)	61.3 (24.1)	65.8 (25,9)
	420	Hand length	17.9 (7.0)	19.3 (7.6)	20.6 (8.1)
	411	Hand breadth	8.2 (3.2)	8.9 (3.5)	9.6 (3.8)
	416	Hand circumference	20.3 (8.0)	21.8 (8.6)	23.4 (9.2)

General Notes:

(a) Gravity conditions – the dimensions apply to a 1–G condition only. Dimension expected to change significantly due to microgravity are marked.

(b) Measurement data – the number adjacent to each of the dimension are reference codes. The same codes are in NASA RP 1024, Volume 2. NASA RP 1024, Volume 2 provides additional data for these measurements plus an explanation of the measurement technique.

Notes for application of dimensions to microgravity conditions:

(1) Stature increases approximately 3 percent over the first 3 to 4 days in weightlessness (See NASA–STD–3000, Volume I, Figure 3.2.3.1–2, for information). Almost all of this change appears in the spinal column and thus affects (increases) other related dimensions, such as sitting height (buttock–vertex), shoulder height –sitting, eye height, sitting, and all dimensions that include the spine.

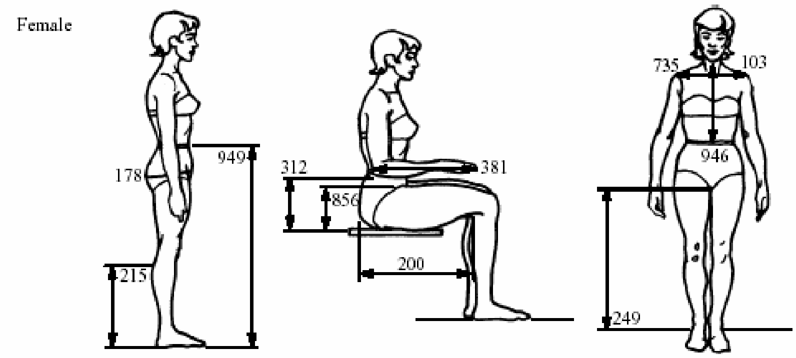
(2) Sitting height would be better named as buttock–vertex in microgravity conditions, unless the crewmember were measured with a firm pressure on shoulders pressing him or her against a fixed, flat "sitting" support surface. All sitting dimensions (vertex, eye, shoulder, and elbow) increase in weightlessness by two changes:

(a) Relief of pressure on the buttock surfaces (estimated increase of 1.3 to 2.0 cm (0.5 to 0.8 inches).

(b) Extension of the spinal column as explained in note (1) above (3 percent of stature on ground).

(4) Knee height–sitting may increase slightly in microgravity due to relief of the pressure on the heel which it occurs when it is measured on the ground. The increase is probably not more than 2 to 3 mm (0.1 inch).

Table A.5. Body size of the 40-year-old Japanese female for year 2000 in 1-g conditions (5 of 12)



Notes	No.	Dimension	5th Percentile cm (inches)	50th Percentile cm (inches)	95th Percentile cm (inches)
	949	Waist height	90.1 (35.5)	96.7 (38.1)	103.4 (40.7)
	249	Crotch height	65.2 (25.7)	70.8 (27.8)	76.1 (30.0)
	215	Calf height	25.5 (10.0)	28.9 (11.4)	32.3 (12.7)
	103	Biacromial breadth	32.4 (12.8)	35.7 (14.1)	39.0 (15.40
1	946	Waist front			
	735	Scye circumference	32.3 (12.7)	36.1 (14.2)	39.8 (15.7)
	178	Buttock circumference	79.9 (31.5)	87.1 (34.3)	94.3 (37.1)
1, 2	312	Elbow rest height	20.7 (8.2)	25.0 (9.9)	29.3 (11.5)
	856	Thigh clearance	11.2 (4.4)	12.9 (5.1)	14.5 (5.7)
	381	Forearm–hand length	37.3 (14.7)	41.7 (18.4)	44.6 (17.6)
	200	Buttock–popliteal length	37.9 (14.9)	41.7 (18.4)	45.5 (17.9)

General Notes:

(a) Gravity conditions – the dimensions apply to a 1–G condition only. Dimension expected to change significantly due to microgravity are marked.

(b) Measurement data – the number adjacent to each of the dimension are reference codes. The same codes are in NASA RP 1024, Volume 2. NASA RP 1024, Volume 2, provides additional data for these measurements plus an explanation of the measurement technique.

Notes for application of dimensions to microgravity conditions:

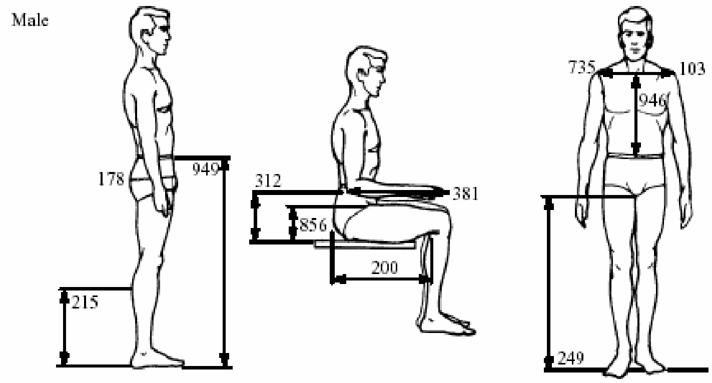
(1) Stature increases approximately 3 percent over the first 3 to 4 days in weightlessness (See NASA–STD–3000, Volume I, Figure 3.2.3.1–2, for information). Almost all of this change appears in the spinal column and thus affects (increases) other related dimensions, such as sitting height (buttock–vertex), shoulder height –sitting, eye height, sitting, and all dimensions that include the spine.

(2) Sitting height would be better named as buttock–vertex in microgravity conditions, unless the crewmember were measured with a firm pressure on shoulders pressing him or her against a fixed, flat "sitting" support surface. All sitting dimensions (vertex, eye, shoulder, and elbow) increase in weightlessness by two changes:

(a) Relief of pressure on the buttock surfaces (estimated increase of 1.3 to 2.0 cm (0.5 to 0.8 inches).

(b) Extension of the spinal column as explained in note (1) above (3 percent of stature on ground).

Table A.6. Body size of the 40-year-old American male for year 2000 in 1-g conditions (6 of 12)



Notes	No.	Dimension	5th Percentile cm (inches)	50th Percentile cm (inches)	95th Percentile cm (inches)
	949	Waist height	100.4 (39.5)	108.3 (42.6)	116.2 (45.7)
	249	Crotch height	79.4 (31.3)	85.4 (34.0)	93.3 (36.7)
	215	Calf height	32.5 (12.8)	36.2 (14.3)	40.0 (15.7)
	103	Biacromial breadth	37.9 (14.9)	41.1 (16.2)	44.3 (17.5)
1	946	Waist front	37.2 (14.6)	40.9 (16.1)	44.6 (17.5)
	735	Scye circumference	44.4 (17.5)	49.0 (19.3)	53.6 (21.1)
	178	Buttock circumference	91.0 (35.8)	100.2 (39.4)	109.4 (43.1)
1, 2	312	Elbow rest height	21.1 (8.3)	25.4 (10.0)	29.7 (11.7)
	856	Thigh clearance	14.5 (5.7)	16.8 (6.6)	19.1 (7.5)
	381	Forearm–hand length			
	200	Buttock–popliteal length	46.9 (18.5)	51.2 (20.2)	55.5 (21.9)

General Notes:

(a) Gravity conditions – the dimensions apply to a 1–G condition only. Dimension expected to change significantly due to microgravity are marked.

(b) Measurement data – the number adjacent to each of the dimension are reference codes. The same codes are in NASA RP 1024, Volume 2. NASA RP 1024, Volume 2 provides additional data for these measurements plus an explanation of the measurement technique.

Notes for application of dimensions to microgravity conditions:

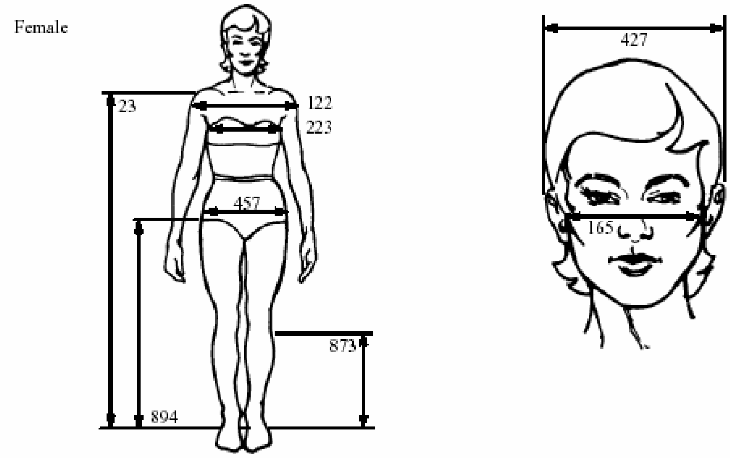
(1) Stature increases approximately 3 percent over the first 3 to 4 days in weightlessness (See NASA–STD–3000, Volume I, Figure 3.2.3.1–2, for information). Almost all of this change appears in the spinal column and thus affects (increases) other related dimensions, such as sitting height (buttock–vertex), shoulder height –sitting, eye height, sitting, and all dimensions that include the spine.

(2) Sitting height would be better named as buttock–vertex in microgravity conditions, unless the crewmember were measured with a firm pressure on shoulders pressing him or her against a fixed, flat "sitting" support surface. All sitting dimensions (vertex, eye, shoulder, and elbow) increase in weightlessness by two changes:

(a) Relief of pressure on the buttock surfaces (estimated increase of 1.3 to 2.0 cm (0.5 to 0.8 inches).

(b) Extension of the spinal column as explained in note (1) above (3 percent of stature on ground).

Table A.7. Body size of the 40-year-old Japanese female for year 2000 in 1-g conditions (7 of 12)



Notes	No.	Dimension	5th Percentile cm (inches)	50th Percentile cm (inches)	95th Percentile cm (inches)
1, 3	23	Acromial (shoulder) height	119.6 (47.1)	127.1 (50.0)	134.5 (53.0)
	894	Trochanteric height	71.0 (28.0	76.7 (30.2)	82.4 (32.5)
	873	Tibiale height	35.9 (14.1)	39.3 (15.5)	42.7 (16.8)
	122	Bideltoid (shoulder) height	35.6 (14.0)	38.9 (15.3)	42.1 (16.6)
	223	Chest breadth	24.5 (9.7)	26.8 (10.5)	29.0 (11.4)
	457	Hip breadth	30.5 (12.0)	32.9 (12.9)	35.3 (13.9)
	165	Bizygomatic (face) breadth	13.3 (5.2)	14.5 (5.7)	15.7 (6.2)
	427	Head breadth	14.4 (5.7)	15.6 (6.1)	16.8 (6.6)

General Notes:

(a) Gravity conditions – the dimensions apply to a 1–G condition only. Dimension expected to change significantly due to microgravity are marked.

(b) Measurement data – the number adjacent to each of the dimension are reference codes. The same codes are in NASA RP 1024, Volume 2. NASA RP 1024, Volume 2 provides additional data for these measurements plus an explanation of the measurement technique.

Notes for application of dimensions to microgravity conditions:

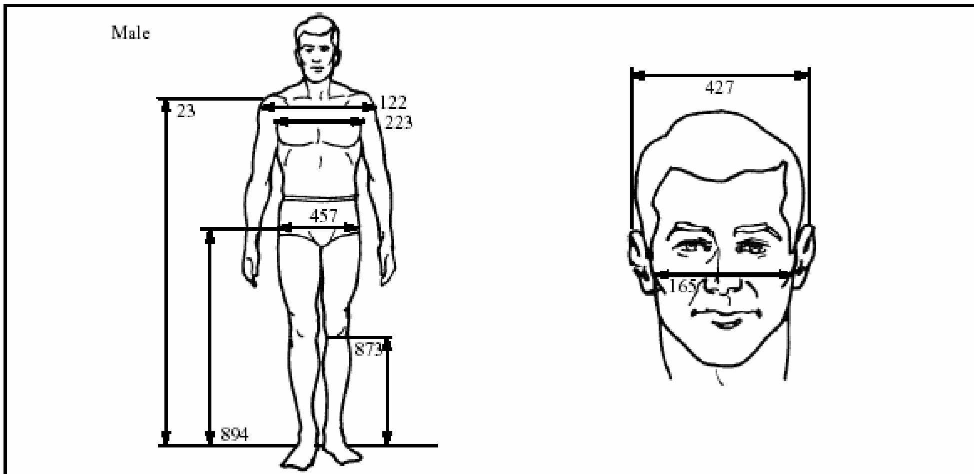
(1) Stature increases approximately 3 percent over the first 3 to 4 days in weightlessness (See NASA–STD–3000, Volume I, Figure 3.2.3.1–2, for information). Almost all of this change appears in the spinal column and thus affects (increases) other related dimensions, such as sitting height (buttock–vertex), shoulder height –sitting, eye height, sitting, and all dimensions that include the spine.

(3) Shoulder or acromial height, sitting or standing, increases during weightlessness due to two factors:

(a) Removal of the gravitational pull on the arms

(b) Extension of the spinal column as explained in Note (1) above (3 percent of stature on ground).

Table A.8. Body size of the 40-year-old American male for year 2000 in 1-g conditions (8 of 12)



Notes	No.	Dimension	5th Percentile cm (inches)	50th Percentile cm (inches)	95th Percentile cm (inches)
1, 3	23	Acromial (shoulder) height	138.0 (54.3)	147.6 (58.1)	157.3 (61.9)
	894	Trochanteric height	88.3 (34.8)	96.6 (37.6)	102.9 (40.5)
	873	Tibiale height	x	x	x
	122	Bideltoid (shoulder) height	44.6 (17.6)	48.9 (19.3)	53.2 (20.9)
	223	Chest breadth	29.7 (11.7)	33.2 (13.1)	36.7 (14.4)
	457	Hip breadth	32.7 (12.9)	35.8 (14.1)	39.0 (15.4)
	165	Bizygomatic (face) breadth	13.4 (5.3)	14.3 (5.6)	15.1 (6.0)
	427	Head breadth	14.8 (5.8)	15.7 (6.2)	16.5 (6.5)

General Notes:

(a) Gravity conditions – the dimensions apply to a 1–G condition only. Dimension expected to change significantly due to microgravity are marked.

(b) Measurement data – the number adjacent to each of the dimension are reference codes. The same codes are in NASA RP 1024, Volume 2. NASA RP 1024, Volume 2 provides additional data for these measurements plus an explanation of the measurement technique.

Notes for application of dimensions to microgravity conditions:

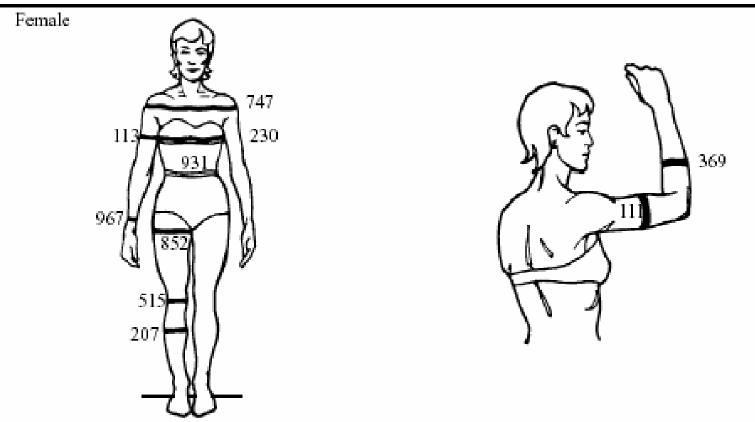
(1) Stature increases approximately 3 percent over the first 3 to 4 days in weightlessness (See NASA–STD–3000, Volume I, Figure 3.2.3.1–2, for information). Almost all of this change appears in the spinal column and thus affects (increases) other related dimensions, such as sitting height (buttock–vertex), shoulder height –sitting, eye height, sitting, and all dimensions that include the spine.

(3) Shoulder or acromial height, sitting or standing, increases during weightlessness due to two factors:

(a) Removal of the gravitational pull on the arms

(b) Extension of the spinal column as explained in Note (1) above (3 percent of stature on ground).

Table A.9. Body size of the 40-year-old Japanese female for year 2000 in 1-g conditions (9 of 12)



Notes	No.	Dimension	5th Percentile cm (inches)	50th Percentile cm (inches)	95th Percentile cm (inches)
	747	Shoulder circumference	x	x	x
	230	Chest circumference	73.2 (28.8)	82.1 (32.3)	90.9 (35.8)
6	931	Waist circumference	55.3 (21.8)	63.2 (24.9)	71.2 (28.0)
5	852	Thigh circumference	45.6 (17.9)	51.6 (20.3)	57.7 (22.7)
5	515	Knee circumference	31.0 (12.2)	34.6 (13.6)	38.2 (15.0)
5	207	Calf circumference	30.3 (11.9)	34.1 (13.4)	37.8 (14.9)
	113	Biceps circumference, relaxed	21.8 (8.8)	25.5 (10.1)	29.3 (11.5)
	967	Wrist circumference	13.7 (5.4)	15.0 (5.9)	16.2 (6.4)
	111	Biceps circumference, flexed	x	x	x
	369	Forarm circumference, relaxed	19.9 (7.8)	22.0 (8.7)	24.1 (9.5)

General Notes:

(a) Gravity conditions – the dimensions apply to a 1–G condition only. Dimension expected to change significantly due to microgravity are marked.

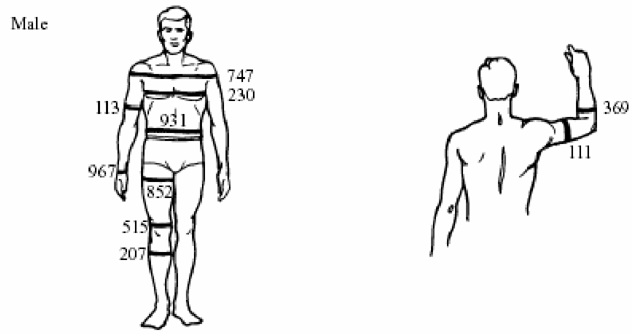
(b) Measurement data – the number adjacent to each of the dimension are reference codes. The same codes are in NASA RP 1024, Volume 2. NASA RP 1024, Volume 2 provides additional data for these measurements plus an explanation of the measurement technique.

Notes for application of dimensions to microgravity conditions:

(5) Leg circumferences and diameters significantly decrease during the first day in microgravity. See NASA RP 1024, Volume 1, appendix C, for details and measurements of actual persons.

(6) Waist circumference will decrease in microgravity due to fluid shifts to the upper torso. See Figure 3.2.3.1–2 for measurements on actual persons.

Table A.10. Body size of the 40-year-old American male for year 2000 in 1-g conditions (10 of 12)



Notes	No.	Dimension	5th Percentile cm (inches)	50th Percentile cm (inches)	95th Percentile cm (inches)
	747	Shoulder circumference	109.5 (43.1)	119.2 (46.9)	128.8 (50.7)
	230	Chest circumference	89.4 (35.2)	100.0 (39.4)	110.6 (43.6)
6	931	Waist circumference	77.1 (30.3)	89.5 (35.2)	101.9 (40.1)
5	852	Thigh circumference	52.5 (20.7)	60.0 (23.6)	67.4 (26.5)
5	515	Knee circumference	35.9 (14.1)	39.4 (15.5)	42.9 (16.9)
5	207	Calf circumference	33.9 (13.3)	37.6 (14.8)	41.4 (16.3)
	113	Biceps circumference, relaxed	27.3 (10.7)	31.2 (12.3)	35.1 (13.8)
	967	Wrist circumference	16.2 (6.4)	17.7 (7.0)	19.3 (7.6)
	111	Biceps circumference, flexed	29.4 (11.6)	33.2 (13.1)	36.9 (14.5)
	369	Forarm circumference, relaxed	27.4 (10.8)	30.1 (11.8)	32.7 (12.9)

General Notes:

(a) Gravity conditions – the dimensions apply to a 1–G condition only. Dimension expected to change significantly due to microgravity are marked.

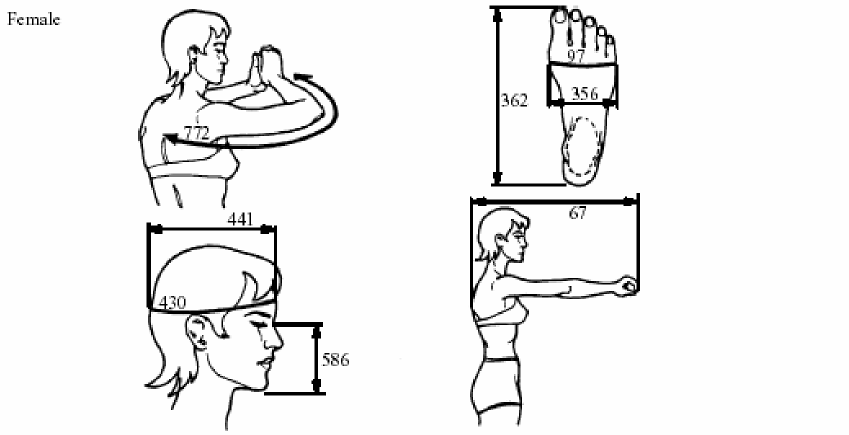
(b) Measurement data – the number adjacent to each of the dimension are reference codes. The same codes are in NASA RP 1024, Volume 2. NASA RP 1024, Volume 2 provides additional data for these measurements plus an explanation of the measurement technique.

Notes for application of dimensions to microgravity conditions:

(5) Leg circumferences and diameters significantly decrease during the first day in microgravity. See NASA RP 1024, Volume 1, appendix C, for details and measurements of actual persons.

(6) Waist circumference will decrease in microgravity due to fluid shifts to the upper torso. See Figure 3.2.3.1–2 for measurements on actual persons.

Table A.11. Body size of the 40-year-old Japanese female for year 2000 in 1-g conditions (11 of 12)



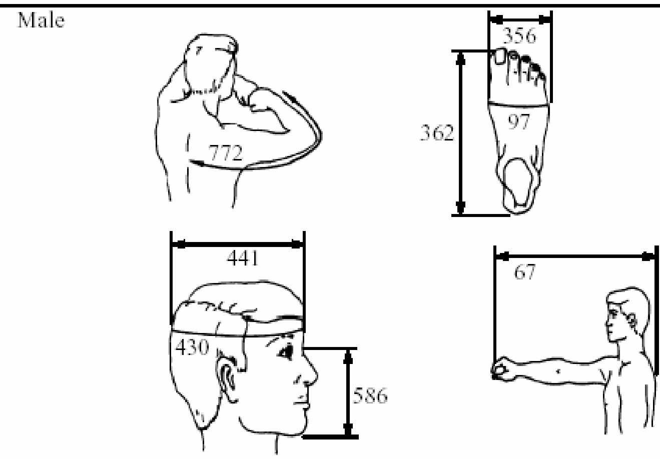
Notes	No.	Dimension	5th Percentile cm (inches)	50th Percentile cm (inches)	95th Percentile cm (inches)
	67	Thumb–tip reach	65.2 (25.7)	71.6 (28.2)	78.0 (30.7)
	772	Sleeve length	x	x	x
	441	Head length	16.7 (6.6)	18.2 (7.2)	19.6 (7.7)
	430	Head circumference	53.2 (20.9)	55.2 (21.7)	57.2 (22.5)
	586	Menton–sellion (face) length	9.0 (3.5)	10.8 (4.2)	12.6 (5.0)
	362	Foot length	21.3 (8.4)	22.9 (9.0)	24.4 (9.6)
	356	Foot breadth	8.6 (3.4)	9.3 (3.7)	10.0 (3.9)
	97	Ball of foot circumference	21.0 (8.3)	22.7 (8.9)	24.3 (9.6)

General Notes:

(a) Gravity conditions – the dimensions apply to a 1–G condition only. Dimension expected to change significantly due to microgravity are marked.

(b) Measurement data – the number adjacent to each of the dimension are reference codes. The same codes are in NASA RP 1024, Volume 2. NASA RP 1024, Volume 2 provides additional data for these measurements plus an explanation of the measurement technique.

Table A.12. Body size of the 40-year-old American male for year 2000 in 1-g conditions (12 of 12)



Notes	No.	Dimension	5th Percentile cm (inches)	50th Percentile cm (inches)	95th Percentile cm (inches)
	67	Thumb–tip reach	74.9 (29.5)	81.6 (32.1)	88.2 (34.7)
	772	Sleeve length	86.2 (33.9)	92.0 (36.2)	97.9 (38.5)
	441	Head length	18.8 (7.4)	20.0 (7.9)	21.1 (8.3)
	430	Head circumference	55.5 (21.8)	57.8 (22.8)	60.2 (23.7)
	586	Menton–sellion (face) length	11.1 (4.4)	12.1 (4.8)	13.1 (5.2)
	362	Foot length	25.4 (10.0)	27.3 (10.8)	29.3 (11.5)
	356	Foot breadth	9.0 (3.6)	9.9 (3.9)	10.7 (4.2)
	97	Ball of foot circumference	23.1 (9.1)	25.1 (9.9)	27.2 (10.7)

General Notes:

(a) Gravity conditions – the dimensions apply to a 1–G condition only. Dimension expected to change significantly due to microgravity are marked.

(b) Measurement data – the number adjacent to each of the dimension are reference codes. The same codes are in NASA RP 1024, Volume 2. NASA RP 1024, Volume 2 provides additional data for these measurements plus an explanation of the measurement technique.

Table A.13. Whole body center of mass location of the American male crew member (1 of 2)

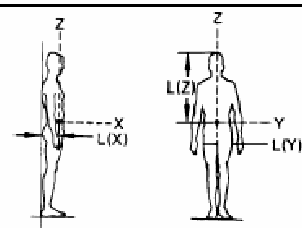
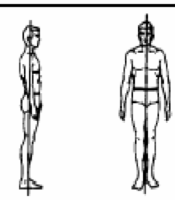
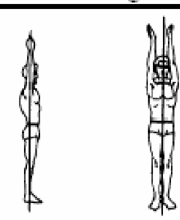
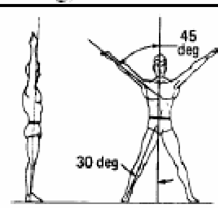
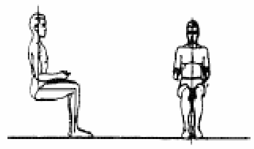
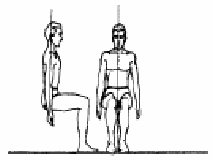
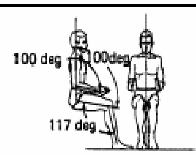
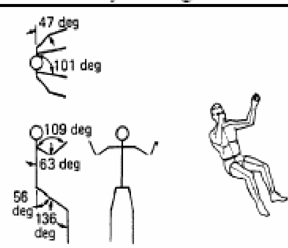
	cm (in.)			
	Dimension	5th percentile	50th percentile	95th percentile
 L(Y) = 1/2 distance between anterior superior iliac spine landmarks (1/2 bispinous breadth)				
 1. Standing	L(X)	8.6 (3.4)	9.1 (3.6)	9.6 (3.8)
	L(Y)	11.7 (4.6)	12.5 (4.9)	13.3 (5.2)
	L(Z)	75.7 (29.8)	80.2 (31.6)	84.7 (33.3)
 2. Standing, Arms Over Head	L(X)	8.7 (3.4)	9.1 (3.6)	9.4 (3.7)
	L(Y)	11.7 (4.6)	12.5 (4.9)	13.3 (5.2)
	L(Z)	69.9 (27.5)	80.2 (29.1)	77.9 (30.7)
 3. Spread Eagle	L(X)	8.2 (3.2)	8.6 (3.4)	9.0 (3.6)
	L(Y)	11.7 (4.6)	12.5 (4.9)	13.3 (5.2)
	L(Z)	69.4 (27.3)	73.5 (28.9)	77.5 (30.5)

Table A.14. Whole body center of mass location of the American male crew member (2 of 2)

	cm (in.)			
 4. Sitting	L(X)	19.4 (7.7)	20.6 (9.1)	21.8 (8.6)
	L(Y)	11.7 (4.6)	12.5 (4.9)	13.3 (5.2)
	L(Z)	65.2 (25.7)	68.6 (27.0)	71.9 (28.3)
 5. Sitting, Forearms Down	L(X)	18.9 (7.4)	20.0 (7.9)	21.1 (8.3)
	L(Y)	11.7 (4.6)	12.5 (4.9)	13.3 (5.2)
	L(Z)	66.0 (26.0)	69.3 (27.3)	72.5 (28.6)
 6. Sitting, Thighs Elevated	L(X)	17.6 (6.9)	18.8 (7.4)	20.1 (7.9)
	L(Y)	11.7 (4.6)	12.5 (4.9)	13.3 (5.2)
	L(Z)	57.3 (22.5)	59.4 (23.4)	61.5 (24.2)
 7. Mercury Configuration	L(X)	19.4 (7.6)	20.5 (8.1)	21.5 (8.5)
	L(Y)	11.7 (4.6)	12.5 (4.9)	13.3 (5.2)
	L(Z)	66.8 (26.3)	69.9 (27.5)	73.0 (28.7)
 8. Relaxed (weightless)	L(X)	18.0 (7.1)	18.8 (7.4)	19.6 (7.7)
	L(Y)	11.7 (4.6)	12.5 (4.9)	13.3 (5.2)
	L(Z)	68.0 (26.8)	70.9 (27.9)	73.7 (29.0)

Notes:
(1) These data apply to 1–g conditions. To estimate center of mass location in microgravity, multiply the L(z) figure by 0.9.
(2) The American male crewmember population is defined in 3.2.1.

Table A.15. Whole body center of mass location for the American male crew members of different sizes

Location of center of mass, cm = [A x (stature, cm)] + [B x (weight, lbs)] + [C]						
Posture	Dimension	A	B	C	SE (2) (cm)	R (3)
1. Standing	L(X) L(Y) L(Z)	– 0.035 0 0.486	0.024 0.021 –0.014	11.008 8.609 – 4.775	0.33 0.89 1.33	0.7636 0.4310 0.9329
2. Standing (arms over head)	L(X) L(Y) L(Z)	– 0.040 0 0.416	0.020 0.021 – 0.007	12.632 8.609 0.305	0.45 0.89 1.52	0.5823 0.4310 0.8927
3. Spread eagle	L(X) L(Y) L(Z)	– 0.031 0 0.392	0.020 0.021 0.002	10.443 8.609 2.547	0.36 0.89 1.48	0.6706 0.4310 0.8921
4. Sitting	L(X) L(Y) L(Z)	0.080 0 0.344	0.010 0.021 – 0.004	4.450 8.609 7.327	0.56 0.89 1.46	0.7900 0.4310 0.8632
5. Sitting (thighs elevated)	L(X) L(Y) L(Z)	0.041 0 0.212	0.022 0.021 – 0.002	7.405 8.610 21.582	0.66 0.89 1.24	0.7104 0.4310 0.7801
6. Sitting (with arms down)	L(X) L(Y) L(Z)	0.075 0 0.355	0.010 0.021 – 0.010	4.628 8.609 7.389	0.51 0.89 1.56	0.8030 0.4310 0.8489
7. Mercury configuration	L(X) L(Y) L(Z)	0.076 0 0.311	0.008 0.021 – 0.002	5.253 8.609 14.425	0.54 0.89 1.80	0.7828 0.4310 0.7841
8. Weightless	L(X) L(Y) L(Z)	0.077 0 0.218	0.001 0.021 0.017	4.692 8.609 28.552	0.60 0.89 3.16	0.6973 0.4310 0.5015

Notes:
(1) – Refer to Figure 3.3.7.3.2.1–1 for measurement landmarks.
(2) SE = Standard error of the estimate.
(3) R = Multiple correlation coefficient.
(4) These data apply to 1–g conditions. To estimate center of mass location in microgravity, multiply the L(z) figure by 0.9.
(5) The American male crewmember population is defined in 3.2.1.

Table A.16. Body segment mass for American male crew member (1 of 2)

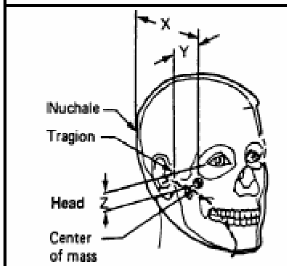
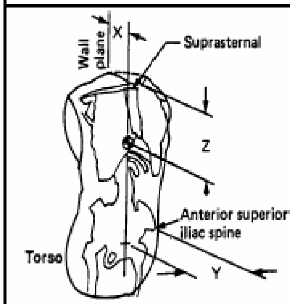
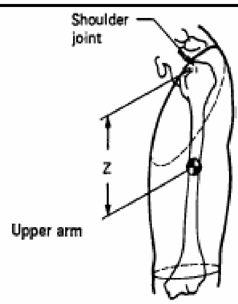
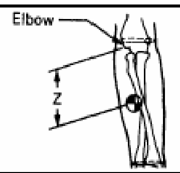
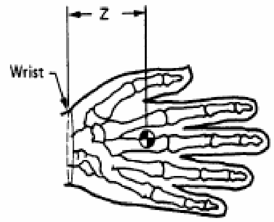
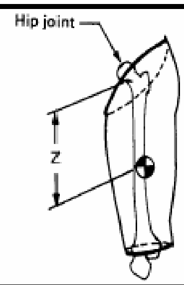
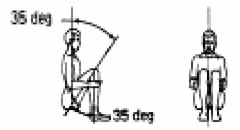
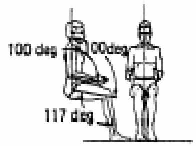
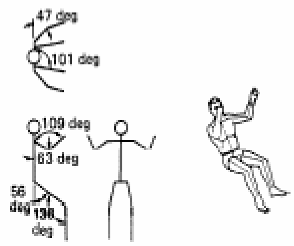
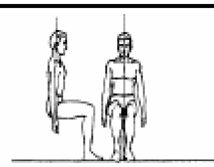
	Center of mass location, cm (in.)								
	5th percentile			50th percentile			95th percentile		
	X	Y	Z	X	Y	Z	X	Y	Z
	9.4 (3.7)	6.8 (2.7)	2.1 (0.8)	10.4 (4.1)	7.2 (2.8)	2.3 (0.9)	11.5 (4.5)	7.7 (3.0)	2.5 (1.0)
	8.4 (3.3)	13.8 (5.4)	21.0 (8.3)	10.0 (3.9)	15.8 (6.2)	21.8 (8.6)	11.6 (4.6)	17.8 (7.0)	22.6 (8.9)
	*	*	14.1 (5.6)	*	*	14.9 (5.0)	*	*	15.7 (6.2)
	*	*	10.9 (4.3)	*	*	11.5 (4.5)	*	*	12.1 (4.8)

Table A.17. Body segment mass for American male crew member (2 of 2)

Center of mass location, cm (in.)									
	5th percentile			50th percentile			95th percentile		
	X	Y	Z	X	Y	Z	X	Y	Z
	*	*	5.1 (2.0)	*	*	5.6 (2.2)	*	*	6.0 (2.4)
	*	*	17.0 (6.7)	*	*	18.0 (7.1)	*	*	19.1 (7.5)

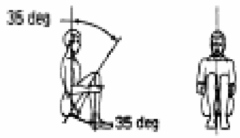
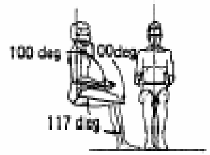
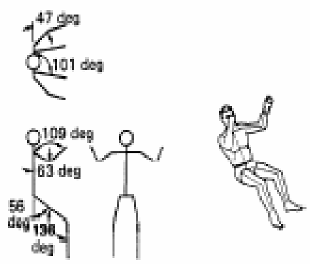
Notes:
(4) These data apply to 1–g conditions only.
(2) The American male crewmember population is defined in 3.2.1.
(3) * Assume symmetry.

Table A.18. Whole body moment of inertia for American male crew member (1 of 2)

Moment of inertia, g–cm² x 10⁶, (lb–in–sec²)				
Posture	Axis	5th percentile	50th percentile	95th percentile
 6. Sitting, Thighs Elevated	X	37.6 (33.3)	48.7 (43.1)	59.8 (52.9)
	Y	37.2 (32.9)	46.6 (41.2)	55.8 (49.3)
	Z	23.9 (21.1)	33.7 (29.8)	43.5 (38.5)
 7. Mercury Configuration	X	62.5 (55.3)	82.2 (72.7)	101.8 (90.0)
	Y	69.6 (61.6)	95.5 (84.5)	121.3 (107.3)
	Z	31.9 (28.2)	43.0 (38.0)	54.0 (47.8)
 8. Relaxed (weightless) (Does not account for spinal lengthening)	X	88.0 (77.8)	114.5 (101.3)	140.9 (124.6)
	Y	84.1 (74.4)	109.6 (96.9)	134.8 (119.2)
	Z	39.8 (35.2)	50.5 (44.7)	61.2 (54.1)
 5. Sitting, Forearms Down	X	59.2 (52.4)	77.6 (68.6)	96.0 (84.9)
	Y	63.9 (56.5)	86.3 (76.3)	108.6 (96.0)
	Z	30.9 (27.3)	42.8 (37.9)	54.6 (48.3)

Notes:
(4) These data apply to 1–g conditions only.
(2) The American male crewmember population is defined in 3.2.1.

Table A.19. Whole body moment of inertia for American male crew member (2 of 2)

Moment of inertia, g–cm^2 x 10^6, (lb–in–sec^2)				
Posture	Axis	5th percentile	50th percentile	95th percentile
 6. Sitting, Thighs Elevated	X	37.6 (33.3)	48.7 (43.1)	59.8 (52.9)
	Y	37.2 (32.9)	46.6 (41.2)	55.8 (49.3)
	Z	23.9 (21.1)	33.7 (29.8)	43.5 (38.5)
 7. Mercury Configuration	X	62.5 (55.3)	82.2 (72.7)	101.8 (90.0)
	Y	69.6 (61.6)	95.5 (84.5)	121.3 (107.3)
	Z	31.9 (28.2)	43.0 (38.0)	54.0 (47.8)
 8. Relaxed (weightless) (Does not account for spinal lengthening)	X	88.0 (77.8)	114.5 (101.3)	140.9 (124.6)
	Y	84.1 (74.4)	109.6 (96.9)	134.8 (119.2)
	Z	39.8 (35.2)	50.5 (44.7)	61.2 (54.1)

Notes:
(4) These data apply to 1–g conditions only.
(2) The American male crewmember population is defined in 3.2.1.

APPENDIX B

Table B.1. Technical drawings of Destiny module

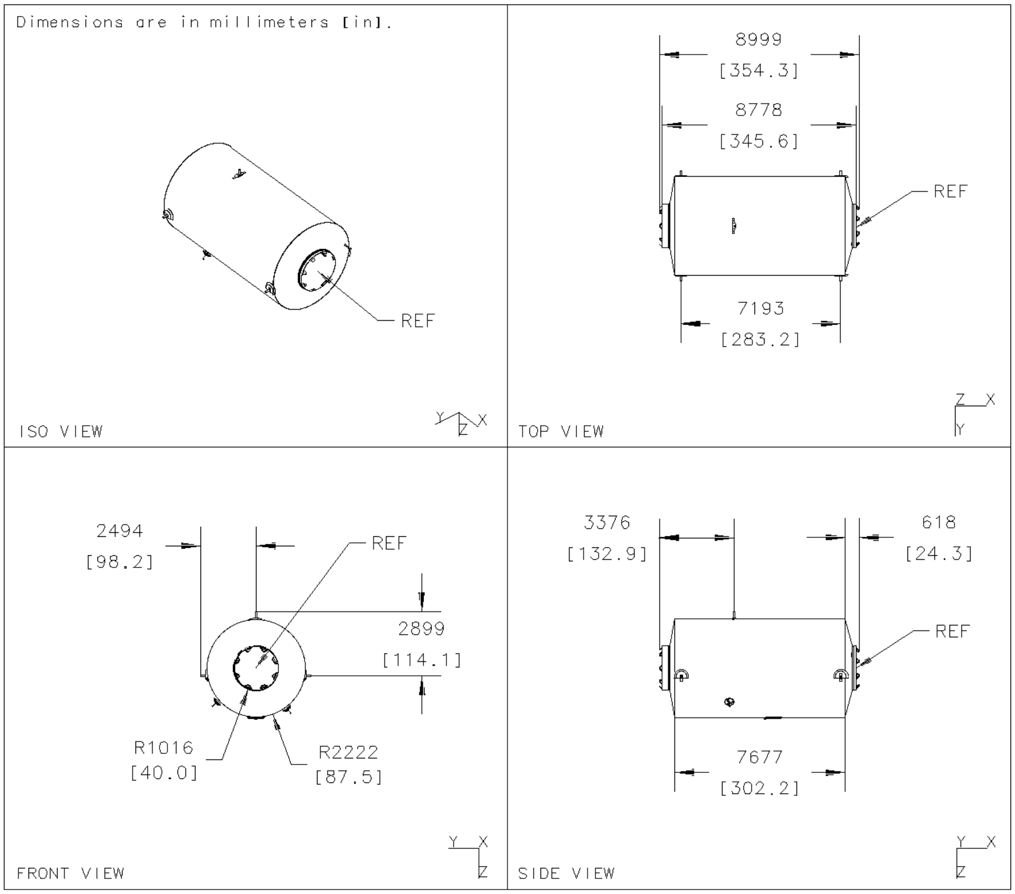


Table B.2. Technical drawings of Unity module

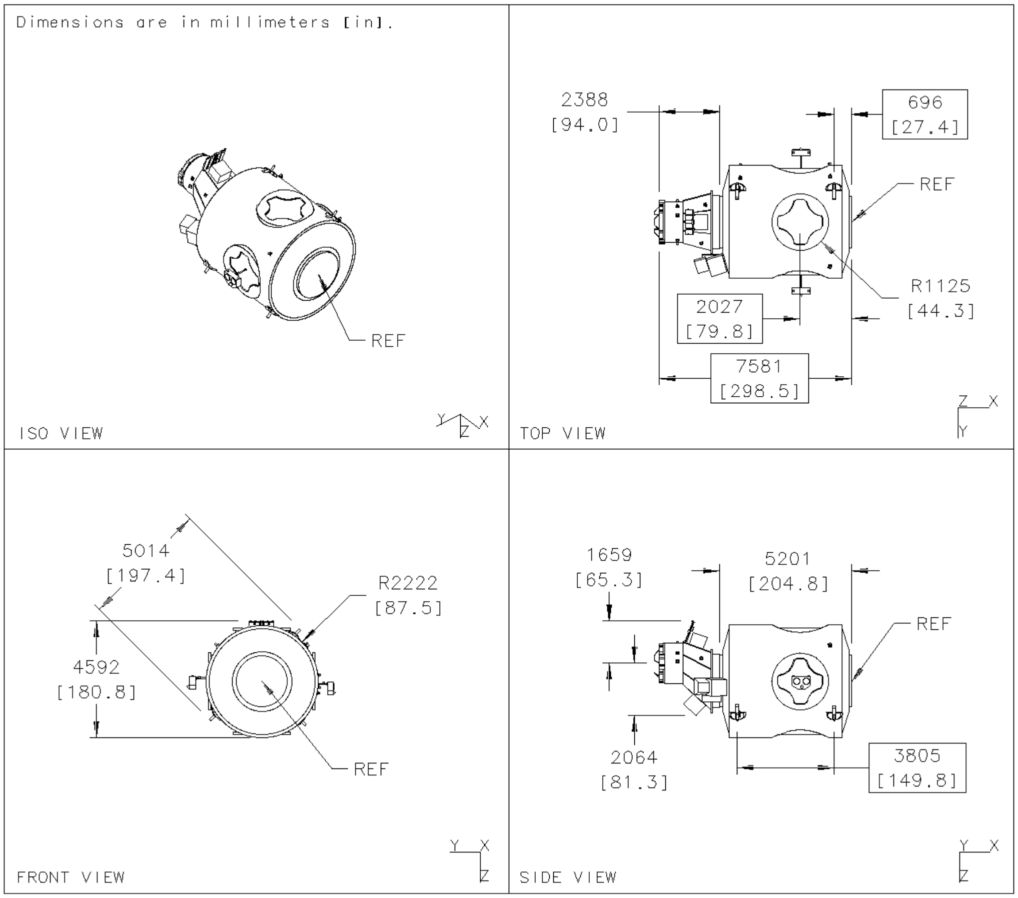
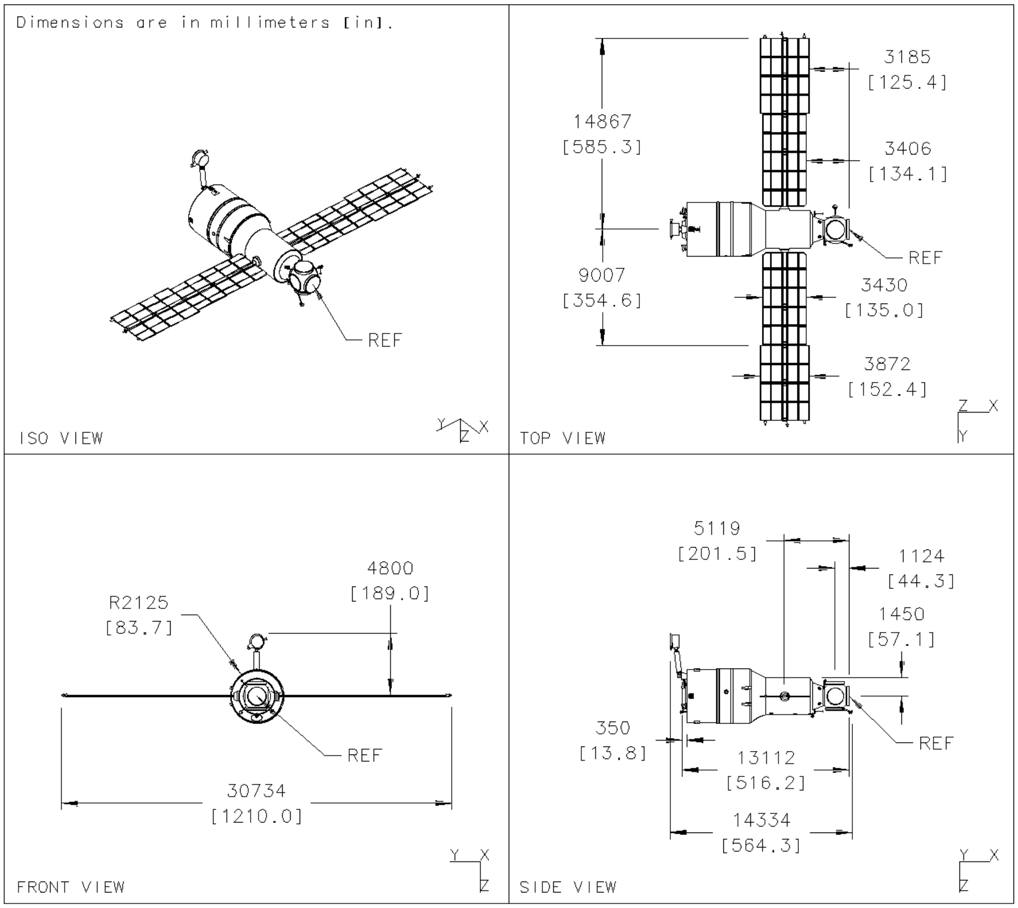


Table B.3. Technical drawings of Zvezda module



APPENDIX C

VIDEOTAPE OBSERVATION

C1

Time: 22 January 2003

Place: Zvezda Module

Activity: Treadmill Exercise

User Name: Ken Bowersox

Duration of the Videotape: 6 minutes and 29seconds

Reference Address: http://spaceflight1.nasa.gov/gallery (keyword: treadmill)

NOTES: Ken Bowersox, wears the Lower Extremity Monitoring Suit (LEMS) and participates in the FOOT, experiment. He starts running and accelerates until the 7^{th} second. At the 7^{th} second, he stops and takes a break. He seems uncomfortable. At 17^{th} second he starts running again. He sometimes falters during the exercise session. At 37^{th} second he takes a break again and rearranges his belt. After 10 seconds from this break, he starts running again. There is no display or control equipment of the Treadmill. The astronaut sometimes looks at his watch. He runs approximately with the same speed till the end of the videotape.

C2

Time: 21 December 2001

Place: Zvezda Module

Activity: Treadmill Exercise

User Name: Frank Culbertson

Duration of the Videotape: 48 seconds

Reference Address: http://spaceflight1.nasa.gov/gallery (keyword: treadmill)

NOTES: Frank Culbertson is keeping fit on the Treadmill in Zvezda Service Module. The astronaut is restrained from waist to the equipment. It is understood that one of the crew members is recording him. This time the astronaut is straighter. The dinner table is very close and has sharp edges. There are foot rails near the Treadmill.

C3

Time: 4 April, 2007

Place: Destiny Module and Unity Module

Activity: Cycle Ergometer Exercise and iRED Exercise

User Name: Suni Williams and Mike Lopez-Alegria

Duration of the Videotape: 1 minute 58 seconds

Reference Address:

http://www.spaceflightnowplus.com/index.php?k=expedition+14&t=ISS+Expedition+14

Video name: Expedition 14: Exercising on ISS

NOTES: While cycling, Suni Williams communicates with the ground by the help of a microphone. She introduces the Cycle Ergometer display which is very mechanical and primitive in form as its surface looks unfinished. It does not look hi-tech as well. She sometimes stops while she is speaking. She has a back support which gives an angular body shape to her. She is restrained from her waist to the wall where the equipment is attached, but it is very loose. The equipment has very sharp edges. The Cycle Ergometer has a display angle of which can be adjusted. After 1 minute and 20 seconds, Astronaut Mike Lopez-Alegria cycles on the Cycle Ergometer while Suni Williams is doing other jobs in Destiny. They do not communicate. Mike Lopez-Alegria leans forward to reach the control panel which is in horizontal position. He forces himself to reach the panel and has to untie his restraint belt. After this activity, Mike Lopez-Alegria introduces bench press on iRED for 10seconds.

C4

Time: 4 December 2006

Place: Destiny Module

Activity: Cycle Ergometer Exercise

User Name: Thomas Reiter

Duration of the Videotape: 4 minutes 23 seconds

Reference Address: http://www.space-multimedia.nl.eu.org/index.php?option=com_content&task=view&id=1227&Itemid=2

Video name: Fitness check flight engineer Thomas Reiter on the CEVIS (Cycle Ergometer)

NOTES: Thomas Reiter is cycling on CEVIS for Periodic Fitness Evaluation with Oxygen Uptake Measurement (PFE-OUM). He firstly sets ups the equipment for the test and starts cycling. After 3 minutes and 29 seconds, he tries to reach the control panel but this is difficult for him. The experiment looks very complicated. No one is in the module while he is cycling. The module looks crowded with objects.

C5

Time: 2004

Place: Tour in the ISS

Activity: Explaining the modules (Destiny, Airlock, Unity and Zvezda)

User Name: André Kuipers

Duration of the Videotape: 10minutes

Reference Address: http://www.esa.int/esa-mmg/mmg.pl?b=b&mission=Delta%20 (Astronaut%20Kuipers) &start=1

Video Name: Eleven Days in Space

NOTES: André Kuipers is having fun while guiding the modules. He uses handrails in order to flow from one place to another. However, when he doesn't have the chance to find a hand rail near to him, he holds the edges or corners of any equipment close to him. He begins introducing Destiny module and explains some of the equipment located there. Equipment are located very close to each other and they look technologic. However, they are in mess and cables of them are not hidden. On the floor, there is a window for astronauts to view the outside space. He seems to enjoy watching from window. He opens it but he says it is night time. There are many computers, labtops and videotape systems besides the equipment. They are screwed, hanged or sticked with velcro. Laptop computers are left open and there is some work on them. Artificial lighting is used in the environment but it is dark in the transitional parts between the modules. Afterwards, he enters to Unity which is also called Node 1 where there is the enterance to the airlock. iRED is located in this module. Node 1 seems tidier. Then he introduces the airlock and the MPLM. MPLM is attached to the cargo module. This is where he sleeps at night. Afterwards, he enters the docking module where there are a lot of stuff lying around. The last module he is introducing is the Zvezda Service Module which is a Russian Module. Zvezda module is the most crowded module and the equipment in the module seems to be located randomly. Here, while he is touring the module, astronaut Alexander Kaleri is exericising on Treadmill. He can not get close to him as there can be an accident. He introduces how they eat on the dinner table in the Zvezda Module.

APPENDIX D

D.1.a. Interview Questions For ISS Expedition Crew Member

1. In ISS, what was going well (as you wished) or not well (not as good as you wished) while exercising? Could you explain them indicating the equipment and exercise area you used?
2. What did you mostly feel/ think lacking in exercise areas in ISS? What sorts of physical changes do you suggest for the exercise areas in ISS?
3. Were you comfortable with the exercise equipment in ISS? What improvements related with the exercise equipment are necessary for your comfort?
4. Do you think the exercise equipment should be located in the same module or seperated in different modules as it is in ISS? Why? What sorts of physical changes do you suggest in terms of the exercise equipment layout in the modules of ISS?
5. What other activities did you do or want to do while exercising in ISS? Which activity areas do you think are visually and/or spatially and/or functionally compatible with exercise areas? In terms of exercise area layout in the station, were there something insufficient/ disturbing/ unusual?
6. Do you prefer exercise activity to be an individual (private) or a group (social) activity? In ISS, are the exercise areas sufficient for positive social interaction among crew members? If not what are the reasons?

D.1.b. Theme of the questions

1. Introductory contextual question- Evaluating main likes and dislikes related with the exercise areas.

2. Evaluation of the exercise areas with a focus of design modification

3. A) Evaluation of comfort level with the exercise equipment

B) Evaluations of the needs related with the exercise equipment with a focus of design modification to increase comfort

4. Evaluation of the equipment layout in the modules with a focus of design modification

5. A) Evaluation of compatibility of exercise activity with other activities

B) Evaluation of the exercise areas based on layout and configuration in the station in terms of compatibility with other activities.

6. A) Evaluation of exercise areas in terms of privacy and community needs.

B) Evaluation of exercise areas in terms of social interaction levels

D.2.a. Interview Questions for the Designers of the Exercise Areas for ISS

1. What should be the main concerns while designing exercise countermeasure equipment?
2. What are the main constraints while planning the exercise countermeasure equipment?
3. Do you think ground based values correspond with the ones on space?
4. What improvements can be made in terms of volume, size, structure and form of the equipment?
5. What should be the main concerns while designing monitoring devices of the equipment?
6. What should be the main concerns while designing restraint systems of the equipment in order to increase the crew comfort?
7. While designing the next equipment or the improved one for ISS, which feedbacks of the astronauts should be taken in to consideration?
8. What additional studies should be done to improve the effectiveness, productivity, safety and health of the crew members? What should be beyond current approach?
9. Do you think there is enough space for exercising in ISS? If not what can be done to get more space?
10. Do you think the exercise equipment should be located in the same module or separated in different modules as it is in ISS? Why?
11. In ISS, exercise area is spatially, visually and functionally combined with other areas? Do you think this is right? What should be the layout of the exercise area?
12. Do you think the astronauts are comfortable while doing different activities in the same module together? Are there anyone disturbed?
13. What should be the environmental conditions in an exercise area?
14. Is there a need for vibration or shock isolation system?
15. What can be suggested to increase the leisure level of the exercise activity?
16. Do you recommend other activities to be done together while exercising?

D.2.b. Theme of the Questions for the Designers of the Exercise Areas for ISS

1. Evaluation of main concerns while designing exercise equipment

2. Evaluation of main constraints while designing exercise equipment

3. Evaluation of research criteria and approach

4. Evaluation of anthropometrical concerns while designing exercise equipment with a focus of volume, size, structure and form of the equipment

5. Evaluation of operational concerns while designing monitoring devices of the equipment

6. Evaluation of operational concerns while designing restraint systems of the equipment

7. Evaluation of research criteria and approach

8. Evaluation of research criteria and approach

9. Evaluation of interior volume utilization of the exercise areas in ISS

10. Evaluation of layout and configuration of the exercise areas in ISS

11. Evaluation of layout and configuration of the exercise areas in ISS

12. Evaluation of layout and configuration of the exercise areas in ISS with a focus of understanding the behavioral concerns

13. Evaluation of environmental conditions in ISS

14. Evaluation of environmental conditions in ISS

15. Evaluation of design of the exercise areas in ISS with a focus of understanding the behavioral concerns

16. Evaluation of layout and configuration of the exercise areas with a focus of understanding the behavioral concerns